PROSEU

Prosumers for the Energy Union: mainstreaming active participation of citizens in the energy transition

Report on local, national and EU scenarios

(Deliverable D5.2)

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Summary of PROSEU

PROSEU aims to enable the mainstreaming of the renewable energy Prosumer phenomenon into the European Energy Union. Prosumers are active energy users who both consume and produce energy from renewable sources (RES). The growth of RES Prosumerism all over Europe challenges current energy market structures and institutions. PROSEU's research focuses on collectives of RES Prosumers and will investigate new business models, market regulations, infrastructural integration, technology scenarios and energy policies across Europe. The team will work together with RES Prosumer Initiatives (Living Labs), policymakers and other stakeholders from nine countries, following a quasi-experimental approach to learn how RES Prosumer communities, start-ups and businesses are dealing with their own challenges, and to determine what incentive structures will enable the mainstreaming of RES Prosumerism, while safeguarding citizen participation, inclusiveness and transparency. Moving beyond a case by case and fragmented body of research on RES Prosumers, PROSEU will build an integrated knowledge framework for a socio-political, socioeconomic, business and financial, technological, socio-technical and socio-cultural understanding of RES Prosumerism and coalesce in a comprehensive identification and assessment of incentive structures to enable the process of mainstreaming RES Prosumers in the context of the energy transition.

Summary of PROSEU's Objectives

Eight key objectives at the foundation of the project's vision and work plan:

- **Objective 1:** Document and analyse the current state of the art with respect to (150-200) RES Prosumer initiatives in Europe.
- **Objective 2:** Identify and analyse the regulatory frameworks and policy instruments relevant for RES Prosumer initiatives in nine participating Member States.
- **Objective 3:** Identify innovative financing schemes throughout the nine participating Member States and the barriers and opportunities for RES Prosumer business models.
- **Objective 4:** Develop scenarios for 2030 and 2050 based on in-depth analysis of technological solutions for RES Prosumers under different geographical, climatic and socio-political conditions.
- **Objective 5:** Discuss the research findings with 30 relevant stakeholders in a Participatory Integrated Assessment and produce a roadmap (until 2030 and 2050) for mainstreaming RE Prosumerism.
- **Objective 6:** Synthesise the lessons learned through experimentation and co-learning within and across Living Labs.
- **Objective 7:** Develop new methodological tools and draw lessons on how the PROSEU methodology, aimed at co-creation and learning, can itself serve as an experiment with institutional innovation.
- **Objective 8:** Create an RES Prosumer Community of Interest.

PROSEU Consortium Partners

Logo	Organisation	Type	Country
	FCIENCIAS.ID	Private non-profit association	Portugal
	UPORTO	University	Portugal
	ICLEI EURO	Small and medium-sized enterprise	Germany
	CLIENTEARTH	Non-governmental organisation	United Kingdom
	UNIVLEEDS	University	United Kingdom
	DRIFT	University	the Netherlands
	UNIZAG FSB	University	Croatia
	LEUPHANA	University	Germany
	ECO-UNION	Non-governmental organisation	Spain
	IÖW	Private non-profit limited company	Germany
	CE Delft	Small and medium-sized enterprise	the Netherlands

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Executive summary

In order to fulfil the Objective 4 of the PROSEU project, this deliverable analyses various technical scenarios of renewable prosumer integration to determine the full potential for the uptake of such technologies.

Three general scenarios were developed with three different reference years:

- Reference scenario: 2015, 2030, 2050
- Renewables scenario: 2030, 2050
- Autarky scenario: 2030, 2050

The Reference scenario ensures comparability with business as usual. The renewables scenario shows the impact of maximizing the energy production with renewable prosumer technologies and the Autarky scenario shows how storage technologies can improve self-sufficiency. In order to consider the future technology developments and trends in the energy sector, all the scenarios have been modelled for 2030 and 2050, while the base year has been set as 2015.

The scenarios are developed for different levels of use cases. In total 30 local technology deployment scenarios are analysed, along with the analysis of 28 countries and the EU.

For the 30 local deployment scenarios in total 10 use cases were analysed. The use cases have been selected in such a way that a broad range of climate, geographical social and political conditions are considered so that the results could be replicated to similar cases throughout Europe.

These 30 local deployment scenarios have been developed by using UNIZAG FSB and IÖW models in order to show various benefits of the renewable prosumerism. The positive impact of prosumerism ranges from the environmental benefit where such configurations result in significant CO_2 emissions savings, to economic benefits where it was proven that in most cases the use of renewable prosumerism technologies results in lower overall costs for the system/prosumer. Depending on the selected configuration of the system, different renewable autarky levels can be achieved for heating and electricity sectors, ranging from lower values to a 100%. This depends on the space restrictions for integrating renewable technologies, the energy consumption patterns, as well as the geographical and climate conditions.

Furthermore, the scenarios have also been developed for each member state and the EU as a whole, to account for the potential uptake of the technologies at member state and EU level. A division is made between residential buildings and utility buildings. For the generation of energy, individual technologies and collective technologies are taken into account. This leads to an overview of the technical potential contributions of prosumers to the share in energy generation and the level of autarky that could be reached.

1. Introduction

In order to analyse the full potential of renewable prosumerism in Europe, its technical and economic aspects must be elaborated in detail. Different technologies can be used to produce heat and electricity by a prosumer/prosumer community, and their utilisation usually depends on different parameters, including geographic, climate and socio-political conditions. Therefore, in order to understand how these technologies can be integrated, at which costs and with which benefits, it is necessary to analyse various scenarios which consider different geographical conditions, climate conditions and ways of utilization from the prosumer side. When doing such an analysis, a longer time frame needs to be considered in order to account for the efficiency and cost changes of the renewable technologies in question.

This deliverable presents the continuation of PROSEU deliverable D5.1, which consisted of a technology database for heating, electricity and cogeneration technologies. These data have been used as an input for the modelling of the scenarios in this deliverable. By using three different models from UNIZAG FSB, IÖW and CE DELFT, scenarios on local, national and EU level have been developed. This included 30 scenarios on the individual, neighbourhood and city level elaborated through UNIZAG FSB and IOW models and national and EU scenarios elaborated by using CE DELFT model. For the local scenarios, use cases have been selected by considering coverage of different geographical and climate conditions so that a broad variety of conditions can be taken into account. In these scenarios, different technologies have been analysed, including their combinations. The results provided the environmental effect of integrating renewable prosumerism technologies, as well as their economic effect and the overall share of autarky (i.e. self-consumption of produced renewable energy). All the scenarios have been modelled for 2030 and 2050 to show the effect of the technology development. In addition, the Reference scenario has also been modelled for the base year, which has been selected as 2015 due to the best availability of data for this year.

Furthermore, the scenarios have also been upscaled to the EU level by using the CE DELFT model CEPROM. EU level scenarios were developed to account for the potential uptake of the technologies at member state and EU level for 2015, 2030 and 2050 providing an overview of the potential contributions of prosumers to the various energy system functions for the individual members and the EU as a whole. The results from this deliverable will be used to form the technology recommendations for renewable energy prosumers in Task 5.4 of the PROSEU project.

2. Description of models used

For the modelling of the scenarios as a part of this deliverable, three different models have been used. These will be described in the following subchapters. The reasoning behind using different models was in the fact that the IÖW model is best suitable for the individual level cases, UNIZAG FSB model for larger cases, e.g. neighbourhoods and cities and CE DELFT model for the national and EU level.

2.1 UNIZAG FSB tool

The developed model can provide hourly operation of the heating and power system by using optimization approach. It includes various heating technologies such as cogeneration, electrical heater, heat pump and solar thermal, including thermal storage. Besides mentioned, it also takes into account generic district unit which covers the residual heating demand. Similarly, electricity demand could be provided with photovoltaics (PV), wind turbine and cogeneration power plant, while the shortages are covered with the power grid. In order to store excess of electricity production, battery technologies could be used. This model could be used in order to analyse penetration of variable renewable sources into the medium sized energy system

The model is written in Julia programming language as linear programming problem[1]. Julia is a high-level, high-performance dynamic programming language for numerical computing. It is free and open source under the MIT license. The syntax is similar to MATLAB and has great connection with Python. In order to create the optimization model, JuMP was used. It is a modelling language for mathematical optimization embedded in Julia. It supports broad range of commercial, free and open-source solvers, while at the same time guarantees speed. While a core of the optimization problem is written in Julia, some parts are written directly in Python by using NumPy package. It is a package for scientific computing with Python. It enables easy and comfortable handling of large amount of data in a form or arrays or matrices.

Below, the model will be presented in detail: optimization variables, constraints and objective functions. Optimization solver seeks to define optimization variables in such a way that it satisfies constraints and at the same time minimizes an objective function. For a purpose of the simulation, the objective function is the minimization of the total system's running cost. The heating model has following variables: Operation of district heating unit, electrical heater units, heat pump units, cogeneration units, solar thermal units, including the operation of a short-term or seasonal storage system. Mentioned variables are continuous, which means that they can achieve any value in a defined range. The operation of each supply unit is calculated based on the constraint that its value can be between zero and the maximum capacity of the given technology. For the storage system, the boundaries are that in every moment the charging/discharging operation is between the maximum charging and maximum discharging and that the state of charge of the storage system is between its maximum state of charge and the required technical minimum.

[1] Clp has been used as the optimization solver

Every mentioned optimization variable is optimized for every time step t, meaning that for every mentioned supply capacity or thermal storage, there are 8760 operation variables to be optimized in one year.

Besides optimization variables, optimization problems usually have constraints. The basic constraint of the model is that heat and electricity demand must be satisfied from supply units and storage units in every time step. For the storage systems, the difference between the state of charge in each time step, the state of charge in a previous time step, charge/discharge in that time step and the loss of the storage system needs to be equal to zero. Also, the state of charge at the start and the end of the year need to be the same and are not equal to zero.

Supply from the intermittent renewable energy sources i.e. their availability is hourly distribution defined prior to the start of the simulation module and therefore this makes a constraint for the supply coming from these sources.

Objective function is defined as a minimization of total system's running cost. It is important to mention that it is also linear, the same as the constraints defined previously. The equation below presents the objective function of the prosumer model with the focus on heating.

$$\min\left(\sum_{t=1}^{tmax}\sum_{i} Q_{i,t}\cdot\left(\left(\frac{c_{fuel,i,t}}{\eta_i}\right)+c_{variable,i,t}\right)-Q_{CHP,el,i,t}\cdot c_{el,i,t}\right)$$

Where $Q_{i,t}$ represents supply in time step t for supply technology i, $c_{fuel,i,t}$ is specific fuel cost, $c_{variable}$ are variable costs, $Q_{CHP,el,i,t}$ is electrical energy production from cogeneration units, while $c_{el,i,t}$ represents electrical energy price which is payed to the supplier. There is minus sign in front of the last term because sold electricity decreases total running costs. It must be noted that the capital costs are not taken into account in the optimization process, i.e. only the running costs are minimized.

2.1 IÖW Energy Prosumer Model

The IÖW Energy Prosumer Model (EPROM) allows for a novel representation of prosumers, facilitating the evaluation of their economic and ecologic potentials. In addition, the effects of prosumers on the energy system in terms of reduction of grid roll-out, displacement of conventional energies or distribution effects can be estimated (IÖW 2018).

The model simulates energy production and consumption minute-by-minute for a whole year considering seasonal and short-term effects (e.g. due to clouds). Consumption is modelled bottom-up including over 30 electrical devices, with each electrical device having an individual minutely load profile. The devices used by the prosumer and their efficiency can be determined by chance or set manually. The same applies for the operating time of the devices, which can be set by a probability function on a daily basis.

The model focuses on PV systems for energy generation. Again, the model is able to simulate different orientations every minute. Furthermore, various heating technologies (e.g. solar heating, heat pump, low-temperature boiler, hot water storage tank, and freshwater station) can be represented, allowing for an integrated analysis of the power and heat supply.

For the coordination of production and consumption, partially automated as well as fully automated ("smart") energy management systems are available. Stationary battery storage or electric cars can also be taken into consideration. Due to the modular construction, numerous other technologies can be integrated, or measured load profiles can be evaluated for comparison.

The main results of the simulations are self-consumption rates and self-sufficiency rates resulting from different technology options and operating scenarios. Alongside, the quantitative and temporal shift of energy supply into and from the grid is also shown. These data form the basis for the economic analysis and, through aggregation, enable the estimation of technical, economic, and social-ecological effects on various stakeholders in the energy system.

The EPROM was originally designed to simulate a current German household in Lindenberg near Berlin. In the PROSEU project, the model was extended to simulate also other locations in different climate zones as well as specifications of households. Moreover, implemented technologies were modelled with changing efficiencies to simulate different moments in time.

2.2 CE Delft Prosumers Model (CEPROM)

The CE Delft Prosumers Model (CEPROM) simulates the maximum potential of energy generation with prosumer technologies and the use of this energy in households and tertiary buildings. The model calculates the technical potential of prosumer technologies in all member states and the EU. The technical potential is the potential that can maximally be reached if all households and buildings in the tertiary sector will start using a prosumer technology to heat or cool their buildings and generate all renewable energy that is needed to cover their own demand, given certain practical boundary conditions and provided that it is technically possible.

A wide range of prosumer technologies are included in the model, as it includes technologies that generate electricity or heat (or both) and technologies that can story energy. In the following table the types of technologies included in the model are listed.

Table 1 Technologies used in CEPROM

Technology	Type
Solar PV	Generation of electricity
Wind turbines	Generation of electricity
Hydro power (small scale)	Generation of electricity
Solar thermal	Generation of heat
Heat pump	Generation of heat
Biomass boiler	Generation of heat
District heating	Generation of heat
CHP	Generation of heat and electricity
Thermal energy storage	Heat storage
Batteries	Electricity storage
Electric vehicles	Electricity storage

The technologies can be used by different types of energy citizens. In the model, three different types are distinguished:

- Individual households
- Collectives
- Tertiary buildings[2]

Which technology is suitable for which household, collective or tertiary building depends on different factors. In the model the following key factors are taken into account to determine the technology that can be used:

- Type of building
- Population density of the area
- Climate zone
- Availability of biomass

[2] Tertiary buildings are buildings of organizations or companies active in the service sector. A full list of sub-sectors that part of this sector can be found on https://stats.oecd.org/glossary/detail.asp?ID=2432. A large part of tertiary buildings are used by SMEs. SMEs are defined by the European Commission as having less than 250 persons employed and having an annual turnover of up to EUR 50 million.

- Energy citizen type

These different factors will be elaborated on further in the report (5.4)

The following output is generated by the model:

- Electricity demand in different scenarios and years
- Heat demand in different scenarios and years
- Installed capacity per generation and storage technology and energy citizen type
- Energy production per technology and per energy citizen type
- Percentage of autarky that is reached in different scenarios
- Demand side flexibility

To calculate these outputs, a large number of input data is used. These input data are different for each member state. The general used input data are:

- Population and number of households
- Characteristics of building stock
- Energy demand
- Climate conditions
- Land use

For most of the technologies, also other data are used. These are for example the efficiencies of the technologies. All used date and sources of the data are listed in the appendix. In this model, the costs and emissions are not taken into account.

3. Use cases

In order to achieve the goal of 30 scenarios for Task 5.2 set in the grant agreement, it has been decided to select 10 use cases each on the individual, neighbourhood and city level. Use cases are briefly described in this section, with the more detailed description of the assumptions provided in the next chapters. The country and EU level descriptions from the Task 5.3 will also be elaborated in this section.

3.1 Individual level

The goal on the individual level is to show the effects of different technologies on typical individual prosumers in different locations of the EU. EPROM is used to model individual prosumers, being considered most suited to model the effects of different climate zones and technologies on households (compare 2.1).

According to the Köppen-Geiger climate classification, there are four dominant climate zones in the EU (Beck et al. 2018):

1. Oceanic climate (Cfb): e.g. London, Paris, Amsterdam, Brussels
2. Continental climate (Dfb): e.g. Vienna, Warsaw, Stockholm
3. Mediterranean climate (Csa): e.g. Rom, Lisbon, Athens
4. Semi-arid climate (BSk): e.g. Murcia, Lampedusa

In order to show the effects for prosumers of different climate zones on an individual level, an individual household of each EU climate zone was selected. Figure 1 shows the distribution of the different climate zones across Europe and the selected locations of the modeled households.

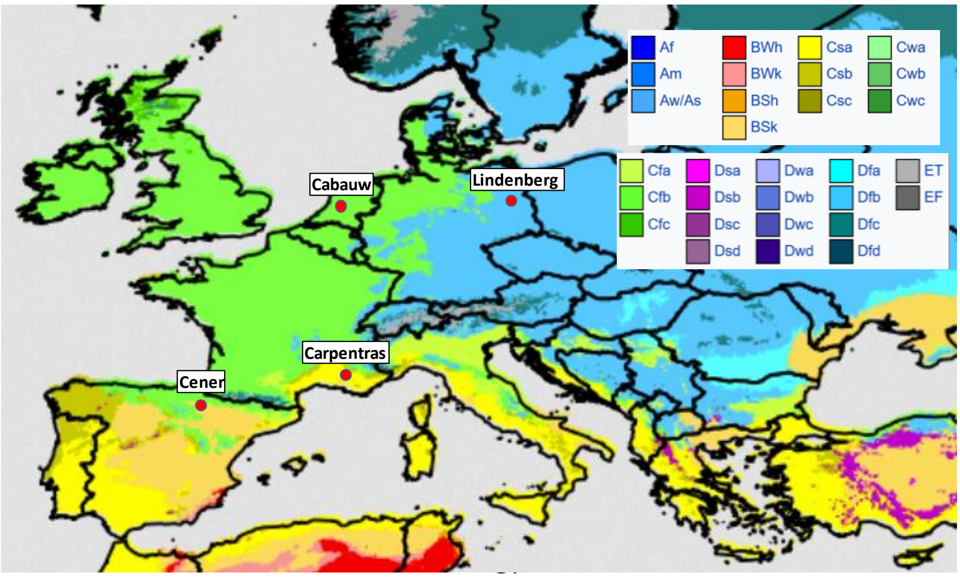

Figure 1 Map of EU including selection of individual households and Köppen-Geiger climate classification based on Beck et al. (2018).

Various reasons played a role in the location selection in the four climate zones. To show a variety of prosumers, a different country was selected for each of the four climate zones. The selection of the countries was partly due to the focus on certain countries of the EU in the PROSEU project and partly due to data availability. As the EPROM relies on minutely data, the selection was restricted to a limited number of locations providing data on this level of detail. As described in 2.1, EPROM was originally designed to model a household in Lindenberg 60 km southeast of Berlin. Therefore, Lindenberg was chosen for the modelling of a prosumer in a continental climate zone. Cabauw was chosen for the oceanic climate zone based on its proximity to one of the Living Labs of Proseu (Aardehuis). This allows on one hand for the validation of the input data and results from this report by available data provided by the partner, and on the other hand the results of this report can be used by Aardehuis's citizens to compare their own figures with simulated scenarios. In order to represent France, as one of the largest economies in Europe and one of the focal points of PROSEU, Carpentras has been selected for the Mediterranean climate zone. As semi-arid climate conditions can only be found in parts of Spain, the National Renewable Energy Centre of Spain (CENER) near Pamplona (Olano, Xabier (2015) was selected as the use case, being the only provider of weather data in minutes. Pamplona has semi-arid climate that borders on an oceanic climate.

At all four selected locations, a typical household in a single-family house is simulated. A single-family house was chosen in order to integrate the most possibilities prosumer technologies on an individual level. In comparison to blocks of flats there is for example more available rooftop area per person that can be utilized for PV and solar thermal. Additionally, it is more likely that there is only one owner facilitating decisions on investments. In order to show a variance of households, different numbers of persons living in the household are modelled. As shown in Table 2, almost 70 % of the population in the selected four countries live in households with two, three or four members. Although a considerable high proportion of people also lives in single person households, it is assumed that single-person households are less likely to live in single-family houses. Therefore, the focus of this study at the individual level is on two, three, and four-person households in single-family houses.

Table 2 Number of different household sizes in France, Germany, Netherlands and Spain based on Eurostat (2011)

	1P HH	**2P HH**	**3P HH**	**4P HH**	**5P HH**	**Total**
	in Mio.	in Mio.	in Mio.	in Mio.	in Mio.	in Mio.
France	9.43	9.19	4.07	3.43	1.29	27.91
Germany	13.76	12.58	5.18	3.73	1.15	36.93
Netherlands	2.71	2.44	0.90	0.97	0.32	7.44
Spain	4.19	5.44	3.92	3.35	0.86	18.08

3.2 Neighbourhood level

On the neighbourhood level three different neighbourhoods from three different regions are being modelled. Figure 2 shows a map with the selected use cases on a neighbourhood level. With Lanište and Klausenerplatz two locations are in a region with continental climate The goal was to show differences in the results in neighbourhoods with similar climate conditions but different economic, political and local settings. The third neighbourhood is located in Netherlands with an oceanic climate. Not only the climate conditions but also the size of the neighbourhood is different to the other two use cases and therefore adds to the variety of modelled prosumer neighbourhoods. A brief description for each neighbourhood is given in the following subchapters.

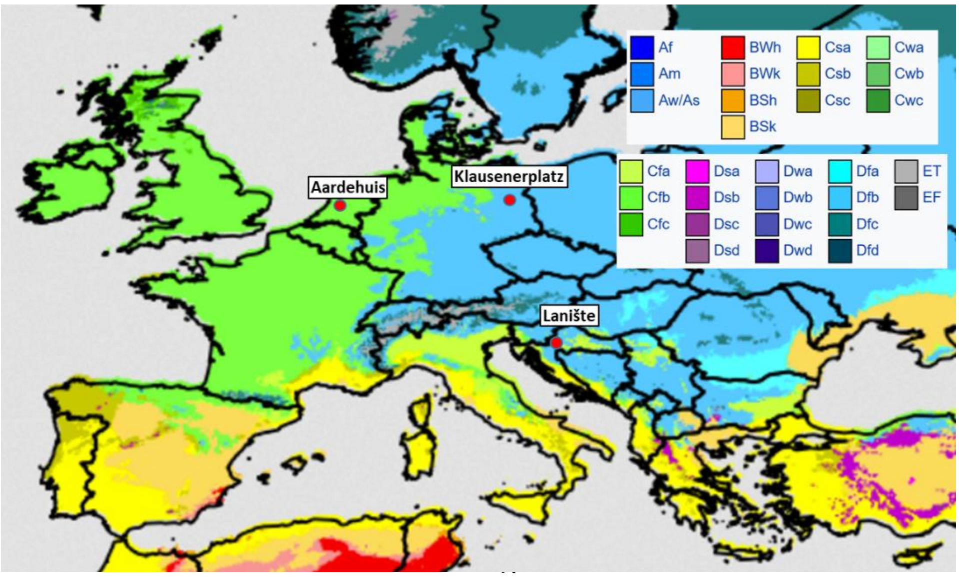

Figure 2 Map of EU including selection of neighbourhoods and Köppen-Geiger climate classification based on Beck et al. (2018).

3.2.1 The neighbourhood of Ardehuis in the city of Olst

The neighbourhood of Aardehuis (meaning 'Earth House') in the town of Olst is located in Netherlands. Aardehuis was selected since it is one of the Living Labs[3] in the PROSEU project and Aardehuis provided real data. Hence, results of the simulation can be validated. Moreover, results of simulations with alternation of technologies can provide a better understanding on potential effects of investments in other technology for the neighborhood. Based on the Köppen-climate classification the climate is classified as oceanic climate. The aerial overview is shown in Figure 3.

[3] see https://proseu.eu/living-labs

Figure 3 Aerial view of the neighbourhood of Aardehuis (Google Maps 2020)

The community of Aardehuis consists of 25-households with 77 people striving for self-sufficiency by generating their own electricity and the use of wood stoves and heat pumps to cover heat demand. Households are constructed as "Earthships" designed for off grid living. (Vereniging Aardehuis 2020) Twelve of the buildings have tire walls – filled with rammed earth – and eleven buildings are built with straw walls with wood frame supporting the roof. All houses are equipped with a total of 77 kWp of PV and partly with solar thermal. Heating demand is covered predominantly with wood stoves and to a lower percentage with heat pumps. The overall electricity demand – based on information by the households – is approximately 130 MWh per year including electricity for heat pumps, electric appliances and light and one electric vehicle. The total heating demand is approximately 241 MWh per year.[4] Currently a communal battery and a charging solar carport are installed and measures for energy-saving implemented.

3.2.2 The neighbourhood of Lanište in the city of Zagreb

The neighbourhood of Lanište is located in the capital of Croatia, the city of Zagreb. It consists mostly of blocks of apartment buildings, a hotel and a primary school and has a population of 3468. It has been selected as a use case due to the good amount of data available from previous analyses. Based on its location the climate is classified as the Continental Climate. The aerial overview of the neighbourhood is shown in Figure 4.

[4] The total heat demand was calculated based on m^3 of burned wood assumed generated electricity with present heat pumps.

Figure 4 Aerial view of the neighbourhood of Lanište in Zagreb (Google Maps 2020)

Most of the buildings have flat rooftops, suitable for the installation of the solar technologies. However, such building blocks also have the potential to install cogeneration units, heat pumps, storage technologies and electric heaters in the existing boiler rooms in the basement of the building, making them an interesting case for the integration of renewable prosumer technologies. Also, the green areas in the neighbourhood present a good opportunity for integrating larger underground thermal storages. Currently, the heating demand of the neighbourhood is 30.1 GWh and it is completely covered by individual heating units, while the electricity demand amounts to 4 GWh, completely covered by the electricity grid.

3.2.3 The neighbourhood of Klausenerplatz in the city of Berlin

The neighbourhood of Klausenerplatz is located in the capital of Germany, Berlin. It presents one block of buildings surrounded by streets from the north, west and south side, and the park, i.e. the Klausenerplatz itself from the east side. The neighbourhood has a population of 876 and has been selected due to a very detailed set of data available for all the relevant parameters. The city, as well as the neighbourhood have a Continental Climate.

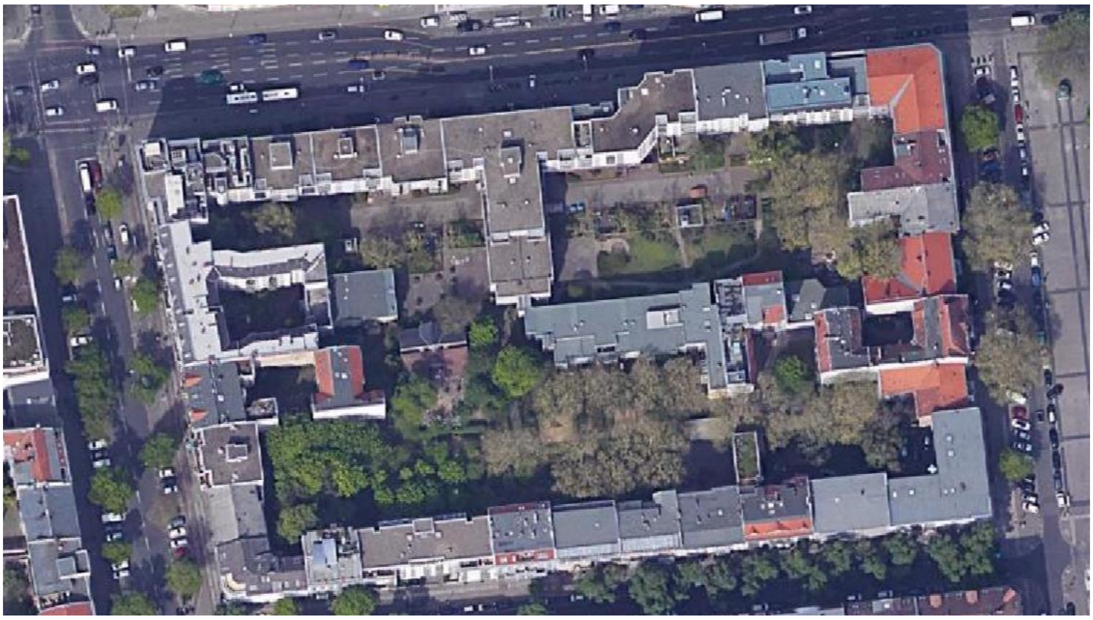

Figure 5 Aerial view of the Klausenerplatz neighbourhood in Berlin (Google Maps 2020)

As can be seen in Figure 5, the rooftops are of mixed shapes, but most of them are still flat, enabling integration of solar and micro wind technologies at site. Furthermore, there are some green areas in between buildings which could be used for underground storage solutions and the buildings themselves have additional space in the basement or the existing boiler rooms for the integration of other renewable prosumer technologies. It presents a medium sized neighbourhood, compared to Lanište which is of larger size. As mentioned earlier, detailed data was available for Klausenerplatz, which made it one of the most accurate use cases. Its heating demand equals to 6.2 GWh and is completely covered by individual heating units, while the electricity demand equals to approximately 1 GWh. There are currently no renewable technologies installed at site.

3.3 City level

Figure 6 shows a map with the selected use cases on a city level.

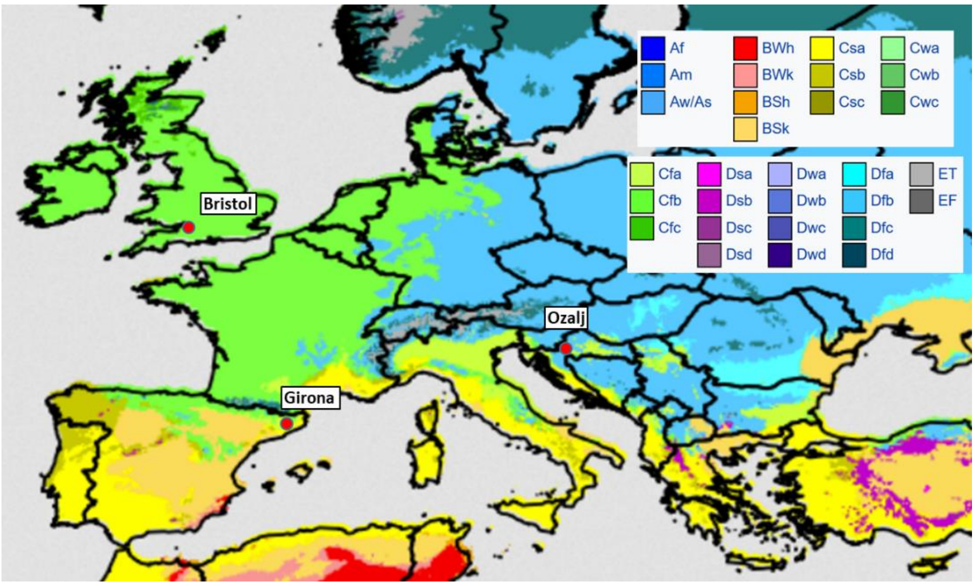

Figure 6 Map of EU including selection of cities and Köppen-Geiger climate classification based on Beck et al. (2018).

City level use cases have been selected in such a way that the diversity of climate conditions, geographic conditions and social conditions is considered. Also, cities throughout Europe differ in sizes significantly. The idea was to consider this fact as well, by selecting three levels of cities: small (Ozalj), medium (Girona) and large sized city (Bristol).

3.3.1 City of Ozalj

The city of Ozalj is located around 60 km south-west from Zagreb, with a population of 1880. It is a small rural city with mostly individual households, i.e. private houses and just a small share of apartment buildings located in the city centre. It has been chosen for the analysis because of the detailed data available through past projects, as well as its climate characteristics. Based on the Koppen classification, its climate is oceanic. The aerial overview of the city can be seen in Figure 7

Figure 7 Aerial view of the city of Ozalj (Google Maps 2020)

Its framework conditions are somewhat different than for the other use cases since it is a rural town with mostly individual houses and therefore has a much higher specific energy consumption per person. Also, some technologies are more difficult to integrate in such cases, which will be elaborated in more detail in chapter 5. The overall heating demand has been mapped in detail in previous projects and amounts to 90.9 GWh. It is covered exclusively by individual heating solutions, using mostly locally available biomass in an unsustainable manner due to old and inefficient furnaces with high local pollutant emissions. Electricity demand equals to 13.4 GWh and is covered by the power grid, with no prosumer technologies being utilized now.

3.3.2 City of Girona

Girona is located in the north east of Spain in the Catalonia region, nearby the city of Barcelona. It is a medium sized city with a population of 101,852, which has been selected for the analysis due to one of the projects Living Labs being based in Girona and due to its climate and geographical characteristics. Its climate is classified by the Koppen classification as Mediterranean Climate.

Data on energy consumption has mostly been acquired through publicly available data sets, which resulted in a lower accuracy of the input data compared to the neighbourhood and individual level use cases. This will be elaborated in more detail in chapter 5. Due to its location, the city is especially suitable for the integration of solar technologies. The overall heating demand of the city amounts to 342.6 GWh and is covered by individual heating solutions, while the overall electricity demand of the city equals to 451.8 GWh. It can be noticed that the electricity demand is higher than the heating demand, which was not the case in previous use cases. This is due to the location and the climate of Girona, where the cooling needs are much higher and are covered by electricity, i.e. by air conditioning units. The aerial overview of the city is shown in Figure 8

Figure 8 Aerial view of the city of Girona (Google Maps 2020)

3.3.3 City of Bristol

Bristol is in the west of the United Kingdom, at the border of England and Wales. It has a population of 535,907 and can be classified as the larger city. Like Girona, this city has been selected as a use case because of the Living Lab in Bristol, but also due to its climate and geographic specifics. Its climate is classified as Oceanic Climate.

Data on this use case have been gathered from various sources, including consortium partners and publicly available data sources. However, it must be pointed out that the availability of energy consumption data in UK is rather limited and therefore several assumptions had to be made. This decreased the accuracy of the results, but still gave a good representation of the large city in north western Europe. Detailed assumptions will be elaborated in chapter 5. The overall heating demand is 3,554.3 GWh and is covered by the individual heating solutions. On the other hand, the electricity demand amounts to 1,044.1 GWh and is completely covered by the electricity grid, i.e. there are no prosumer technologies being utilized at the moment.

Figure 9 Aerial view of the city of Britol (Google Maps 2020)

3.4 Country level

For the country level, all 27 member states and the UK[5] are analysed. All member states have different conditions that are relevant to determine the potential of prosumers.

The conditions that are taken into account are:

- Number of households
- Number of tertiary building
- Building stock: used to determine potential production of solar PV.
- Degree of urbanization: Each of the degrees of urbanization (urban, suburban, rural) is considered separately. This categorization is used to determine preference heating technologies.
- Energy demand: used to determine potential heating technologies and potential amount of energy production with prosumer technologies.
- Climate conditions: used to determine preference heating technologies and potential for solar and wind energy.
- Land use: used to determine potential biomass availability for heating (amount of woodland) and potential for ground-based solar PV (available bare land area).
- Subsurface conditions: used to determine whether a member state can use thermal energy storage.
- Current numbers of heating technologies and energy production prosumers: used for Reference scenario.

[5] At the start of the project, the United Kingdom was still a member of the EU, therefore, they are also taken into account in this analysis.

The following figures show some of the conditions that are used to determine the potential spread of technology use throughout Europe. The boundaries that are used for the categories of biomass availability and cooling degree days will be elaborated on in 5.4.

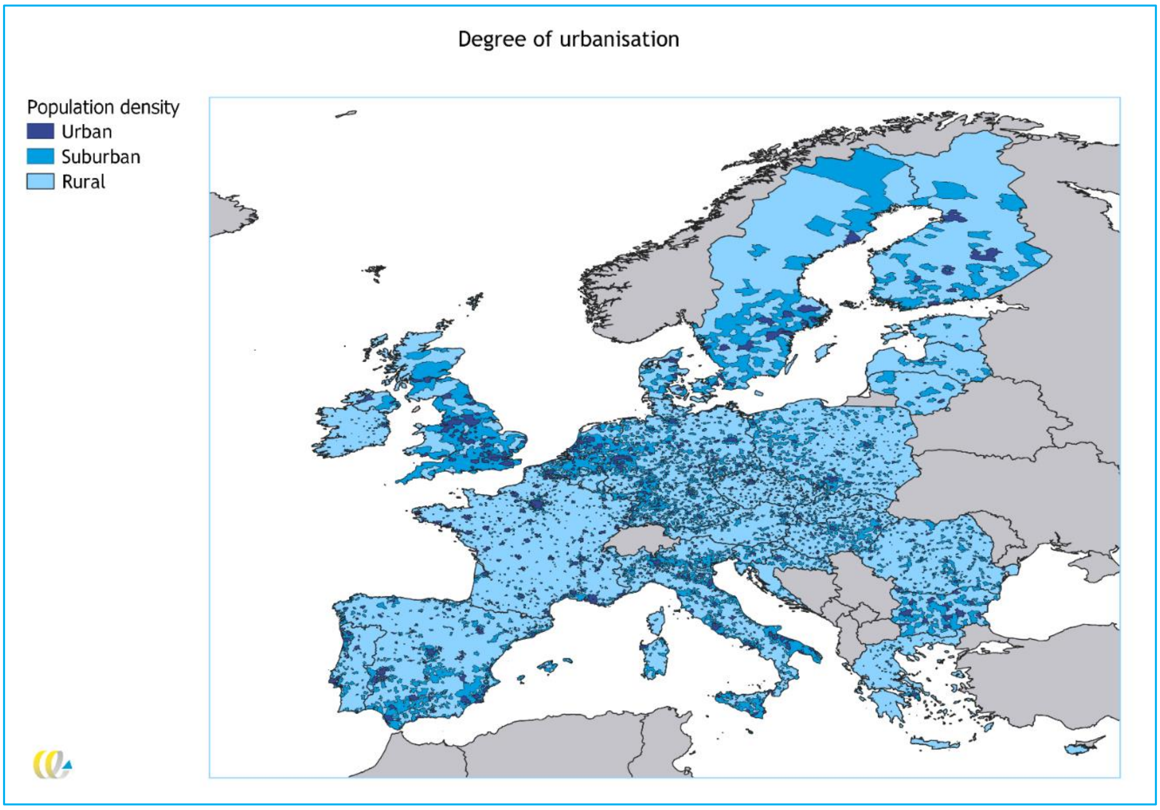

Figure 10 Degree of urbanisation

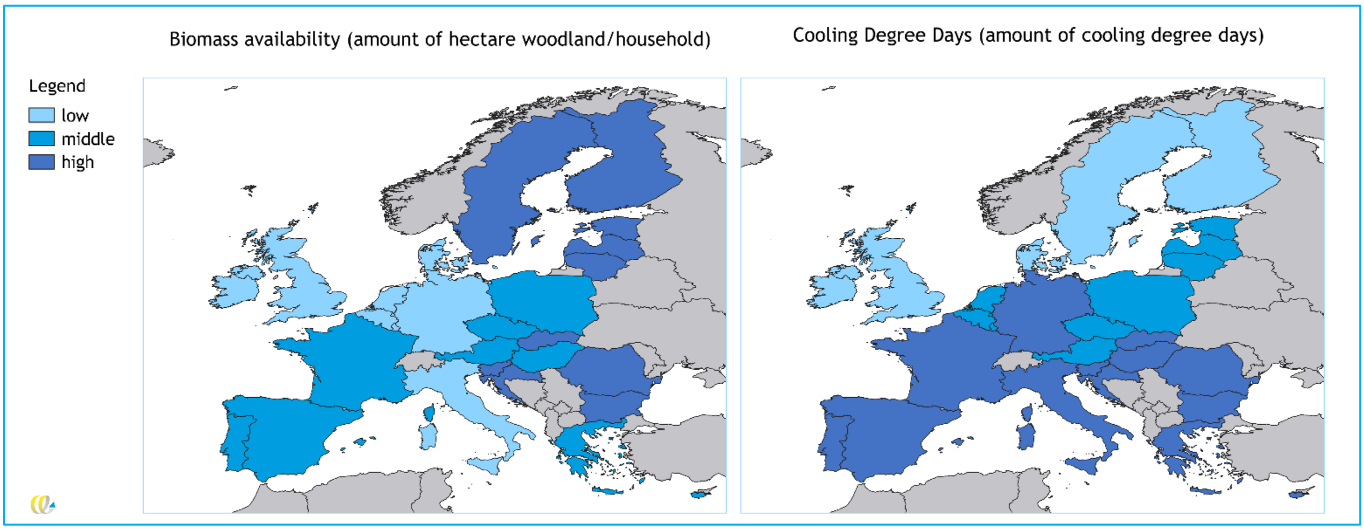

Figure 11 Biomass availability and CDD

Table 3 presents the number of households and utility buildings per member state and the energy demand for heating and cooling and electric devices and lighting in buildings.

Table 3 Number of households and utitlity buildings and energy demand 2015

Member state	Households	Utility buildings	Heating and cooling demand (TWh)	Electricity demand (TWh)
Austria	3,816,000	650,000	65	32
Belgium	4,699,000	1,170,000	90	32
Bulgaria	2,940,000	590,000	20	32
Croatia	1,487,000	510,000	20	32
Cyprus	298,000	309,000	8	32
Czech Republic	4,644,000	700,000	66	32
Denmark	2,373,000	760,000	46	32
Estonia	572,000	816,000	9	32
Finland	2,623,000	1,523,000	62	32
France	28,931,000	6,130,000	429	32
Germany	40,258,000	11,890,000	666	32
Greece	4,376,000	1,190,000	52	32
Hungary	4,152,000	410,000	59	32
Ireland	1,731,000	430,000	29	32
Italy	25,789,000	2,990,000	410	32
Latvia	833,000	140,000	13	32
Lithuania	1,332,000	200,000	13	32
Luxembourg	229,000	39,000	7	32
Malta	173,000	39,000	2	32
Netherlands	7,622,000	1,128,000	117	32
Poland	14,110,000	2,650,000	182	32
Portugal	4,083,000	940,000	22	32
Romania	7,470,000	880,000	53	32
Slovakia	1,847,000	90,000	26	32
Slovenia	883,000	945,000	11	32
Spain	18,376,000	2,980,000	173	32
Sweden	5,100,000	460,000	82	32
United Kingdom	28,269,000	7,110,000	375	32
Total	**219,016,000**	**47,669,000**	**3,109**	**885**

3.5 EU level

The results of the country analysis are added to present EU results.

4. Scenarios

In this section, a description of the main scenarios will be elaborated. For the individual, neighbourhood and city level use cases, overall 30 scenarios have been modelled, i.e. 3 scenarios per use case. These included:

- Reference scenario
- Renewables scenario
- Autarky scenario

The reason for choosing 3 different levels of use cases is to show the specifics of each of these categories. On the individual level, the most precise results can be shown for the single prosumer and its effects on the economics and the environmental aspects of the individual household. These can be used by all the interested citizens who want to install renewable energy technologies at their houses and become prosumers in different geographical regions of Europe.

On the neighbourhood level, the idea is to show the effect of installing renewable technologies by individual consumers on the overall energy and economic balance of the neighbourhood. However, the input data, as well as the results are more aggregated in this case and do not show the benefits of each individual household but rather the whole neighbourhood. These are also selected in different geographical areas to cover different political, economic and climate conditions. City level use cases present even more aggregated results for the whole city, showing the overall benefits on the energy system.

In general, the Reference scenario provides only business-as-usual changes in demands, prices, technological parameters, etc. but does not incorporate any changes in technology mix being used to produce energy, i.e. no additional uptake of prosumers is expected.

Contrary, the Renewables scenario analyses the introduction or upscaling of present renewable prosumer technologies for energy production, taking into account different political, economic, geographical and climate conditions when selecting technologies and their capacities. The idea is to investigate how different prosumer technologies can be implemented based on the above-mentioned conditions. In the Renewables scenario, maximum integration of prosumer technologies has been analysed until 2050, taking into account the available area and the specifics of each neighbourhood. However, these scenarios do not take into account the implementation of energy storage but rather the full exploitation of renewable energy generation in the existing system, with excess production being sold to the grid or wasted (in case of solar thermal).

Finally, the Autarky scenario analysis the possibility of achieving high shares of autarky of the prosumers, taking into account energy storage technologies, additionally to the Renewables scenario. In this scenario, electric battery storage and thermal energy storage have been added, still taking into account the space restrictions of the use cases, which are usually rather significant in the highly urbanised neighbourhoods, but smaller in the rural areas.

The Reference scenario was modelled for 2015, 2030 and 2050, in order to consider changes in prices, demands, technological parameters, etc. On an individual level the Renewables and Autarky scenario were modelled for hypothetical households in 2015, 2030 and 2050. Hence, comparisons between a prosumer household and a conventional household are possible for three different times. Contrary on a neighbourhood and city level the Renewables and Autarky scenario were only modelled for 2030 and 2050, since these use cases are based on existing cases. Hence, only possible paths of development are of interest. The assumptions made for each scenario and use case are elaborated in the next section.

5. Methodology and Assumptions

The scenarios on an individual, neighbourhood and city level have been elaborated by using different tools (i.e. EPROM and UNIZAG FSB tool) and on different levels of use cases. Therefore, it is necessary to define certain key performance indicators, which will enable the comparison of the results from all 30 scenarios. Key performance indicators are used to compare the economic, environmental and energy performance of the scenarios, and have been calculated for each scenario. These are:

- CO_2 emissions of the heat production units
- CO_2 emissions of the electricity production units
- Levelized cost of heat (LCOH) for the heating system
- Levelized cost of electricity (LCOE) for the electricity system
- Overall share of renewable prosumer technologies in the production of heat (renewable autarky)
- Overall share of renewable prosumer technologies in the production of electricity (renewable autarky)

The CO_2 emissions for the heating sector have been calculated by multiplying the fuel consumption of each individual production unit by the emission factor of that fuel (Rutz et al. 2019). Fuel consumption has been calculated by taking into account the efficiency of a certain technology, based on D5.1 (Novosel et al. 2019).

The CO_2 emissions of the electricity sector have been calculated by multiplying the electricity demand supplied by the grid with the emission factor of power production in Europe, according to the EU Reference scenario 2016: Energy, transport and GHG emissions (Capros et al. 2016). The changes of the emission factor until 2050 are based on the same reference.

The renewable autarkies of both the heating and the electricity sector have been calculated by determining the amount of heat/electricity produced from renewable energy sources and dividing it by the overall heating/electricity demand. It should be noted that for technologies like heat pumps or electric boilers, only the part of heat which was produced by using the electricity from locally installed PVs or wind turbines has been considered for the calculation of renewable autarky.

The LCOH and LCOE have been calculated in a similar fashion by summing up all the discounted investment costs, operation and maintenance costs and fuel costs and dividing them by the overall heating/electricity demand. The investment is discounted by using the Capital Recovery Factor, which was also used to take into account changes in the fuel costs until 2050, based on Capros et al. (2016). For the individual, neighbourhood and city level, LCOH and LCOE calculations were done on the system level, i.e. calculating the overall levelized cost of the electricity/heating sector in the city. For that reason, the cost of electricity/heat supplied from grid or other sources is also taken into account in the calculations. Electricity prices for electricity retrieved from the grid are based on the current electricity prices (Eurostat 2020) and the expected increase in electricity prices in future years (Capros et al 2016). The average increase of electricity prices in Europe of 12 % until 2030 and 10% until 2050 is used for all use cases. In between years the increase from 2015 to 2030 and the decrease from 2030 to 2050 is kept linear. Since the electricity price in the EU Reference scenario is only decreasing slightly by 0.1 % p.a.

between 2030 and 2050 and projections after 2050 are highly uncertain the price for 2050 is kept stable for later years than 2050.

For the country and EU level, another methodology is used with other output. The calculations made on individual, neighbourhood and city level are too specific for the country level. For the methodology and output on country level, see section 5.4.

5.1 Individual level

As described in chapter 2.2, the EPROM requires minutely accurate input for the electricity, warm water and heating demand, the individual composition of the household as well as weather data of the location of the household. To ensure that no outliers occur due to unusual weather conditions during a particular year, all households included are simulated for five consecutive years from 2013 to 2017. An average of these five years is shown in the results section (compare 6.1). As described in chapter 3.1, a typical household from four different countries in four different climate zones is simulated in the years 2015, 2030 and 2050 on an individual level. The assumptions used to model these households are described below.

5.1.1 Individual - Reference scenario

The Reference scenario sets the benchmark for the other scenarios. While the assumptions outlined in detail in this section apply to all three scenarios to ensure comparability, specific assumptions are applied for the Renewables scenario and the Autarky scenario and are described in 5.1.2 and 5.1.3.

Electricity Demand

Based on current figures on total energy need (Capros et al. 2016) and the share of energy for appliances, light and cooking[6] (Eurostat 2019b) the need for electricity per person was calculated. A summary of the results is displayed in Table 4.

To calculate the electricity demand per household, the size of the households as well as the housing type (flats vs. houses) were taken into account, being the major factors for varying electricity demand. Due to a lack of data for France, Netherlands and Spain the varying demand of different household sizes was calculated based on German data.

[6]It is assumed that cooking is done with electricity since the share of fuel in the final energy consumption in the residential sector for cooking is the highest for electricity in France, Germany and Spain (Eurostat 2017) and the majority of households in the Netherlands also own an electric stove (Papachristos 2014)

Table 4 Electricity Need per Person based on (Capros et al. 2016) and (Eurostat 2019b)

	Total Energy Need 2015	**Population**	**Energy Need per person and year**	**Share of Energy for Appliances/Light/Cooking**	**Electricity per Person and year**
	TWh	in Mio.	in kWh	%	kWh
France	456.4	63.0	7,240	23%	1,642
Germany	618.4	80.7	7,661	16%	1,255
Netherlands	111.6	16.9	6,600	20%	1,290
Spain	174.4	46.3	3,764	37%	1,377

Taking into account the share of houses and flats in each country (Eurostat 2011) and the average differences in electricity demand between household sizes and type of housing (Kampagnenbüro des Stromspiegels 2019), the average electricity demand per household in single-family houses was calculated for all locations. For the calculation of electricity demand for 2030 and 2050, it was assumed that the share of houses to flats and the share of energy appliances, light and cooking will not change. Based on the expectations for total energy demand in 2030 and 2050 (Capros et al. 2016) the demand per household was calculated using the same methodology as before for 2015. Hence, the change in electricity demand varies to a small degree between household sizes.

Table 5 Electricity demand for 2, 3 and 4 Person household in 2015, 2030, 2050. Based on Capros et al. (2016), Eurostat (2019a), Eurostat (2019b) and Kampagnenbüro des Stromspiegels (2019)

	Ø Demand 2P HH	**Ø Demand 3P HH**	**Ø Demand 4P HH**	**Change of Demand 2030 vs. 2015**	**Change of Demand 2050 vs. 2015**
	kWh	kWh	kWh	Approx.	Approx.
France	3,867	4,822	5,548	-16%	-29%
Germany	2,924	3,665	4,221	-3.5%	+8%
Netherlands	3,094	3,842	4,432	-10%	-6.5%
Spain	3,483	4,379	5,032	+/- 0%	-2%

Heating demand

The heating demand per household was calculated using the average living space per person and average heating demand per m². Firstly, the living space per person for different household sizes was calculated for each country based on the average total living space (Rovers 2019) and taking into consideration dependencies on number of people living in the household and the type of the building (Statistisches Bundesamt 2019).

Table 6 Average living space per person depending on type of housing and household size based on Statistisches Bundesamt (2019) and Rovers (2019)

	Ø living space	**Ø living space in SFH**	**Ø living space in 2PHH in SFH**	**Ø living space in 3PHH in SFH**	**Ø living space in 4PHH in SFH**
	m^2/pP	m^2/pP	m^2/pP	m^2/pP	m^2/pP
France	39.9	60.50	53.98	38.60	31.06
Germany	42.9	64.89	64.05	45.8	36.85
Netherlands	41	53.62	48.39	34.60	27.84
Spain	33	50.04	50.26	35.94	28.92

Secondly, heating demand per square meter was calculated by the total energy need (Capros et al 2016), share of energy for heating (Eurostat 2017), population size and average living space.

Table 7 Heating demand per m^2 in 2015

	Energy Need per Person in 2015	**Share of Energy for Heating**	**Ø living space per person**	**Energy need per square meter**
	kWh		in m^2	kWh/(m^2a)
France	7,239.6	66.1 %	39.9	119.9
Germany	7,661.3	67.1 %	42.9	119.8
Netherlands	6,600.4	63.6 %	41	102.3
Spain	3,763.6	43.4 %	33	49.5

Finally, the total heating demand per household is calculated by the multiplication of energy demand per square meter (compare Table 6) and average living space per household (compare Table 7).

For the calculation of the heating demand per household for 2030 and 2050 it is assumed that the share of energy for heating and average living space per person remain constant, since we want to compare the same household in different years. The population and total energy demand per household change according to the EU Reference scenario (Capros et al 2016). Based on this calculation the heating demand will decrease in all countries from 2015 to 2030. In 2050, heating demand will fall even more in France and remain constant in Spain. In Germany and Netherlands, energy demand per m^2 will increase. Even though the total energy demand per m^2 might increase in Germany and Netherlands, it seems implausible that the same building will have a higher energy demand in the coming years, due to probable refurbishments and improved insulation. Since the same buildings are observed over the years for this study, we use the same heating demand per m² as in 2030 for Germany and Netherlands. The total heating demand is distributed throughout the year according to a norm profile. The norm profile dependent on ambient temperatures is generated according to Hellwig (2003) and BDEW (2018).

Table 8 Heating demand per m² in 2015, 2030 and 2050

	Energy need per square meter in 2015	**Energy need per square meter in 2030**	**Energy need per square meter in 2050**
	kWh/(m²a)	kWh/(m²a)	kWh/(m²a)
France	119.9	104.2	90.1
Germany	119.8	113.0	113.0
Netherlands	102.3	94.1	94.1
Spain	49.5	47.5	47.5

Warm water demand

The energy demand for warm water contributes 14.8 % of the energy demand in European households (Eurostat 2017). It is assumed that this figure includes losses for storage and distribution inside the house but does not include energy need for heating water inside a washing machine or dishwasher. According to the TABULA framework losses due to storage and distribution are approximately as high as the actual need for energy demand (Loga et al. 2015).

Based on the energy need per person per year (without losses for distribution and storage) (q_N), the heat capacity of water (c), the density of heated water (ρ), the temperature of heated water (ϑ_N) and temperature of ground water (ϑ_k) the amount of warm water used per day (v_N) can be calculated with the following equation:[7]

$$v_N = q_N/(\rho * c(\vartheta_N - \vartheta_k))$$

Ground water temperature is assumed roughly equal to the medium air temperature (NGWA 1999). For calculating medium ground temperature, the years 2013 to 2017 were used. The heated water is assumed to be 40 °C.

[7] Calculation is based on VDI 2067 Blatt 12

Table 9 Warm water demand per person in 2015

	Share of Energy for Warm water	Energy Need per person for Warm water (excl. losses)	Temperature ground water	Mean daily draw-off volume
		kWh	Ø °C	Litre/per Person
France	11.1 %	400	13.6	36
Germany	16.1 %	616	10.1	49
Netherlands	16.7 %	550	10.7	44
Spain	19.1 %	372	13.0	33

For the model, norm profiles according to Jordan and Vajen (2001) are created to spread the demand over the day. For 2030 and 2050, the average daily withdrawal rate is assumed to be equal to 2015, as the majority of this rate comes from personal hygiene, whose demand for hot water is not expected to change in the future.

Electrical devices in households

As described in 2.1, EPROM simulates load profiles of certain devices. The selected devices are based on statistics on consumer technologies present in households and on real available load profiles of the appliances (Instituto Nacional de Estadística 2020; van Thiel 2017; Statistisches Bundesamt 2019; IDEA 2011). Moreover, as indicated in the literature, the proportion of households that own certain devices depends on the number of persons living in the household. As soon as the share of households owning a particular device is above 50 %, it is assumed that the simulated typical household owns this device. Besides smaller devices such as notebooks, toasters and smartphones, the most energy-intensive devices are electro ovens, refrigerators, dishwashers, washing machines and dryers. All these energy-intensive devices, except a dryer, are assumed present in all simulated households. As indicated by the Statistisches Bundesamt (2019), the proportion of households owning a dryer in Germany is only above 50% for 3-5 person households. Dryers are not typically present in Spanish households and due to similar climate conditions, this is also assumed for the Mediterranean part of France (Internal Manager-Institute for Diversification and Saving of Energy 2011).

It is assumed that the ownership of electrical devices for each household does not change in the scenarios for 2030 or 2050. This simplification is made because first, it is not possible to foresee such changes for a long-time span and second, the impact of such changes are not considered to be significant for the calculations. Even though load profiles might change due to higher efficiencies of devices and new or disappearing devices, overall demand is fixed.

Generating Plants

In the Reference scenario in the typical household there are neither for electricity generation nor for heating production EE-prosumer technologies present. Hence, the entire electricity demand is covered by the grid. The electricity price for the electricity from the grid for the four selected countries is calculated according to the methodology outlined in the chapter 4 and shown in Table 10.

Table 10 Electricity Prices from the grid in 2015, 2030 and 2050

	Electricity price in 2015	Electricity price in 2030	Electricity price in 2050
	Cent/kWh	Cent/kWh	Cent/kWh
France	16.8	18.9	18.6
Germany	29.5	33.0	32.5
Netherlands	18.5	20.7	20.4
Spain	23.7	26.6	26.1

The CO_2 emissions associated with electricity from the grid are calculated based on the national energy mix according to the EU Reference scenario (Capros et al 2016) and the specific CO_2 emissions per produced kWh due to different production technologies (Schlömer et al. 2014). Table 11 displays the percentage of production technology per country and CO_2 emissions depending on the technology for electricity generation.

Table 11 Share of sources for electricity generation 2015 and CO_2 emissions of each source of electricity

Technology for Electricity Production	France	Germany	Netherlands	Spain	Emissions in g CO_2 eq/kWh
Nuclear	76,1%	15,0%	3,6%	0,0%	12
Solids	1,5%	42,3%	27,4%	80,0%	820
Gas	4,4%	14,4%	52,7%	6,4%	490
Biomass	1,8%	9,1%	7,8%	8,0%	230
Hydro	10,9%	3,5%	0,1%	0,3%	24
Wind	3,7%	10,2%	6,7%	5,3%	11,5
Solar	1,5%	5,4%	1,0%	0,0%	45
Others	0,2%	0,2%	0,7%	0,0%	-

Multiplying the share of each electricity generation source by the specific emissions in g CO_2 eq/kWh leads to the total emissions of electricity retrieved from the grid in each country. For 2030 and 2050 it is assumed that the specific CO_2 emissions per production remain the same. Multiplying the projected share of each source of electricity production by the associated emissions gives a projection of the CO_2 emissions for electricity from the grid in 2030 and 2050.

Table 12 CO_2 Emissions from the electricity from the grid in 2015, 2030 and 2050

	CO_2 Emissions of electricity from the grid in 2015	CO_2 Emissions of electricity from the grid in 2030	CO_2 Emissions of electricity from the grid in 2050
	g CO_2 eq/kWh	g CO_2 eq/kWh	g CO_2 eq/kWh
France	57	37	51
Germany	494	466	305
Netherlands	435	307	236
Spain	682	627	211

In 2017, gas was the main fuel used to meet heating and warm water needs (Eurostat 2017). Hence, the Reference scenario takes into account a condensing gas-fired boiler to provide hot water and heating. Since condensing boilers already have a high efficiency of almost 100% (Paschotta 2019), no efficiency gains are expected in the future.

To cover the heating demand, the maximum heating load is calculated based on the heating profile generated with the weather data for the years 2013 to 2017 and the annual heating demand. The capacity of the condensing boiler is set to cover the heating need in at least 97.5 % of all-time steps in all of the five years. Since the heating demand is assumed to decrease in the coming years, the capacity needed to cover the heating demand in 2030 and 2050 is slightly lower. To cover the heat demand for warm water, an additional 0.3 kW per person is assumed (Bonin 2009).

Table 13 Assumed capacity in KW of installed condensing boilers

	Installed Capacity 2015 in 2PHH	Installed Capacity 2015 in 3PHH	Installed Capacity 2015 in 4PHH	Change Capacity 2030 vs. 2015	Change Capacity 2050 vs. 2015
	kW	kW	kW		
France	6.6	7.3	7.9	-12%	-22.8%
Germany	6.4	7.0	7.7	-5.2%	-5.2%
Netherlands	4.0	4.5	5.0	-7.0%	-7.0%
Spain	2.5	2.8	3.2	-3.2%	-3.2%

According to Novosel et al. (2019), the costs for the investment and installation of condensing boilers are estimated at 420 €/KW in 2015, 391 €/KW in 2030 and 353.5 €/KW in 2050. The operating and maintenance costs are 1.5 €/KW. Natural gas prices for households varied between 6.3 Cent/kWh for Germany and 9.2 Cent/kWh for the Netherlands (Eurostat 2019b). The average natural gas import prices are predicted to increase in Europe from 40$/BOE in 2015 to 69$/ BOE in 2030 and 79$/ BOE in 2050 (Capros et al 2016). For the time period after 2050, the assumed natural gas price in the model remains stable due to large uncertainties for estimates that lie so far in the future. It is assumed that consumer prices will change accordingly.

Table 14 Natural Gas Prices from the grid in 2015, 2030 and 2050

	Natural Gas price in 2015	Natural Gas price in 2030	Natural Gas price in 2050
	Cent/kWh	Cent/kWh	Cent/kWh
France	7.4	12.7	14.5
Germany	6.3	10.9	12.5
Netherlands	9.2	15.9	18.2
Spain	7.4	12.7	14.5

In this study, only emissions from technologies in operation are considered, i.e. in the case of the Reference scenario only emissions from the combustion of natural gas. The emission factor for natural gas is 179 g CO_2 /kWh (Juhrich 2016).

5.1.2 Individual - Renewables scenario

In comparison to the Reference scenario, the households in the renewables scenario are equipped with low emissions technologies for heat and electricity production. While the generating plants for electricity and heat production are changed in this scenario, assumptions for heat and electricity demand as well as the devices in the household consuming electricity are kept the same to ensure comparability between the different scenarios.

Only certain EE-prosumer technologies are feasible for instalment on an individual level. This part of the study will focus on the most dominant of these technologies. According to the renewable energy progress report solar thermal for heat and PV for electricity production is one of the main sources (7 %) of renewable energy produced in Europe in 2014 (European Commission 2015). While biomass (47 %), hydropower (17 %), wind (11 %) and biofuels (9 %) are renewable energy sources even more relevant on a European level, these are considered less relevant on an individual household level. Additional to solar thermal, heat pumps are main sources of renewable energy for heating (5 %). This technology is especially relevant on an individual level in combination with PV allowing the use of own produced electricity to provide a household with heat. Hence, solar thermal and heat pumps are looked at for household heat provision and PV plants for electricity production.

The amount of solar thermal and PV that can be installed depends mainly on the available rooftop area. To assess the available rooftop area a simplified approach according to Corradini et al. (2012) based on the living space (compare Table 6) is used. Due to building conditions, such as roof slopes or multi-story single family houses, only 50 % of the households living space is considered to be relevant roof top area. Furthermore, it will be assumed that another 10 % of this area cannot be used due to other limitations (e.g. for example chimney, windows or shadow).

On an individual level it will be assumed that in summer 3m² of solar thermal per person can cover most of the need for warm water and heating (The Renewable Energy Hub 2019). The remaining available roof top is used to install PV. In this model, three different PV and solar thermal modules are being modeled for 2015, 2030 and 2050 to reflect increasing efficiencies according to Novosel et al. (2019). The modules for 2030 and 2050 need slightly less m²/kWp and hence the installed capacity increases. All PV modules are in a 35° angle facing south for a maximum production of electricity (Energysage 2020).

Table 15 Assumed kWp per household

	Installed Capacity 2015 in 2PHH	**Installed Capacity 2015 in 3PHH**	**Installed Capacity 2015 in 4PHH**	**Change Capacity in 2030 & 2050**
	kWp	kWp	kWp	
France	6.53	8.17	8.87	2030 vs. 2015
Germany	7.92	10.01	10.98	+23%
Netherlands	5.76	7.14	7.70	2050 vs. 2015
Spain	6.02	7.49	8.09	+32%

To cover the need for heating a heat pump is installed in addition to solar thermal. The capacity of the heat pump is equal to the capacity of a condensing boiler in the Reference scenario. The modelled heat pump is an air to water heat pump being currently the dominant form of heat pumps in Europe (European Commission n.d.). Even though heat pumps are already a mature technology small efficiency gains can be expected for 2030 (+10%) and 2050 (+15%) (Novosel et al. 2019).

For increasing efficiencies of heating plants, a buffer storage will be modelled. The buffer storage allows heat generated by solar thermal and heat pumps to be stored for later use and hence, to increase efficiencies and the use of multiple production technologies in one heating system. The modelled buffer storage has a size of 750 litre, which is considered to be suitable for an individual household (Viessmann n.d.).

Besides the modelled generation plants for electricity and heat an electric vehicle is being modelled. Since electric vehicles change the demand for energy, the comparison between scenarios with respect to emissions and costs is more difficult. Therefore, only the amount of electricity an electric vehicle could additionally consume from self-produced electricity will be displayed. For 2015 the most sold electric vehicle in Europe Nissan Leaf with 36 kWh is modelled (Pontes 2019). With falling prices for batteries and mass production of electric vehicles it is assumed that the trend of past years continues and the battery capacity for electric vehicles is increasing over time. For 2030 the Tesla Model 3 with 72.5 kWh is modelled being already one of the most sold cars in parts of Europe. For 2050 the Tesla Model S, already offering a reach of above 500 Km, is modelled with 95 kWh.

Investment, management and operation costs and lifetime of technologies are based on Novosel et al. (2019). CO_2 emissions of operating solar technologies are zero. As CO_2 emissions for a heat pump depend on the source of electricity, they are also considered zero for self-produced electricity with PV. For electricity retrieved from the grid to run the heat pump, emission factors as in the Reference scenario are used (compare Table 12).

5.1.3 Individual - Autarky scenario

In the Autarky scenario, demand and household devices are equal to the Reference scenario and the Renewables scenario. For electricity and heat production, the same production plants as in the Renewables scenario are modelled. Additionally, batteries are implemented to increase autarky allowing the decoupling of production from consumption to a certain degree. While PV is produced during daylight with a peak at midday, a large part of electricity is consumed during hours with no sunshine when households consume electricity for electric light, cooking and television. The size of the battery is linked to the size of the PV capacity. Hence, for each kWp of installed PV capacity, one kWh battery capacity is being installed to reach a high percentage of autarky (Weniger et al. 2013). Bigger batteries could increase autarky only slightly, since stored electricity in batteries can only be discharged partially at a certain size during night (Weniger et al. 2013). For the Autarky scenario, it will also be observed how much batteries of EV's can increase the amount of self-used electricity. In comparison to the Renewables scenario however, it is simulated that batteries from EV's can not only be charged but also discharged and hence act as an extra storage. Like the Renewables scenario, the implementation of EV's increases the electricity demand and makes comparisons difficult. Hence, the focus of the analysis will lie on the amount of electricity that can be used additionally due to the use as a storage. Battery prices and efficiencies for 2015, 2030 and 2050 are set according to Novosel et al. (2019).

5.2 Neighbourhood level

5.2.1 Ardehuis

The goal of this use case is to show the effect of different technologies in a neighbourhood like Aardehuis in Netherlands (compare 3.2.1). The data provided by Aardehuis is on one hand used for the validation of the simulation results and on the other as a Reference scenario showing the degree of autarky, self-consumption, prices and CO_2 emissions possible in the present. In the Renewable and the Autarky scenario other technologies are implemented. This neighbourhood is modelled using EPROM. Since Aardehuis is a small neighbourhood with only 24 households, consumption patterns of individual households have a large influence on overall self-consumption rates and the use of standardized demand curves is not advisable.

Aardehuis – Reference scenario

As described in chapter 3.2.1 the neighbourhood Aardehuis consists of 24 households located in Netherlands. Without taking electricity demand for heat pumps and the electric vehicle into account the electricity demand per household for appliances and light is currently on average almost at the same level as calculated for Netherlands in Table 5. Therefore, for 2030 and 2050 the same changes in demand for electricity as observed on an individual level will be assumed. For being able to compare results also with figures on the individual level the electricity demand for the one present electric vehicle will not be taken into account in the Reference scenario.

The heating demand is kept constant for 2015, 2030 and 2050 and is covered by the present technologies, i.e. heat pumps and wood stoves. As the buildings in Aardehuis are constructed as "Earthships" they have a lower energy need compared to conventional buildings. The current need for energy of 83 kWh/m² already lies below the energy need of an individual household. Additionally, no major changes in the construction resulting in less energy need can be expected.

For covering the electricity demand it will be assumed that currently installed PV panels of in total 77 kWp will be replaced in 2030 and in 2050 with new panels having a higher efficiency and hence, higher electricity production according to Novosel et al. (2019). The rest of the needed electricity will be retrieved from the grid.

In the Reference scenario the autarky in heat and electricity are calculated based on self-consumption rates provided by the households. Resulting key figures are displayed for the neighbourhood as a whole and not for every individual household. CO_2 emissions for electricity are calculated based on the share of electricity retrieved from the grid and the share of self-produced electricity. For self-produced electricity zero CO_2 emissions are assumed in line with the assumptions made on the individual level. For electricity retrieved from the grid the same CO_2 emissions/kWh values for the Netherlands as in the individual scenario are assumed (compare Table 12). CO_2 emissions for heating are a mixture of emissions for used electricity from the grid to run heat pumps and of CO_2 emissions for burning wood in the wood stoves. CO_2 emissions of burning wood in stoves depend on the type of wood used and how the wood was grown. For wood from a sustainable, reforested source the CO_2 emitted is equal to the CO_2 extracted from the atmosphere and hence, can be considered CO_2 neutral. In this model we assume that burned wood is not from a sustainable, reforested source and hence, not CO_2 neutral. The

CO_2 emitted per kWh is assumed to be 0,39 kg CO_2 / kWh (Quaschnig 2015). Costs for installation and operation and maintenance of wood stoves are according to Hartmann et al. (2019).

Table 16 Heating demand, electricity demand and electricity prices for Aardehuis for 2015, 2030 and 2050 in all the scenarios

	2015	**2030**	**2050**
Heating demand (MWh)	240	240	240
Electricity demand for Appliances and light (MWh)	95	85	89
Electricity prices (€/kWh)	18.5	20.7	20.4
CO_2 *emissions (g* CO_2 eq/kWh)	435	307	236

Aardehuis – Renewables scenario

In the Renewables scenario, the demand for heat and warm water is kept equal to the Reference scenario to ensure comparability. Contrary to the Reference scenario the whole available roof top area is be used to install PV panels and solar thermal. Although, buildings in Aardehuis are predominant single-floored with flat roofs, there are some limitations to solar installations due to shadow and other constructions. Hence, for calculating the available roof top area for solar only 60 % of living space is taken into account resulting in a total of 1.713 m² available for solar energy.

The heat generation is completely covered by solar thermal, heat pumps and electric boilers in order to lower CO_2 emissions compared to the Reference scenario. The heating is generated individually in each household and capacity of needed heat pumps is calculated analogue to the individual case (compare chapter 5.1.2). A total of 77 KW of heat pumps are being installed to cover heating demand. Additionally, an additional 3 m² of solar thermal per person is assumed. Hence, for the 77 inhabitants in total 231 m² of solar thermal is installed. For increasing efficiency and storing solar heat a buffer storage of 750 l per household is modelled.

While heating is generated individually by each household the electricity production is assumed to be owned by the whole neighbourhood. Due to a wider spread of electricity demand and a smoothing of the demand curve a larger share of self-produced electricity can be used. The remaining roof top area not used for solar thermal is used to install PV. With an available rooftop area of 1,713 m² and 231 m² of solar thermal installed there is still space for 1,482 m² of PV. The assumed need of space for PV modules simulated in 2030 are 0.15 Wp/m² and 0.189 Wp/m² in 2050. Hence, the installed capacity increases from 2030 to 2050. All PV modules are in a 35° angle facing south for a maximum production of electricity (Energysage 2019). Table 17 summarizes made assumptions regarding technologies for heating and electricity.

Table 17 Capacities of technologies for heating and electricity assumed for 2030 and 2050 in the Renewables scenario for Aardehuis

	2030	**2050**
Heat pump capacity (kW)	77	77
Solar thermal panels capacity (m^2)	231	231
PV capacity (kWp)	328	349

Aardehuis – Autarky scenario

For the Autarky scenario, the assumptions regarding demand and production of heat and electricity stay the same. In addition, a community energy storage is modelled. When more electricity is produced in the PV panels than the neighbourhood uses the excess electricity will charge the community energy storage. When demand is higher than production the battery will be unloaded, if there is still electricity in the battery. The size of the community energy storage is assumed equal to the size of installed PV capacity. Efficiency of batteries are assumed to increase and prices to decrease slightly in future years according to Novosel et al. (2019).

5.2.2 Lanište

Lanište – Reference scenario

The input data for the Reference scenario has been taken from the previous analysis performed by UNIZAG FSB, mainly from the energy demand map of Croatia developed as a part of the RESFLEX project (Croatian Energy Transition, 2019). Therefore, more detailed data sets were available, making the results of this case more accurate than the city level cases. As mentioned, heat and electricity demand have been acquired from the RESFLEX energy demand map, while it has been accurately assumed that all the buildings in the neighbourhood use individual gas boilers for heating. The electricity is supplied from the electricity grid, i.e. no prosumer technologies are being utilized at the moment. Investment costs for the current system, as well as its operation and maintenance costs were taken from D5.1 (Novosel et al., 2019), while the electricity prices were taken from online database (Statista, 2019). Reference scenario was modelled in the Microsoft Excel software. The output data in the Reference scenario include production from each unit (fuel consumption), overall costs and overall pollutant emissions. The whole Reference scenario, including 2030 and 2050, has also been modelled in Excel.

Main assumptions in the Reference scenario can be listed as follows:

- Existing heat production units used until 2050, only their efficiencies and costs change based on the D5.1
- No renewable prosumer technologies used
- Heat demand changes based on the building refurbishment rate of 0.5% annually, as expected in the Reference scenario for Croatian Low Carbon Strategy (Ministry of Environmental Protection and Energy of the Republic of Croatia, 2017)

- Electricity demand changes based on the average national growth in the last 5 years (Eurostat, 2019)
- Electricity price increases by 12% in 2030 and by 10% in 2050 compared to 2015 (Capros et al., 2016)
- Fuel prices do not change
- The emission factor for power production sector changes according to the EU Reference scenario 2016: Energy, transport and GHG emissions (Capros et al., 2016)

Energy demands and prices are assumed to be the same in all the elaborated scenarios for Lanište. They are shown in Table 18.

Table 18 Heating demand, electricity demand and electricity prices for Laništein 2015, 2030 and 2050 in all the scenarios

	2015	**2030**	**2050**
Heating demand (MWh)	30,109	29,107	27,422
Electricity demand (MWh)	4,000	4,855	5,924
Electricity prices (€/kWh)	0.1312	0.1469	0.1443

Lanište - Renewables scenario

In order to model Renewables and Autarky scenario, the input data needed to be on an hourly level. Therefore, the model required hourly data on heat demand, electricity demand, wind speed, solar irradiation and outside air temperature. Meteorological data has been taken from Meteonorm (Meteonorm, 2019), while the heating demand was transformed into hourly data by using degree hour method (Durmayaz et al., 2000) and the electricity demand was transformed by using the annual electricity demand curve for Croatia (ENTSO-E, 2019). The capacities of the heating and electricity production technologies in this scenario have been defined in such a way that the figures remain realistic and achievable until 2050 and by taking into account maximum amounts of a certain technology per household. This means that the local space boundaries are taken into account since the technologies need to be installed at the site of the consumers or at their vicinity.

Lanište is a neighbourhood in Zagreb and is therefore geographically located in south east Europe, giving it a high potential for the utilization of solar technologies. Furthermore, all of the rooftops in the neighbourhood are flat, providing more available space for the integration of this technology. Also, solar is still rather underutilized in Croatia and such a technology is rather well perceived by the local citizens overall resulting in its high potential. The assumption was made that 50% of the available rooftop space has been covered by solar technologies by 2030 and 100% by 2050, while 65% of it is covered by PV and the rest with solar thermal collectors. When it comes to the term “available area”, it has been calculated by defining the overall rooftop area of the city from the digital cadastre in Croatia (Geoportal, 2019), assuming that all of the rooftops are flat. Then the available area has been reduced by additional 20% in order to take into account chimneys and other objects already placed on the roof. Finally, it was assumed that 65% of the area will be covered by PV and 35% by solar thermal as mentioned before.

Furthermore, since the neighbourhood consists mostly of apartment building blocks with additional available area in the basements/existing boiler rooms, this area can be used for integrating the air to water heat pump units. The assumptions, given the space limits and the exiting heating demand, is that each building has approximately one 60 kW heat pump unit. Furthermore, heat produced from the solar thermal collectors can be stored at the small buffer tanks built for that purpose, which were assumed at 30 m^3 per building by 2030 and double by 2050. These can be installed also in the basement of the building blocks or in the yards surrounding the buildings. Overall capacities of heating production prosumer technologies are shown in Table 19.

Table 19 Capacities of heating technologies assumed for 2030 and 2050 in the Renewables scenario for Lanište

	2030	**2050**
Heat pump capacity (kW)	5,000	5,000
Solar thermal panels capacity (m^2)	6000	12,000
Buffer tank (kWh)	50,000	100,000

Regarding the electricity production technologies, the mean wind speeds were analysed, and it was concluded that they are rather too small for the integration of the wind turbine technologies. Therefore, prosumer technologies used for electricity production in this scenario include only PV panels, as shown in Table 20.

Table 20 Capacities of electricity production prosumer technologies assumed for 2030 and 2050 in the Renewables scenario for Lanište

	2030	**2050**
PV capacity (kW)	1,192	2,384

Lanište - Autarky scenario

The main difference between the Autarky and Renewables scenarios is in the capacity of the storage technologies in order to achieve high shares of autarky of the neighbourhood. For heat, this is achieved by introducing the underground thermal storage systems or so called seasonal thermal storage which can store large amounts of water, i.e. heat. The potential for integration of such storage technologies is high in this neighbourhood due to the green areas available between the building blocks. These can be used for such a purpose.

On the other hand, electricity storage is achieved through electric batteries, where it is assumed that by 2050 there are two 14 kWh battery packs installed per building. Technological details of the battery pack are taken for Tesla Powerwall (Tesla, 2019). The capacities of storage technologies in Lanište autarky are shown in Table 21.

Table 21 Assumed capacities of heat and electricity storage units until for 2030 and 2050 in Autarky scenario for Lanište

	2030	2050
Thermal storage capacity (MWh)	700	1,200
Electric battery capacity (MWh)	1.4	3

5.2.3 Klausenerplatz

Klausenerplatz - Rreference scenario

The input data for Klausenerplatz neighbourhood in Berlin has mostly been received from the consortium partners of the PROSEU project, IÖW. The provided data set included data on overall heating demand, electricity demand, available rooftop area for solar technologies, number of buildings, type of heating system, etc. Costs and technological data of the existing technologies has been taken from D5.1 and the whole scenario has been modelled in Microsoft Excel, as in the previous case. The assumptions of the reference case are:

- Existing heat production units used until 2050, only their efficiencies and costs change based on the D5.1
- No renewable prosumer technologies used
- Heat demand changes based on the building refurbishment rate of 1% annually
- Electricity demand changes based on the average national growth in the last 5 years (Eurostat, 2019)
- Electricity price increases by 12% in 2030 and by 10% in 2050 compared to 2015 (Capros et al., 2016)
- Fuel prices do not change
- The emission factor for power production sector changes according to the EU Reference scenario 2016: Energy, transport and GHG emissions (Capros et al., 2016)

The current energy demands and electricity prices, as well as for 2030 and 2050 are shown in Table 22.

Table 22 Heating demand, electricity demand and electricity prices for Klausenerplatz in 2015, 2030 and 2050 in all the scenarios

	2015	2030	2050
Heating demand (MWh)	6,228	5,791	5,168
Electricity demand (MWh)	1,034	1,143	1,288
Electricity prices (€/kWh)	0.2950	0.3305	0.3246

Klausenerplatz - Renewables scenario

The input data for Klausenerplatz renewables was converted to hourly values by using the same methods as in the previous case. Due to the geographical characteristics, it is expected that the impact of solar technologies will be lower than in the southern European cases. Still, the amount of available space for solar thermal and PV has been taken from the available data set, as mentioned earlier. It has to be mentioned that not all of the available rooftop area is used for solar technologies, since micro wind turbines will also be installed at their site.

Furthermore, heat pump and cogeneration units are assumed to be installed by 2050, with 100 kW micro cogeneration units being installed at 5 buildings (due to their higher installed capacities) by 2050 and 15 kW heat pumps at all the buildings. In order to store the heat from solar collectors, small 15 m^3 buffer tanks are assumed in the basements of the existing buildings by 2030 and 30m^3 by 2050. The capacities of heat production prosumer technologies are shown in Table 23.

Table 23 Capacities of heating technologies assumed for 2030 and 2050 in the Renewables scenario for Klausenerplatz

	2030	**2050**
Heat pump capacity (kW)	500	500
Cogeneration capacity (kW)	500	500
Solar thermal panels capacity (m^2)	3,372	6,744
Buffer tank (kWh)	10,000	20,000

On the other hand, besides the PV and cogeneration technologies being analysed until 2050, the wind speed data showed that the potential for utilizing wind technologies is relatively high and therefore additional wind turbine capacities are assumed, placed on the rooftops of the existing buildings. It has to be taken into account that only micro wind turbines can be built in such a site. Relatively small 2 kW micro wind turbines have been assumed on the rooftops, 21 of them by 2030 and 42 by 2050.

Table 24 Capacities of electricity production prosumer technologies assumed for 2030 and 2050 in the Renewables scenario for Klausenerplatz

	2030	**2050**
PV capacity (kW)	280	560
Cogeneration capacity (kW)	225	225
Wind turbine capacity (kW)	42	84

Klausenerplatz - Autarky scenario

In Klausenerplatz Autarky scenario, electric batteries are added in order to decrease the amount of electricity exported to the grid. One 14kWh battery per building is added until 2030 and two until 2050. Also, higher capacities of thermal storage have been added in forms of larger tanks placed in the inner backyard of the building block, i.e. 2800 m^3 by 2030 and double that amount by 2050. Overall capacities of the storage technologies can be seen in Table 25.

Table 25 Assumed capacities of heat and electricity storage units until for 2030 and 2050 in Autarky scenario for Klausenerplatz

	2030	2050
Thermal storage capacity (kWh)	62,082	124,164
Electric battery capacity (kWh)	490	980

5.3 City level

5.3.1 Ozalj

Ozalj - Reference scenario

The input data for modelling the base year have been taken from previous research by UNIZAG FSB (CoolHeating, 2018). The required data included the overall heat demand of the city, overall electricity demand, share of different technologies used for heating (gathered from surveying as a part of the CoolHeating project), data on national emission factors for electricity from grid, as well as for different fuels used for heating (Rutz et al., 2019), cost data for fuel and electricity, as well as investment costs for the current system (taken from D5.1). The base year has been modelled in Microsoft Excel. The main assumptions for the Reference scenario include:

- Existing heat production units used until 2050, only their efficiencies and costs change based on the D5.1
- No renewable prosumer technologies used
- Heat demand changes based on the building refurbishment rate of 0.5% annually
- Electricity demand changes based on the average national growth in the last 5 years (Eurostat, 2019)
- Electricity price increases by 12% in 2030 and by 10% in 2050 compared to 2015 (Capros et al., 2016)
- Fuel prices do not change
- The emission factor for power production sector changes according to EU Reference scenario 2016: Energy, transport and GHG emissions (Capros et al., 2016)

Heat and electricity demand, as well as electricity prices are assumed to be the same throughout all the scenarios and are presented in Table 26

Table 26 Heating demand, electricity demand and electricity prices for Ozalj in 2015, 2030 and 2050 in all the scenarios

	2015	2030	2050
Heating demand (MWh)	90,920	87,895	82,807
Electricity demand (MWh)	13,425	16,295	19,883
Electricity prices (€/kWh)	0.1312	0.1469	0.1443

Ozalj - Renewables scenario

The input data for Ozalj renewables was formatted in the same way as the previous cases, taking the same national data as Lanište. Since the city is in south east Europe, with relatively high solar irradiation and lower costs for solar thermal technologies, it was assumed that 50% of available rooftop area will be covered by solar technologies by 2030, and 100% of the available area by 2050. Solar is also rather unexploited in Croatia at the moment, therefore having a significant potential and it is recognized by citizens as a sustainable technology.

The available area has been calculated like the Lanište case, with some differences. It has been calculated by defining the overall rooftop area of the city from the digital cadastre in Croatia (Geoportal, 2019), assuming that all of the rooftops are sloped. Than the available area has been calculated by dividing this number by 2, since the panels are expected to be installed only on the southern side and reducing it by additional 20% in order to take into account chimneys and other objects already placed on the roof. Finally, it was assumed that 65% of the area will be covered by PV and 35% by solar thermal. A small 10 m^3 buffer system has been assumed per building until 2030 and 20 m^3 until 2050 in order to store the extra heat production during the day for the night hours.

Another interesting technology for this area is the heat pump, which could use various heat sources for its operation. In these scenarios, an air to water heat pump has been analysed. Its capacity has been determined by assuming one 10 kW unit per building. It must be noted that the heat pump will increase the overall electricity consumption of the city by a large margin and therefore increase the overall utilization of the PV system. Electric heaters have also been assumed at one 10 kW unit per building, adding on the thermal capacity of the system.

Finally, in order to cover the remaining heat demand, it is expected that the biomass district heating system will be built, taking into account the local political conditions, since such system is planned to be built in the next couple of years. However, even if such system is not built, the amount of heat it supplies to the final users could represent any other type of heating, e.g. the fossil fuel or biomass boilers that are still being used. Therefore, it presents an exogenous variable in the modelling. The assumed capacities of the heating technologies for 2030 and 2050 can be seen in Table 27.

Table 27 Capacities of heating technologies assumed for 2030 and 2050 in the Renewables scenario for Ozalj

	2030	**2050**
Heat pump capacity (kW)	10,670	10,670
Electric boiler capacity (kW)	10,670	10,670
Solar thermal panels capacity (m^2)	17,430	34,425
Buffer tank (kWh)	264,200	528,410

Regarding electricity production, the only prosumer technology will be the PV system on the rooftop, since the mean wind speeds are not high enough to install wind turbines, while small and micro cogeneration units would not be that easy to build due to the lack of space when the geographic characteristics of the city and the existing technologies are taken into account. Therefore, the rest of the demand will be covered by the electricity grid. The assumed capacity of PV for 2030 and 2050 is shown in Table 28.

Table 28 Capacities of electricity production prosumer technologies assumed for 2030 and 2050 in the Renewables scenario for Ozalj

	2030	**2050**
PV capacity (kW)	3,464	6,841

Ozalj - Autarky scenario

The capacities of the heat and electricity production technologies, as defined in the Reference scenario remain the same in the Autarky scenario. However, in this scenario the idea is to increase the capacities of storage technologies so that the maximum autarky of the system is achieved. Same as in the Reference scenario, the capacities have been defined so that the installed capacities per household are in a realistic range and are not exaggerated.

In order to increase the production from the solar thermal collectors, a larger thermal storage is needed. For that reason, usually an underground storage is built with capacities of up to 1 million m^3 or even more. However, in these scenarios it is assumed that no single large storage unit is being built but rather a number of small units, each corresponding to one household. Still, the underground storage is considered here in such a way that a certain number of neighbouring houses share one larger underground storage. Other heat production units are also allowed to store heat in these systems.

From the electricity production side, an electric battery is added in order to decrease the number of hours when electricity is exported to the grid in order to achieve a higher degree of self-sustainability. It is assumed that by 2050 each household has two 14 kWh battery packs. The capacities of both the heat and electricity storage in the Autarky scenario are shown in Table 29.

Table 29 Assumed capacities of heat and electricity storage units until for 2030 and 2050 in Autarky scenario for Ozalj

	2030	**2050**
Thermal storage capacity (MWh)	660	1,321
Electric battery capacity (MWh)	14.5	29

5.3.2 Girona

Girona - Reference scenario

The input data for modelling the base year in Girona have been taken from various online databases. Similar to previous cases, the required input data consisted of the heating demand, acquired from the Hotmaps project (Hotmaps, 2019) and the electricity demand acquired from the municipality of Girona (Girona Open data, 2019). Furthermore, due to the lack of more detailed data, it was assumed that all the households use natural gas boilers for heating and do not have any prosumer technologies for electricity production. All the technological data and costs of the existing system until 2050 have been taken from D5.1.

The base year has been modelled in Microsoft Excel as in previous case and the output data of the model remain the same. The main assumptions for the Reference scenario include:

- Existing heat production units used until 2050, only their efficiencies and costs change based on the D5.1
- No renewable prosumer technologies used (rough assumption due to the lack of more precise data)
- Heat demand changes based on the building refurbishment rate of 1% annually
- Electricity demand changes based on the average national growth in the last 10 years (Eurostat, 2019)
- Electricity price increases by 12% in 2030 and by 10% in 2050 compared to 2015 (Capros et al., 2016)
- Fuel prices do not change
- The emission factor for power production sector changes according to the EU Reference scenario 2016: Energy, transport and GHG emissions (Capros et al., 2016)

Heat and electricity demand, as well as electricity prices are assumed to be the same throughout all of the scenarios and are presented in Table 30.

Table 30 Heating demand, electricity demand and electricity prices for Girona in 2015, 2030 and 2050 in all the scenarios

	2015	**2030**	**2050**
Heating demand (MWh)	342,570	318,696	284,428
Electricity demand (MWh)	451,840	390,504	324,735
Electricity prices (€/kWh)	0.2309	0.2586	0.2539

Girona - Renewables scenario

The structure of the input data for Renewables and Autarky scenarios remains the same as in the previous use cases. Meteorological data has also been taken from Meteonorm (Metonorm, 2019), heat demand calculated by using degree hour method and the electricity demand transformed by using the annual electricity demand curve for Spain (ENTSO-E, 2019).

Due to the location of the city in the southern Europe, the emphasis was put on the utilization of the solar technologies due to their higher yield and lower costs in these regions. However, the data on the rooftop areas in the city was not available and was therefore assumed. The rough assumption, made by visually inspecting the aerial view of the city, was that 2.5% of the overall city area could be covered by solar technologies. Then, the assumptions for 2030 and 2050 were the same as in the previous cases, i.e. only 50% of the available area is covered until 2030 and 100% until 2050, with 35% being covered by solar thermal and 65% by PV. A small 5m^3 buffer system has also been assumed per building by 2030 and 10m^3 unit by 2050.

Furthermore, air to water heat pumps and electric heaters have also been analysed in this scenario, assuming one 10 kW unit in every fifth building for both technologies. Since the heating demand is decreasing until 2050, the capacities of all the heat production technologies, except the solar thermal, remain the same both in 2030 and 2050. The capacities of the prosumer heating technologies are shown in Table 31.

Table 31 Capacities of heating technologies assumed for Girona in 2030 and 2050 in the Renewables scenario

	2030	**2050**
Heat pump capacity (kW)	19,898	19,898
Electric boiler capacity (kW)	19,898	19,898
Solar thermal panels capacity (m^2)	420,000	840,000
Buffer tank (kWh)	1,102,846	2,205,693

When it comes to the electricity production technologies, only the PVs are considered until 2050. Wind technologies have not been considered since the mean wind speed in the area is below 3 m/s on the annual level. The remaining electricity demand will be covered by the electricity grid. The capacities can be seen in Table 32.

Table 32 Capacities of electricity production prosumer technologies assumed for 2030 and 2050 in the Renewables scenario for Girona

	2030	**2050**
PV capacity (kW)	83,460	166,920

Girona - Autarky scenario

Like the previous use cases, the production capacities of electricity and heat production units remain the same as in the Reference scenario. The changes occur in the capacity of energy storage technologies in order to achieve highest degree of autarky possible. Therefore, for the electricity storage, one battery pack is assumed per building until 2030 and two battery packs until 2050, due to significantly higher installed capacities of PV than previous cases.

For thermal storage, a 2.5 times higher capacity is assumed in comparison with the Reference scenario in order to utilize as much as possible solar thermal energy. Here, several underground seasonal thermal storage units are considered due to the characteristics of the city and the high potential for such a technology. The capacities for heat and electricity storage technologies are shown in Table 33.

Table 33 Assumed capacities of heat and electricity storage units until for 2030 and 2050 in Autarky scenario for Girona

	2030	2050
Thermal storage capacity (MWh)	11,028	22,057
Electric battery capacity (MWh)	139	279

5.3.3 Bristol

Bristol - Reference scenario

As in previous cities which have been modelled as a part of this analysis, the same input data was also required for the city of Bristol. Data was also gathered from the online databases and D5.1 mostly, including the overall heat demand of the city (Hotmaps, 2019), overall electricity demand (Centre of Sustainable Energy, 2009), share of different technologies used for heating (received from the PROSEU consortium partners UNILEEDS) and data on various costs (D5.1) and emission factors of the existing system.

The calculations of the Reference scenario have also been done in the Microsoft Excel software. The main assumptions that have been made until 2050 are:

- Existing heat production units used until 2050, only their efficiencies and costs change based on the D5.1
- No renewable prosumer technologies used (rough assumption due to the lack of more precise data)
- Heat demand changes based on the building refurbishment rate of 1% annually
- Electricity demand changes based on the average national growth in the last 10 years (Eurostat, 2019)
- Electricity price increases by 12% in 2030 and by 10% in 2050 compared to 2015 (Capros et al., 2016)
- Fuel prices do not change
- The emission factor for power production sector changes according to the EU Reference scenario 2016: Energy, transport and GHG emissions (Capros et al., 2016)

Similar to the previous cases, the heat and electricity demand changes are the same for all of the scenarios and are shown in Table 34.

Table 34 Heating demand, electricity demand and electricity prices for Bristol in 2015, 2030 and 2050 in all the scenarios

	2015	2030	2050
Heating demand (MWh)	3,554,000	3,305,220	2,949,820
Electricity demand (MWh)	1,931,000	1,567,515	1,187,291
Electricity prices (€/kWh)	0.2125	0.2380	0.2338

Bristol - Renewables scenario

The structure of the input data is the same as in the previous cases, including the sources used for the meteorological data, while the electricity demand was transformed by using the annual electricity demand curve for United Kingdom (ENTSO-E, 2019).

Contrary to the previous cities being analysed, Bristol is in northern Europe, meaning that the yield of the solar technologies will be significantly lower than for the southern Europe. However, this will be complemented by other prosumer technologies as elaborated in the next paragraphs.

It is still assumed that a certain amount of solar technologies will be installed on the rooftops. Due to the lack of the more detailed data on the rooftop area, the available space for its installation has been defined as 5% of the overall city area and the shares of PV and solar thermal have been kept the same as in previous cases. Furthermore, it was assumed that 5% of households (only building blocks) have installed a mini cogeneration 100kW unit at their site. Electric boilers have not been taken into account in this use case, as well as the heat pumps. Furthermore, a 10 m^3 buffer storage is also assumed to be installed at one third of households until 2050. The capacities of the heating technologies can be seen in Table 35.

Table 35 Capacities of heating technologies assumed for Bristol in 2030 and 2050 in the Renewables scenario

	2030	**2050**
Solar thermal panels capacity (m^2)	2,030,000	4,060,000
Cogeneration thermal capacity (kW)	743,030	743,030
Buffer tank (kWh)	6,589,844	10,983,073

When the wind speed data was inspected, the conclusion has been made that there is a high potential for the utilization of the wind energy. Therefore, alongside PV and cogeneration, micro wind turbines are assumed to be built until 2050, with a quarter of households owning a 10 kW wind turbine until 2030 and half of them until 2050. The remaining electricity demand will be covered by the electricity grid. The capacities can be seen in Table 36.

Table 36 Capacities of electricity production prosumer technologies assumed for 2030 and 2050 in the Renewables scenario for Bristol

	2030	**2050**
PV capacity (kW)	403,390	806,780
Cogeneration electric capacity (kW)	334,363	334,363
Wind turbine capacity (kW)	371,515	743,030

Bristol - Autarky scenario

Finally, in the Autarky scenario, the overall installed capacities of prosumer technologies in Bristol remain the same as in the Reference scenario but significantly higher capacities of storage technologies are added in order to increase the level of overall energy self-sustainability in the city.

For that reason, the underground thermal storage units have been assumed, with overall around 5,000,000 m^3 of storage volume until 2050 in the city. Due to the high amount of green areas, it is concluded that it will not be a problem to install such a capacity in the city. Furthermore, it is assumed that by 2030 a fifth of the households in Bristol have installed a 14 kWh electric battery pack. This figure is assumed to increase by 2050 to half of the existing households in order to decrease the export of the renewable electricity to the grid. The installed capacities of the storage technologies in the Autarky scenario are shown in Table 37.

Table 37 Assumed capacities of heat and electricity storage units until for 2030 and 2050 in Autarky scenario for Bristol

	2030	**2050**
Thermal storage capacity (MWh)	65,898	109,830
Electric battery capacity (MWh)	416	1,040

5.4 Country level

In this paragraph the methodology used in CEPROM is further elaborated: which technologies are included. under which conditions are they used, what are the main assumptions? Key parameters are selected to decide which technology suits best in which situation. The key parameters that are taken into account are:

Type of building

Different types of buildings have different heating and electricity demands. Also, they have different opportunities for generating energy, because, for example, they do not have the same amount of area available on the roof top. The model distinguishes three types of buildings:

- Individual households
- Multifamily households
- Utility buildings

Degree of population density

The population density of an area determines the availability of space for renewable energy production. More space means in general more opportunities to locally generate energy. but also means less suitable for large scale heating technologies such as district heating. The model distinguishes three levels of population density:

- Urban
- Suburban
- Rural

Type of energy citizen

The type of energy citizen is mainly important for the generation of energy. Households can generate energy individually but can also set up or join energy collectives. It is assumed that multifamily households that generate energy always participate in collectives to do so. The tertiary sector can generate energy on their own buildings or, if enough space is available. around their building. The model distinguishes three types of energy citizens:

- Households
- Collectives
- Tertiary sector

Biomass availability for the use of biomass in heating technologies

Biomass is seen as a prosumer technology in regions where biomass is locally available. The model uses the average availability of woodland per household in each country to determine if biomass can be used as a prosumer technology. The model distinguishes three categories:

- Average of less than 0.5 hectare of woodland per household
- Average of between 0.5 and 1.0 hectare of woodland per household
- Average of more than 1.0 hectare of woodland per household

Number of cooling degree days (CDD)[8]

If cooling is needed in households or utility buildings. a technology to generate cooling is needed. In case a heat pump is applied for heating, no separate technology for cooling is needed, so the model prefers to use a heat pump when there is a significant cooling demand. The model distinguished three categories of cooling demand:

- Less than 20 CDD (no cooling needed)
- Between 20 and 50 CDD (cooling is only needed in utility buildings)
- More than 50 CDD (cooling is needed in residential and utility buildings)

To decide which technology can be applied in which situation, the main starting point is to use as much as possible renewable energy generated by the prosumers. In the paragraphs below, for each technology, the conditions and assumptions for the use of that technology are elaborated. An overview of the key parameters, the used data and the choice of technologies can be found in the appendix, section 9.

It should be noted that CEPROM is not a detailed optimization model. In reality, using the maximum share of renewable energy generated by consumers, is not necessarily always the situation that is most desirable. The social and technical consequences of going fully for an energy system driven by prosumers is not taken into account in the model. The outcome of the model shows the technical potential that could be achieved, but the costs of such a change in energy system and the effort in organizing this change are not taken into account.

For the Renewables scenario and Autarky scenario, the technical potential of all prosumer technologies is calculated for 2050. A linear interpolation between 2015 and 2050 is used to determine values for 2030.

5.4.1 Heating/cooling generation

CHP

In CEPROM, cogeneration or combined heat and power (CHP) is seen as a prosumer technology if the energy carrier that is used is produced by the user itself. In case of the CHP, this is only the case if biomass is used which is grown on the property of the user itself. With this definition, you need a certain amount of woodland[9] in the country to be able to say in general that there is enough biomass to feed the CHP. Furthermore, it is likely that only households or utility buildings in rural areas have enough

[8] With the Cooling Degree Days index (CDD), the yearly need for cooling can be calculated. If the average mean air temperature throughout a day is higher than 24°C than there is a cooling demand. The amount of CDD per day = Average day temperature - 21°C (Eurostat)

[9] Other types of biomass and locally produced biogas can also be used for a CHP, but these are not taken into account.

biomass of their own to meet the heat demand. Finally, a CHP is not likely to be used by individual households, since the technology asks for a fairly stable energy demand and is rather expensive for an individual household.

We therefore assume that CHP can be used by prosumers in a certain region under the following conditions:

- Average of at least 0.5 hectare of woodland per household
- Only in rural area
- Only in combination with multifamily households and utility buildings
- Both in Renewables scenario and Autarky scenario

Biomass boiler

Similar to CHP, the biomass boiler can be seen as a prosumer technology if the biomass that is used, is produced by the prosumer itself. This means that the prosumer should have enough biomass on his own property to meet the heat demand. With this definition, you need a certain amount of woodland in the country to be able to say in general that there is enough biomass to feed the biomass boiler. Furthermore, it is likely that only households or utility buildings in rural area have enough biomass of their own to meet the heat demand. In the model. the biomass boiler is only used by individual users.

Conditions and assumptions:

- Average of at least 0.5 hectare of woodland per household
- Only in rural area
- Only in combination with single family households. Multifamily households or tertiary buildings will use a CHP in case they have enough biomass.
- Cooling demand of less than 50 cooling degree days. In case there is a significant cooling demand. the heat pump is preferred over the biomass boiler, because the heat pump can also cool the building with a high energy efficiency.
- 50% of single-family households, under the above conditions, with an average between 0.5- and 1.0-hectare woodland per household
- 100% of single-family households, under the above conditions, with an average of more than 1.0 hectare woodland per household
- Both in Renewables scenario and Autarky scenario

District heating

District heating can be a collective prosumer technology, if the connected households or utility buildings are part of an energy collective that is the owner of the heat grid and heat source. The heat source should in this case be renewable and local, for example a geothermal plant or a biomass CHP plant with local biomass. It is hard to determine in general that a certain heat grid can meet these conditions.

Therefore, district heating in the model is seen as non-prosumer technology. Heat grids are in general more suitable in urban areas where the population density is high.

Conditions and assumptions:

- Only in urban area
- Residential buildings with less than 50 cooling degree days
- Utility buildings with less than 20 cooling degree days
- Both in Renewables scenario and Autarky scenario

Heat pump

A heat pump is a technology that uses the heat from surroundings (air/ground/water) and is driven by electricity. This technology can be seen as a prosumer technology when the heat pump is installed next to a residential building or utility building which uses the heat itself. An advantage of the heat pump is that it can also produce cooling with energy from the surroundings. Heat pumps could be used in both areas with a low and a high population density. Heat pumps are more efficient in buildings with a low, continuous heat demand. For buildings with a high heat demand, this may imply that they need extra insulation and another heat transfer system, such as low temperature radiators or floor heating.

Conditions and assumptions:

- Residential buildings in urban area with a cooling demand of more than 50 cooling degree days
- Utility buildings in urban area with a cooling demand of more than 20 cooling degree days
- All buildings in suburban area
- All buildings in rural area in member states with an average of less than 0.5 hectare woodland per household (otherwise buildings use a biomass boiler or a CHP)
- 50% of single-family households, under the above conditions. with an average between 0.5- and 1.0-hectare woodland per household
- Both in Renewables scenario and Autarky scenario

Solar thermal

Solar thermal energy can be used to capture the heat from the sun. In our model, this technology is combined with other technologies, since solar thermal on itself will not produce enough heat to cover the heat demand of a building, especially not in winter when demand is highest. If it is used by a prosumer, it will be placed on the rooftop of a building. In our model, it is only used as an option for individual households or utility buildings to produce (part of) the heat for tap water. A small buffer tank is also applied to store the heat for a few days. Solar thermal competes with PV panels in terms of needed roof top area. Under the conditions and assumption mentioned below, all solar thermal panels are applied to cover the demand. The remaining roof area is available for solar PV panels.

Conditions and assumptions:

- It is only used to generate heat for hot tap water
- In case it is applied, it could only generate 50% of the energy demand for hot tap water
- It is applied in combination with district heating. It is only used to cover 50% of the demand for tap water. but the heat could also be inserted into the heat network.
- It is applied in combination with CHP and biomass boilers. Less biomass is needed when part of the heat is produced by solar thermal
- It is not applied in combination with heat pumps, since heat pumps need a lot of electricity that can be generated with PV-panels

5.4.2 Electricity generation

In the model. there are five technologies taken into account to generate electricity:

1. Solar PV on rooftops
2. Solar PV on land
3. Wind turbines
4. Hydro power (small scale)
5. CHP

Not all electricity generated with these five technologies can be assigned to prosumers. For wind turbines and ground based solar PV, it is assumed that only the electricity generated from wind turbines and solar parks within 5 km around a city or town (each type of population density area) is assigned to prosumers that live or are situated in that area, see Figure 12 and Figure 13. Overlapping areas are filtered out, to determine the available area that can be used for wind and ground based solar. Another assumption is that wind turbines and ground based solar are not placed in urban or suburban areas. because in general there is not enough space left for energy generation. Not the whole 5 km zone is assumed to be suited for electricity generation: specific criteria are used for both solar and wind within the boundaries of the area.

The technical potential of wind energy is based on the article 'Wind potentials for EU and neighbouring countries' (Dalla Longa, et al., 2018). For ground based solar, it is assumed that 3% of bare land is available for solar parks ((Ruiz, et al., 2019); (JRC, ongoing). It is assumed that around cities, the percentage of bare land is the same as elsewhere in the country. To determine per member state if prosumers invest in wind or ground based solar energy, climate conditions are taken into account.

It is also assumed that prosumers do not generate more electricity than what they need for consumption themselves. The model adds up all electricity that is needed for electric devices, heat technologies and electric vehicles and aims to cover that in the Renewables scenario and the Autarky scenario with as much generation of electricity by prosumers as possible.

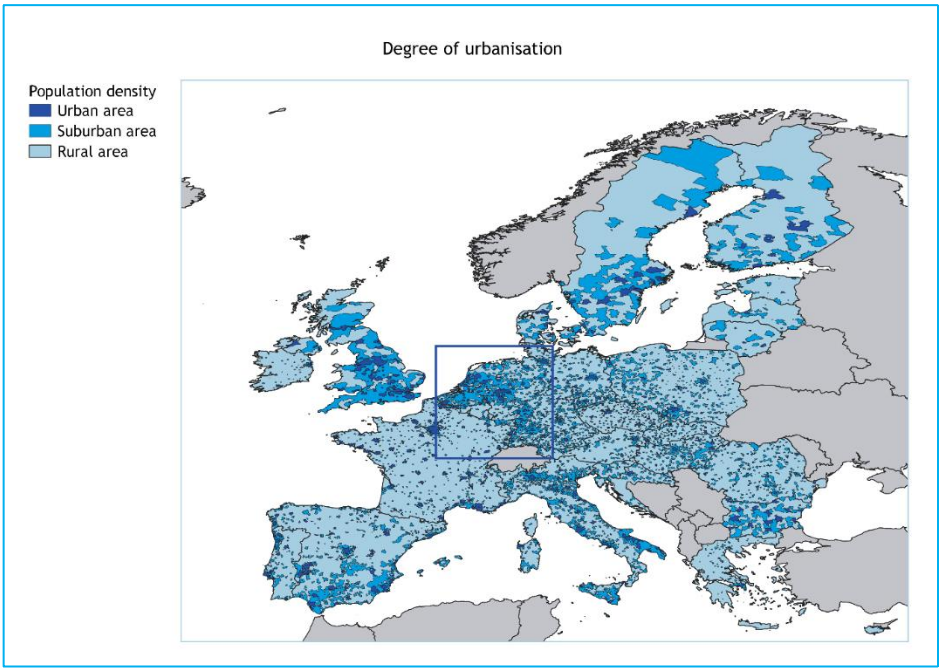

Figure 12 Degree of urbanisation with location to zoom in for buffer zone maps

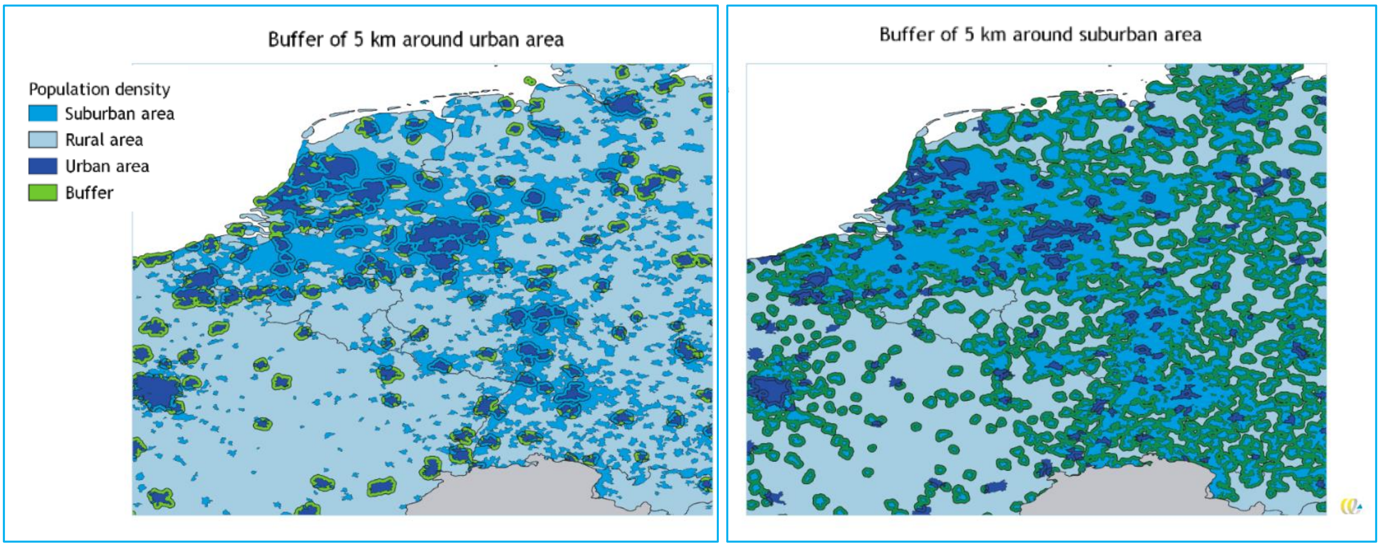

Figure 13 Impression of buffer zones

Finally, it is assumed that small scale hydro power and solar PV on land are both technologies that can only be invested in by energy collectives. Collectives consist of groups of individual or multifamily households. The tertiary sector can generate energy by solar PV on rooftops and, if they have enough space around their building, by using small wind turbines.

The methodology to decide on which technology will generate the electricity demand of the prosumers, is placed in the decision tree in Figure 14. It is assumed that solar panels on roofs are preferred over collective options like hydro, solar parks and wind farms. In case CHP is used as a heating technology, it is assumed that all electricity that is generated is used. Furthermore, it is assumed that the production of each technology in Reference and Autarky scenario will not be lower than the production in the Reference scenario.

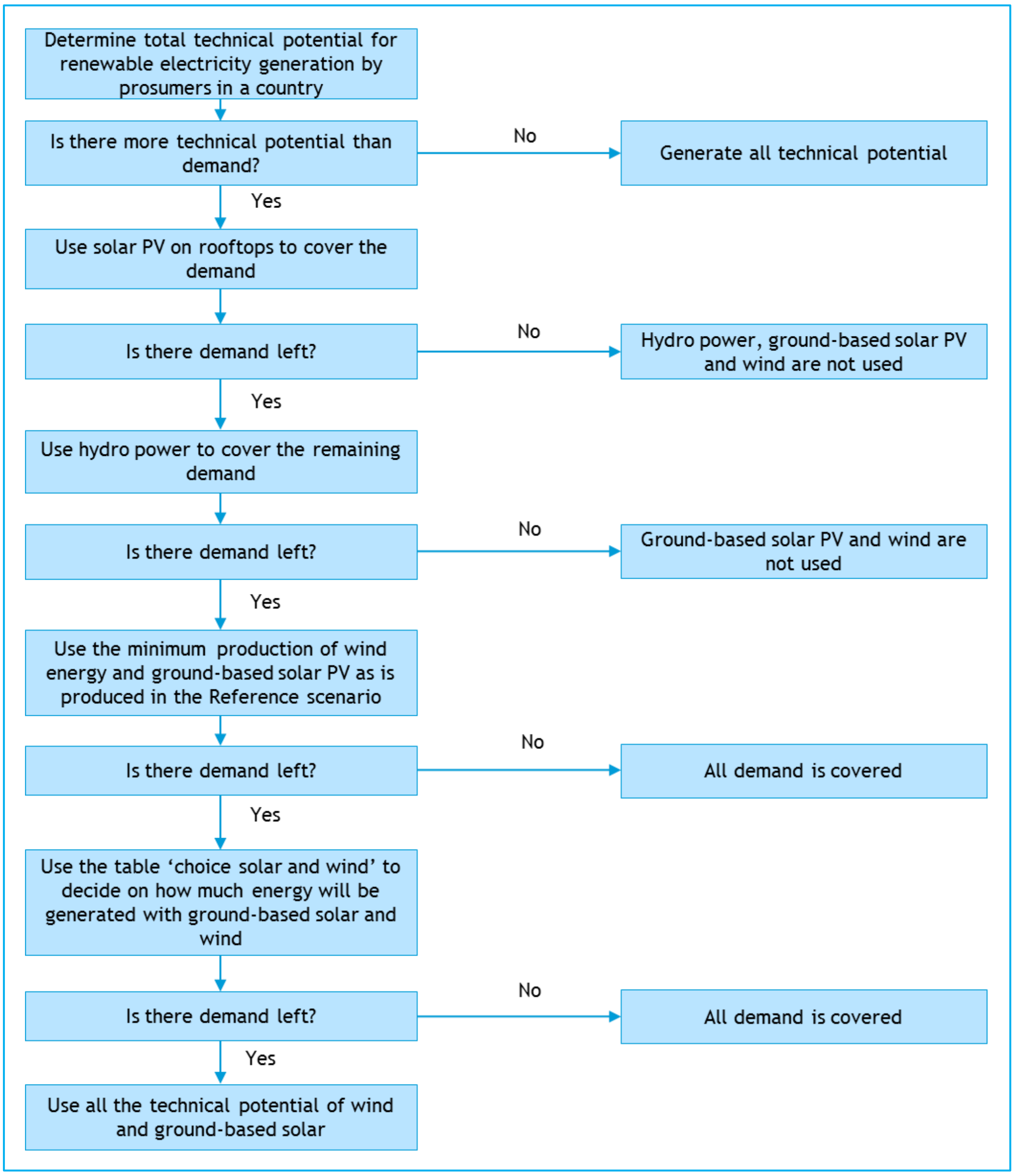

Figure 14 Decision tree on how to decide which technology is used to fill the electricity demand

In case the technical potential of energy generated by solar parks and wind energy is higher than the demand, a choice between the two is made by the model. This choice depends on the average solar irradiation and power density in the country. This choice is based on the yield of each technology. In countries with high solar irradiation. solar PV is financially and spatially a good option. For countries with high wind power density, wind turbines give good revenues. CE Delft has categorized the solar irradiation and power density of wind in three categories. that indicate a low, middle or high solar irradiation or wind power density, see Figure 15.

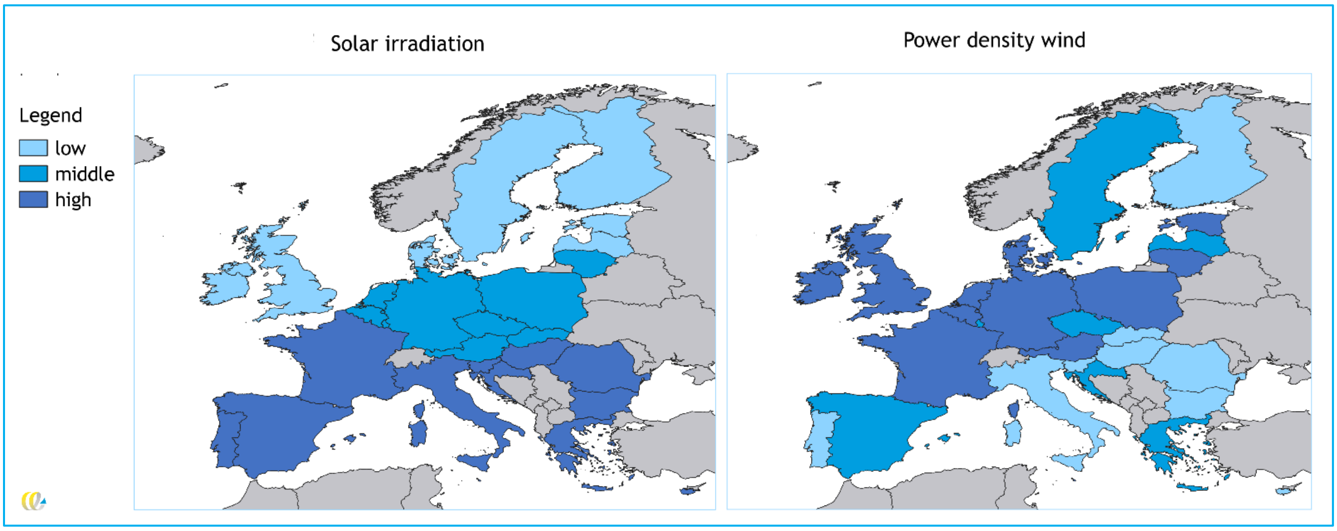

Figure 15 Solar irradiation and power density of wind

In Table 38 the choice on what percentage of prosumers will potentially invest in which technology is presented.

Table 38 Choice between solar parks and wind turbines

Combination	**Power density of wind (W/m²)**	**Solar irradiation (kWh/m²/year)**	**Choice**
1	< 275	< 1,000	Both (50% wind/50% solar PV)
2	< 275	1,000 – 1,250	Both (25% wind/75% solar PV)
3	< 275	> 1,250	100% solar PV
4	275 – 350	< 1,000	Both (75% wind/25% solar PV)
5	275 – 350	1,000 – 1,250	Both (50% wind/50% solar PV)
6	275 – 350	> 1,250	Both (25% wind/75% solar PV)
7	> 350	< 1,000	100% wind
8	> 350	1,000 – 1,250	Both (75% wind/25% solar PV)
9	> 350	> 1,250	Both (50% wind/50% solar PV)

Wind

Wind turbines is one of the technologies that can be used by prosumers to generate electricity. The potential production of electricity with wind turbines depends on the power density of wind which is different for each member state.

Conditions and assumptions:

- Wind turbines are not placed by individual households, only collectives (which could include individual households) and the tertiary sector invest in wind
- Utility buildings need enough space around their building to place a wind turbine. It is assumed that only utility buildings in rural area potentially have their own wind turbine.
- Collectives in all types of population density areas could participate
- The choice between wind turbines and solar parks is represented in the Table 38.

5.4.3 Solar

PV panels can be placed on rooftops or in ground-based solar parks. The current electricity generation of solar PV and the forecast for 2030 and 2050 per member state as calculated by PRIMES for the EU Reference scenario are used in the model for the Reference scenario. The current distribution of solar PV over residential roofs, commercial roofs and ground-based parks is taken from the EU market Outlook (Solar Power Europe. 2019).

Solar roofs

Solar PV can be placed on rooftops of residential and utility buildings. The technical potential depends on the solar irradiation and the available rooftop area. It is assumed that 40% of the available rooftop area can be used for solar energy (Defaix, et al., 2012). Solar PV competes with solar thermal for available roof area. In the paragraph on solar heat, assumptions for applying solar heat are stated. The rest of the available roof area is utilized by solar PV.

Conditions and assumptions:

- All types of energy citizens can use solar PV on rooftops
- Multifamily houses can place solar PV on their rooftops in the form of collectives
- In all climate conditions, solar PV on rooftops can be applied
- In all types of population densities, solar PV on rooftops can be applied

Ground based

Solar parks can be placed on bare land. It is assumed that 3% of the bare land[10] can be used (P. Ruiz. 2019). It is assumed that only the electricity generated from solar parks within 5 km around each type of population density area is assigned to prosumers that live or are situated in that area. see Figure 13.

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[10] Area with no dominant vegetation cover. It is assumed that bare land can be used for solar parks since it is not used for other purposes.

Conditions and assumptions:

- Only collectives invest in ground-based solar PV
- Collectives in all types of population density areas could participate
- The choice between wind turbines and solar parks is represented in the Table 38.

Hydro power (small scale)

Hydro power is also a technology to generate electricity. The current electricity generation of hydro power and the forecast for 2030 and 2050 per member state from PRIMES are used for the Reference scenario. For the Renewables and Autarky scenario, the technical potential mentioned in a study of EC is used (EC, SETIS, 2011). To determine the share of hydro power of prosumers, only small hydro power projects are taken into account. At this moment, only a very small part of the hydro power projects are owned by collectives. In the model it is assumed that in 2030 and 2050, 20% of the new small hydro power projects can be owned by prosumer collectives.

Conditions and assumptions:

- Technical potential in Reference scenario are used for Renewables and Autarky scenario
- Only collectives can generate electricity with hydro power

CHP

The CHP generates both heat and electricity. The conditions under which the CHP is applied in the model, are described in the previous paragraph. It is assumed that all electricity produced by the CHP is used when a CHP is placed to cover for heating demand.

5.4.4 Energy storage

In the Autarky scenario, prosumers are likely to use options to store heat or electricity. The aim is that prosumers will use, as much as possible. the energy that they have generated directly or from heat storage or battery storage. The share of energy needed from the grid is in this scenario as small as possible. If we look at electricity, it is technically possible to store all energy produced by prosumers in batteries so that they can use energy from the battery all year long. This, however, leads to really large batteries, which is not desirable from a practical point of view. taking into account economic, sustainability and spatial aspects. The same can be argued for heat: self-produced heat can also be stored in very large buffer tanks, but this is costly and not desirable if we look at cost and spatial aspects. In the model, we optimize the size of energy storage economically. Only if an increase in battery size leads to a significant increase in share of autarky, it is applied.

Heat storage

It depends on the heat technology that a prosumer uses if storage of heat is desirable.

ATES

Aquifer thermal energy storage (ATES) can be applied to store heat and cold for the heating and cooling of buildings. The advantage is that less energy is needed to heat and cool the building, because the energy is already stored in the ground. This way, a higher degree of autarky can be reached. The construction of an ATES has a large impact on the surroundings, therefore it is assumed that it will, under the conditions and assumptions mentioned below, only be placed in combination with newly build residential and utility buildings.

Conditions and assumptions:

- Always in combination with a heat pump
- Only in combination with multifamily households or utility buildings
- Only in newly build buildings
- In combination with utility buildings when the amount of cooling degree days is higher than 20.
- In combination with multifamily households when the amount of cooling degree days is higher than 50.
- The subsurface conditions of the member state need to be suitable (see Figure 16).

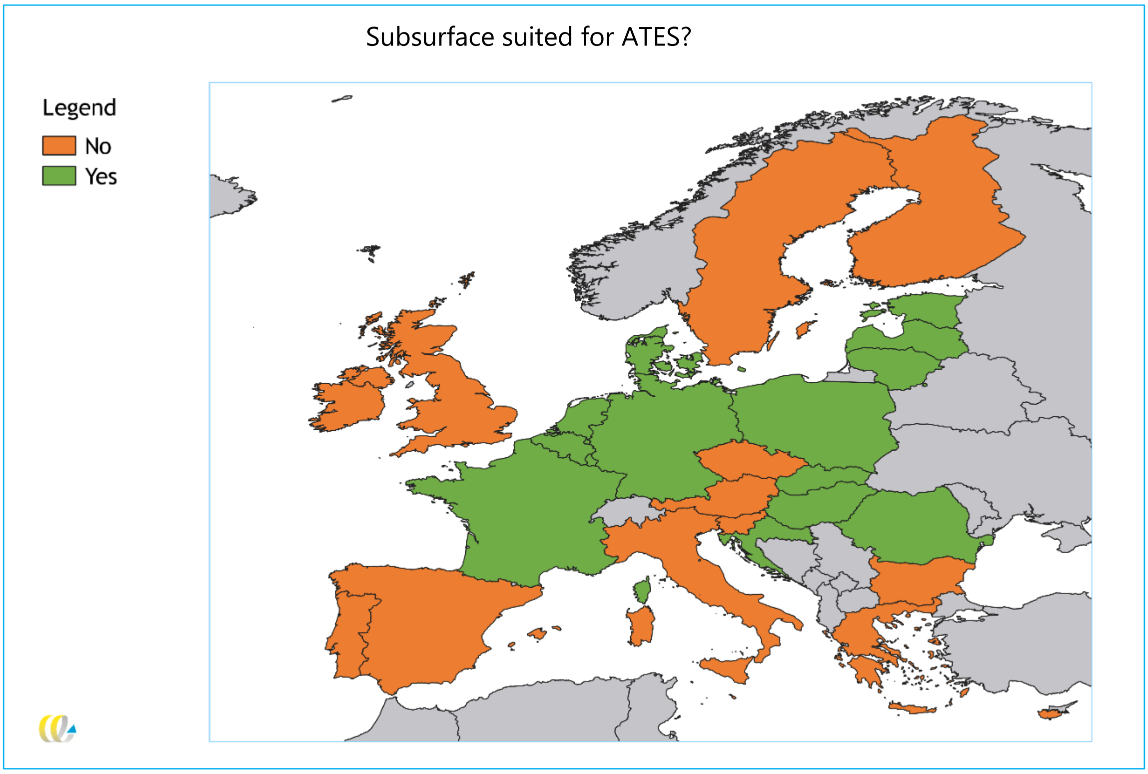


Figure 16 Subsurface suited for ATES?

Small buffer tank

Heat can also be stored in small hot water buffer tanks inside buildings. This is useful to store generated energy for a couple of days when it is generated and not used right away, for example with solar thermal energy. In the model it is assumed that the heat pump, the biomass boiler, the CHP and solar thermal are all combined with a small buffer tank to store heat for tap water. In the model, no calculation is made of the amount of heat that is stored in small buffer tanks, but it is taken into account in the efficiencies of heating tap water.

Electricity storage

To obtain maximum autarky, generated energy that cannot be used directly by prosumers. can be stored in batteries instead of supplied to the electricity grid. For the calculation of the share of autarky, the results from our model are used is a separate tool. This tool calculates the energy demand and the generation of electricity day by day. It also calculates the percentage of generated electricity that can be used directly, the percentage that is stored in the battery and the percentage that is needed from the grid.

To calculate how much energy can directly be used by prosumers, the following assumptions are made:

- The electricity demand for electric devices of households and tertiary building is on average equal each day of the year.
- The heat pump needs most of its energy for heating in winter (except for heating of tap water) (see Table 39)
- Cooling with heat pump or air-conditioning is only needed in summer (see Table 39)
- The demand for electricity for electric vehicles is on average equal each day of the year
- The generation of wind is higher in winter and is on average equal throughout the day. For het generation of wind an average daily wind profile of a country in the EU is used.
- The generation of solar energy is higher in summertime and has a peak around noon. For het generation of solar an average daily solar profile of a country in the EU is used.
- The generation of electricity from a CHP is in line with the heat demand profile of a heat pump.
- The generation of electricity of hydro power is on average equal each day of the year.

Table 39 Monthly share of electricity demand for heat pumps

Month	Electricity demand heat pump: heating[11]	Electricity demand heat pump: heating: cooling[12]
January	17%	0%
February	15%	0%
March	13%	0%
April	7%	0%
May	4%	9%
June	2%	15%
July	2%	21%
August	2%	35%
September	3%	15%
October	7%	6%
November	12%	0%
December	16%	0%

During the day, there are also differences in generation and demand. This is taken into account to calculate how much of the generated energy can directly be used in households or tertiary buildings, see Table 40. This indicates the average percentage of generated energy that can directly be used for different appliances for one day. For example, solar energy is all generated during the day, electric vehicles are charged at night, so there is only an overlap of about 10% in the supply and demand.

For the calculation of the percentage autarky, it is assumed that the energy that is generated in one day, can all be used for the demand of that day. In reality, it is possible that either:

- The battery is full and there is no energy demand at a certain time, while there is energy generation. In that case, the generated energy should be inserted into the grid.
- The battery is empty and the energy generated at a certain moment is not enough to fulfil the demand at that moment. In that case, electricity from the grid is needed.

It is also assumed that the part of the energy that is generated during a day which is not needed for the demand of that day, is stored in the battery, with a maximum of the capacity of the battery. The energy stored in the battery can be used for the demand of the following day, or any day after, in case the daily demand is lower than the daily generation.

Table 40 Direct use of generated energy in one day[13]

	Wind	Hydro	CHP	Solar
Electric devices	40%	40%	50%	34%[14]
Electric vehicles	40%	40%	50%	10%
Heat pump heating	50%	50%	0%	40%
Heat pump cooling	50%	50%	0%	60%

[11] Based on average gas use of households in the Nederlands
[12] Source: (Luca Cirillo, 2016)
[13] Estimations made by CE Delft
[14] Source: Luthander et al., 2015, Photovoltaicself-consumption in buildings: A review

Batteries

Batteries are applied in the model in the Autarky scenario at locations where electricity is generated. For the collective options: ground-based solar PV, wind turbines and hydro power, large batteries are placed at the site where the energy is generated. The excess electricity generated with solar PV on roofs is stored in a home-battery. The excess electricity that is generated with the CHP is stored in the battery of the building, and that battery will also be used to store electricity from solar PV on rooftops. Figure 17 gives a schematized overview of the use of battery in the calculation tool. It is assumed in this scenario that in 2050 all locations with generation of electricity have batteries and that in 2030 43% of locations with electricity generation have batteries (linear increase from 2015 to 2050). The size of the batteries are chosen in such a way, that the batteries can cover the daily demand as much as possible, but without making it too costly:

- For solar PV 60% of the maximum generation in one day can be stored in the battery
- For wind 80% of the maximum generation in one day can be stored in the battery
- For hydro power the average daily energy generation can be stored in the battery
- For CHP. the maximum daily generation can be stored in the battery

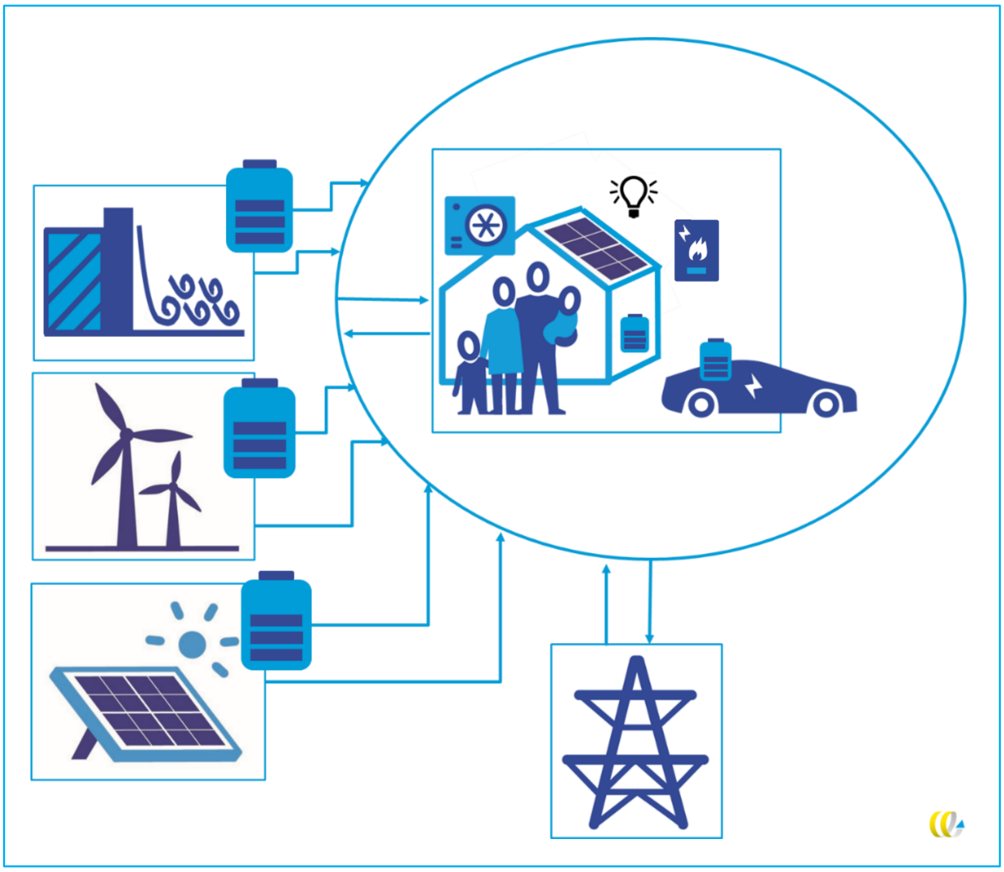


Figure 17 Schematized image of battery use in calculation tool

Electric vehicles

Electric vehicles can use electricity from the grid but also electricity generated by prosumers. The amount of kWh that electric vehicles use is input for the calculation of the amount of renewable energy needed. Electric vehicles can also be used for storage of electricity. This is not taken into account in the calculation of the percentage of autarky, though. It is difficult to determine how much the electric vehicle can add to the share of autarky of a household. For electricity generated with solar PV on rooftops or with CHP, the battery of the EV cannot be used much, as it is assumed that the car is used during the day, at the moment that most energy is generated by solar PV and CHP. When the electric vehicle is parked in front of the residential building during the night, it could help, especially in wintertime when there is not much solar energy, to increase the share in autarky.

Conditions and assumptions:

- Electric vehicles are only assigned to households
- Electric vehicles are applied in all scenarios
- The battery of the electric vehicles is charged at night at residential buildings
- The battery of the electric vehicles could be used for households during night time, but this is not taken into account in the calculation.

5.5 EU level

The results of the country analysis are added to present EU results.

6. Results

The results of the scenarios will be presented in the following subchapters.

6.1 Individual level

Based on the assumptions and methodology elaborated in chapter 5.1, this section presents the results on the individual level. For each use case the key performance indicators (KPI) and load curves for heating and electricity consumption are shown.

6.1.1 France (Carpentras) - Mediterranean climate

The results for the year 2015 are shown in Table 41. The range for each KPI shows the differences between different household sizes. CO_2 emissions are displayed as total emissions per household. Hence, the lower number reflects the emissions for a 2-person household and the higher number the emissions for a 4-person household. The results show a comparison with the Reference scenario with CO_2 emissions of 3,204 kg/a. The emissions in the Renewables and Autarky scenario are only 2-5 % of the emissions of the Reference scenario for the heating sector. While in the Reference scenario the heat production is based on natural gas, the heat production in the Renewable and Autarky scenario is based on clean solar thermal and on heat pumps. Electricity for the heat pump is provided partly by PV and partly by the grid. Since CO_2 emissions for electricity from the grid are quite low, due to a high share of nuclear energy, the CO_2 emissions remain low even when operating a heat pump. The CO_2 emissions for electricity are 20 % lower in the Renewables scenario and 50 % lower in the Autarky scenario.

The LCOH in 2015 is similar in all three scenarios. The LCOE in the Renewables scenario is 3 cent/kWh lower in comparison to the Reference and the Autarky scenario, despite not taking into account the revenues from electricity sales to the grid. In the Renewables scenario, 7,000-10,000 kWh and in the Autarky scenario, 5,000-7,000 kWh are fed into the grid. Furthermore, a higher LCOE in the Autarky scenario compared to the Renewables scenario shows that batteries are not yet economically profitable. Even if more electricity can be self-consumed, the LCOE is higher due to the costs of investing in storage technology. Storage technologies however increase self-sufficiency in the heating sector to 60-67% and in the electricity sector to 50-52%.

In addition to the simulation shown in Table 41, a household with an electric vehicle was simulated. Part of the additional electricity needed to charge the electric vehicle could be covered by the electricity produced by the household. In the Renewables scenario, 480-520 kWh could be charged with self-generated electricity and 548-651 kWh in the Autarky scenario. This corresponds to a reach of 2,900 to 3,200 km in the Renewables scenario and 3,300-3,900 km in the Autarky scenario for the modelled electric vehicle.

Table 41 KPIs for France (Carpentras) in 2015 through all 3 scenarios

	CO_2 heating (kg/a)	*CO_2 electricity (kg/a)*	*LCOH (€/kWh)*	*LCOE (€/kWh)*	*Autarky heating (%)*	*Autarky electricity (%)*
France Reference	3,204-3,855	221-317	0.12-0.13	0.18	0	0
France Renewables	145-160	177-252	0.11-0.12	0.15	38-48	20
France Autarky	90-96	111-152	0.12-0.13	0.18	60-67	50-52

Table 42 shows the results for the year 2030. Due to higher production and an increase in self-sufficiency in heating and electricity, CO_2 emissions decreased compared to 2015. The LCOE in the Autarky scenario is now lower than in the Renewables scenario. Depending on the price of electricity fed into the grid, this indicates that storage technologies could be profitable, as the LCOE is lower but less electricity is fed into the grid than in the Renewables scenario. In the Autarky scenario, 9,000-12,000 kWh and in the Renewables scenario 11,000-15,000 kWh are fed into the grid. Assuming that the revenues for feeding into the grid are equal to the LCOE for PV production, the sum of revenues and costs for the household are almost equal. This shows that storage technologies have neither a positive nor a negative impact on the LCOE costs for the household. The installation of storage technologies however increases autarky to 69-75 % in the heating sector and 61-64 % in the electricity sector and also has a positive effect on the LCOH. More electricity can be used for the heat pump from self-produced PV, which is cheaper than buying from the grid. The LCOH in the Autarky scenario is 42 % lower in the Renewables scenario and 47 % in the Autarky scenario.

The simulation with one electric vehicle per household showed that an additional 1,000-1,200 kWh of self-generated electricity could be used by the household in the Renewables scenario and 1,100-1,300 kWh in the Autarky scenario. This corresponds to a reach of 7,000 to 8,000 km for the modelled electric vehicle.

Table 42 KPIs for France (Carpentras) in 2030 through all 3 scenarios

	CO_2 heating (kg/a)	*CO_2 electricity (kg/a)*	*LCOH (€/kWh)*	*LCOE (€/kWh)*	*Autarky heating (%)*	*Autarky electricity (%)*
France Reference	2,811-3,403	121-174	0.17	0.19	0	0
France Renewables	70-79	94-135	0.10-0.11	0.15	42-52	22-23
France Autarky	34-37	47-63	0.09-0.10	0.14	69-75	61-64

The results for 2050 are presented in Table 43. Due to higher electricity production and better efficiency of heating technologies, autarky in heating increases to 45-56 % in the Renewables scenario and 75-81 % in the Autarky scenario. In 2050 the LCOE in the Autarky scenario is considerably lower than in the Renewables scenario. Assuming the household generates revenue from selling the PV at LCOE of PV to the grid, the total energy costs for the household are also lower in the Autarky scenario than in the Renewables scenario. In addition, autarky increases to 75-81 % for heating and 68-70 % for electricity. This also has a positive effect on the LCOH, which decreases to 8-9 cents/kWh in the Autarky scenario and 9-10 cents/kWh in the Renewables scenario. The total CO_2 emissions are 76-63 kg/a in the Autarky scenario and 183-236 kg/a in the Renewables scenario. This is only 5 % of CO_2 emissions of the Reference scenario in 2015.

With the inclusion of an electric vehicle, an additional 1,250-1,450 kWh of self-produced electricity could be used by the household in the Renewables scenario and in the Autarky scenario. This corresponds to 7,000-8,000 km of clean driving with the modelled electric vehicle.

Table 43 KPIs for France (Carpentras) in 2050 through all 3 scenarios

	CO_2 heating (kg/a)	*CO_2 electricity (kg/a)*	*LCOH (€/kWh)*	*LCOE (€/kWh)*	*Autarky heating (%)*	*Autarky electricity (%)*
France Reference	2,458-2,996	138-199	0.19-0.20	0.19	0%	0%
France Renewables	78-87	105-149	0.09-0.10	0.15	45-56	24-25
France Autarky	32-34	44-59	0.08-0.09	0.13	75-81	68-70

Figure 18 shows the thermal load during a winter day and a summer day. The heat demand is the sum of demand for heating and warm water. While on a winter day demand for heating is constant with some peak values of hot water demand, in summer only hot water is demanded. In times of heat demand but neither heat pump nor solar thermal energy availability, the heating demand is covered by the buffer tank. It is therefore evident that during a winter day between 10:00 and 17:00, the entire heating demand can be covered by solar thermal energy. Before and after, the demand is usually covered by the heat pump. Moreover, some of the peaks in the evening due to the warm water demand are covered by an electric boiler. During a summer day, the whole demand can be covered by solar thermal or by the energy stored in the buffer tank.

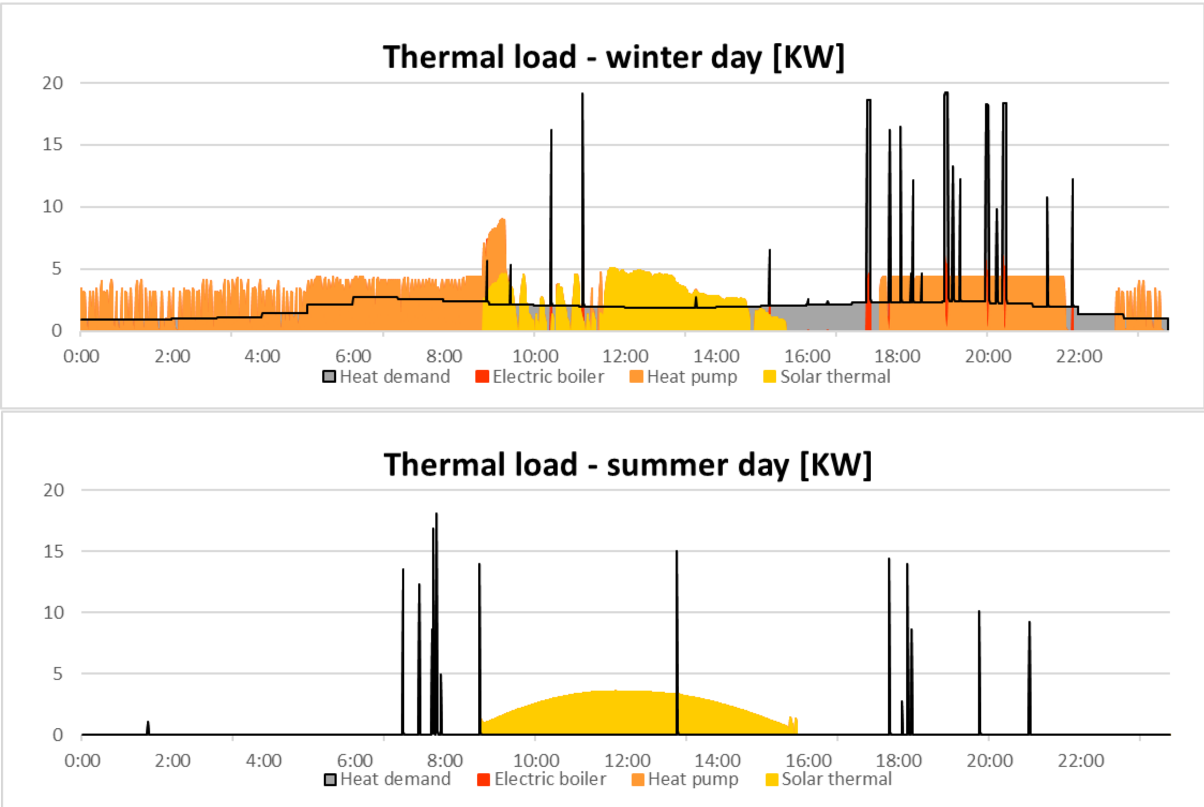
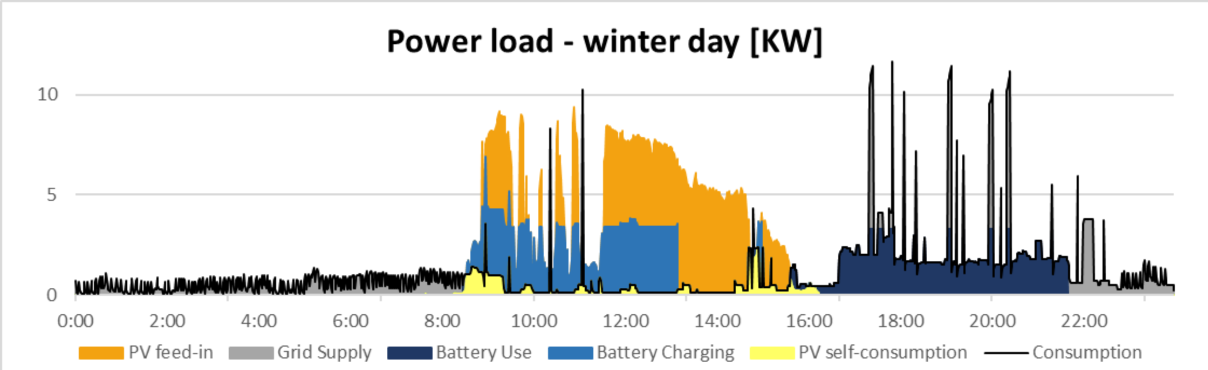


Figure 18 Heat production in French household in Autarky scenario in 2050 during winter (up) and summer (down)

Looking at the power load in Figure 19 for the same days in winter and summer as in Figure 18, it can be seen that on a summer day, most of the electricity demand can be covered by PV production or the stored electricity in the battery. Only in the late afternoon the demand exceeds the maximum loading speed of 3.3 KW of the battery, so that part of the electricity has to be taken from the grid. This shows that not always battery capacity, but also the discharge speed is important when aiming for maximum autarky. However, in winter the capacity of the battery is also a limiting factor and a larger battery would make even higher autarky possible. During the day, part of the electricity produced is fed into the grid and at night the battery is empty and the household has to retrieve electricity from the grid.



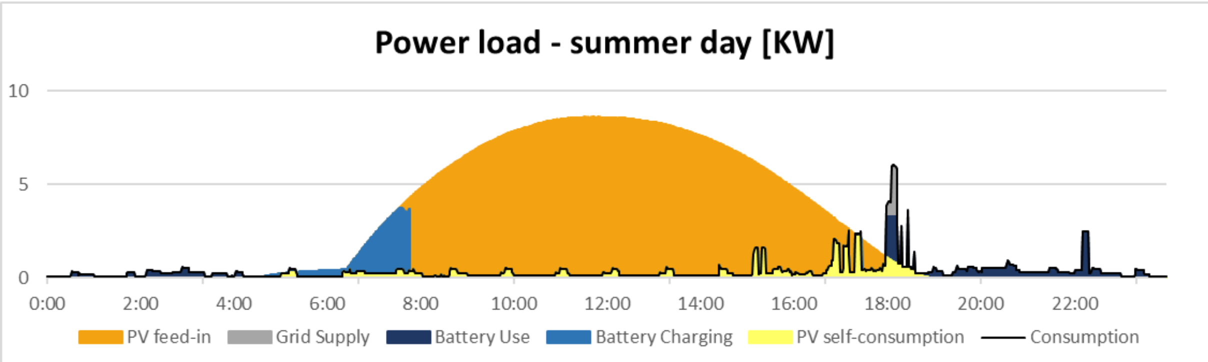


Figure 19 Electricity production in French household in Autarky scenario in 2050 during winter (up) and summer (down)

6.1.2 Germany (Lindenberg) – Continental Climate

Table 44 shows the results for 2015. It is visible that heat generation using a combination of heat pumps and solar thermal energy can reduce emissions for heating by almost 50 % in the Renewables scenario and 65 % in the Autarky scenario compared to the Reference scenario. Nevertheless, the LCOH in 2015 are higher in both scenarios compared to the base case. The main reason is a relatively low price for natural gas used in the Reference scenario, which is however most likely to rise in the near future (Capros et al. 2016). Furthermore, the introduction of a price for CO_2 emissions in the heating sector will also add to the profitability of renewable heating technologies in Germany (Die Bundesregierung 2020). The CO_2 emissions for the use of electricity will decrease according to the share of autarky in electricity. In the Renewables scenario, 18 % and in the Autarky scenario 41-42 % of electricity demand for appliances and light can be covered by self-generated electricity. Due to the low cost of PV-generated electricity, the total LCOE for the household drops to 27 cents/kWh in the Renewables Scenario and to 28 cents/kWh in the Autarky scenario.

Higher LCOE in the Autarky scenario compared to the Renewables scenario show that currently the benefit from higher self-consumption of PV cannot compensate the battery costs. Moreover, the revenues from selling electricity to the grid are not included in the calculations. In the Renewables scenario 6,300 -8,000 kWh and in the Autarky scenario 4,500 kWh – 6,500 kWh are fed into the grid. For Germany, a household with an electric vehicle was simulated in addition to the simulation shown in Table 44. In the Renewables scenario and in the Autarky scenario, 400-550 kWh could be charged with self-generated electricity. This corresponds to 2,400-2,700 km of clean driving for the modelled electric vehicle.

Table 44 KPIs for Germany (Lindenberg) in 2015 through all 3 scenarios

	CO_2 *heating* *(kg/a)*	CO_2 *electricity* *(kg/a)*	*LCOH* *(€/kWh)*	*LCOE* *(€/kWh)*	*Autarky heating (%)*	*Autarky electricity (%)*
Germany Reference	3,788-4,588	1,435-2,066	0.11	0.31	0	0
Germany Renewables	1,875-2,246	1,168-1,679	0.14-0.15	0.27	28-34	18
Germany Autarky	1,358-1,602	848-1,202	0.15-0.16	0.28	46-51	41-42

The results for 2030 are displayed in Table 45. Compared to 2015, the electricity price and price for generation of heat is expected to increase in the Reference scenario in 2030. Since a large share of electricity is still retrieved from the grid, the LCOE for the household in the Renewables scenario increases compared to 2015. On the other hand, the LCOE for the Autarky scenario is decreasing below the LCOE for the Renewables scenario, showing that batteries in combination with PV are profitable by 2030. The LCOH is expected to decrease due to higher efficiency and lower investment costs. Compared to 2015, CO_2 emissions for heating and electricity are reduced by another 20 % and compared to the Reference scenario by 60 % in the Renewables scenario and 73 % in the Autarky scenario. In 2030, the LCOH in the Renewables scenario and the Autarky scenario is slightly lower compared to the LCOH in the Reference scenario. Keeping a price for CO_2 emissions for heating in mind, the prosumer technologies are also favourable from an economic point of view. In 2030, the simulation with one electric vehicle per household showed that an additional 800-1000 kWh of self-produced electricity could be used by the household. This corresponds to a reach of 5,200 to 6,600 km for the modelled electric vehicle. No major differences between the Renewables scenario and the Autarky scenario are visible.

Table 45 KPIs for Germany (Lindenberg) in 2030 through all 3 scenarios

	CO_2 *heating* *(kg/a)*	CO_2 *electricity* *(kg/a)*	*LCOH* *(€/kWh)*	*LCOE* *(€/kWh)*	*Autarky heating (%)*	*Autarky electricity (%)*
Germany Reference	3,588-4,358	1301-1874	0.14	0.33	0	0
Germany Renewables	1,470-1,792	1,047-1,509	0.13-0.14	0.27	29-34	19-20
Germany Autarky	961-1,167	687-988	0.12-0.13	0.24	51-54	47-48

As displayed in Table 46, in 2050 almost half of the electricity and heating demand in the Autarky scenario can be covered by own renewable production technologies. Furthermore, an additional 10,000-13,000 kWh are fed into the grid in the Renewables scenario and an additional 8,000-11,000 kWh in the Autarky scenario. Overall, more electricity is fed in the grid than retrieved. Compared to 2030, the LCOH decreases further as more self-generated electricity can be used, prices fall, and efficiency increases slightly. Both the LCOE and the LCOH are significantly lower in both scenarios compared to the Reference scenario. Emissions can be reduced by up to 83% in the heating sector and by up to 49% in the electricity sector. With the inclusion of an electric vehicle, an additional 850-1,100 kWh of self-generated electricity could be used by the household in the Renewables scenario and in the Autarky scenario. This corresponds to 4,800-6,350 km of clean driving with the modelled electric vehicle.

Table 46 KPIs for Germany (Lindenberg) in 2050 through all 3 scenarios

	$CO_{2\ heating}$ (kg/a)	*$CO_{2\ electricity}$ (kg/a)*	*LCOH (€/kWh)*	*LCOE (€/kWh)*	*Autarky heating (%)*	*Autarky electricity (%)*
Germany Reference	3,588-4,358	953-1,372	0.16	0.32	0	0
Germany Renewables	942-1,127	768-1,091	0.11-0.12	0.26-0.27	29-36	19-21
Germany Autarky	620-716	508-697	0.11-0.11	0.23-0.23	52-57	47-50

In Figure 20 the heat demand and production of heating technologies during a summer and a winter day are displayed. The heating demand on a winter day is higher than on a summer day. Peak values are visible on both days due to the warm water demand. In winter, the main heat source is a heat pump, which covers most of the demand. Only during midday, solar thermal energy can cover part of the demand. During peak periods, electric boilers occasionally provide some extra heat to fill shortages in the demand. If no heating technology produces heat, the demand is covered by the storage tank.

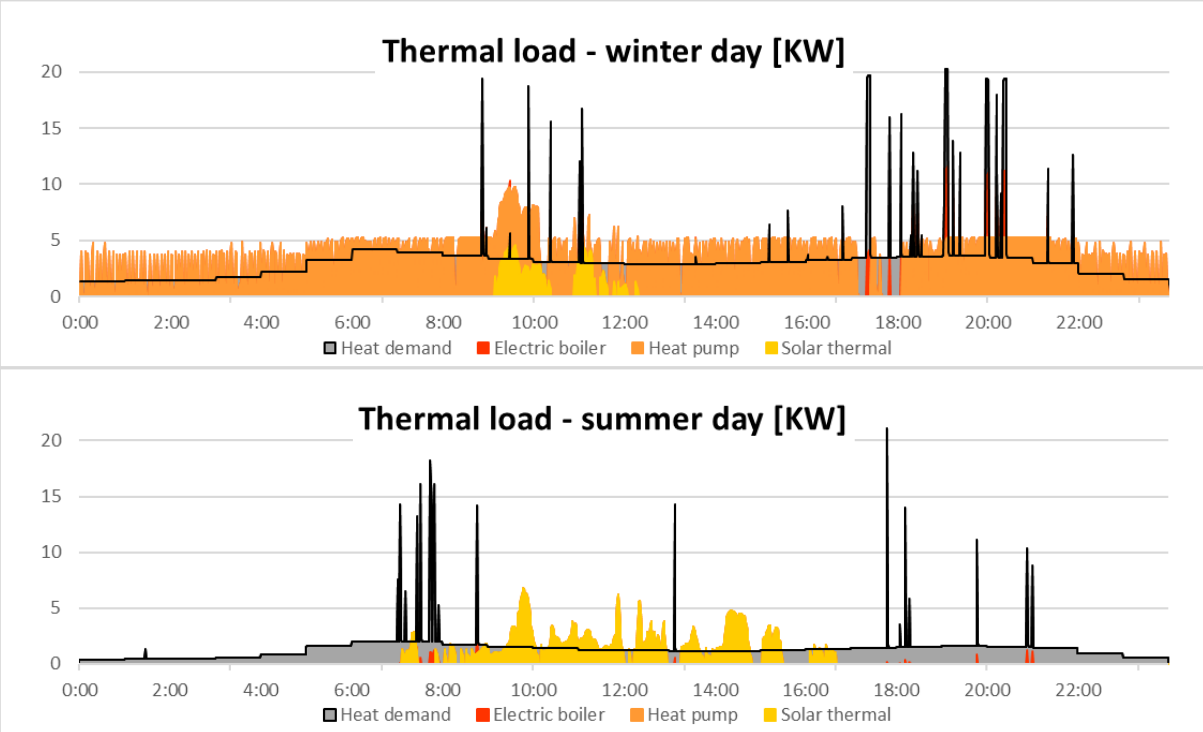


Figure 20 Heat production in German household in Autarky scenario in 2050 during winter (up) and summer (down)

Figure 21 shows the production, consumption and storage of electricity in a German household in winter and summer. It shows that the overall demand during winter is considerably higher than in summer. This is due to the electricity demand of the heat pump. On a winter day during midday, the electricity demand can be covered by PV production. Excess electricity charged into the battery can be used between 15:00 and 18:00. The maximum charging speed of 3.3 KW limits charging. Otherwise, even a higher share of electricity could have been charged into the battery and used later.

In summer, PV production exceeds the electricity demand by far. Between 4:00 and 9:00 the battery is charged. After 17:00 the charged electricity is used to a large extend to cover the demand. Only during a peak around 18:00 the required load exceeds the maximum discharge capacity and therefore part of the electricity must be taken from the grid.

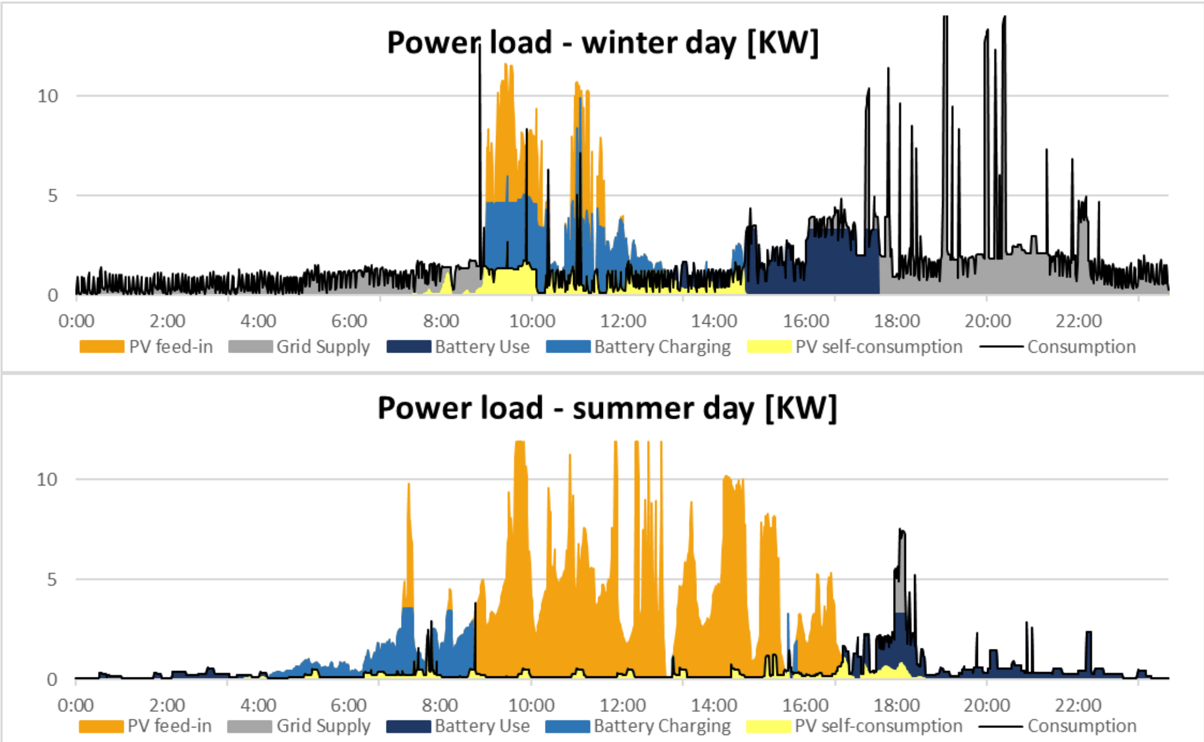


Figure 21 Electricity production in German household in Autarky scenario in 2050 during winter (up) and summer

6.1.3 Netherlands (Cabauw) – Oceanic Climate

The results in the Reference scenario are shown in Table 47. A household with prosumer technologies for electricity and heat emits more than 60 % less CO_2 in the heating sector in the Renewables scenario and more than 70 % less in the Autarky scenario. CO_2 emissions in the electricity sector are 18-19 % lower in the Renewables scenario and 43-45 % lower in the Autarky scenario. This is due to the CO_2 free electricity production with PV systems and less need for electricity from the grid. Contrary to the use cases in the other countries, the LCOH in the Renewable and Autarky scenario is already lower than the Reference scenario in 2015, as the Netherlands have higher prices for natural gas compared to other countries. However, since the LCOE in the Autarky scenario is again higher than in the Renewables scenario, batteries are also in this use case not profitable yet. In the Netherlands, the simulation of one extra electric vehicle per household shows that, similar to Germany, 400-550 kWh of self-produced electricity could be used to recharge electric vehicles. This corresponds to 2,400-2,700 km of clean driving for the modelled electric vehicle.

Table 47 KPIs for Netherlands (Cabauw) in 2015 through all 3 scenarios

	$CO_{2\ heating}$ (kg/a)	*$CO_{2\ electricity}$ (kg/a)*	*LCOH (€/kWh)*	*LCOE (€/kWh)*	*Autarky heating (%)*	*Autarky electricity (%)*
Netherlands Reference	2,506-3,092	1,346-1,928	0.15-0.16	0.19	0	0
Netherlands Renewables	1,000-1,200	1,104-1,564	0.12-0.14	0.17	34-42	18-19
Netherlands Autarky	696-815	771-1,067	0.13-0.14	0.20	53-59	43-45

Table 48 shows the results for all three scenarios for the year 2030. While CO_2 emissions in the Reference scenario dropped only slightly in comparison to 2015, CO_2 emissions fell by a further 40 % in the Renewables scenario and 50 % in the Autarky scenario. Autarky in the Renewables scenario is 37-47 % for heating and 20 % for electricity. With storage technologies, self-sufficiency increases to 51-53 % in the electricity sector and 60-64 % in the heating sector. The gap between the LCOH in the Renewables scenario and Autarky scenario increased. In 2030, LCOHs are 15-16 cent/kWh in the Reference scenario and 10-12 cent/kWh in the Renewable and Autarky scenario. The LCOE is slightly lower in the Autarky scenario. However, 7,000-9,000 kWh are fed into the grid in the Renewables scenario and only 5,000-7,000 kWh in the Autarky scenario. In 2030 the simulation with one electric vehicle per household showed that an additional 800-1,000 kWh of self-produced electricity could be used by the household to chance the electric vehicle. This corresponds to a reach of 5,200 to 6,600 km for the modelled electric vehicle. No major differences between the Renewables scenario and the Autarky scenario are visible.

Table 48 KPIs for Netherlands (Cabauw) in 2030 through all 3 scenarios

	$CO_{2\ heating}$ (kg/a)	*$CO_{2\ electricity}$ (kg/a)*	*LCOH (€/kWh)*	*LCOE (€/kWh)*	*Autarky heating (%)*	*Autarky electricity (%)*
Netherlands Reference	2,325-2,884	1,208-1,733	0.15-0.16	0.21	0	0
Netherlands Renewables	566-704	679-979	0.10-0.12	0.17	37-44	20
Netherlands Autarky	335-426	405-595	0.10-0.11	0.16	60-64	51-53

The results for all three scenarios in 2050 are shown in Table 49. The total CO_2 emissions of 956 -1,304 kg CO_2 per year in the Renewables scenario are 72 % below the Reference scenario. In the Autarky scenario, total CO_2 emissions are 84% below the Reference scenario. Both LCOH and LCOE are considerably lower than in the Reference scenario. With the inclusion of an electric vehicle, an additional 850-1,100 kWh of self-generated electricity could be used by the household in the Renewables scenario and in the Autarky scenario. This corresponds to 4,800-6,350 km of clean driving with the modelled electric vehicle.

Table 49 KPIs for Netherlands (Cabauw) in 2050 through all 3 scenarios

	$CO_{2\ heating}$ (kg/a)	$CO_{2\ electricity}$ (kg/a)	*LCOH* (€/kWh)	*LCOE* (€/kWh)	*Autarky heating (%)*	*Autarky electricity (%)*
Netherlands Reference	2,325-2,884	1,255-1,800	0.15-0.16	0.20	0	0
Netherlands Renewables	422-524	534-770	0.09-0.10	0.17	38-45	21-22
Netherlands Autarky	244-309	310-458	0.09-0.10	0.15-0.16	62-66	53-54

Figure 22 shows the thermal load of one winter day and one summer day in a Dutch household. It is visible that most of the heat on a winter day is generated by the heat pump and only part of the heat demand can be covered by solar thermal. In the graph for the winter day, it most visible that the heat production exceeds the actual heat demand for most of the day. This is because part of the generated heat is lost in storage. During peaks the electric boiler provides the rest of the required heat. In summer, the base heat demand is very low except of peaks due to the hot water demand. The whole demand can be covered by solar thermal energy.

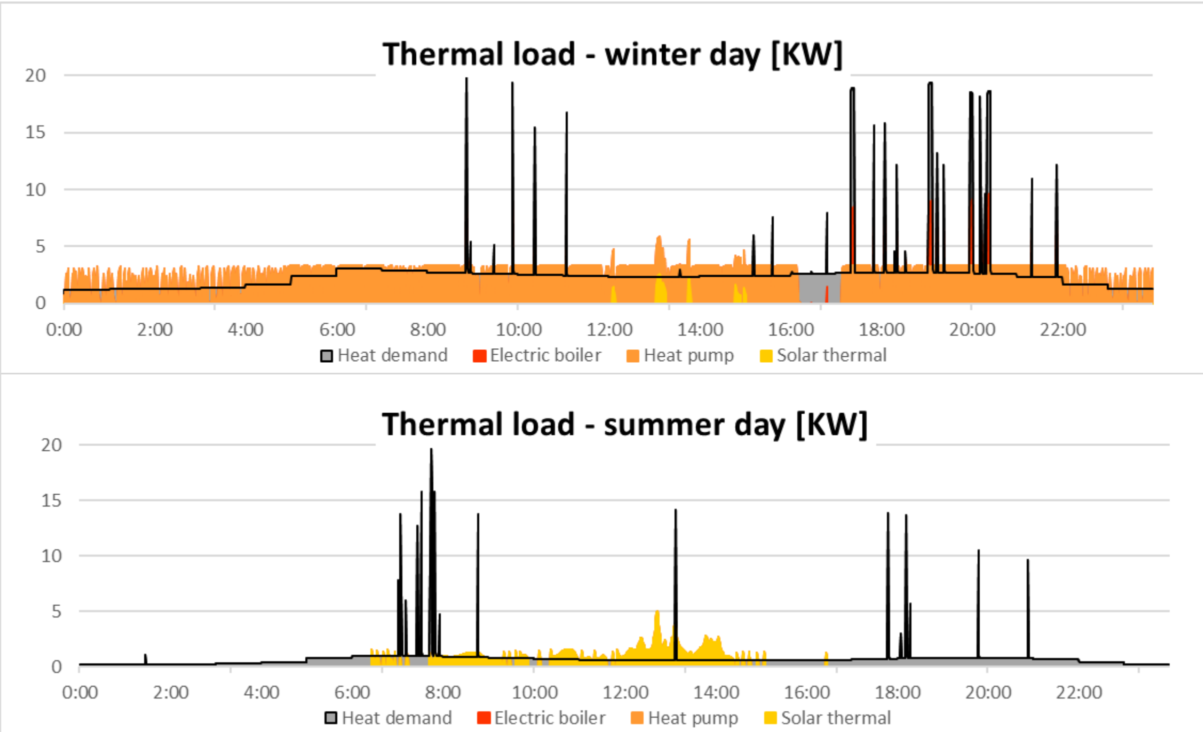


Figure 22 Heat production in Dutch household in Autarky scenario in 2050 during winter (up) and summer (down)

Figure 23 shows the power load during a winter and a summer day. On a winter day, only part of the electricity demand can be covered by self-generated electricity. From 16:00 to next day, the demand must be covered by the grid. On a summer's day, however, almost the entire demand can be covered by self-generated electricity, either directly or stored in the battery. Only during the afternoon peak, some of the electricity demand has to be covered by the grid, because the discharge speed of the battery is not high enough to cover the whole demand.

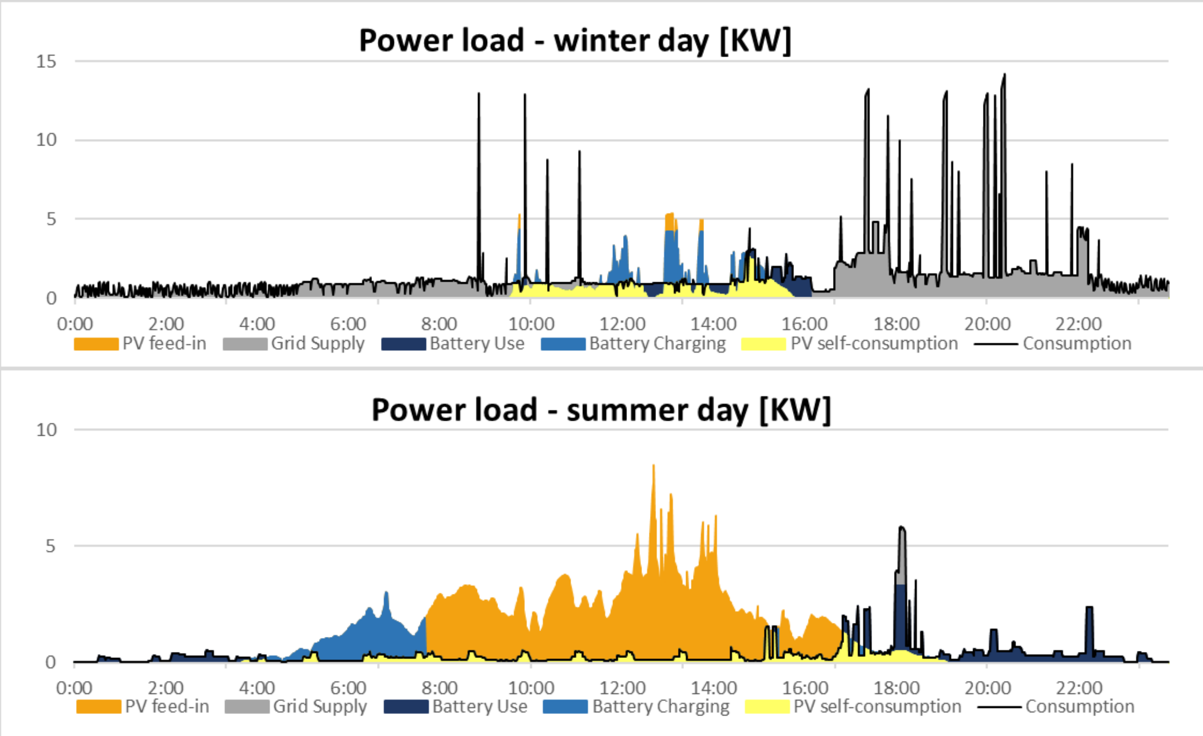


Figure 23 Electricity production in Dutch household in Autarky scenario in 2050 during winter (up) and summer

6.1.4 Spain (CENER) - Semi-arid climate

Table 50 shows the results for all three scenarios in 2015. Different to the other use cases, the LCOE in Spain for the Renewables Scenario and the Autarky scenario are already similar in 2015. This shows that in Spain the benefit of consuming more self-produced electricity already covers the costs of the battery. In the Renewables scenario, however, 1,800-2,500 kWh less electricity is fed into the grid. Assuming a type of revenue for electricity sold, it shows that batteries are also not profitable in Spain in 2015, although this is the use case with the most favourable conditions. Nevertheless, batteries can increase the autarky from 24 % to 64-65 % in the electricity sector and from 53-64 % to 76-81 % in the heating sector. By 2015, the emissions of a prosumer household in the heating sector are already 55 % lower in the Renewables scenario and 79 % lower in the Autarky scenario. In the electricity sector, the emissions are 24 % and 64 % lower. The LCOH is higher compared to the other use cases, because heat from solar thermal cannot be used as much as in the other countries. Even though Spain has the highest solar thermal generation, almost 35 % of the generated solar heat cannot be used because the thermal storage capacity is exceeded. In the other use cases, the share lies between 16-26 %. It should be analysed whether a smaller collector is more efficient or whether seasonal storages can increase profitability. In Spain the simulation of an extra electric vehicle shows that 470-530 kWh of self-produced electricity could be used for charging electric vehicles. This corresponds to 2,900-3,250 km of clean driving for the modelled electric vehicle.

Table 50 KPIs for Spain (CENER) in 2015 through all 3 scenarios

	$CO_{2\ heating}$ (kg/a)	$CO_{2\ electricity}$ (kg/a)	LCOH (€/kWh)	LCOE (€/kWh)	Autarky heating (%)	Autarky electricity (%)
Spain Reference	1,337-1,693	2,376-3,432	0.15-0.16	0.25	0	0
Spain Renewables	607-693	1,814-2,621	0.15-0.18	0.21	53-64	24
Spain Autarky	284-328	853-1,243	0.15-0.18	0.21	76-81	64-65

Table 51 shows the results for all three scenarios for the year 2030. While the LCOE increases slightly in the Reference scenario and remains the same in the Renewables scenario, the price decreases by 6 Cents/kWh in the Autarky scenario. This is mainly due to expected falling prices for batteries. Since self-produced PV is significantly lower than electricity from the grid, the share of self-consumed electricity mainly determines the LCOH, as the heat pump is the main source for heating. In the Renewables scenario, the LCOH is 5-8 cents/kWh lower than LCOH in the Reference scenario. In the Autarky scenario the LCOH is 6-9 Cents/kWh lower than LCOH of the Reference scenario. The emissions from the heating sector are 63 % lower in the Renewables scenario and 86 % lower in the Autarky scenario. Emissions in the electricity sector are 24 % lower in the Renewables scenario and 71-72 % lower in the Autarky scenario. The simulation with one electric vehicle per household showed that an additional 1,000-1,200 kWh of self-produced electricity could be used by the household in 2030. This corresponds to 6,800-8,000 km of clean driving for the modelled electric vehicle.

Table 51 KPIs for Spain (CENER) in 2030 through all 3 scenarios

	$CO_{2\ heating}$ (kg/a)	$CO_{2\ electricity}$ (kg/a)	LCOH (€/kWh)	LCOE (€/kWh)	Autarky heating (%)	Autarky electricity (%)
Spain Reference	1,290-1,639	2,180-3,149	0.19-0.20	0.26	0	0
Spain Renewables	474-553	1,648-2,380	0.12-0.14	0.21	54-65	24
Spain Autarky	177-211	620-913	0.11-0.13	0.15	80-84	71-72

In Table 52 the results for 2050 for all three scenarios are shown. CO_2 emissions are again significantly lower compared to 2030, mainly because CO_2 emissions for electricity from the grid are expected to decrease from 627 g CO_2 eq/kWh in 2030 to 211 g CO_2 eq/kWh in 2050 due to a higher share of renewables in Spain's energy mix in 2050 (compare Table 11). Hence, in the Reference scenario the CO_2 emissions for the electricity retrieved from the grid decreases by 67 % from 2030 to 2050. In the Renewables scenario, CO_2 emissions decrease in 2050 compared to 2030 in the electricity sector, mainly due to lower emissions from the grid and partly due to a slightly higher electricity self-sufficiency of 25 %. In the Autarky scenario, autarky increases to 74-75 % in the electricity sector and 82-86 % in the heating sector. This is the highest share of autarky in all use cases due to high electricity production from PV (also in winter months) and the lowest heating demand. In order to reach an even higher share of electricity, larger batteries with higher charging and discharging speed are required. With the inclusion of an electric vehicle, an additional 1,150-1,350 kWh of self-produced electricity could be used by the household in the Renewables scenario and in the Autarky scenario. This corresponds to 6,500-7,800 km of clean driving with the modelled electric vehicle.

Table 52 KPIs for Spain (CENER) in 2050 through all 3 scenarios

	CO_2 heating (kg/a)	*CO_2 electricity (kg/a)*	*LCOH (€/kWh)*	*LCOE (€/kWh)*	*Autarky heating (%)*	*Autarky electricity (%)*
Spain Reference	1,290-1,639	718-1,038	0.21-0.23	0.26	0	0
Spain Renewables	154-179	536-775	0.11-0.13	0.20	55-65	25-25
Spain Autarky	53-63	185-272	0.10-0.12	0.14	82-86	74-75

Figure 24 shows the thermal load during one winter day and one summer day. For the year 2050, it is visible that there is a lower heat demand compared to the other use cases. The entire heating demand in the summer can be covered by solar thermal energy. In winter, part of the heating demand has to be covered with heat pumps and at peak times by an electric boiler. However, most of the electricity used in the heat pumps is from self-produced electricity and is therefore CO_2 free. In the graph for the summer day, a high production of solar thermal energy and a low demand is visible. Excess heat can be partly stored in the buffer tank, but as soon as the buffer tank reaches a certain temperature, excess heat has to be relieved. As described above 35 % of solar thermal heat is relieved. Therefore, seasonal storage to cover the demand in winter or less solar thermal energy should be considered.

Figure 25 shows the power load for Spain during one winter day and one summer day in 2050. On a summer day a large share of the produced electricity has to be fed into the grid. Between 5:00 and 9:00 the battery is charged. After 9:00 all the electricity produced is fed into the grid. On the displayed winter day, the charging speed is a limiting factor, as not all of the excess electricity can be charged into the battery at noon leaving the battery not fully charged. Hence, after 23:00, electricity has to be retrieved from the grid. A higher charging speed could increase the share of self-produced electricity on this winter day.

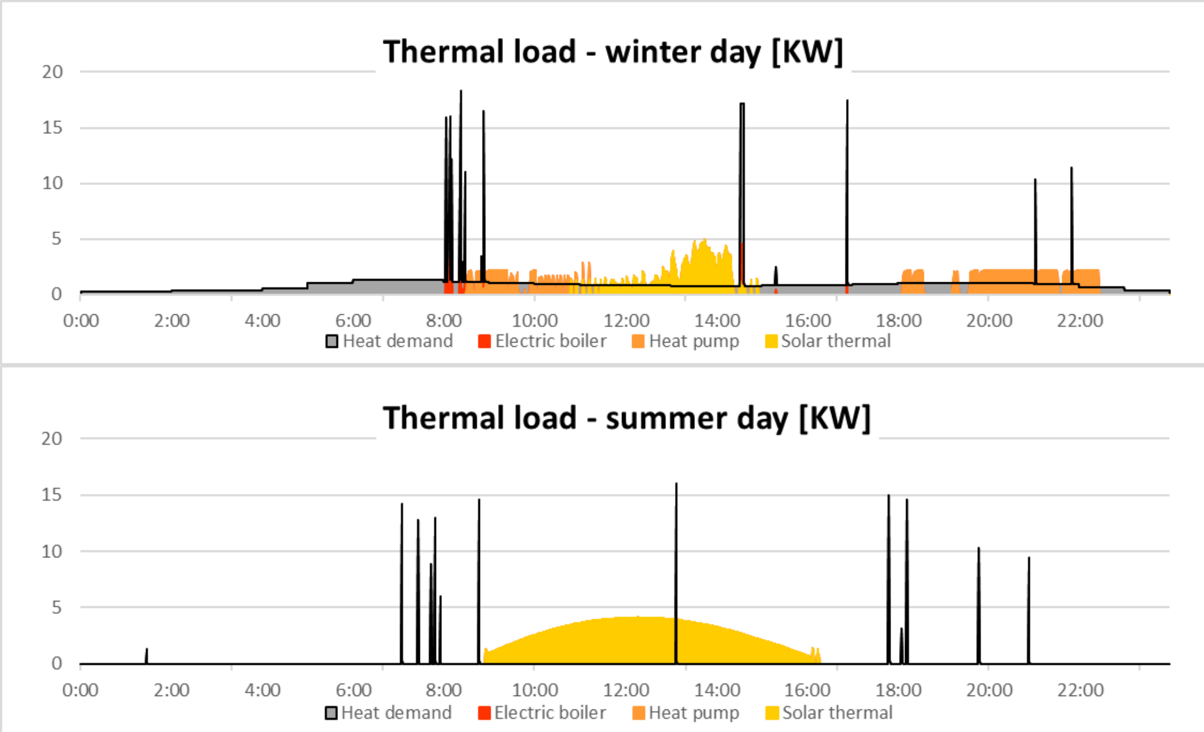


Figure 24 Heat production in Spanish household in Autarky scenario in 2050 during winter (up) and summer (down)

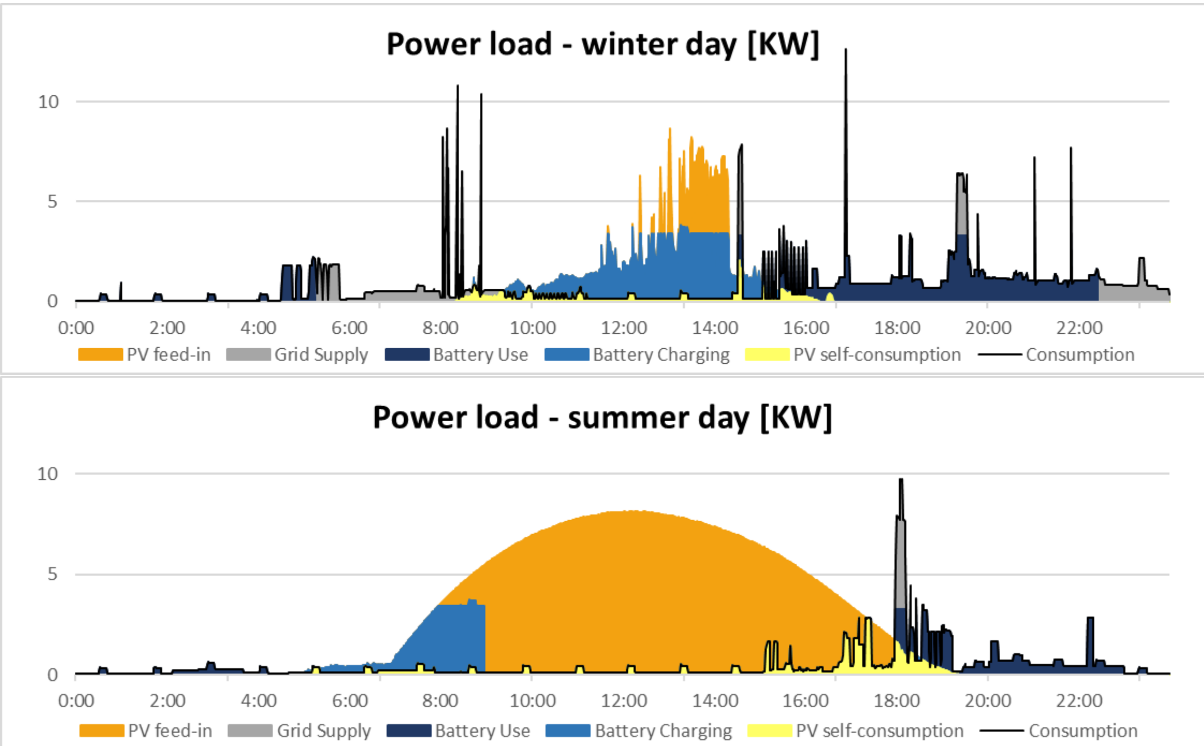


Figure 25 Electricity production in Spanish household in Autarky scenario in 2050 during winter (up) and summer (down)

6.2 Neighbourhood level

6.2.1 Aardehuis

Based on the installed capacities of the heating and electricity production technologies elaborated in chapter 5 and the simulation with EPROM, the resulting KPI have been calculated for each of the scenarios. These can be seen in Table 54 for 2030 and in Table 55 for 2050. In order to compare these results with the base year, its results have been presented in Table 53.

Table 53 KPIs for Aardehuis in the base year

	$CO_{2\ heating}$ (t/a)	*$CO_{2\ electricity}$ (t/a)*	*LCOH (€/kWh)*	*LCOE (€/kWh)*	*Autarky heating (%)*	*Autarky electricity (%)*
Base year	76.68	33.35	0.13	0.17	13	19

In 2030 it is expected that the share of autarky in the electricity sector in Aardehuis will increase in the Reference scenario compared to 2015 since it is assumed that installed PV panels will be replaced by better PV panels that produce more electricity. Due to a higher share of self-consumed electricity and lower emissions from the electricity retrieved from the grid the CO_2 emissions in the electricity sector will decrease to 19.6 t/a.

In comparison the autarky in the electricity sector in the Renewables scenario is slightly lower than in the Reference scenario. This might be surprising at first glance since one would expect higher autarkies in the Renewables scenario. While in the Reference scenario autarky is based on the sum of self-consumed electricity of each individual household in the Renewables scenario the neighbourhood is looked at as one and hence, a smoothing of the load curve could cause higher autarkies. The reason for lower autarky is that in the Renewables scenario besides some stored heat from solar heating the largest share of heating in the winter and during night is done with heat pumps. Hence, the electricity demand is especially high when no PV electricity is available. This effect outweighs the positive effect of shared consumption and production. Less autarky in the Renewables scenario compared to the Reference scenario causes also slightly higher LCOE and CO_2 emissions since a larger share of electricity has to be retrieved from the grid. With the inclusion of batteries in the Autarky scenario the share of autarky in the electricity sector increases to 66 %. This lowers CO_2 emissions and LCOE compared to the Reference scenario. Lower LCOE also shows that batteries are profitable in Aardehuis by 2030.

Contrary to the electricity sector the autarky in the heating sector is in both scenarios higher in 2030 compared to the Reference scenario. The mix of heat pumps and solar thermal is also favourable from an economic point of view with lower LCOE compared to the Reference scenario. The emissions drop 88 % in the Renewables scenario and 94 % in the Autarky scenario.

Table 54 The resuting KPIs for Aardehuis in 2030 through all 3 scenarios

	CO_2 heating (t/a)	*CO_2 electricity (t/a)*	*LCOH (€/kWh)*	*LCOE (€/kWh)*	*Autarky heating (%)*	*Autarky electricity (%)*
Aardehuis Reference	75.58	19.64	0.13	0.16	13	25
Aardehuis Renewables	9.79	19.99	0.08	0.17	54	23
Aardehuis Autarky	4.28	8.75	0.07	0.09	80	66

In 2050 the autarky in the Renewables scenario is slightly lower in the Renewables scenario than in the Reference scenario. There reason for that is that in 2050 the share of electricity demand of heat pumps compared to the total heat demand of the neighbourhood decreases. On the one hand electricity demand for lighting and appliances is assumed to increase 4.7 % compared to 2030 and on the other hand heat pumps have higher efficiencies and need less electricity. Hence, the negative effect of heat pumps on autarky explained above decreases. Due to even lower emissions from the grid and higher shares of self-consumed electricity the CO_2 emissions in the electricity sector decrease in all three scenarios. In the Autarky scenario 81 % of the heating can be done with self-produced clean heating technologies and hence the emissions drop to 3.05 t CO_2 /a. The LCOH is in the Renewable and the Autarky scenario considerably lower than in the Reference scenario showing that individual LCOH for heat pumps and PV are lower than heat production with wood as done to a large share in the Reference scenario.

Table 55 The resuting KPIs for Aardehuis in 2050 through all 3 scenarios

	CO_2 heating (t/a)	*CO_2 electricity (t/a)*	*LCOH (€/kWh)*	*LCOE (€/kWh)*	*Autarky heating (%)*	*Autarky electricity (%)*
Aardehuis Reference	75.11	15.98	0.12	0.16	13	24
Aardehuis Renewables	7.32	15.86	0.07	0.16	55	24
Aardehuis Autarky	3.05	6.6	0.06	0.08	81	68

Figure 26 shows the thermal load in the neighbourhood of Aardehuis during a winter day and a summer day. It is visible that the heating demand in the winter is primarily covered with heat pumps and in the summer with solar thermal. Where peaks are present due to warm water demand electric boilers provide the needed extra heat.

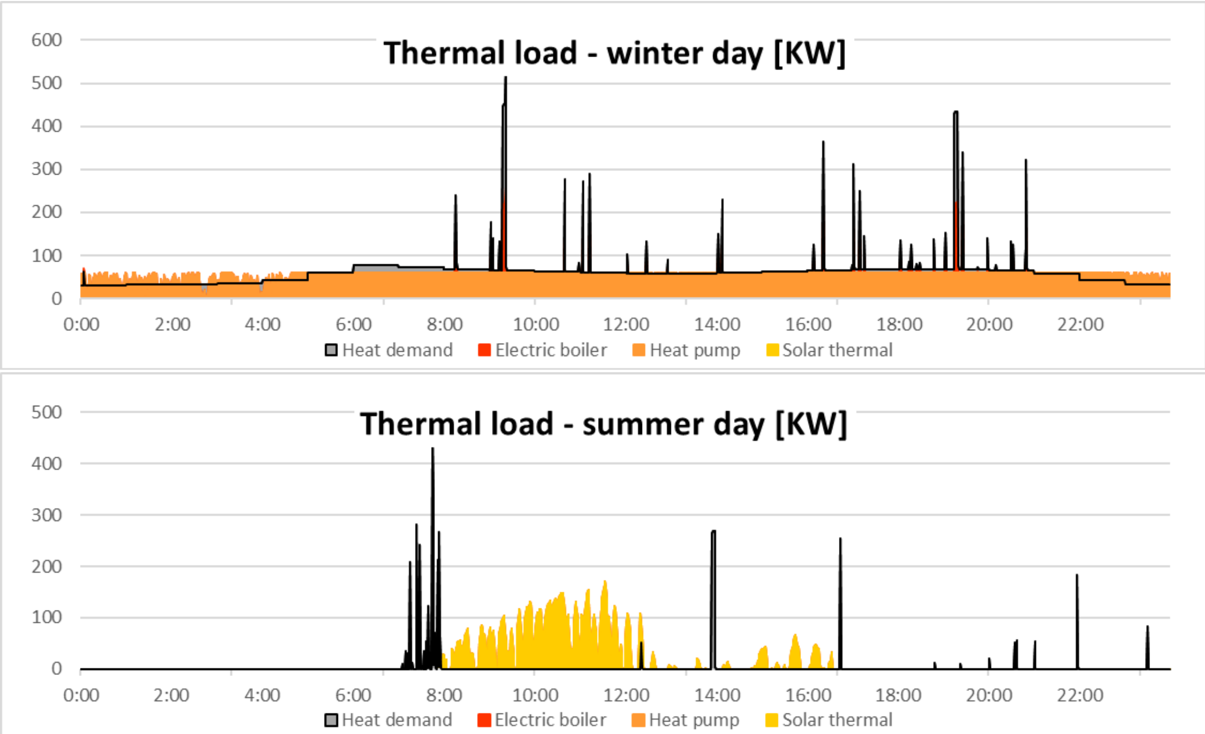


Figure 26 Heat production in Aardehuis in Autarky scenario in 2050 during winter (up) and summer (down)

Figure 27 shows the power load of Aardehuis during a summer and during a winter day. It is visible that in summer the battery is loaded in the first few hours of PV production and can almost cover the whole demand during times with no PV production. Contrary on a winter day the battery will almost not be used because almost all the electricity produced is directly used by the neighbourhood. When this is the case for a larger period of time the neighbourhood could consider using the battery for other purposes like renting storage capacity to a grid operator or other actors with an interest in storage capacity.

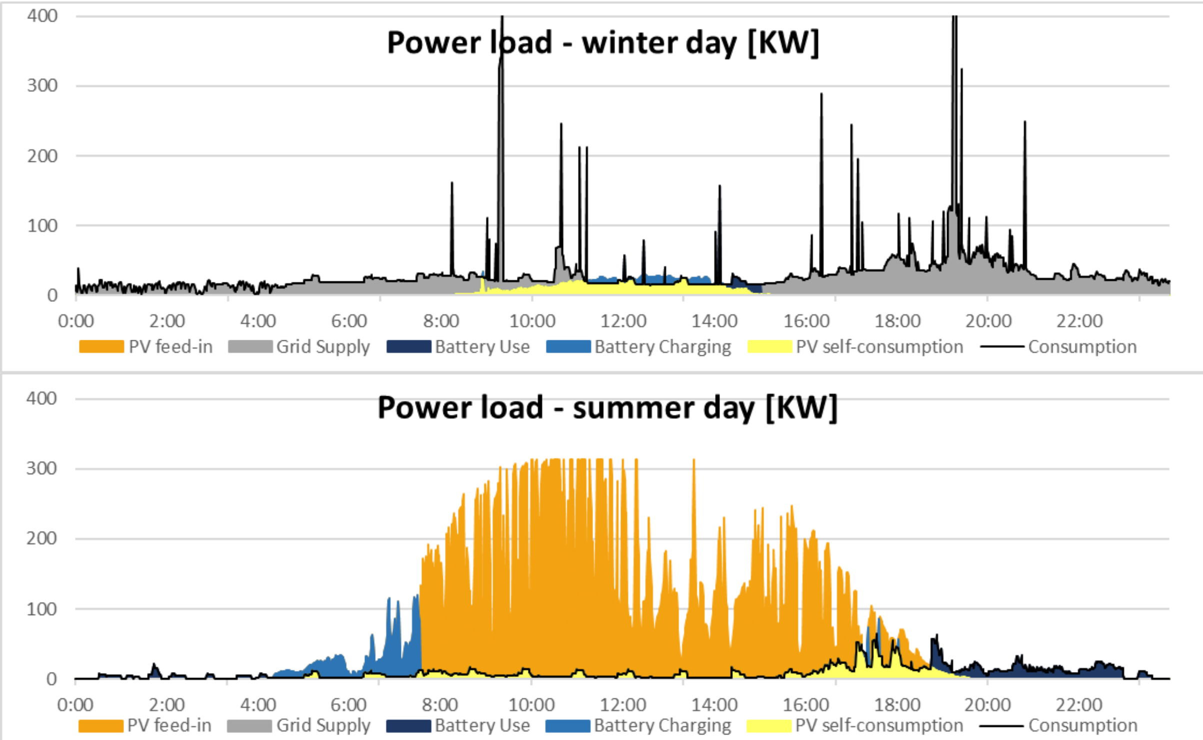


Figure 27 Electricity production in Aardehuis in Autarky scenario in 2050 during winter (up) and summer

6.2.2 Lanište

Based on the installed capacities of the heating and electricity production technologies elaborated in the section Assumptions, and the optimisation of their operation through UNIZAG FSB model, the resulting key performance indicators (KPI) have been calculated for each of the scenarios. These can be seen in Table 57 for 2030 and in Table 58 for 2050. In order to compare these results with the base year, its results have been presented in Table 56.

Table 56 KPIs for Lanište in the base year

	$CO_{2\ heating}$ (t/a)	*$CO_{2\ electricity}$ (t/a)*	*LCOH (€/kWh)*	*LCOE (€/kWh)*	*Autarky heating (%)*	*Autarky electricity (%)*
Base year	7,800.46	1040	0.175	0.131 (electricity price)	0	0

Table 57 The resuting KPIs for Lanište in 2030 through all 3 scenarios

	CO_2 *heating* (t/a)	CO_2 *electricity* (t/a)	*LCOH* (€/kWh)	*LCOE* (€/kWh)	*Autarky heating (%)*	*Autarky electricity (%)*
Lanište Reference	6,967.25	878.78	0.186	0.147 (electricity price)	0	0
Lanište Renewables	2,203.83	813.46	0.096	0.141	19.4	7.4
Lanište Autarky	2,057.15	806.37	0.093	0.140	22.8	8.2

By 2030 the CO_2 emissions of the heating sector in the neighbourhood decrease slightly in Lanište Reference due to the increase of the efficiency of the currently used fossil fuel boilers. However, this decrease is significantly higher in Renewables and Autarky where the emissions of the heating sector decrease by 72% and 74% respectively, compared to 2015 values. Such high savings are achieved due to switch from the fossil fuel sources to electrically driven solutions, which have a much lower emission factor. However, decreases in the electricity sector are not so significant due to the fact that PVs could cover only up to 8.2% of the demand in Autarky, since the operation of heat pumps and electric boilers increased the electricity demand and PVs were used also for their operation. This is reflected in much better KPIs from the heat side than from the electricity side. Still, the costs of the system, shown as LCOH and LCOE are significantly lower than in Reference. Here it must be noted that LCOH and LCOE have been calculated for the whole system and not separately for each technology in order to compare the result in an easier manner.

Table 58 The resuting KPIs for Lanište in 2050 through all 3 scenarios

	CO_2 *heating* (t/a)	CO_2 *electricity* (t/a)	*LCOH* (€/kWh)	*LCOE* (€/kWh)	*Autarky heating (%)*	*Autarky electricity (%)*
Lanište Reference	6,356.6	710.90	0.186	0.144 (electricity price)	0	0
Lanište Renewables	1029.87	612.15	0.089	0.134	32.3	13.9
Lanište Autarky	890.54	586.26	0.084	0.129	39.5	17.5

When the results from 2050 are taken into account, it can be concluded that 88.6% of CO_2 savings can be achieved in Lanište Autarky compared to 2015 and 86% compared to Reference in 2050. Significant savings can also be achieved in Renewables both in the heating and the electricity sector. The emissions of the electricity sector decrease by 45.7% in Autarky, which is rather lower than for the heating sector due to the aforementioned reasons.

LCOH in Autarky is 42% lower than the base year and 32% lower than Renewables, showing significant economic benefits of renewable prosumer technology integration. Furthermore, LCOE in both Autarky and Renewables is lower than the electricity price in the Reference. Finally, despite the figures for autarky in heating and electricity being relatively moderate, it has to be noted that heat is produced exclusively from the prosumer technologies as elaborated in the Assumptions section, but only the renewable autarky has been calculated, meaning that heat which was produced by heat pumps and electric boilers by using electricity from the gird was not taken into account. Even in the Autarky scenario, 8% of the produced electricity is still being sold to the grid and therefore higher electricity storage capacities would be needed to increase the share of electrical autarky, which could be integrated in the neighbourhood due to its characteristics and available area. This is also the case for solar thermal, since its potential has not been utilised to the fullest, despite larger thermal storage units being installed.

In order to illustrate the operation of the system with integrated prosumer technologies, the production from different units in one summer and winter week for Lanište Autarky 2050 can be seen in Figure 28 and Figure 29.

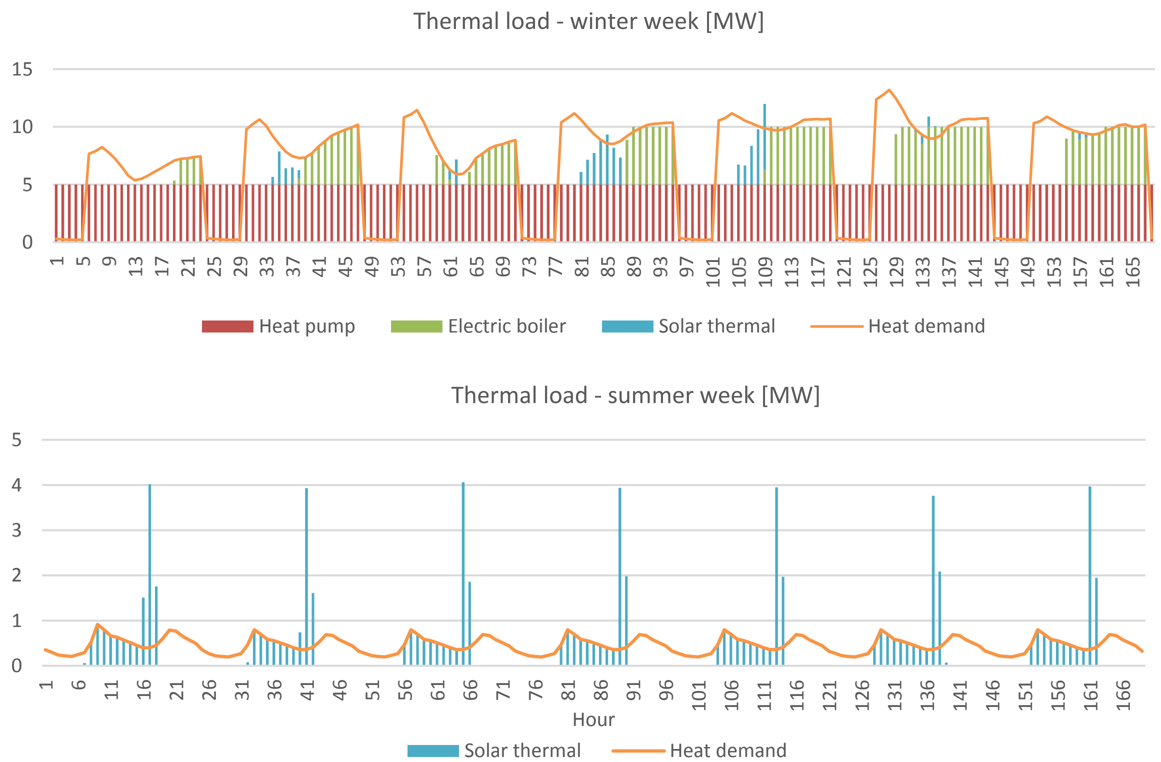


Figure 28 Heat production in Lanište Autarky in 2050 during winter (up) and summer (down)

The parts of the demand which seem not covered by any technology are covered by heat or electricity from energy storage. The figures show that during the summer, the installed capacity of solar thermal is enough to cover the heat demand, however in the winter period heat pumps are also operating and at some period the electric boilers as well. Overall, the heat pumps cover 67% of the heat demand in Autarky, electric boilers 7% and solar collectors 26%.

In the electricity sector, it can be seen that during the winter practically most of the electricity is being imported, especially due to the much higher demand because of the heat pump and electric boiler operation. Also, no PV electricity is being exported to the grid during the winter. However, in summer, the production is much higher and PVs cover the demand during the day and some parts of the night, while during the other times the electricity is still being imported due to the low battery capacity, as mentioned before.

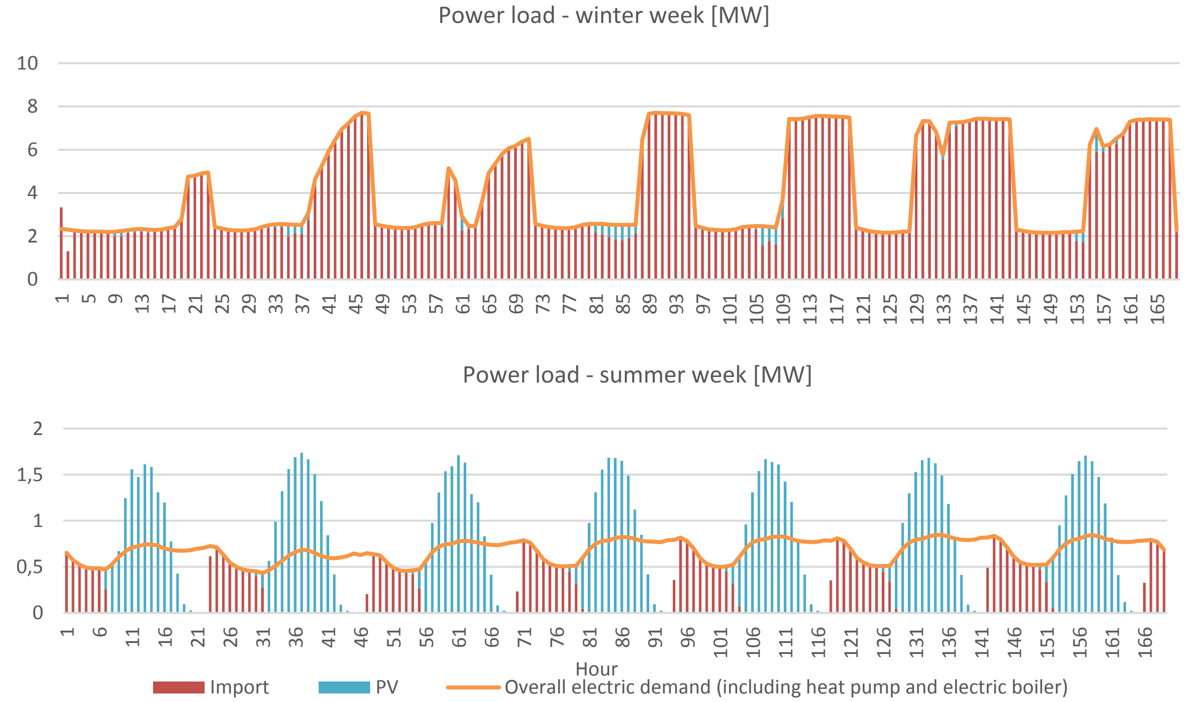


Figure 29 Electricity production in Lanište Autarky in 2050 during winter (up) and summer (down)

6.2.3 Klausenerplatz

Similar as for the Lanište neighbourhood, the resulting KPIs for Klausenerplatz will be presented in this section. These are first calculated for the base year and shown in Table 59. As has already been elaborated in the Assumptions section, there is currently no renewable prosumer technologies in the neighbourhood and the results are therefore rather conservative. Since the same technology mixes are kept for 2030 and 2050 in Klausenerplatz Reference, the results do not change significantly throughout the years.

Table 59 KPIs for Klausenerplatz in the base year

	CO_2 heating (t/a)	*CO_2 electricity (t/a)*	*LCOH (€/kWh)*	*LCOE (€/kWh)*	*Autarky heating (%)*	*Autarky electricity (%)*
Base year	1,613.5	511.19	0.219	0.295 (electricity price)	0	0

However, when renewable prosumer technologies are added for heat and electricity production, the resulting figures change significantly. KPIs for Klasuenerplatz Renewables and Klausenerplatz Autarky for 2030 can be seen in Table 60.

Table 60 The resuting KPIs for Klausenerplatz in 2030 through all 3 scenarios

	CO_2 heating (t/a)	*CO_2 electricity (t/a)*	*LCOH (€/kWh)*	*LCOE (€/kWh)*	*Autarky heating (%)*	*Autarky electricity (%)*
Klausenerplatz Reference	1,386.14	532.64	0.236	0.331 (electricity price)	0	0
Klausenerplatz Renewables	427.33	170.11	0.075	0.293	63.8	79.85
Klausenerplatz Autarky	406.1	136.46	0.071	0.297	66	83.79

The result show that already in 2030 significant CO_2 savings can be achieved in both scenarios, compared to Klausenerplatz Reference. The savings in the electricity sector amount to 68% for Renewables and 74.5% in Autarky compared to reference in 2030. For the heating sector, similar savings are achieved, i.e. 69.2% for Renewables and 70.8% for Autarky. Such higher savings in the electricity sector than in Lanište are achieved because of the small biomass-based cogeneration units. Due to the use of locally available biomass, their CO_2 emissions are counted as zero. This shows the impacts and significant benefits of installing small cogeneration units as a prosumer technology. Furthermore, the costs of the system, presented as LCOH and LCOE show that this configuration result also in less expenses in both scenarios for heat and electricity.

Using biomass cogeneration units in the neighbourhood also results in much higher renewable autarchies for both the electricity and heating sector compared to Lanište. Therefore, such a mix of technologies proves to be a more suitable solution, especially in the locations where solar technologies have lower potential due to the specific climate conditions.

Table 61 The resuting KPIs for Klausenerplatz in 2050 through all 3 scenarios

	CO_2 heating (t/a)	*CO_2 electricity (t/a)*	*LCOH (€/kWh)*	*LCOE (€/kWh)*	*Autarky heating (%)*	*Autarky electricity (%)*
Klausenerplatz Reference	1,081.15	710.90	0.225	0.325 (electricity price)	0	0
Klausenerplatz Renewables	175.49	81.30	0.088	0.273	76.4	84.8
Klausenerplatz Autarky	150.04	47.64	0.064	0.279	80.8	90.9

Finally, when the results for 2050 are calculated, they show even better results, achieving more than 80% of renewable autarky for heating in Klausenerplatz Autarky and more than 90% for electricity. The LCOE and LCOH decrease even further, showing the financial feasibility of switching to renewable prosumer technologies for the consumers. Finally, the achieved CO_2 savings in 2050 are much higher than in 2030, resulting overall in 83.9% savings in Renewables and 86.2% savings in Autarky compared to Reference. These high savings are achieved due to reduced use of the grid electricity for heat pump since cogeneration is producing a high share of needed electricity.

The operation of heat and electricity generation technologies for a typical winter and summer week in Klausenerplatz Autarky 2050 are shown in Figure 30 and Figure 31.

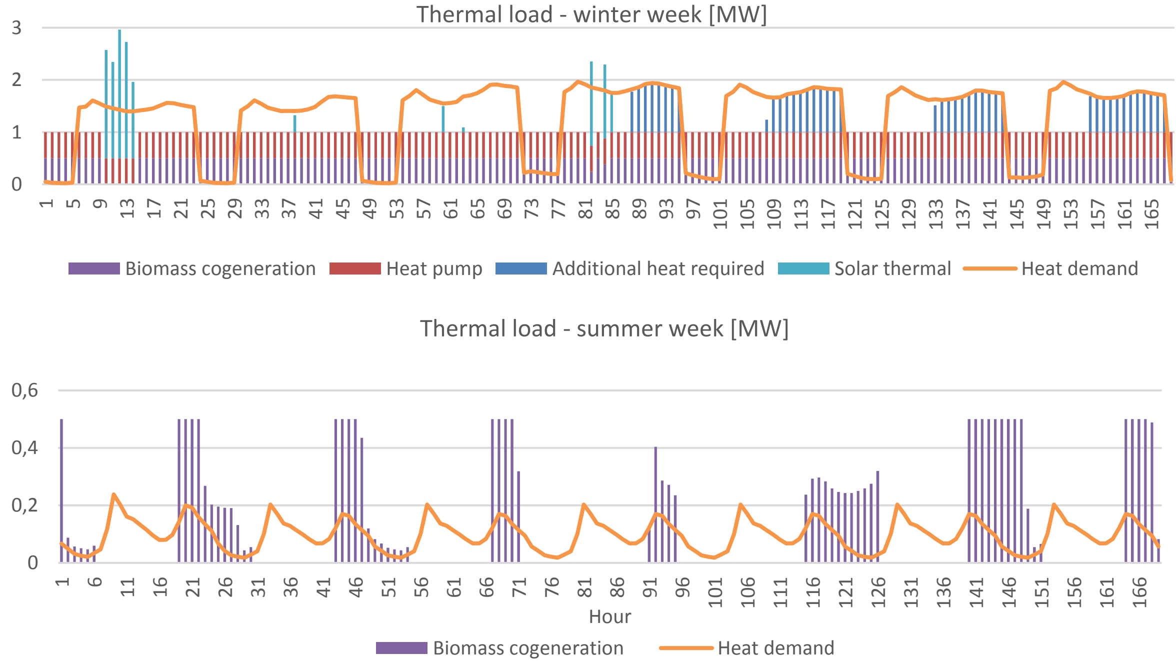


Figure 30 Heat production in Klausenerplatz Autarky in 2050 during winter (up) and summer (down)

It can be seen that the cogeneration plants and heat pumps operate as the base load during the winter, running on the full capacity and supplying heat to the prosumers. Some solar heat is also produced and some additional heat is required since local production units in combination with thermal storage units are not able to cover the whole demand at some times. However, this additional required heat is rather minimal and accounts to only 3.6% of the demand on the annual level. The rest is covered by biomass cogeneration (51.4%), heat pumps (20.7%) and solar thermal (24.3%) on the annual level.

Despite a higher share of solar thermal, it can be noticed that during the summer no heat is produced from this technology. This is a result of the fact that cogeneration units have higher benefits on the system level due to both renewable heat production and the electricity sales. Therefore, they have a priority to solar technologies, since the model optimises the economic function, i.e. provides the operation of system with lowest system costs. In reality, even higher shares of solar technologies would be achieved due to their operation in the summer, but the electric renewable autarky would be reduced in such a case.

From the electricity system perspective, a much higher diversity of production technologies is achieved compared to Lanište. While during the winter some import is required due to higher electricity demands, it is reduced to minimal levels during the summer, where most of the demand is covered by cogeneration, PVs and micro wind turbines. Overall, 9.1% of electricity is imported on the annual level, while the rest of the demand is covered by biomass cogeneration (69.1%), PVs (15.7%) and micro wind turbines (6.1%).

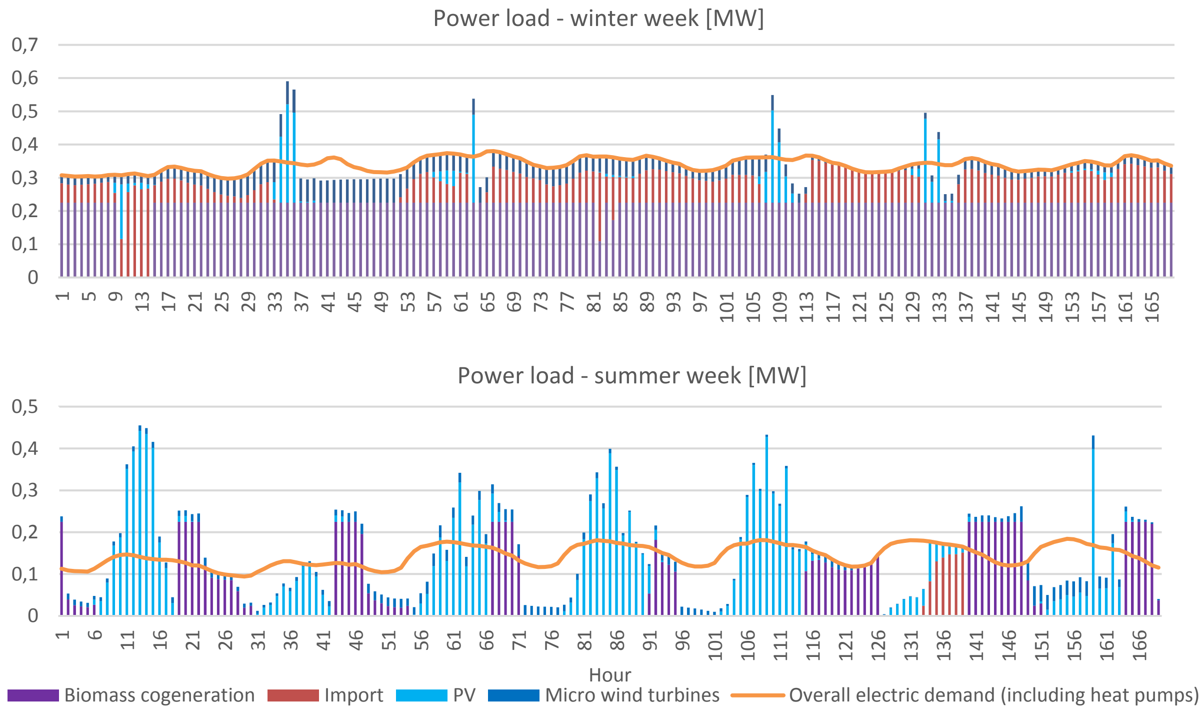


Figure 31 Electricity production in Klausenerplatz Autarky in 2050 during winter (up) and summer (down)

6.3 City level

6.3.1 Ozalj

The base year results for the city of Ozalj can be seen in Table 62. What can be noted when looking at the economic KPIs for the heating sector in the base year, are the low costs for heating. These occur due to the current energy sources used for heating, i.e. a large share of logwood. This biomass, which is burned in an unsustainable fashion, has very low costs to the final users since most of the citizens own a part of the forest and can have the energy source for free. Therefore, the results for the Ozalj Renewables and Ozalj Autarky will not be so appealing from the economic perspective, but the environmental effect should be in focus in this case. This represents a standard rural city in the south-east Europe and similar situation is present in many others.

Table 62 KPIs for Ozalj in the base year

	CO_2 heating (t/a)	*CO_2 electricity (t/a)*	*LCOH (€/kWh)*	*LCOE (€/kWh)*	*Autarky heating (%)*	*Autarky electricity (%)*
Base year	19,748.8	3,490.51	0.097	0.131 (electricity price)	0	0

When the results from 2030 are considered, it can be seen that rather significant CO_2 emission reductions can be achieved in the heating sector in Renewables and Autarky, compared to the Reference. Here it has to be noted that in such cities, where a lot of biomass is being used in an unsustainable manner, by using old and inefficient furnaces, the emissions of local pollutants (NO_x, SO_x, particulate matter) are much more significant.

Therefore, the real environmental effect of switching to renewable prosumer technologies is even higher, due to reducing local emissions by a significant margin. On the electricity side, the CO_2 emissions decrease slightly due to PV production, but the decrease is not so high due to a large amount of PV production going to the operation of heat pumps and electric boilers.

Due to the aforementioned reasons, LCOH increases in 2030 in both Renewables and Autarky but it can be observed that the increase is not too high, i.e. approximately 37% compared to Reference, which is acceptable when the environmental benefits are taken into account. On the electricity side, the LCOE decreases by 4.8% in both Renewables and Autarky. The renewable autarky of the city by 2030 remains rather low due to low production of electricity from renewable technologies and high consumption of electricity from the electric boilers and heat pumps, which doesn't change much when larger storage capacities are added.

Table 63 The resuting KPIs for Ozalj in 2030 through all 3 scenarios

	CO_2 heating (t/a)	*CO_2 electricity (t/a)*	*LCOH (€/kWh)*	*LCOE (€/kWh)*	*Autarky heating (%)*	*Autarky electricity (%)*
Ozalj Reference	17,567.5	2,949.4	0.102	0.147 (electricity price)	0	0
Ozalj Renewables	8,340.4	2,754.4	0.100	0.141	18.4	6.58
Ozalj Autarky	8,148.4	2,752.9	0.099	0.141	19.5	6.63

In 2050, the environmental impact decreases up to 75.9% in Autarky compared to Reference, showing significant benefits of such a configuration, despite lower renewable autarkies of the system. This also shows benefits of transferring to the highly efficient electrically driven hat production even when it consumes electricity from the grid, especially when the future much higher shares of renewables in electricity production are taken into account.

The difference in LCOH between Reference and Autarky is also reduced to 30%, while renewable autarky in the electricity sector achieves almost 15%, taking into account the physical boundaries and that the production comes only from PVs.

Table 64 The resuting KPIs for Ozalj in 2050 through all 3 scenarios

	CO_2 heating (t/a)	*CO_2 electricity (t/a)*	*LCOH (€/kWh)*	*LCOE (€/kWh)*	*Autarky heating (%)*	*Autarky electricity (%)*
Ozalj Reference	16,330.9	2,385.9	0.105	0.144 (electricity price)	0	0
Ozalj Renewables	4,234.9	2,109.6	0.093	0.130	30.29	11.6
Ozalj Autarky	3,945.4	2,042.1	0.091	0.129	34.3	14.4

The production from different heat production units in typical winter and summer weeks can be seen in Figure 32. It can be seen that during the summer, only solar thermal produces heat and no other unit is required. However, during the winter, most of the heat is produced by electric boilers and heat pumps, and no additional heat is required from the existing heating units. Overall, 23.2% of heat on the annual level is produced from the solar thermal collectors, 23.3% from the electric boilers and 53.5% from the heat pumps

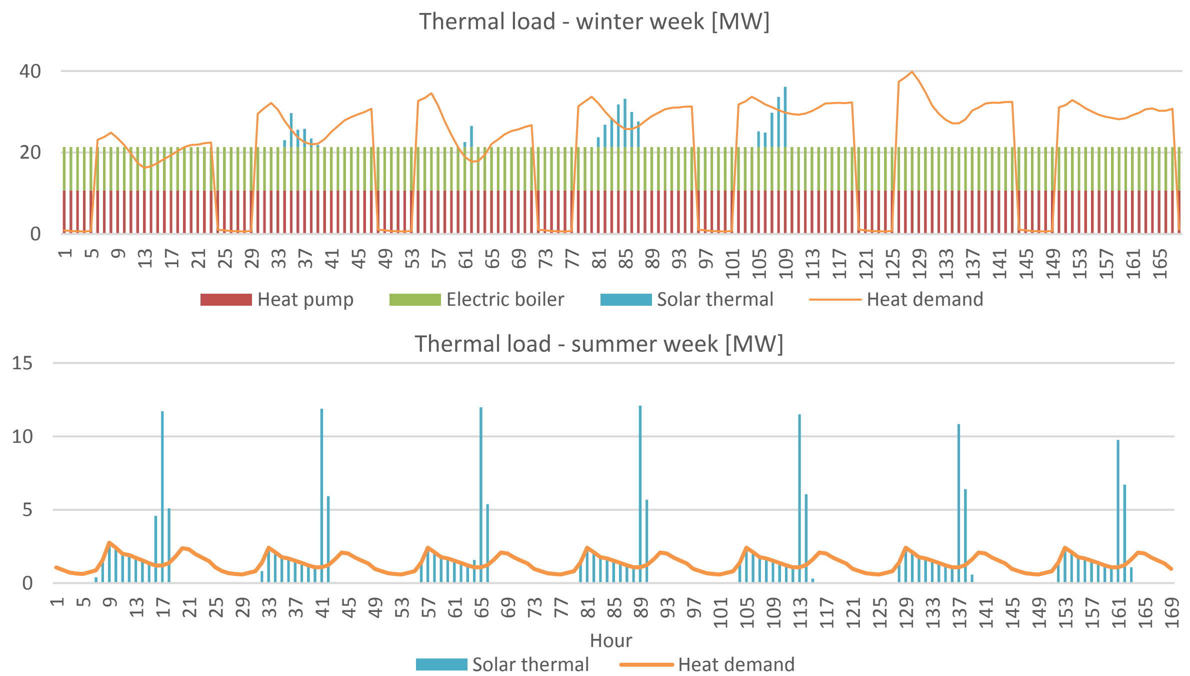


Figure 32 Heat production in Ozalj Autarky in 2050 during winter (up) and summer (down)

From the electricity production side, it can be seen that due to the higher electricity demand from heat pumps and electric boilers, the production from PV is practically negligible during the winter, covering only small shares of the demand. It can also be argued that heat pumps and electric boilers have a function of electricity storage during the winter and no additional battery capacity is needed during these times.

However, in summer, when heat is produced only from the solar collectors, electricity produced from PVs covers he majority of the demand, with only a few hours a day when the electricity is imported from the gird. However, still some electricity is imported, showing that higher capacities of PV and electric battery would be needed to cover the whole demand during the summer.

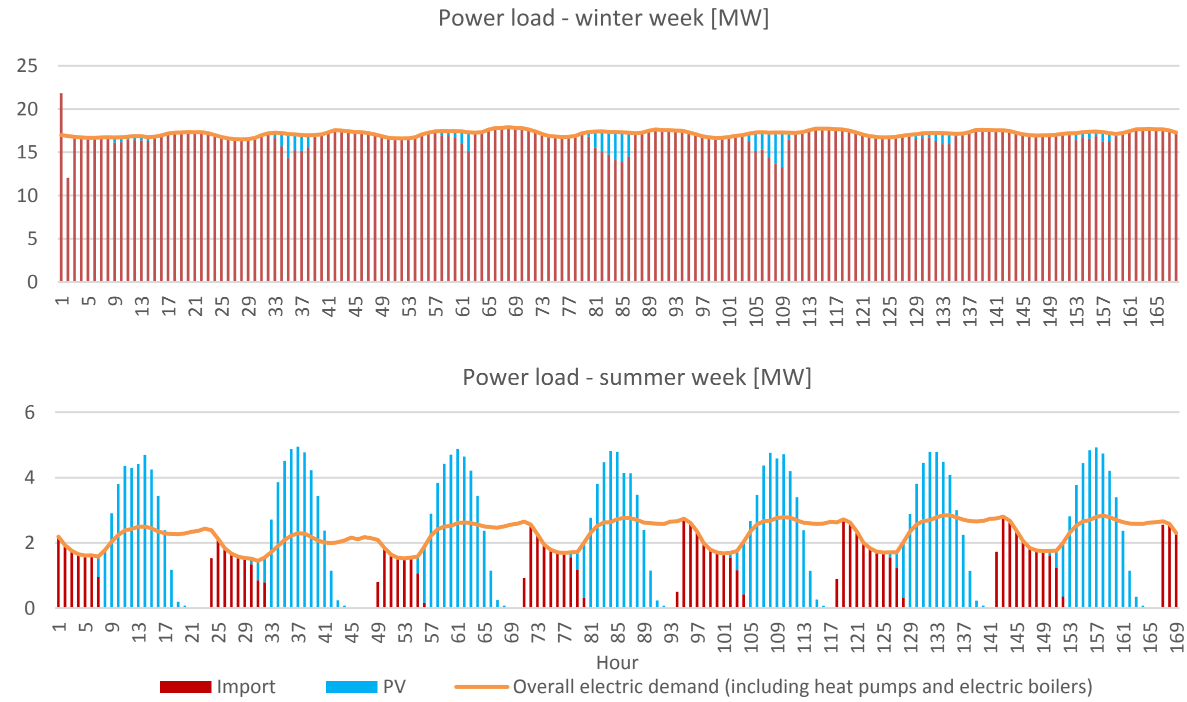


Figure 33 Electricity production in Ozalj Autarky in 2050 during winter (up) and summer (down)

6.3.2 Girona

The results of the bas year calculations for Girona can be seen in Table 65. Compared to the previous use cases, it can be seen that the CO_2 emissions are much higher in the electricity sector than in the heating sector. The reason for that lies in the fact that the electricity consumption in Girona is significantly higher than the heat consumption due to the operation of the air conditioning units in the summer. It was also assumed that no renewable prosumer technologies are currently being used, based on the existing data and therefore the autarky of both heating and electricity sectors remains zero throughout the years.

Table 65 KPIs for Girona in the base year

	$CO_{2\ heating}$ (t/a)	*$CO_{2\ electricity}$ (t/a)*	*LCOH (€/kWh)*	*LCOE (€/kWh)*	*Autarky heating (%)*	*Autarky electricity (%)*
Base year	64,122	121,996	0.197	0.231 (electricity price)	0	0

Furthermore, the result of each of the scenarios for 2030 are shown in Table 66. It can be seen that through the given configuration of the system, significant savings can be achieved already by 2030. This is due to the geographical location of the city, with high solar irradiation, leading to much higher yields of solar technologies for heating and electricity production. It has to be noted that the assumed capacities for solar technologies in the city are maybe conservative and that even higher shares of solar energy could be utilised.

It can be seen that the reductions of CO_2 emissions in the heating sector are significant, with 87% reductions in Girona Renewables and 94.2% in Girona Autarky, compared to Girona Reference in 2030. These are achieved through high shares of solar thermal utilisation, which accounts to 70% in Renewables and 77% in Autarky, but also a high share of electricity for heat pump coming from PVs. However, due to high electricity demand, this share is not as high as in the heating sector and therefore the CO_2 emissions of the electricity sector decrease only by 41.3% in Renewables and 51.1% in Autarky compared to Reference.

Through using such a high amount of solar energy for both heat and electricity production, significant cost decreases can be achieved in these sectors, which shows great economic benefit of solar integration in the southern Europe. Finally, renewable autarkies of both scenarios are significant in the heating sector, achieving almost 90% in Autarky scenario. On the other hand, renewable autarky in the electricity sector is lower, due to high electricity demand but still above 50% in Autarky. It has to be noted that due to lower capacities of batteries in Renewables and Autarky, significant amount of electricity is also sold to the grid, i.e. 215 GWh in Renewables and 163 GWh in Autarky, providing additional benefits to the grid and the prosumers themselves.

Table 66 The resuting KPIs for Girona in 2030 through all 3 scenarios

	$CO_{2\ heating}$ (t/a)	*$CO_{2\ electricity}$ (t/a)*	*LCOH (€/kWh)*	*LCOE (€/kWh)*	*Autarky heating (%)*	*Autarky electricity (%)*
Girona Reference	64,566	53,108	0.229	0.259 (electricity price)	0	0
Girona Renewables	8,848	31,222	0.056	0.184	78.2	40.7
Girona Autarky	3,770	25,967	0.048	0.153	88.4	52.6

When the results from the 2050 are analysed, shown in Table 67, it can be seen that it is possible to achieve the zero emissions in the heating sector by using this configuration of renewable prosumer technologies in Autarky. This is achieved through the combination of lower heat demands, high solar irradiation and larger storage tanks installed at different sites in the city. Therefore, all of the heat demand is covered by heat produced from the solar thermal collectors and the renewable autarky amounts to 100%. This also results in 78% lower LCOH than in Reference, showing that this scenario has by far the best indicators.

From the electricity production side, it can be seen that renewable autarky doesn't reach 100%, which is due to the lack of battery capacities. If higher battery capacities were installed, this would also achieve 100% since the overall amount of produced electricity from PVs exceeds the demand by more than double, at 772 GWh, which also results in high amounts of electricity being sold to the grid.

Table 67 The resuting KPIs for Girona in 2050 through all 3 scenarios

	CO_2 heating (t/a)	*CO_2 electricity (t/a)*	*LCOH (€/kWh)*	*LCOE (€/kWh)*	*Autarky heating (%)*	*Autarky electricity (%)*
Girona Reference	59,502	27,277	0.237	0.254 (electricity price)	0	0
Girona Renewables	157.7	14,956	0.035	0.166	98.8	45.6
Girona Autarky	0	6,567	0.023	0.134	100	75.9

In order to graphically present the results, the operation of the heat production units in Girona Autarky 2050 is shown in Figure 34. Since solar thermal collectors produce all of the heat, the differences between the summer week and the winter week are not significant. In both cases, solar thermal produces heat during the day and stores it in the storage system to be used during the night.

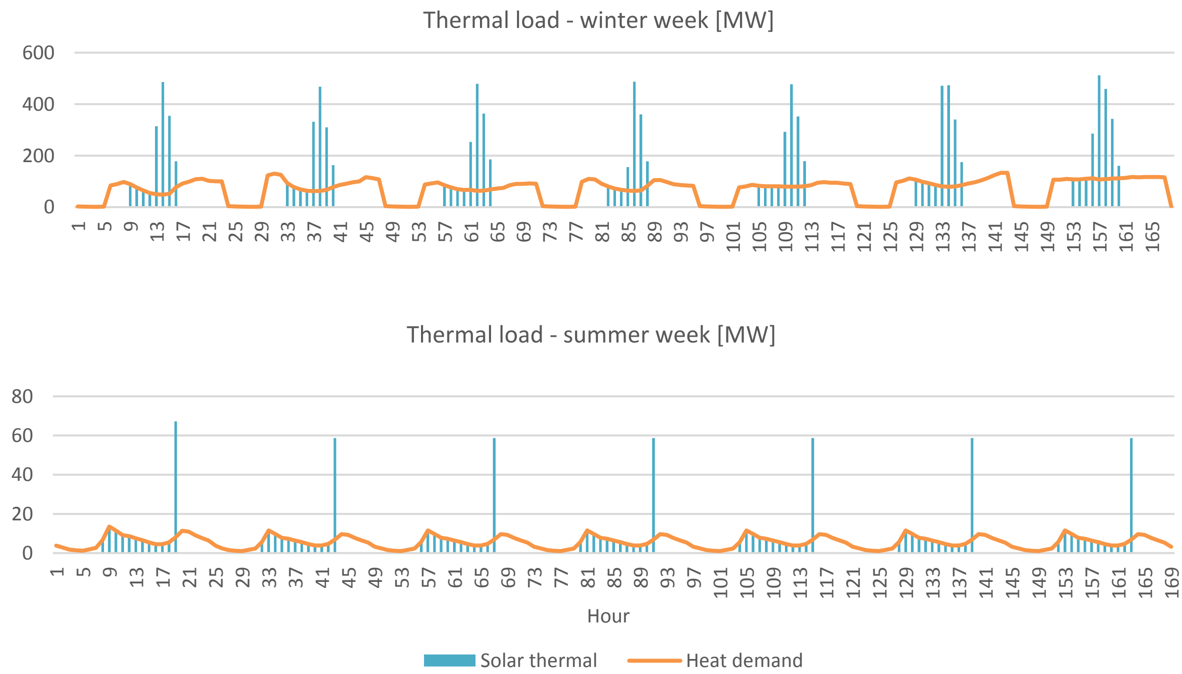


Figure 34 Heat production in Girona Autarky in 2050 during winter (up) and summer (down)

Therefore, it is more interesting to analyse charging and discharging of the thermal storage system. This can be seen in Figure 35. It is interesting to notice that storage is not being charged much during the summer to store the heat for use later in the autumn and winter since the heat production in that months is still high enough to achieve 100% autarky. Therefore, the storage system operates at its full capacity mostly during the winter, spring and autumn.

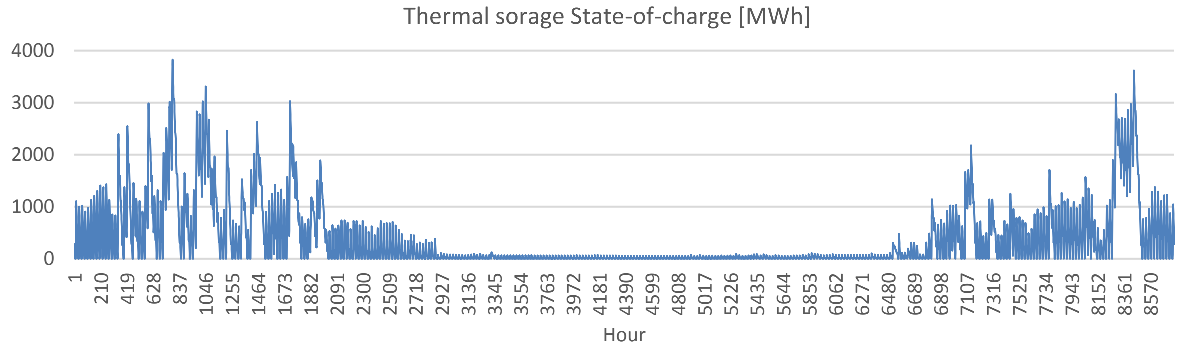


Figure 35 State of charge of the thermal storage during the whole year in Girona Autarky 2050

The production of electricity in winter and summer weeks is shown in Figure 36. Similar to the heat production, electricity is produced during the day and stored in batteries for use later during the night. However, here it has to be noticed that the capacity of the battery is not high enough in order to store all of the electricity for later use. Therefore, still some import is required during the night hours, and most of the electricity produced from PVs is actually sold to the grid, as mentioned before. It can be discussed that such high export of electricity to the grid will further decrease the environmental impact of the grid and will therefore reduce the overall CO_2 emissions of the electricity sector in the city.

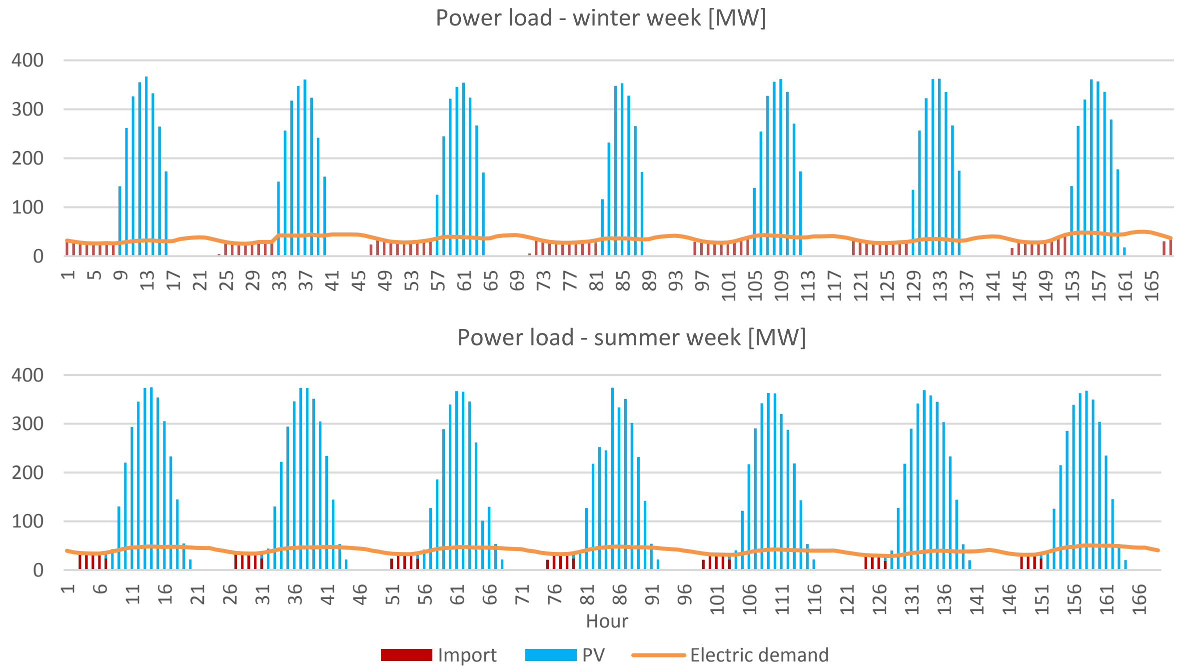


Figure 36 Electricity production in Girona Autarky in 2050 during winter (up) and summer (down)

As in the heat sector, it is interesting to take a look at the battery state of charge, which is presented in Figure 37. It proves that the battery is rather undercapacitated since it is being fully charged and discharged almost every day. Therefore, higher capacities would be needed in order to lower the export to the gird and therefore increase the overall renewable autarky of the energy system in Girona.

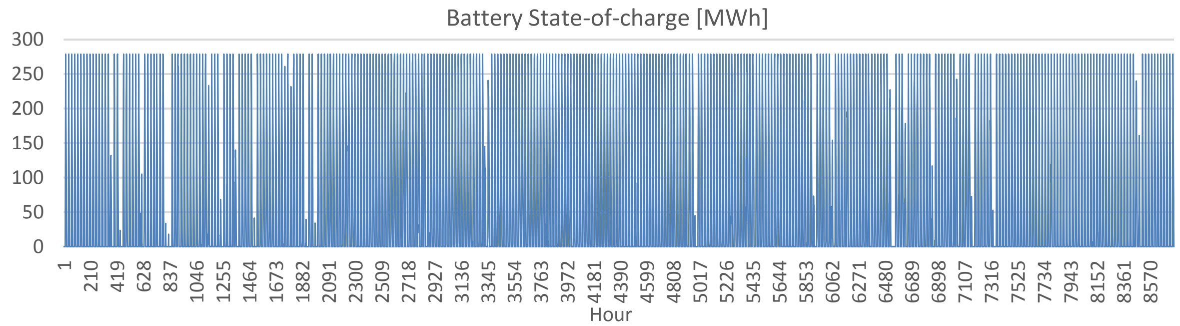


Figure 37 State of charge of the thermal storage during the whole year in Girona Autarky 2050

6.3.3 Bristol

The results for the base year in Bristol can be seen in Table 68. It has already been mentioned that the assumption has been made that there are no prosumer technologies in 2015 due to the lack of more detailed data. Therefore, renewable autarkies for electricity and heating remain zero until 2050.

Table 68 KPIs for Bristol in the base year

	$CO_{2\,heating}$ (t/a)	$CO_{2\,electricity}$ (t/a)	LCOH (€/kWh)	LCOE (€/kWh)	Autarky heating (%)	Autarky electricity (%)
Base year	993,624	708,677	0.223	0.213 (electricity price)	0	0

When the assumed capacities of heating and electricity production technologies are analysed, it can be concluded that with the given configuration, very high renewable autarky can be achieved already in Bristol Renewables in 2030. This also results in much lower LCOH and LCOE than in Bristol Reference. Even higher renewable autarky, as can be seen in Table 69, is achieved in Bristol Autarky.

This in turn leads to 94.3% decrease of CO_2 emissions in the electricity sector and 83% in the heating sector in Autarky compared to Reference. Especially high renewable autarky is achieved in the electricity sector, which is due to the high share of CHP in the production of electricity, which uses renewable biomass.

However, it must be noted that in this case, biomass has been considered as carbon neutral, which doesn't necessarily have to be the case. Therefore, the environmental, as well as autarky results could differ, depending on the availability of renewable and sustainable biomass. However, due to the lack of more detailed data on the availability of sustainable biomass in the region, it has been assumed that all the utilised biomass is sustainable.

With the given configuration of the system, a high amount of electricity is being sold to the grid, which provides additional benefit to the users. Overall, 565 GWh could be exported to the grid in Renewables and 559 GWh in Autarchy.

Table 69 The resuting KPIs for Bristol in 2030 through all 3 scenarios

	CO_2 heating (t/a)	*CO_2 electricity (t/a)*	*LCOH (€/kWh)*	*LCOE (€/kWh)*	*Autarky heating (%)*	*Autarky electricity (%)*
Bristol Reference	728,742	219,452	0.234	0.238 (electricity price)	0	0
Bristol Renewables	153,106	24,198	0.124	0.110	79.2	89
Bristol Autarky	124,421	12,645	0.116	0.087	84.5	94.2

Even better KPIs are achieved for 2050 with the modelled prosumer scenarios, as can be seen in Table 70. Therefore, it can be seen that full renewable autarky in the electricity sector is practically achieved in both Renewables and Autarky scenarios. This is due to higher PV and wind capacities of the system and therefore no difference is made when additional battery capacity is installed. However, in the heating sector the renewable autarky does not reach 100% in neither of the scenarios, but it manages to reach almost 90% in Bristol Autarky. This still results in a certain amount of CO_2 emissions in the heating sector which is nonetheless 86.3% lower in Autarky and 79.4% in Renewables compared to Reference in 2050. Since there is practically no difference between Renewables and Autarky in the electricity sector, the LCOE remains the same and is lower than in the Reference. LCOH is also lower for both scenarios, when compared to Reference. Again, both scenarios result in significant amount of electricity available for export to the grid, i.e. 1,815 GWh in Renewables and 1,986 GWh in Autarky.

Table 70 The resuting KPIs for Bristol in 2050 through all 3 scenarios

	CO_2 heating (t/a)	*CO_2 electricity (t/a)*	*LCOH (€/kWh)*	*LCOE (€/kWh)*	*Autarky heating (%)*	*Autarky electricity (%)*
Bristol Reference	577,200	163,846	0.223	0.234 (electricity price)	0	0
Bristol Renewables	118,693	57	0.165	0.227	79.7	99.9
Bristol Autarky	79,407	0	0.148	0.227	89.6	100

The graphical presentation of the scenario with best KPIs, i.e. Bristol Autarky 2050 can be seen in the following figures. Figure 38 shows heat production from different sources in a typical winter and summer week. It can be seen that during the winter there is some production from solar thermal, while most of the heat is produced by the biomass cogeneration. However, significant amount of heat also needs to be supplied by the additional heat source, e.g. existing fossil fuel boilers, etc. This is due to under capacitated thermal storage system, which results in the fact that 10.4% of heat is still supplied from additional heat sources. The rest is supplied by biomass cogeneration (68.6%) and solar thermal (21%). It can also be noticed that similar to Klasuenerplatz the cogeneration unit is the only one that operates during the summer, due to its superior economic benefits and since the model provides the optimisation based on the lowest cost technology. In the reality, more solar thermal could be utilised during the summer, increasing the autarky of the system.

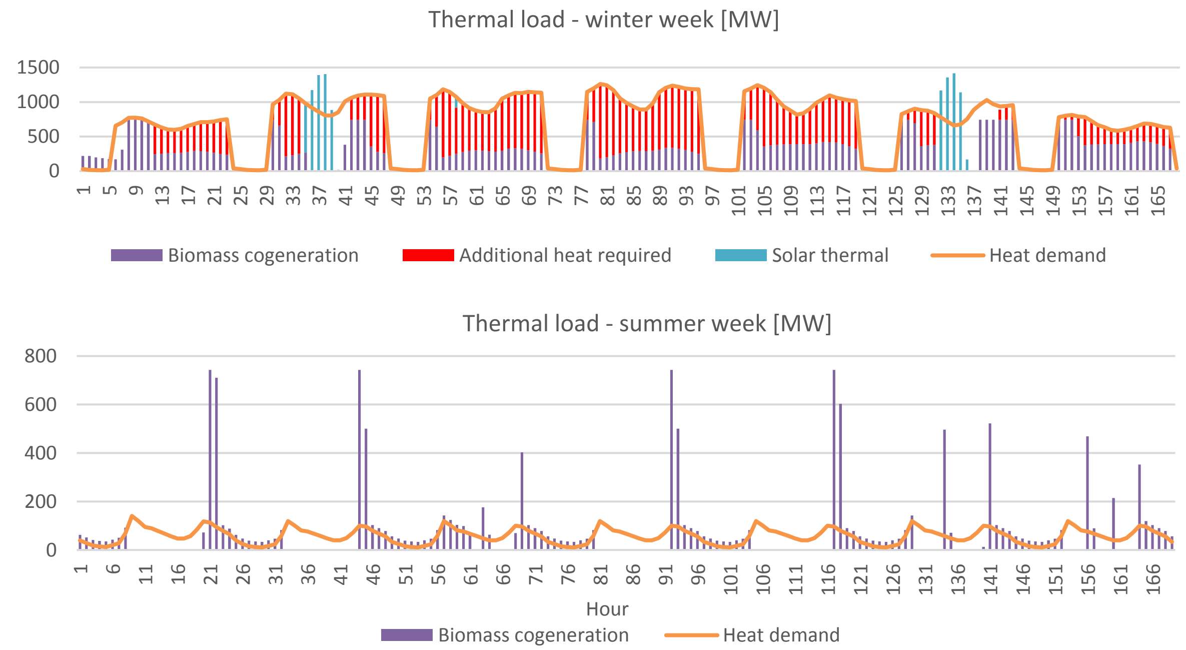


Figure 38 Heat production in Bristol Autarky in 2050 during winter (up) and summer (down)

However, in order to do so, thermal storage system would need to have a higher storage capacity, since currently it fills rather quickly to the maximum at the beginning of summer, as can be seen in Figure 39. This figure also shows that the storage system is actually of seasonal character and should transfer heat produced during the summer months to winter and additionally increase the system autarky.

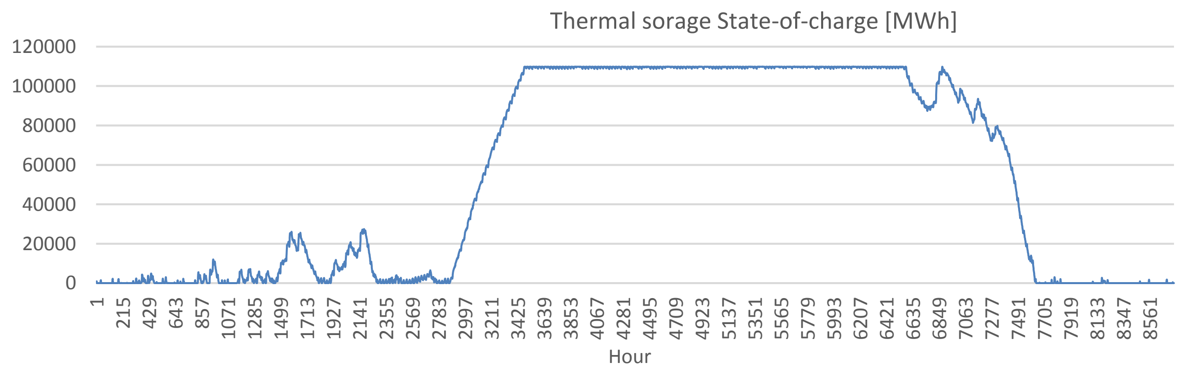


Figure 39 State of charge of the thermal storage during the whole year in Bristol Autarky 2050

Furthermore, in the electricity sector, the electricity production is shown in Figure 40. It can be seen that there is no import in both figures, as has already been showed in the KPIs, making this sector 100 renewable. It can be seen that the highest production during the winter comes from the wind turbines, while during the summer it comes from PVs. Overall, on the annual basis 76.7% of the demand is covered by the cogeneration unit, 10.3% from the PVs and 13% from wind turbines. The rest of the production from PVs and wind turbines is being exported to the grid.

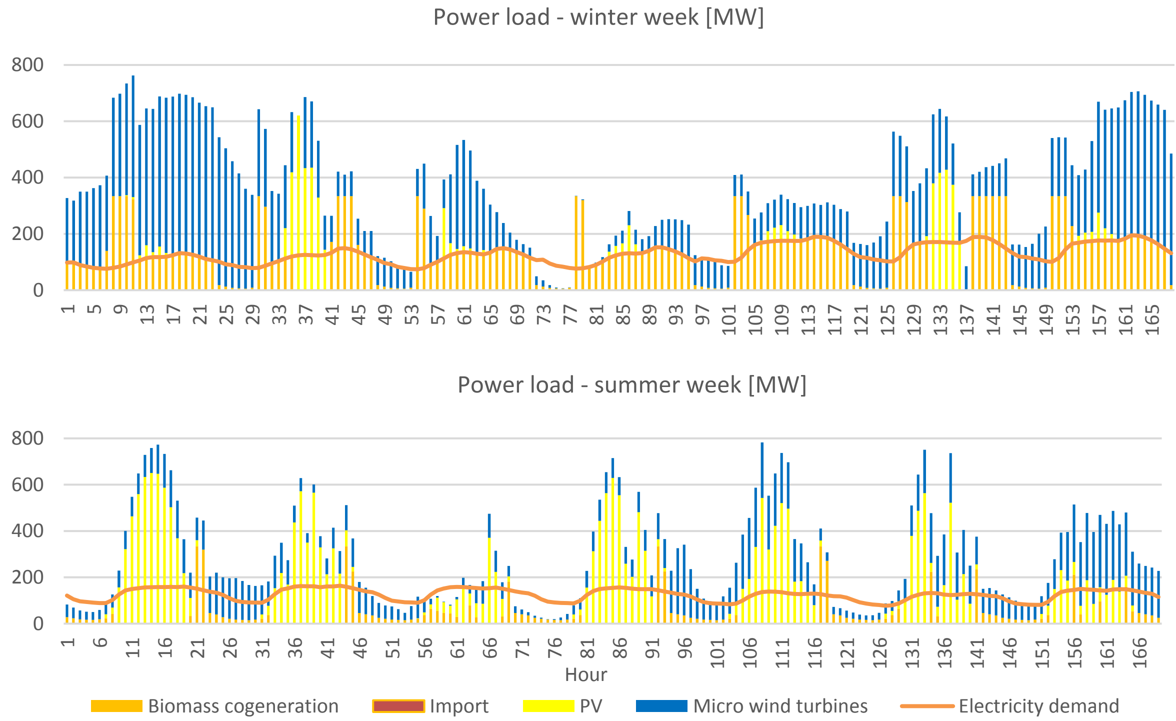


Figure 40 Electricity production in Bristol Autarky in 2050 during winter (up) and summer (down)

It is also useful to take a look at the state of charge of the electric battery, which can be seen in Figure 41. It shows how the battery charges and discharges during the year in order to achieve a 100% renewable autarky. It operates at a much higher rate during winter, spring and autumn since the demand is higher in these period than in the summer, when most of the demand can be covered by PV and wind during the day and just enough electricity is stored to be used during the night.

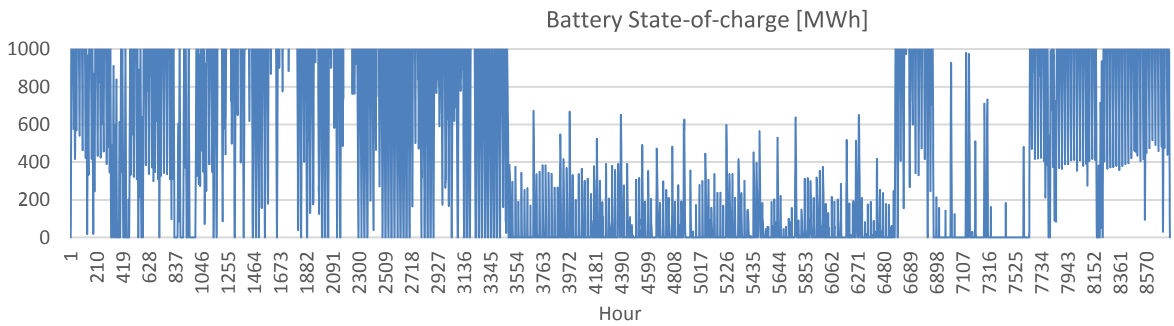


Figure 41 State of charge of the thermal storage during the whole year in Bristol Autarky 2050

6.4 Country level

Based on the methodology and assumptions elaborated in the previous chapter, in this section the results on the country level are presented. The model has generated a lot of output, which is too much to show in the report. Data behind the figures presented in this chapter are placed in appendix 9.2. In Table 71 general data of each country are presented for the Reference scenario. These data are used as input for the Renewables scenario and Autarky scenario. The number of households and number of utility buildings stay the same as well as the heating and cooling demand. The electricity demand, however, will increase in the other scenarios, due to extra use of electric vehicles and heat pumps.

Table 71 Number of households and utitlity buildings and energy demand 2050 (PRIMES)

Member state	Number of households	Number of utility buildings	Heating demand 2050 (TWh)	Cooling demand 2050 (TWh)	Electricity demand 2050 (TWh)
Austria	4,230,000	720,000	52	2	49
Belgium	5,866,000	1,460,000	73	3	89
Bulgaria	2,437,000	489,000	15	4	22
Croatia	1,356,000	465,000	16	2	16
Cyprus	346,000	359,000	2	19	11
Czech Republic	4,831,000	728,000	53	1	53
Denmark	2,637,000	845,000	37	1	41
Estonia	503,000	719,000	8	0	7
Finland	2,876,000	1,670,000	51	1	46
France	31,769,000	6,731,000	343	33	419
Germany	37,304,000	11,018,000	537	11	526
Greece	3,734,000	1,016,000	28	53	52
Hungary	3,961,000	391,000	47	3	47
Ireland	1,864,000	463,000	24	0	23
Italy	27,910,000	3,236,000	291	153	385
Latvia	644,000	108,000	10	0	9
Lithuania	952,000	143,000	10	0	9
Luxembourg	381,000	65,000	6	0	9
Malta	185,000	42,000	1	5	4
Netherlands	7,740,000	1,146,000	95	3	115
Poland	12,806,000	2,405,000	150	4	158
Portugal	3,568,000	822,000	13	13	35
Romania	6,820,000	803,000	42	6	51
Slovakia	1,661,000	81,000	21	0	23
Slovenia	876,000	937,000	9	1	10
Spain	18,275,000	2,964,000	103	104	196
Sweden	6,261,000	565,000	66	2	66
United Kingdom	32,713,000	8,228,000	306	9	325
Total	**224,506,000**	**48,619,000**	**2,408**	**434**	**2,797**

Electricity

In Figure 42, the electricity demand in the different scenarios and reference years is presented. The electricity demand for the Renewables and Autarky scenario are the same, since in the Autarky scenario only storage is added. What becomes clear from the figure is that the increase in electricity demand is significant in all countries. Also, there is a very large difference in electricity demand per country. In Figure 43 the relative change in electricity demand is presented. For most countries the difference between Reference 2050 and Renewables/Autarky 2050 lies around 50%, due to an increase in the use of electric vehicles and heat pumps in the latter two scenarios. In Cyprus and Malta, the relative increase in electricity demand is very high. The current use of electricity is relatively low and therefore the increase in electricity due to electric vehicles is very high.

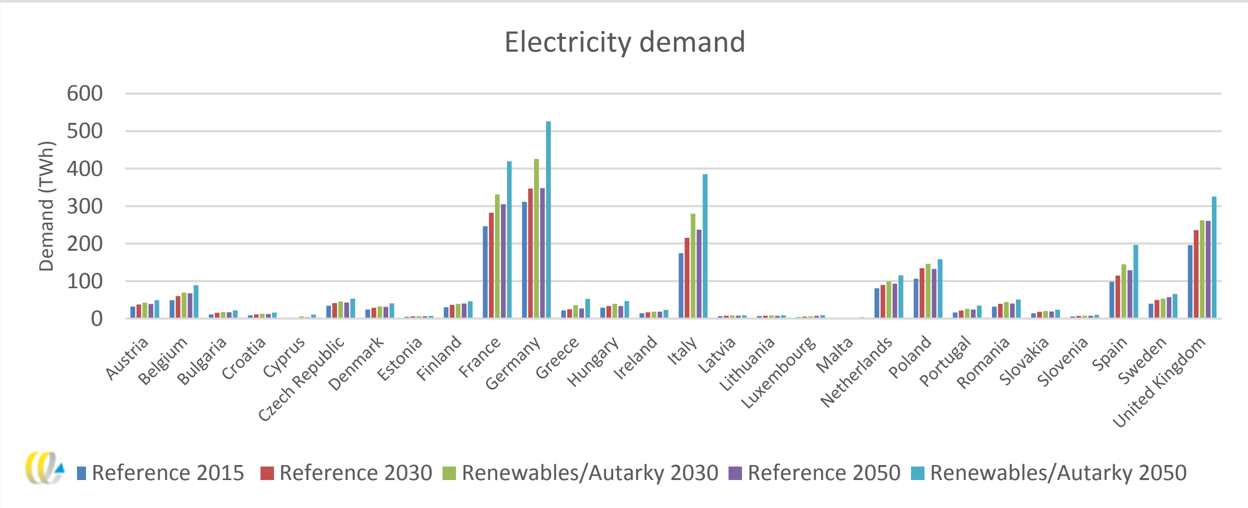


Figure 42 Annual electricity demand in different scenarios and different reference years

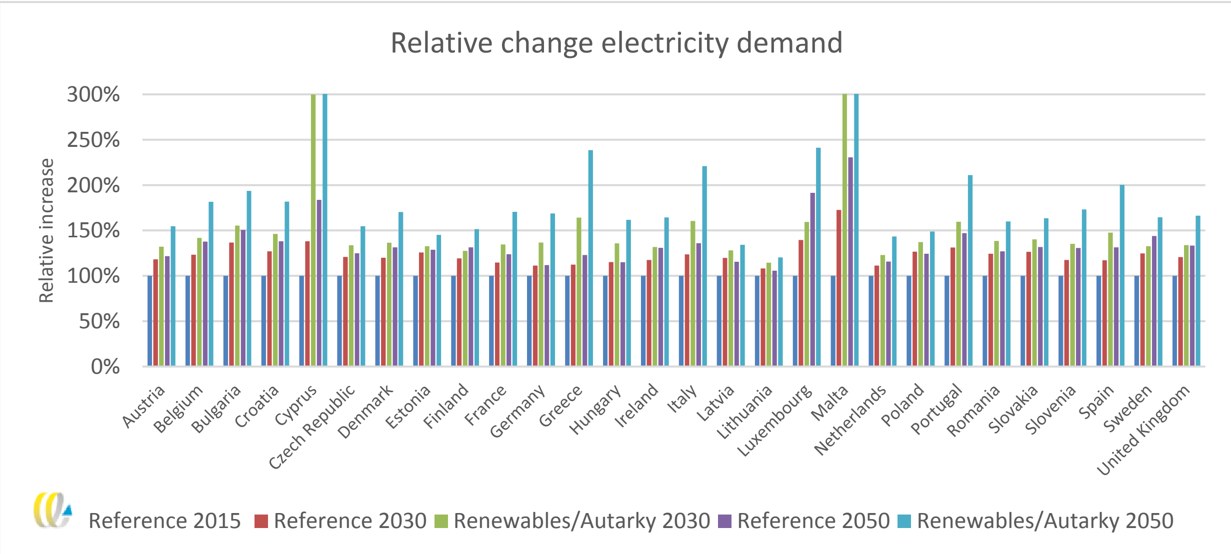


Figure 43 Annual electricity demand in different scenarios and different reference years

The electricity demand can partly be filled with electricity generated with prosumer technologies. In Figure 44 the total generated electricity with prosumer technologies is presented. This figure shows that the current electricity production by prosumers is only a fraction of what they could produce in 2030 and 2050 in the Renewables and Autarky scenario. Currently, in all member states the electricity generated by prosumers is between 0% and 10% of the demand of the electricity demand of the residential and tertiary sector. Only in Denmark, Portugal and Germany this share is over 4%. However the production of prosumers can increase to over 50% of the demand in 2050 for most member states.

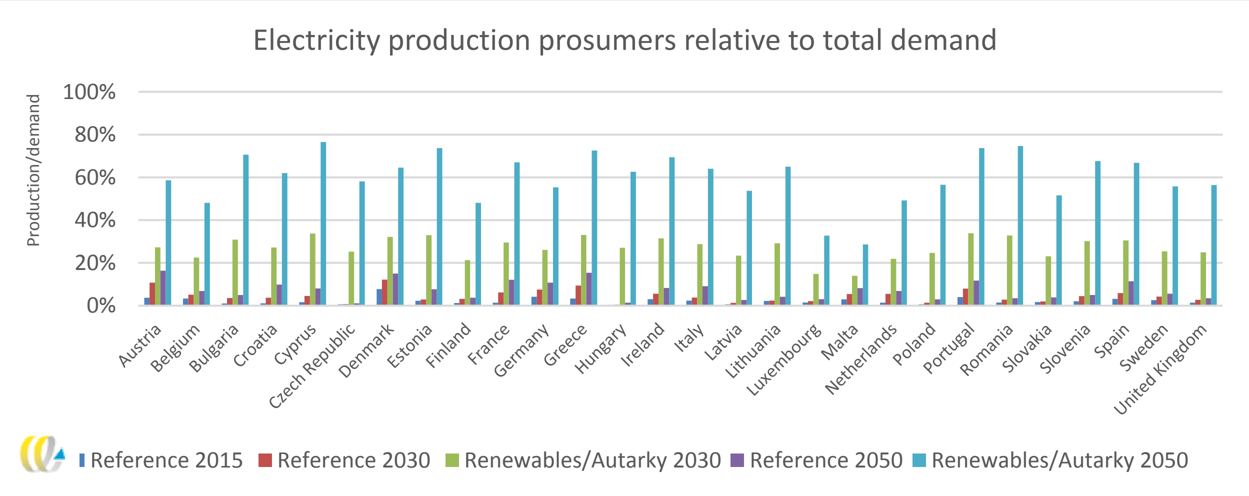


Figure 44 Annual electricity production with prosumer technologies relative to total demand in the residential and tertiary sector,

In Figure 45 the electricity production of different technologies relative to the total demand of the residential and tertiary sector is presented for each country. The potential percentage of energy generated by prosumers varies widely between the different member states, with Luxembourg and Malta having the least potential and Cyprus, Estonia, Greece, Potugal and Romania having the most potential.

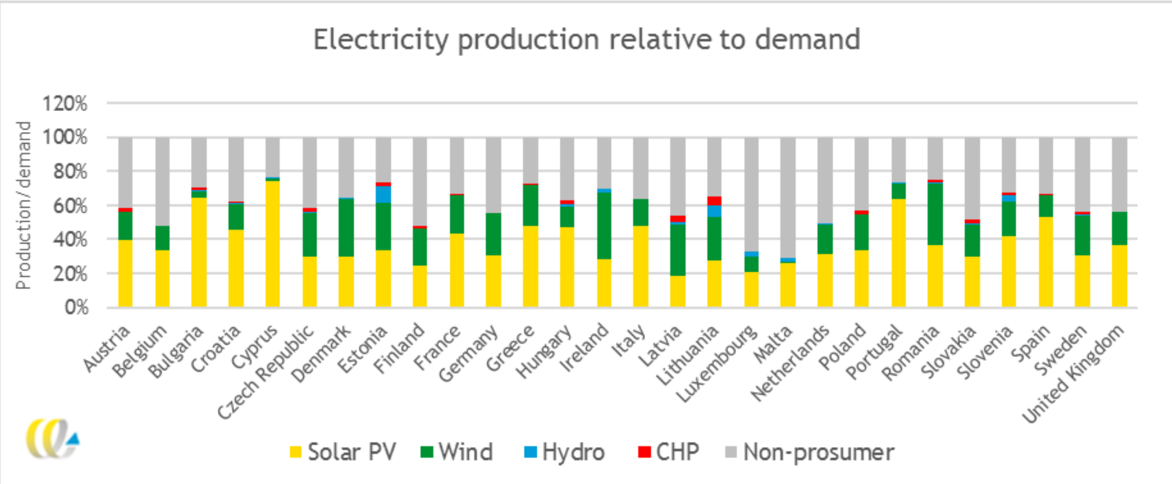


Figure 45 Annual electricity production of prosumer technology relative to total demand residential and tertiary sector in Renewables/Autarky scenario in 2050

In CEPROM, results for households (residential buildings) and the tertiary sector (utility buildings) are separately calculated. In Figure 46 results of technologies used for generation of electricity in households are shown geographically for the Renewables/Autarky scenario in 2050. All technologies, except for the category 'non-prosumer' are prosumer technologies. The figure shows that most countries, except for Malta, can cover the largest part of their electricity demand for households with prosumer technologies. The technologies wind and solar PV roof-based and ground-based can all contribute significantly. Hydro power is applied in very few countries. CPH does not attribute much to the total generation of electricity.

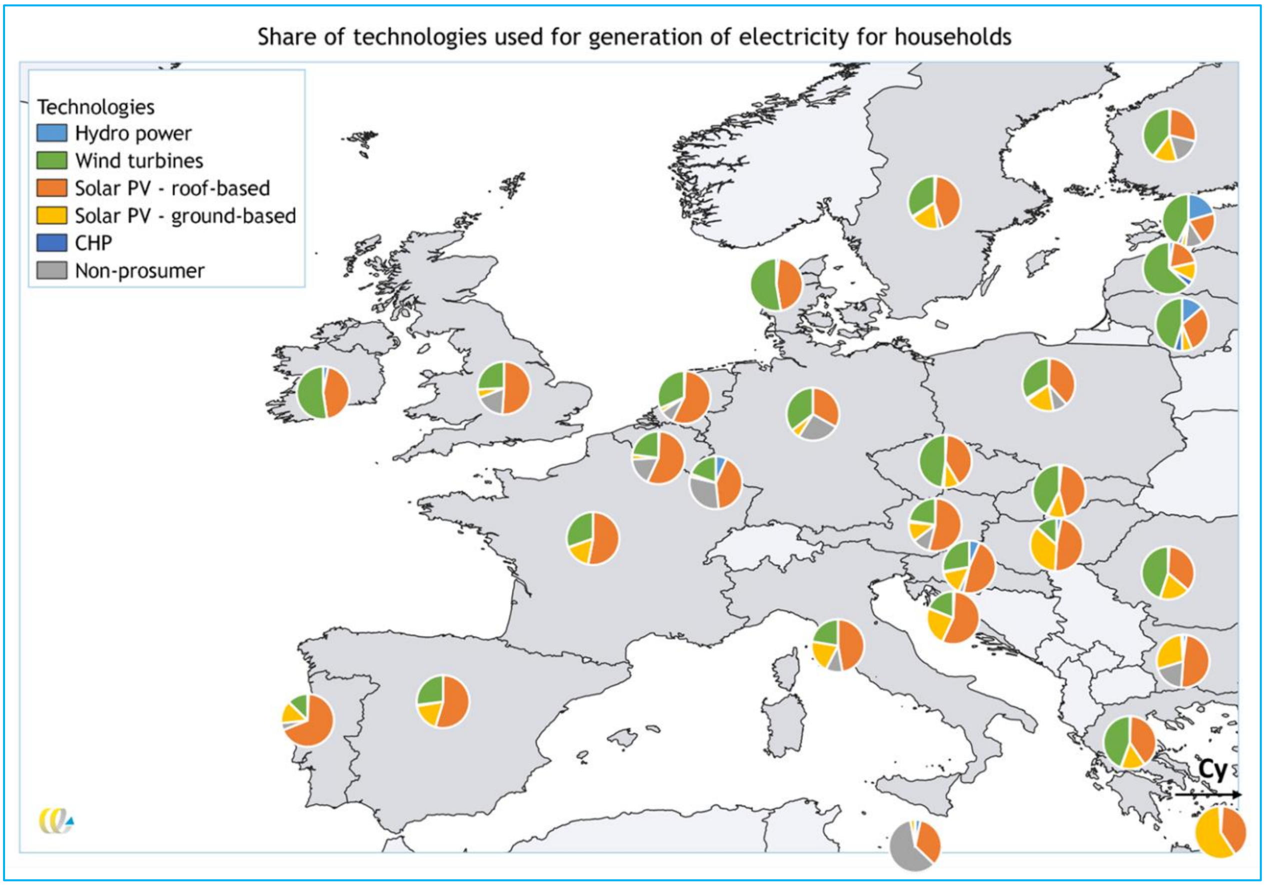


Figure 46 Share of technologies used for generation of electricity for residential buildings in the Renewables/Autarky scenario in 2050

In Figure 47 the results of technologies used for generation of electricity in utility buildings are shown. For utility buildings, other than residential buildings, the largest share in generation of electricity is by non-prosumer technologies. For a large part this can be explained by the assumption in our scenarios that the tertiary sector does not participate in collectives. They will generate their electricity with roof-based solar and small wind turbines on own property. This is not sufficient to cover their electricity demand.

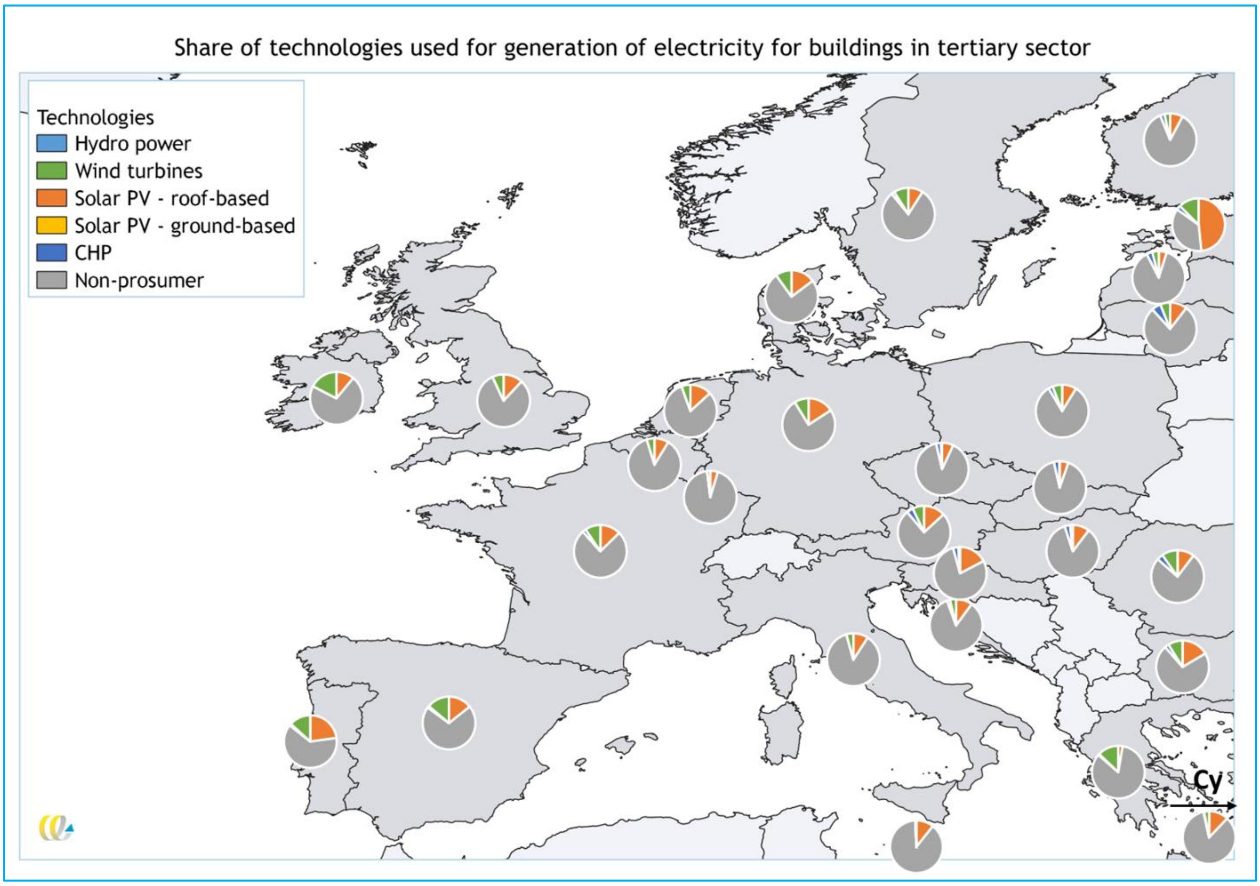


Figure 47 Share of technologies used for generation of electricity for utility buildings in the Renewables/Autarky scenario in 2050

Heating and cooling

The heating demand, contrary to the electricity demand, slightly decreases over the different reference years. However, the cooling demand will increase significantly from 2015 to 2050. It is assumed that at this moment many households and tertiary buildings with a small cooling demand do not have a device to cool, so they do not fill the cooling demand. Therefore, in the current numbers of energy use, cooling is only a very small share compared to heating. In case households and utility buildings will have a heat pump in 2030 or 2050, it is assumed that they will also start using it for cooling, which increases the electricity use for cooling. For some countries, the decrease in heating demand and increase in cooling demand, lead to a small increase in the combined demand for heating and cooling in 2030 and 2050, for some countries in a small decrease.

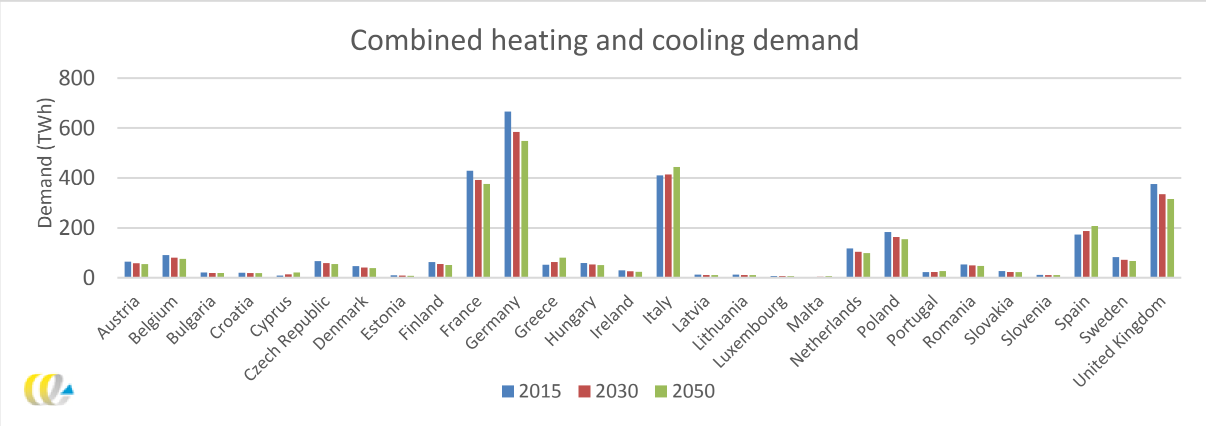


Figure 48 Annual combined heating and cooling demand in the residential and tertiary sector,

In Figure 49 and Figure 50 the share of energy carriers that can be used by prosumers to cover the energy demand for heating and cooling in residential buildings in the Renewables/Autarky scenario is presented. The overall picture is that the heat pump is the technology that fills in the largest part of the heating and cooling demand. In the countries with biomass availability, biomass can also cover a significant part of the heat demand. District heating is only applied in countries with a smaller cooling demand, because it cannot cover cooling demand. Solar heat is applied is all countries, but only contributes for a small part to the demand of heating and cooling.

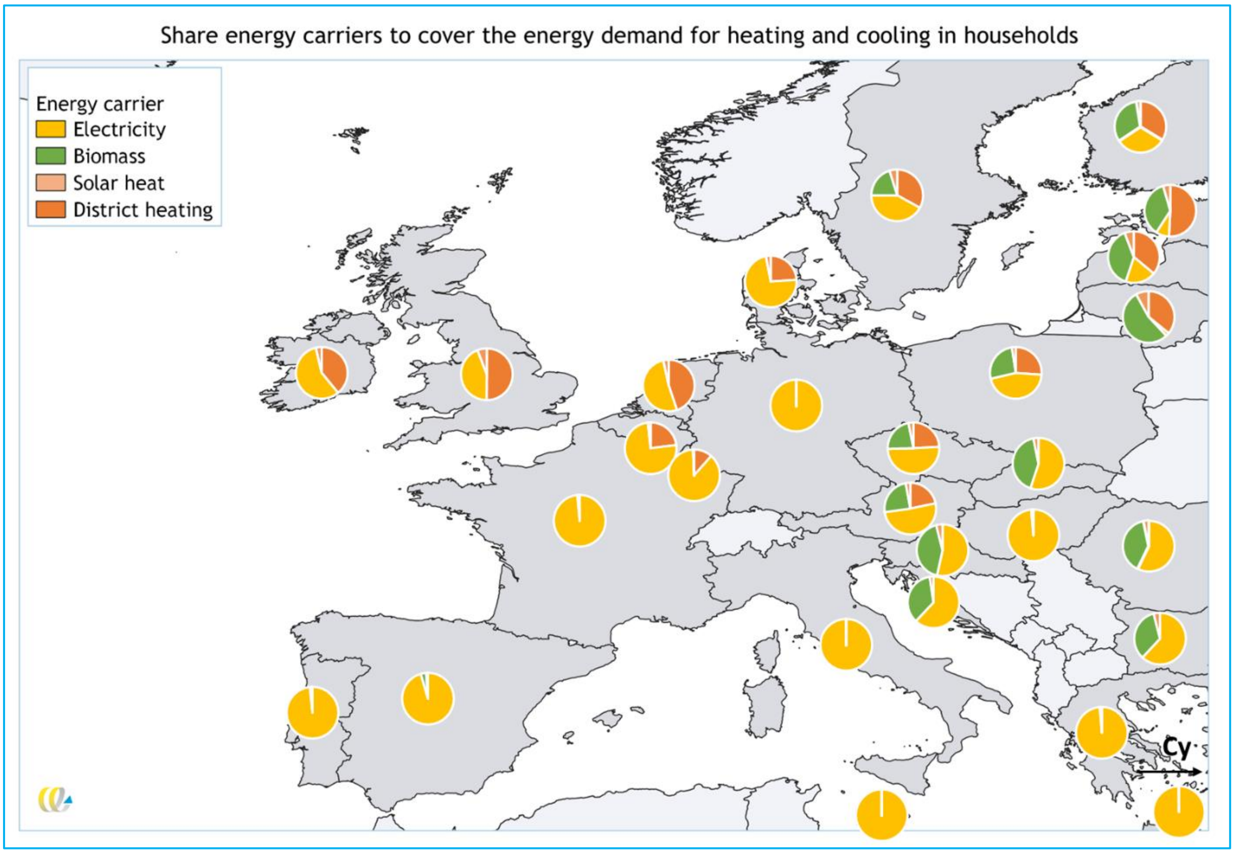


Figure 49 Share of energy carriers used to cover the energy demand for heating and cooling in residential buildings in the Renewables/Autarky scenario in 2050

Figure 50 represents the share of energy carriers used to cover the energy demand for heating and cooling in buildings in the tertiary sector in the Renewables/Autarky scenario in 2050. The difference with residential buildings, is that an even larger part of the heating and cooling demand is filled with heat pumps. The reason for this is the extra cooling demand that utility buildings have compared to households. The application of biomass is also somewhat higher for utility buildings than for households. It is assumed that for utility buildings in urban areas, biomass-fired CHP is a good option.

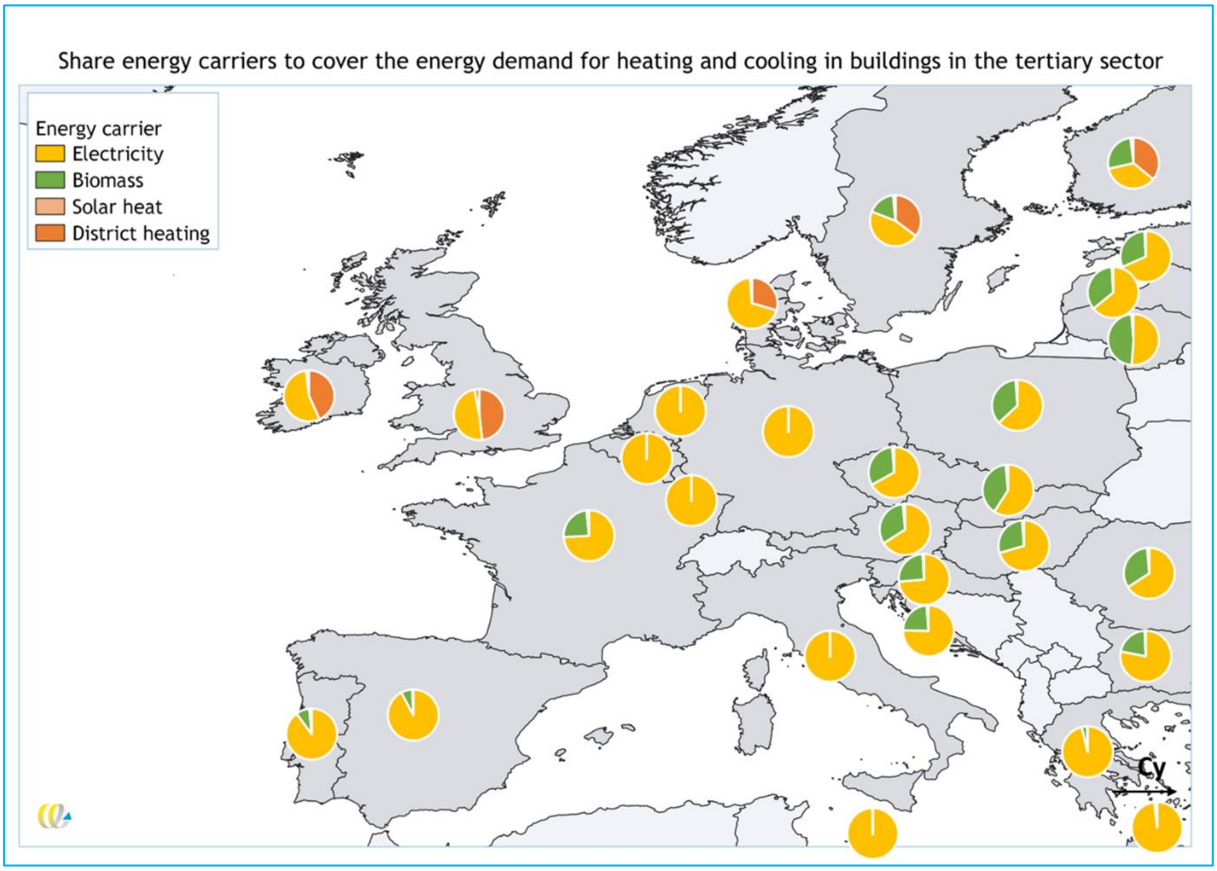


Figure 50 Share of energy carriers used to cover the energy demand for heating and cooling in buildings in the tertiary sector in the Renewables/Autarky scenario in 2050,

Energy storage

In the Autarky scenario, energy storage is taken into account. In Figure 51, the total electricity storage capacity of prosumers is presented in each country in the Autarky scenario in 2050. This storage consists of separate battery storage and storage in batteries of electric vehicles. The amount of storage is linked to the amount of installed capacity of solar PV, wind turbines, hydro power, CHP and electric vehicles. The amount of storage capacity in the Reference scenario is assumed to be negligible compared to the total electricity generation.

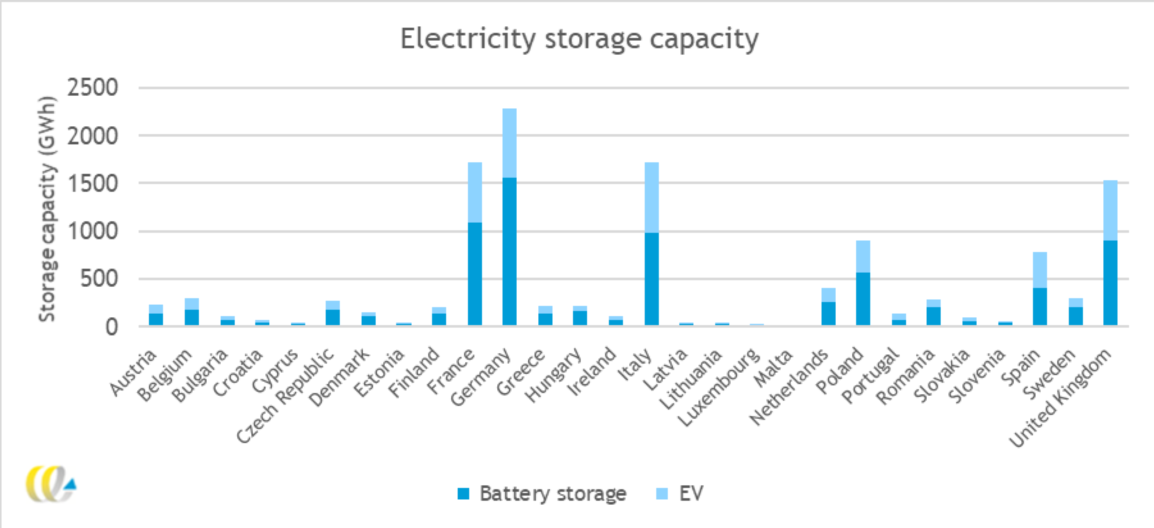


Figure 51 Electricity storage capacity in the Autarky scenario in 2050

Apart from the electricity storage, thermal energy is also stored. This is energy stored in an ATES. In the Netherlands, Sweden and Denmark this is already a common technology to store thermal energy. The possibility to store energy depends on the suitability of the subsurface in the specific country. In the Autarky scenario, it is assumed that only countries with a suitable subsurface will apply ATES[15] (see section Methodology and assumptions).

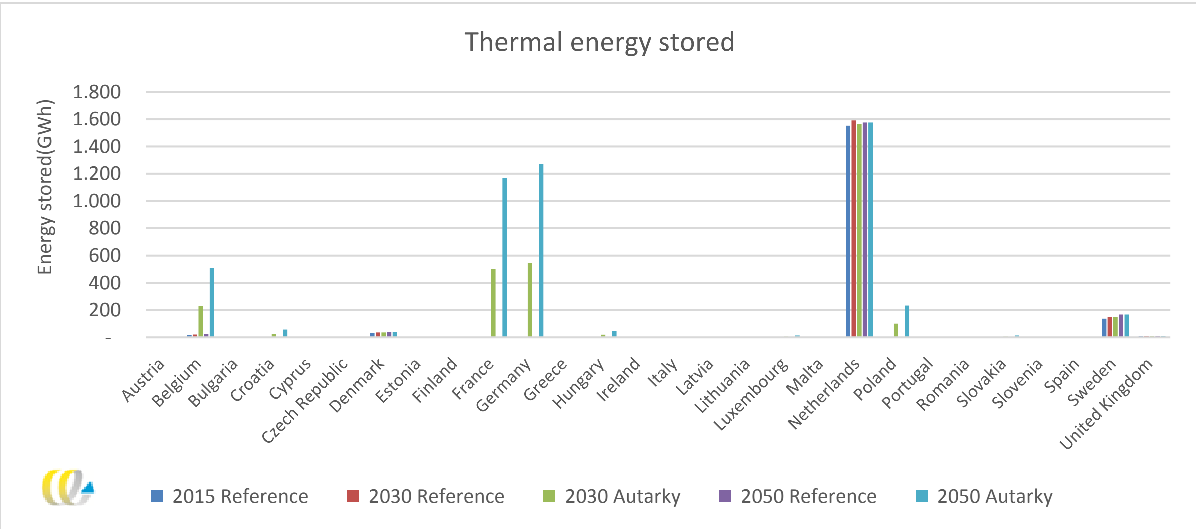


Figure 52 Annual amount of thermal energy stored

Share of autarky

With a separate calculation tool, the autarky percentage per scenario is calculated. For the Renewables scenario the percentage autarky is the percentage energy that is generated with prosumer technologies that can be used directly, as no energy storage is assumed in that scenario. For the Autarky scenario, it is the sum of the direct energy use from prosumer generation and the use of energy from battery storage

[15] It is assumed that the ATES installations that have already been installed will not be removed and that the Autarky scenario will have at least the same amount of energy stored in ATES as the Reference scenario. Because of that, Sweden does have ATES installed, even though the subsurface conditions are generally not suited for ATES.

and thermal energy storage. The results are separately calculated for residential buildings and utility buildings and for electricity, and heating and cooling.

Figure 53 shows the results of the share of autarky in residential buildings in 2050. The highest percentage is reached for electricity use in the Autarky scenario, where between 50% and 95% of electricity demand of electric devices, lighting and electric vehicles can be covered by the prosumer generated electricity. Lithuania and Finland can almost reach 100% autarky of their electricity use, while Malta only reaches just over 50%. For heating and cooling the Renewables and Autarky scenario do not show very big differences. This is mainly because the difference in the share of autarky is only caused by the electricity storage for heat pumps and ATES in combination with heat pumps. Individual technologies on biomass are assumed to be autarkic in both scenarios, just as the use of solar heat. For solar heat, it is assumed that a small buffer tank is also applied in the Renewables scenario. District heating is assumed not to be autarkic.

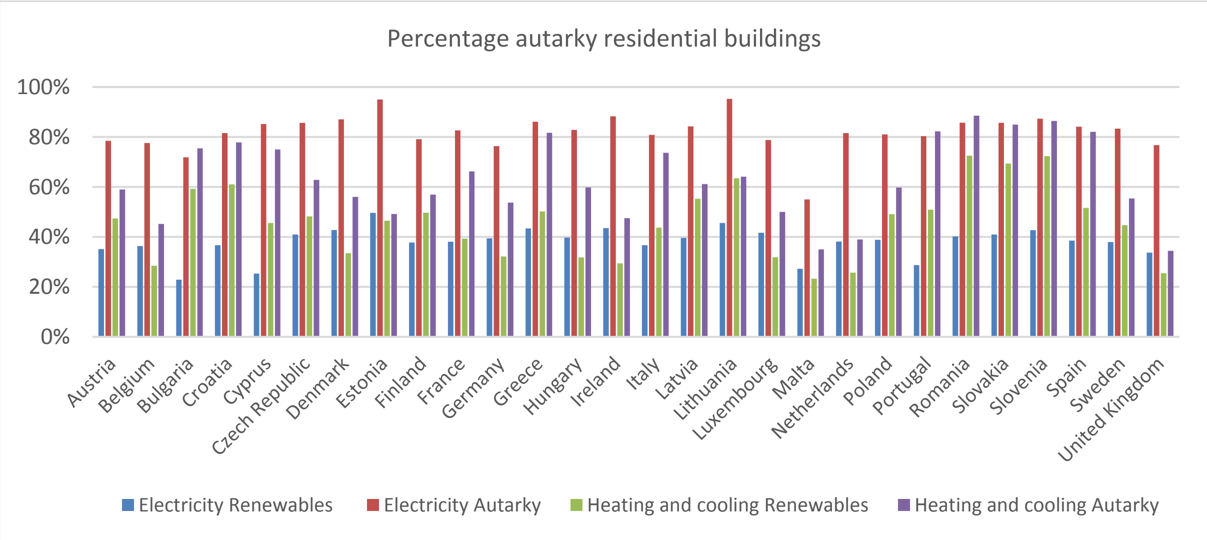


Figure 53 Percentage autarky in residential buildings for electricity and heating and cooling in the scenarios Renewables and Autarky in 2050

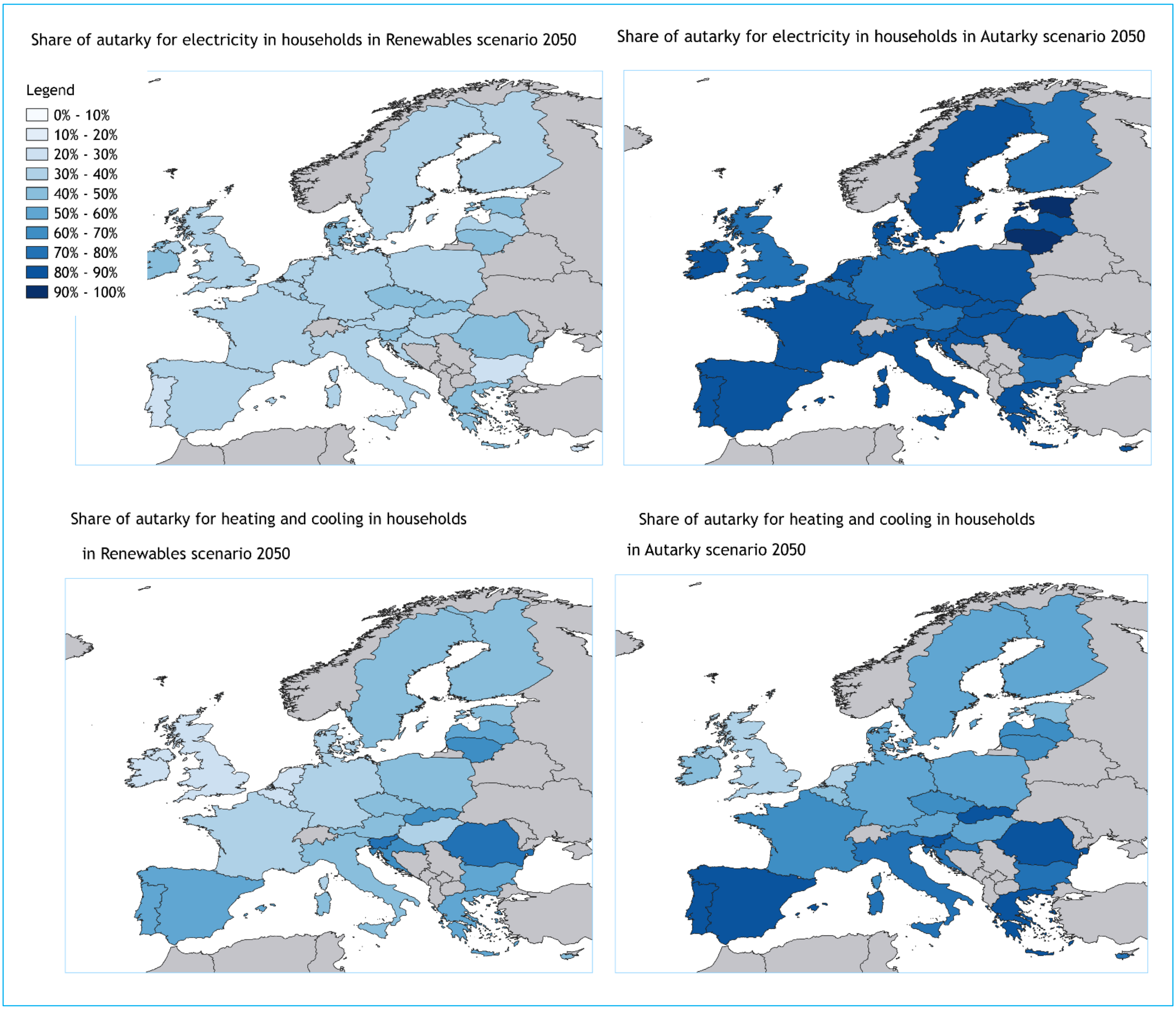


Figure 54 Share of autarky in households in different scenarios in 2050

For utility buildings the results are presented in Figure 55. This figure shows that the share of self-generated electricity that is directly used or used through a battery is lower than for residential buildings. This has to do with, as earlier described, the assumption that the tertiary sector only generates their own energy by PV on rooftops or by small wind turbines on own property. For the heating and cooling demand the results are quite similar to that of residential buildings. The percentage autarky is a little bit lower, also because of the lower share in electricity generation, which has consequences for the autarky percentage of buildings with heat pumps.

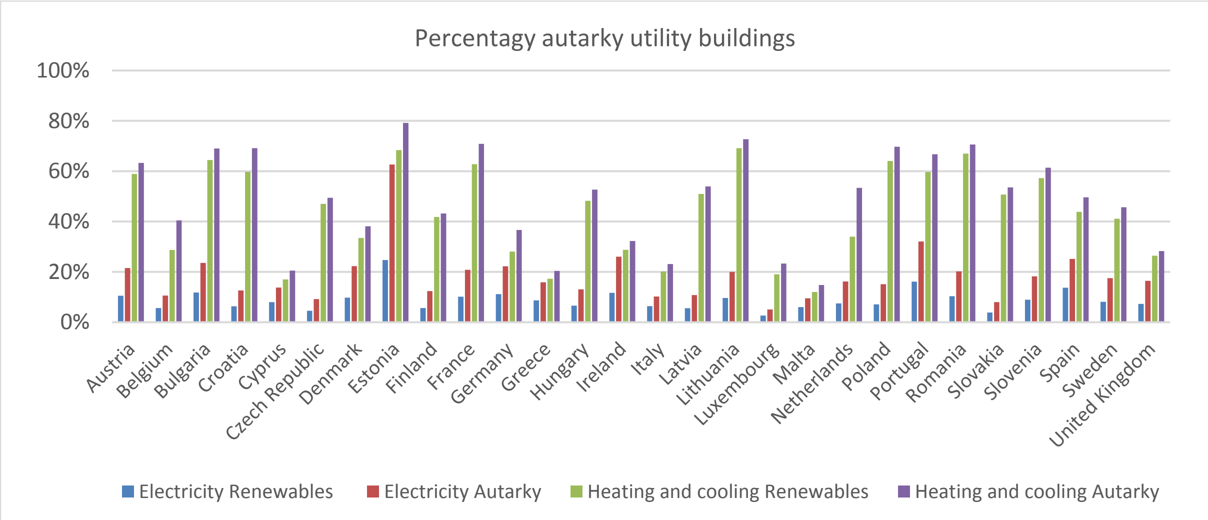


Figure 55 Percentage autarky in utility buildings for electricity and heating and cooling in the scenarios Renewables and Autarky in 2050

6.5 EU level

The following graphs show the results on EU-level. As mentioned before, the EU-results are the sum of the results on country level. Figure 56 presents the share of technologies used for the generation of electricity by prosumers in 2050 in the Renewables/Autarky scenario. For residential buildings, the share of ground-based solar PV is the largest in the total generation of electricity. Wind turbines also have a large share. The generation of electricity with hydro power and CHP, however, is very small. The share of electricity from non-prosumer technologies is 11%. For the tertiary sector, the largest part of electricity comes from non-prosumer technologies. Roof-based solar PV and wind turbines have a share of 12% and 8% in the electricity demand of this sector, CHP contributes less than 0.5%.

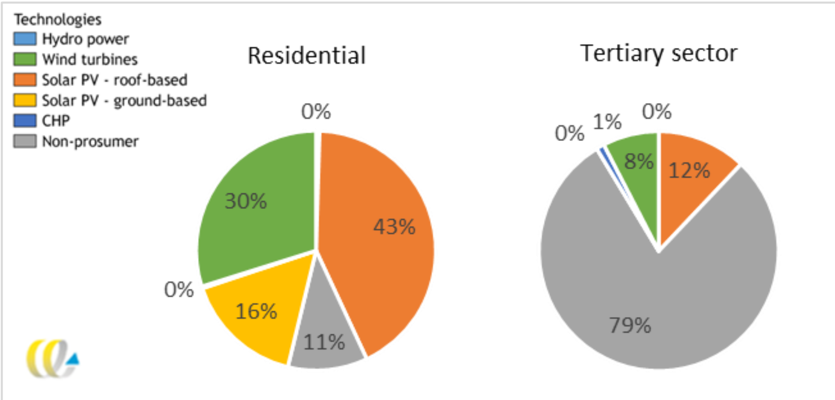


Figure 56 Share of technologies used for generation of electricity in 2050 Renewables/Autarky scenario

Electricity

Figure 57 and Figure 58 present the total electricity production with prosumer technologies for each scenario and for each type of building. In the 2050 Renewables/Autarky scenario the electricity production of prosumers corresponds to 60% of the total electricity demand of the residential sector and tertiary sector.

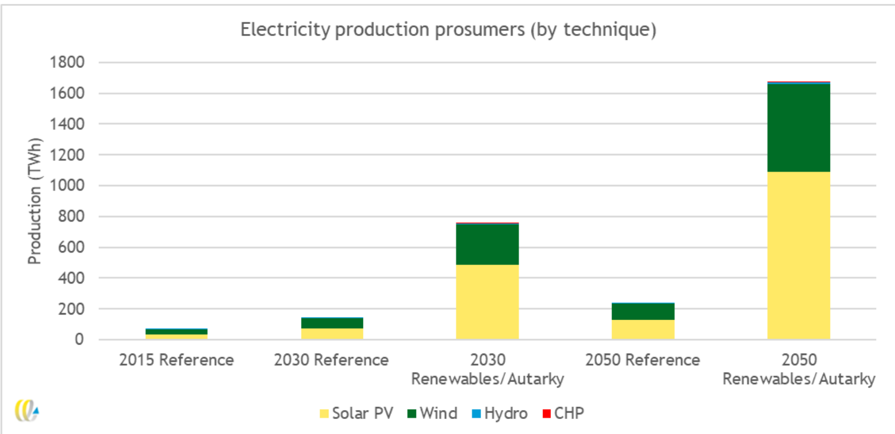


Figure 57 Electricity production prosumers, divided by technology

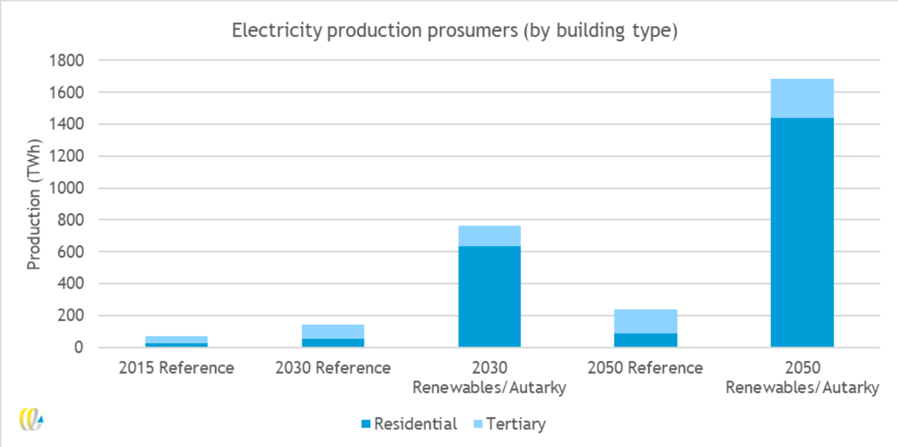


Figure 58 Electricity production by prosumers, divided by residential and tertiary sector

Heating and cooling

Figure 59 presents the share of energy sources used for heating in 2050 in the Renewables/Autarky scenario. For both residential and utility buildings, electricity has by far the largest share. For residential buildings, also district heating has a significant share, followed by biomass, for tertiary buildings this is the other way around. The share of solar heat in the total heating demand of buildings is fairly small in both type of buildings.

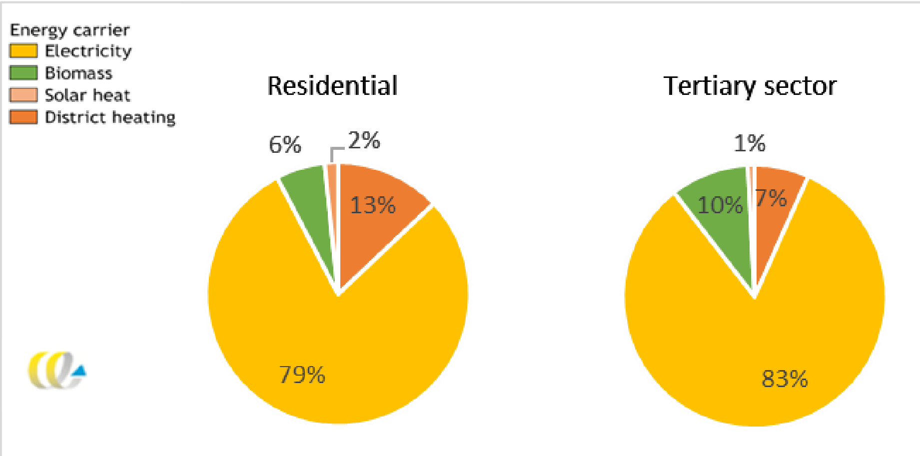


Figure 59 Share of energy sources used for heating in 2050 Renewables/Autarky scenario

These shares correspond to the number of households and utility building presented in Table 72[16].

[16] The total number of technologies used is higher than the total number of households and utility buildings, since multiple technologies can be used in one building.

Table 72 Number of household/utility buildings per energy source used for heating in 2050 Renewables/Autarky scenario

Energy source	Number of households	Number of utility buildings
Electricity	169,634,000	35,029,000
Biomass	16,450,000	7,417,000
Solar heat	51,330,000	13,589,000
District heating	38,421,000	6,172,000

Figure 60 and Figure 61 present the total heating and cooling production by energy source and by type of building.

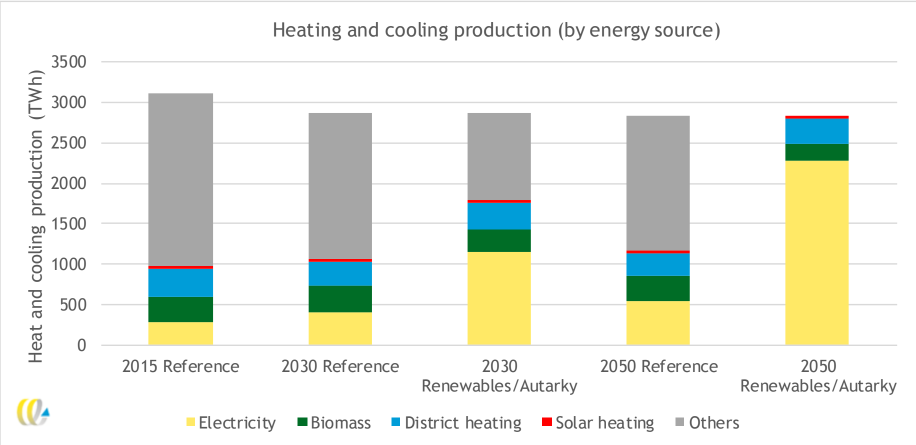


Figure 60 Heating and cooling consumption, divided by energy source

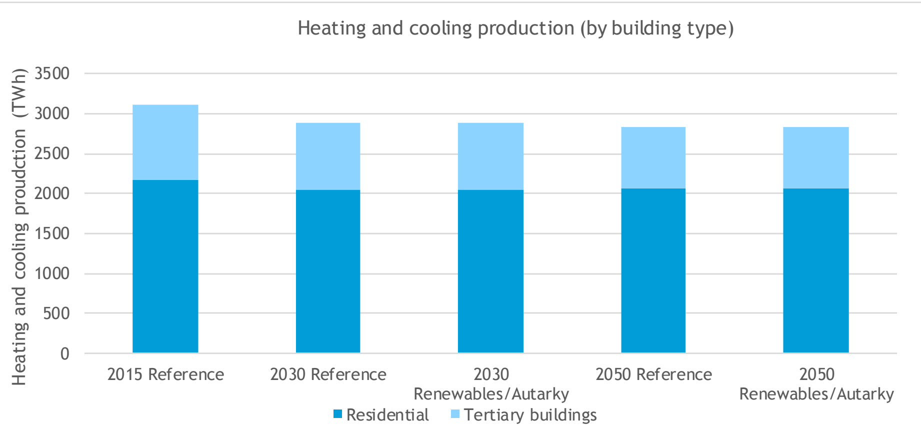


Figure 61 Heating and cooling consumption, divided by residential and tertiary sector

Storage

In Figure 62 the contribution of each member state to the total amount of electricity storage capacity in the Autarky scenario in 2050 is presented. France, Germany, Italy and the United Kingdom have the largest share.

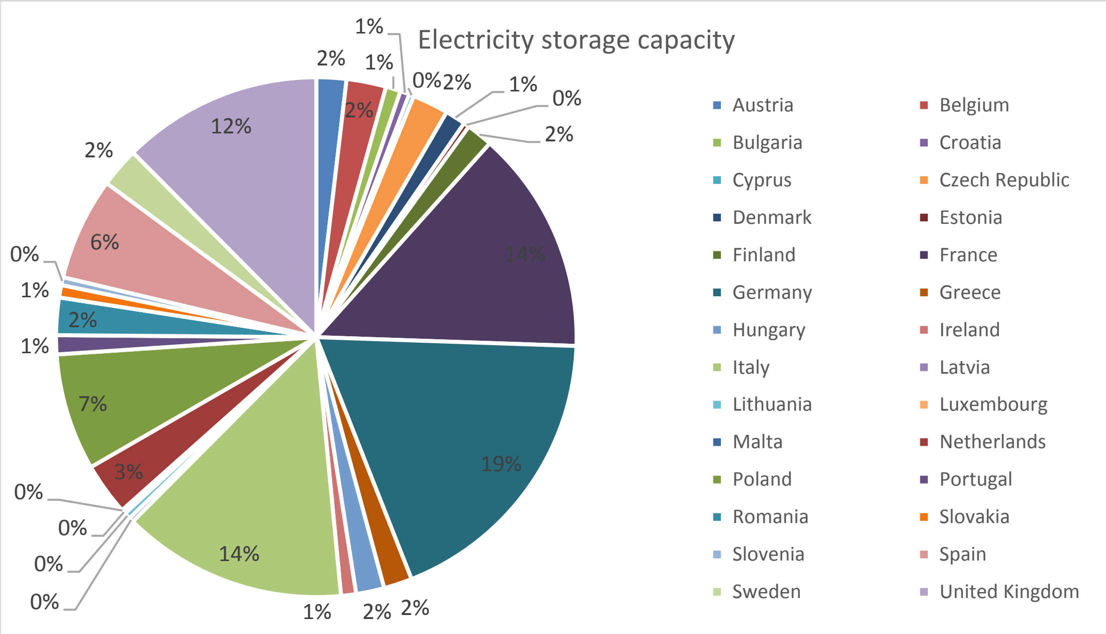


Figure 62 Contribution electricity storage capacity member states to EU-28 total in 2050 Autarky scenario

Figure 63 presents the contribution of the countries to the total amount of thermal energy storage in ATES in the Autarky scenario in 2050, Belgium, France, Germany and the Netherlands have the largest share of ATES in this scenario.

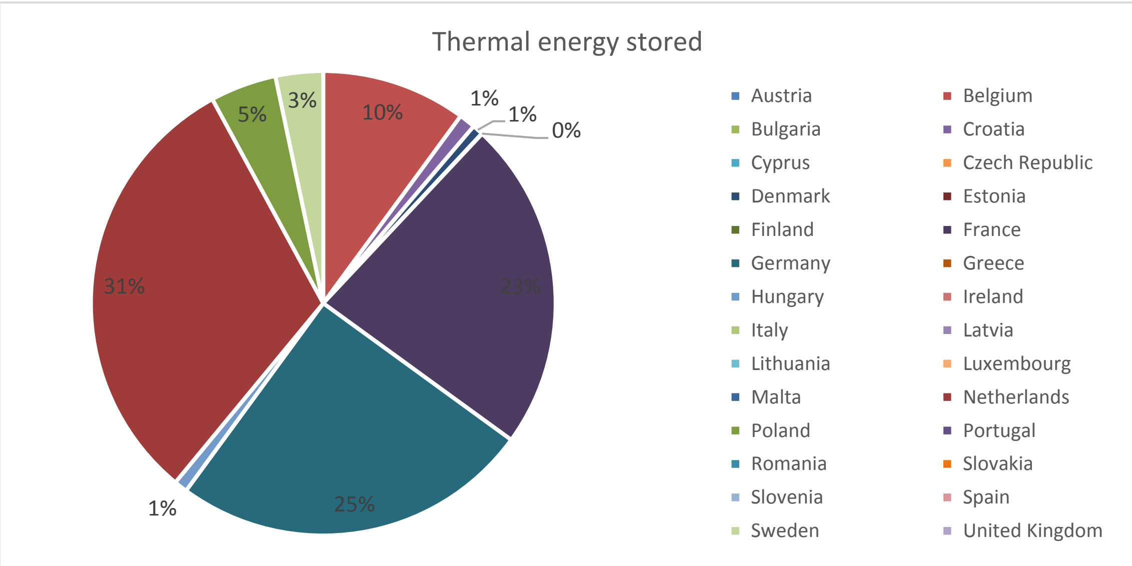


Figure 63 Contribution thermal energy storage member states to EU-28 total in 2050 Autarky scenario

Autarky

Table 73 presents the output of the model of the total share of autarky in the EU in the Renewables and Autarky scenarios in 2050. The share of autarky is the highest for the residential buildings in the Autarky scenario. The autarky of electricity use can go up to 76%, while the share of autarky in heating and cooling reaches 61%.

Table 73 Total share of autarky for the EU in Renewables and Autarky scenario in 2050

Type of building	Scenario	Type of energy	Percentage autarky
Residential	Renewables	Electricity	38%
		Heating and cooling	40%
	Autarky	Electricity	76%
		Heating and cooling	61%
Tertiary	Renewables	Electricity	12%
		Heating and cooling	37%
	Autarky	Electricity	21%
		Heating and cooling	43%

7. Conclusions

Simulations and modelling prosumers on different levels showed that prosumer have high potential to lower CO_2 emissions, but also provide significant economic advantages and facilitate the energy transition of the EU by 2050.

7.1 Individual level

On an individual level, the simulation of households in four different countries and climate zones showed in all use cases that households with prosumer technologies could lower CO_2 emissions considerably, while lowering LCOE and LCOH. The focus on the individual level was on heat pumps and solar thermal for heat production and PV for the production of electricity. It was proven that these three technologies –the most prevalent prosumer technologies on an individual level - all showed favourable outcomes from an economic and environmental perspective.

Even though the positive effect of prosumer technologies was also visible in the Autarky scenario for 2015 and 2030 as well as for the Renewables scenario in 2015, 2030 and 2050, we show in Table 74 the results for the Autarky scenario in 2050 as it is the Scenario with the most significant impact.

Table 74 Comparison of the results for the individual level use cases - Autarky 2050 scenarios

	CO_2 heating (kg/a) [reduction]	*CO_2 electricity (kg/a) [reduction]*	*LCOH (€/kWh) [reduction]*	*LCOE (€/kWh) [reduction]*	*Autarky heating (%)*	*Autarky electricity (%)*
France Autarky 2050	32-34 [-99 %]	44-59 [-69 %]	0.08-0.09 [-57 %]	0.13 [-23 %]	75-81	68-70
Germany Autarky 2050	620-716 [-83 %]	508-697 [-48 %]	0.11 [-31 %]	0.23 [-29 %]	52-57	47-50
Netherlands Autarky 2050	244-309 [-90 %]	310-458 [-75 %]	0.09-0.10 [-39 %]	0.15 [-24%]	62-66	53-54
Spain 2050 Autarky 2050	53-63 [-96 %]	185-272 [-74 %]	0.10-0.12 [-52 %]	0.14 [-46 %]	82-86	74-75

It is visible that emissions of households vary between use cases. The main reason is that the demand for electricity varies and part of the electricity for covering the demand of appliances, light as well as heat pumps is still obtained from the grid. The different emission coefficients of electricity from the grid in g CO_2 eq/kWh result in considerable differences between household emissions in different countries. However, comparing the results of the Autarky scenario in 2050 with the Reference scenario shows that heating emissions could be decreased by 83-99 % and for electricity by 48-75 %. From an economic point of view, prosumer technologies were also positive for the household, since in all countries the LCOE and LCOH were lower in comparison to the Reference scenario. The highest level of autarky achieved, was in Spain in 2050 with 82-85 % self-sufficiency in heat and 73-75 % in electricity. The lowest level of autarky was achieved in Germany with 47-50 % for electricity and 52-57 % for heat. Differences in autarky are mainly due to the differences in heating demand. In Germany and Netherlands, the heat demand is higher than in France and Spain and since PV production during winter is lower, only a smaller share of required electricity for heat pumps can be provided by self-produced electricity. Still the simulations showed that in all countries prosumer technologies increased autarky, lowered costs and reduced emissions.

At this point, it is important to clarify that results on an individual level merely reflect emissions, costs and autarky of a hypothetical household with the chosen technologies equipped. As shown in the description of the models, EPROM does not optimize for costs or emissions. Therefore, even lower costs or fewer emissions can be achieved with other combinations or configurations of technologies. E.g. in the use case of Spain, a high share of thermal energy was lost, and different heat capacities might result in lower costs. In addition, individual CHP units might reduce costs and should be analysed separately for the chosen use cases.

Since on a neighbourhood and city level, except for Aardehuis, the UNIZAG FSB tool was used which optimizes for costs it is not surprising that lower LCOE and LCOH where achieved for similar climate regions.

7.2 Neighbourhood level

In the majority of neighbourhood level use cases, the Autarky scenario proved to have the best KPIs, despite adding extra cost for the integration of electric and thermal storage systems. By integrating storage, it is possible to achieve higher CO_2 emission reductions, low energy costs for the prosumers and higher renewable autarky levels, compared to Reference and Renewables scenarios. In order to compare the results from different use cases, the changes in KPIs in the Autarky 2050 scenarios are presented in Table 75. The changes in KPIs are compared to the Reference 2050 scenarios.

The figures in the table vary depending on the technologies in use and the constraints based on the available area. However, it was shown that in all the cases rather high decreases in CO_2 emissions of the heating sector can be achieved. These are usually higher than for the electricity sector even when low renewable autarkies are achieved due to a rather negative current state of the heating sector with mostly fossil fuels being used. Another reason is switching to the electricity driven heat production technologies like heat pumps and electric boilers, which have significantly lower emission factors even if they are not supplied by the renewable locally produced electricity. On the other hand, high emission reductions (as well as renewable autarky) for the electricity sector in central/northern Europe can be achieved by using small cogeneration units (e.g. in Klausenerplatz), especially if they use sustainable biomass, or another form of renewable fuel. These have significant benefits from the economic perspectives through the production of two forms of energy. However, their size can be a limiting factor.

Another technology which could be used in the northern Europe are micro wind turbines, but these are usually rather limited with application due to the area constraints. Therefore, when looking only at the neighbourhood level, wind technologies did not show high potential. On the other hand, PVs have a much higher potential in the southern Europe, with limited potential in northern and central Europe in terms of providing high levels of renewable autarky. The autarky is even harder to achieve in the electricity sector when electrically driven heat production technologies are used since they increase the consumption of electricity by a large margin and usually decrease the effect of adding a battery storage significantly, as has been shown for the case of Lanište.

Table 75 Comparison of the results for the neighbourhood level use cases – 2050 Autarky scenarios

	CO_2 heating (t/a) [reduction]	*CO_2 electricity (t/a) [reduction]*	*LCOH (€/kWh) [reduction]*	*LCOE (€/kWh) [reduction]*	*Autarky heating (%)*	*Autarky electricity (%)*
Aardehuis Autarky 2050	3.05 [-96 %]	6.6 [-55 %]	0.06 [-50 %]	0.08 [-47 %]	81	68
Lanište Autarky 2050	890.54 [-86 %]	586.26 [-18 %]	0.084 [-55 %]	0.129 [-10 %]	39.5	17.5
Klausenerplatz Autarky 2050	150.04 [-86 %]	47.64 [-93 %]	0.064 [-72 %]	0.279 [-14 %]	80.8	90.9

7.3 City level

On the city level, similar observations can be made, as shown in Table 76. In the southern Europe, it was shown that 100% autarky can be achieved by integrating only the solar technologies and thermal storage. Due to low heat demands and high solar radiation, in cities like Girona there is no need for other technologies. The only precondition is to secure high enough storage content in order to store the heat production during the day and use it later in the night. On the electricity side, higher battery capacities should be installed in order to achieve a 100% renewable autarky, but the electricity production from the assumed capacities is already more than double the electricity demand. All these benefits are achieved with significant cost reductions compared to the Reference scenario and it was shown that solar technologies have the highest potential for achieving a low-cost energy transition in the southern Europe.

However, in the northern Europe, different technology mix should be used to achieve high renewable autarkies in both sectors. This is shown by the fact that solar production could cover only up to 21% of the heating demand in Bristol. Here again, biomass cogeneration proved to be the most valuable technology from the economic and energy perspective, achieving high renewable autarky of the heating sector when combined with solar thermal. However, it must be noted that the reduction of costs compared to the Reference scenario is practically negligible, despite achieving complete renewable autarky by using a mix of wind turbines, PVs and mostly cogeneration. Here it must be noted that high amounts of electricity are excessively produced and can be sold to the network, achieving additional economic benefits for the prosumer.

Finally, using heat pumps showed significant benefits in the form of the emission reductions of the heating sector, despite increasing the overall electricity demand of the system and making it unable to achieve high reductions of KPIs from the electricity sector perspective. This is due to the fact that the emission factors of electricity, even if it is supplied from the gird are much lower than the existing fuel mix which is used for production of heat.

Table 76 Comparison of the results for the city level use cases – 2050 Autarky scenarios

	CO_2 *heating* *(t/a)* *[reduction]*	CO_2 *electricity* *(t/a)* *[reduction]*	*LCOH* *(€/kWh)* *[reduction]*	*LCOE* *(€/kWh)* *[reduction]*	*Autarky heating (%)*	*Autarky electricity (%)*
Ozalj Autarky 2050	3,945.4 [-76 %]	2,042.1 [-14 %]	0.091 [-13 %]	0.129 [-10 %]	34.3	14.4
Girona Autarky 2050	0 [-100 %]	6,567 [-76 %]	0.023 [-90 %]	0.134 [-47 %]	100	75.9
Bristol Autarky 2050	79,407 [-86 %]	0 [-100 %]	0.148 [-34 %]	0.227 [-3 %]	89.6	100

7.4 EU level

The results from the CEPROM-model on country level show that with the use of different heat technologies (mostly heat pumps) and electric vehicles in the Renewables and Autarky scenario, the total electricity demand for households and residential buildings will increase significantly. There are large differences in the share of electricity that can be produced by prosumer technologies throughout the EU. This mostly depends on the available area for solar PV and wind turbines and the climate conditions in the different countries. Figure 64 shows the share for each country in the Renewables/Autarky scenario in 2050. It can be concluded that solar PV, both on roof-tops (often owned by individuals) and ground-based (owned by collectives), has the highest potential, especially in countries in Southern Europe. Generation of electricity with wind turbines owned by prosumer collectives also have a high potential in countries with enough available space around cities and towns and with enough wind power density.

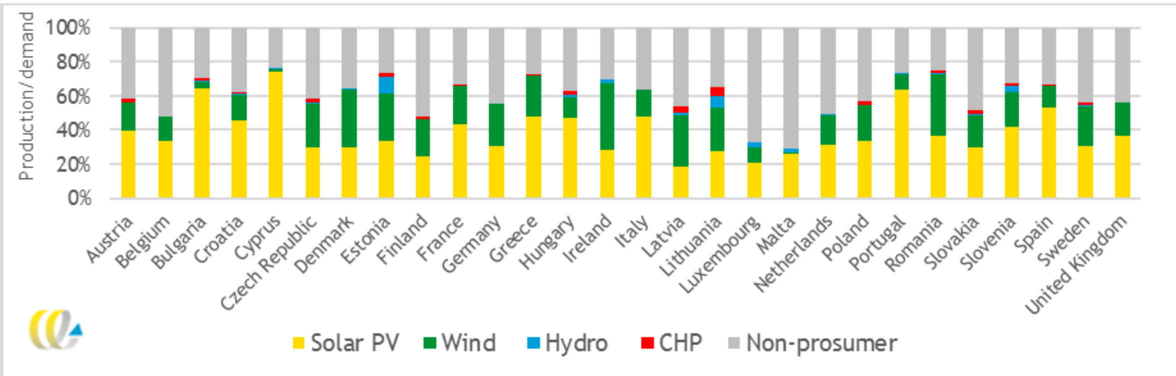


Figure 64 Annual electricity production of prosumer technologies relative to the total demand in the Renewables and Autarky scenario in 2050

The CEPROM results for the EU as a whole and all scenarios are shown in Figure 65. From this figure it becomes even clearer that hydro power and CHP have very minimal contribution to the total potential of generated electricity. It can also be noticed that to reach the outcome of the Renewables/Autarky scenario, the current generation of electricity by prosumers has to increase by a very large amount.

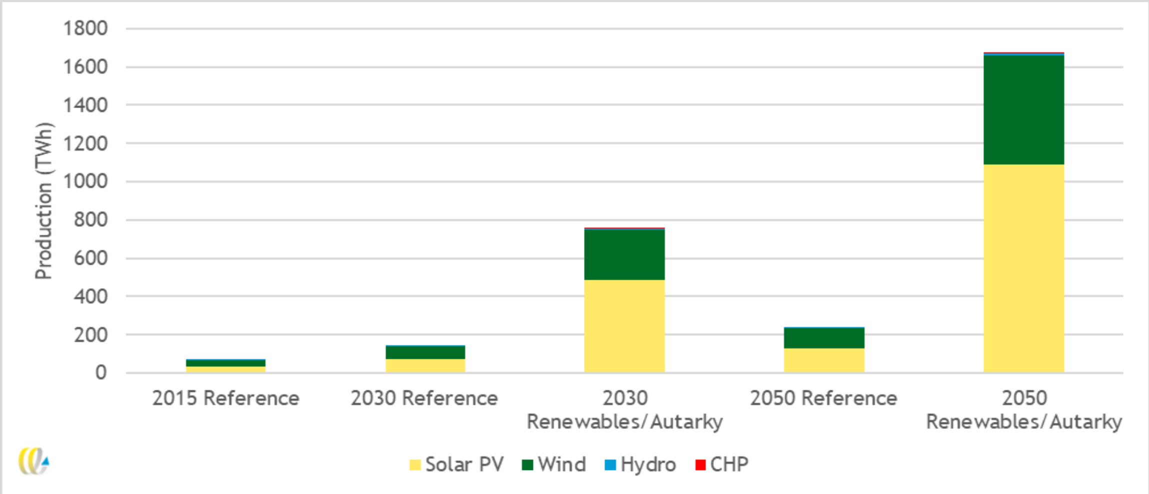


Figure 65 Electricity production prosumers (by technology)

The heating and cooling demand, other than the electricity demand, stays fairly constant over the different scenarios and reference years. The share of technologies that are applied to fill this demand vary between the Reference scenario and the Renewables/Autarky scenario. In the latter scenario, a large part of the heating and cooling consumption is filled with heat pumps, especially in Southern countries that also have a significant cooling demand. In countries with biomass availability, biomass boilers and CHP are also applied. District heating is mainly applied in Northern countries, where the heat demand is high and the cooling demand is low.

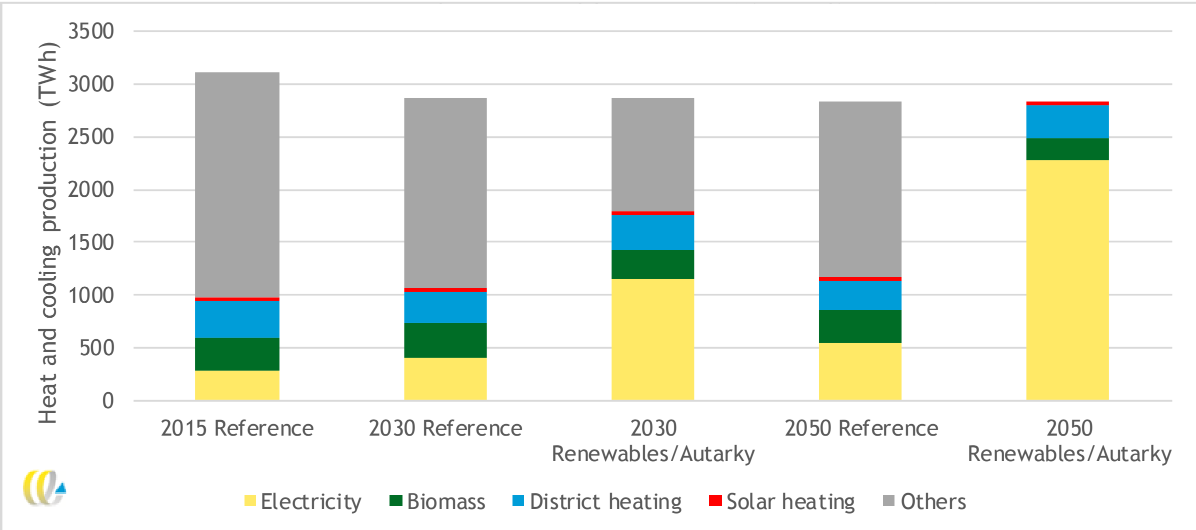


Figure 66 Heating and cooling production, divided by energy source.

The calculation of the share of autarky show that a high level of autarky can be reached for residential buildings, especially for the electricity production in the Autarky scenario. The share of autarky is expressed as a percentage of the self-produced energy that is directly used, or in case of the Autarky scenario, also the electricity used from battery storage, versus energy demand of the specific sector (residential or tertiary buildings). The percentage is mainly based on the amount of electricity production and the percentage of direct energy use and the electricity demand. Tertiary buildings do not reach a high level of autarky, due to the assumption that they only generate electricity by solar PV on their own roof and small wind turbines in case they have enough space around their building.

Table 77 Total share of autarky for the EU in Renewables and Autarky scenario in 2050

Type of building	Scenario	Type of energy	Percentage autarky
Residential	Renewables	Electricity	38%
		Heating and cooling	40%
	Autarky	Electricity	76%
		Heating and cooling	61%
Tertiary	Renewables	Electricity	12%
		Heating and cooling	37%
	Autarky	Electricity	21%
		Heating and cooling	43%

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9. Appendix

9.1.1 Parameters

Table 78 Parameters country archetypes and building stock,

	Reference			Renewables		Autarky		Unit	Reference
Country archetypes	2015	2030	2050	2030	2050	2030	2050		
Boundary cooling degree days									
Lower boundary	20	20	20	20	20	20	20	Degree days	Assumption CE Delft
Upper boundary	50	50	50	50	50	50	50	Degree days	Assumption CE Delft
Boundary biomass availability degree days									
Lower boundary	0.5	0.5	0.5	0.5	0.5	0.5	0.5	Ha/household	Assumption CE Delft
Upper boundary	1	1	1	1	1	1	1	Ha/household	Assumption CE Delft
Dwellings									
number of floors									
single family dwelling	2	2	2	2	2	2	2	#	(Defaix, et al., 2012)
multifamily, high rise	5.75	5.75	5.75	5.75	5.75	5.75	5.75	#	(Defaix, et al., 2012)
Tertiary	4	4	4	4	4	4	4	#	(Defaix, et al., 2012)
Ratio floor area flat/ floor area per house	0.58	0.58	0.58	0.58	0.58	0.58	0.58		Data Netherlands (CBS, 2018)

Table 79 Parameters solar energy (solar PV and solar thermal),

Solar energy	Reference			Renewables		Autarky		Unit	Reference
	2015	2030	2050	2030	2050	2030	2050		
Solar suitable area on rooftops	40%	40%	40%	40%	40%	40%	40%		(Defaix, et al., 2012)
Solar suitable area bare land	3%	3%	3%	3%	3%	3%	3%		(JRC, ongoing), (Ruiz, et al., 2019)
Solar PV									
Efficiency solar PV	15%	19%	23%	19%	23%	19%	23%		(ProsEU, ongoing a)
Performance ratio	80%	80%	80%	80%	80%	80%	80%		(Defaix, et al., 2012)
Fraction commercial PV tertiary prosumer	60%	60%	60%						Estimation CE Delft
Solar Thermal									
Efficiency solar heat north Europe	44%	49%	55%	49%	55%	49%	55%		(ProsEU, ongoing a)
Efficiency solar heat south Europe	40%	45%	50%	45%	50%	45%	50%		(ProsEU, ongoing a)
Irradiance boundary north/south	1250	1250	1250	1250	1250	1250	1250	kWh/m2/year	Assumption CE Delft
Fraction water heating demand covered by solar heating	50%	50%	50%	50%	50%	50%	50%		Assumption CE Delft

Table 80 Parameters electricity production (except solar PV),

Electricity	Reference			Renewables		Autarky		Unit	Reference
	2015	2030	2050	2030	2050	2030	2050		
Wind									
Fraction Tertiary wind on land Reference	10%	10%	10%						Estimation CE Delft
Hydro (small scale)									
Fraction small hydro cooperatives	3%	3%	3%						Estimation CE Delft (Wirling, et al., 2018)
Fraction new small hydro collectives				20%	20%	20%	20%		Assumption CE Delft
Electricity production total									
Boundary solar irradiation									
High	1250	1250	1250	1250	1250	1250	1250	kWh/m2/year	Assumption CE Delft
Low	1000	1000	1000	1000	1000	1000	1000	kWh/m2/year	Assumption CE Delft
Boundary power density wind									
High	350	350	350	350	350	350	350	W/m2	Assumption CE Delft
Low	275	275	275	275	275	275	275	W/m2	Assumption CE Delft

Table 81 Parameters energy storage (thermal storage, batteries and electric vehicles),

Energy storage	Reference			Renewables		Autarky		Unit	Reference
	2015	2030	2050	2030	2050	2030	2050		
Thermal energy storage									
Efficiency storage (full cycle of storing and extracting from storage)	50%	50%	50%	50%	50%	50%	50%		(ProsEU, ongoing a)
Share ATES Reference collectives	30%	30%	30%	30%	30%	30%	30%		(Fleuchaus, et al., 2018)(results Netherlands)
Fraction ATES Reference Tertiary	70%	70%	70%	70%	70%	70%	70%		(Fleuchaus, et al., 2018) (results Netherlands)
Electric vehicles									
Average battery capacity	46	60	60	60	60	60	60	kWh	Current capacity NL (2019), 2030, 2050 (Element Energy, 2019)
Share EV in total fleet passenger cars		15%	46%	23%	69%	23%	69%	%	CE Delft scenarios based on (EC, 2018)
share households	100%	100%	100%	100%	100%	100%	100%	%	Assumption CE Delft
share Tertiary	0%	0%	0%	0%	0%	0%	0%	%	Assumption CE Delft
Charging capacity	3	5	11	5	11	5	11	kW	Estimation CE Delft based on Element Energy (2019)
time plugged in	50%	50%	50%	50%	50%	50%	50%	%	Estimation CE Delft
availability for flex	85%	85%	85%	85%	85%	85%	85%	%	Estimation CE Delft
Percentage electricity from battery	25%	25%	25%	25%	25%	25%	25%	%	Estimation CE Delft
Change in driven km	100%	114%	126%	114%	126%	114%	126%	%	(E3M Lab ; National Technical University of Athens, 2016))
Electricity consumption electric vehicle	0,16	0,15	0,13	0,15	0,13	0,15	0,13	kWh/km	Estimation CE Delft
Stationary Batteries									
Adoption batteries	0%	0%	0%	0%	0%	43%	100%	%	Assumption CE Delft
Charging/discharging	0.4	0.4	0.4	0.4	0.4	0.4	0.4	kW/kWh	Estimation CE Delft
Storage per unit capacity PV									
Solar PV	4	4	4	4	4	4	4	kWh/kWp	Estimation CE Delft
Wind	15.0	15.0	15.0	15.0	15.0	15.0	15.0	kWh/kWp	Estimation CE Delft
Hydro (small scale)	9	9	9	9	9	9	9	kWh/kWp	Estimation CE Delft
CHP	2.0	2.0	2.0	2.0	2.0	2.0	2.0	kWh/kWp	Estimation CE Delft

Table 82 Parameters heating technologies (CHP, district heating, biomass boiler and heat pump),

Heating technologies	**Reference**			**Renewables**		**Autarky**		**Unit**	**Reference**
	2015	2030	2050	2030	2050	2030	2050		
CHP									
Efficiency CHP total	97.3%	97.3%	97.6%	97.3%	97.6%	97.3%	97.6%		(ProsEU, ongoing a)
Efficiency CHP heat	83.0%	83.0%	83.6%	83.0%	83.6%	83.0%	83.6%		(ProsEU, ongoing a)
Efficiency CHP electricity	14.3%	14.3%	14.0%	14.3%	14.0%	14.3%	14.0%		(ProsEU, ongoing a)
Number of CHP (Reference)	0	0	0						Assumption CE Delft, Data unknown
District heating									
Share district heating individual/multifamily households Reference									
Individual households	25%	25%	25%					% in terms of #	Estimation CE Delft
Multifamily households	75%	75%	75%					% in terms of #	Estimation CE Delft
Capacity households: single family	0.09	0.09	0.09	0.09	0.09	0.09	0.09	kW/m2	CE Delft (CEGOIA model)
Capacity collective: multifamily	0.075	0.075	0.075	0.075	0.075	0.075	0.075	kW/m2	CE Delft (CEGOIA model)
Capacity Tertiary	0.075	0.075	0.075	0.075	0.075	0.075	0.075	kW/m2	CE Delft (CEGOIA model)
Biomass boiler									
Share biomass boiler individual/multifamily households Reference									
Individual households	50%	50%	50%					% in terms of #	Estimation CE Delft
Multifamily households	50%	50%	50%					% in terms of #	Estimation CE Delft

Biomass boiler fraction of equivalent full load hours compared to Heatpump	75%	75%	75%	75%	75%	75%	75%	%	Assumption CE Delft
Heat pump									
Share heat pumps individual/multifamily households Reference									
Individual households	75%	75%	75%					% in terms of #	Estimation CE Delft
Multifamily households	25%	25%	25%					% in terms of #	Estimation CE Delft
COP heat pump for space heating	3.5	3.9	4.0	3.9	4.0	3.9	4.0	#	(ProsEU, ongoing a)
COP heat pump for hot water / tap water	2.0	2.3	2.6	2.3	2.6	2.3	2.6	#	(CE Delft, 2017)
COP heat pump for space cooling	2.5	2.9	3.0	2.9	3.0	2.9	3.0	#	COP_c=COP_h -1 (Wikipedia.org, 2020)

9.1.2 Data

Table 83 Overview used data including references,

Description data	Reference
Population member states (2015, 2030, 2050)	(E3M Lab ; National Technical University of Athens, 2016)
Number of households (2015)	(E3M Lab ; National Technical University of Athens, 2016)
Heating and cooling degree days	(Eurostat, 2019)
Land cover (woodland and bare land)	(Eurostat, 2020a) Reference year 2012
Distribution population by housing type and living area	(Eurostat, 2020b) Reference year 2018
Floor area per dwelling	(Eurostat, 2020e) Reference year
Floor area Tertiary	(EC, ongoing) Building Stock Characteristics
New residential buildings per year	(EC, ongoing) Building stock characteristics
Buildings tertiary sector	(Eurostat, 2020c) Reference year 2017
Electricity demand (2015, 2030, 2050)	(E3M Lab ; National Technical University of Athens, 2016)
Installed capacity off-shore and onshore wind	(Eurobserv'er, 2016)
Installed capacity wind and solar PV collectives	(RESCoop, 2015)
Electricity generation wind/solar PV/hydro Reference (2015, 2030, 2050)	(E3M Lab ; National Technical University of Athens, 2016)
Full-load hours generation wind/solar PV/hydro Reference (2015, 2030, 2050)	(E3M Lab ; National Technical University of Athens, 2016)
Mean power density wind power @100m	(Global wind atlas, ongoing)
Technical potential wind	(Dalla Longa, et al., 2018)
Solar irradiation	(Beták, et al., 2012)
Market segmentation solar PV Reference	(SolarPower Europe, 2019)
Solar heat production (2015)	(Eurostat, 2020d) Reference year 2015
Production small hydro	(ESHA, 2012)
Technical potential hydropower	(EC, SETIS, 2011)
Subsurface suitability ATES	(Bloemendal, et al., 2015)
Energy stored ATES	(Fleuchaus, et al., 2018)(Based on results of the Netherlands)
Passenger cars per 1000 inhabitants	(Eurostat, 2020) Reference year 2016
Full electric vehicles	(Eurostat, 2091b)
Households without a car	(ACEA, 2017) (year data between 2010 and 2015)
Delivered energy demand heat (total heat produced)	(Fraunhofer ISI ; TEP Energy GmbH; University Utrecht; ARMINES, 2017)
Equivalent full load hours heat pumps	(EU, 2013)

9.1.3 Matrix technologies

Table 84 Matrix choice heating technologies individual prosumers,

Climate zone	Woodland	Population density	Heat pump	Thermal energy storage	District heating	Biomass boiler	Solar thermal	CHP
CDD <20	>1ha/hh	Rural				1	1	
CDD <20	>1ha/hh	Suburban	1					
CDD <20	>1ha/hh	Urban			1		1	
CDD <20	0.5<ha/hh<1	Rural	0.5			0.5		
CDD <20	0.5<ha/hh<1	Suburban	1					
CDD <20	0.5<ha/hh<1	Urban			1		1	
CDD <20	ha/hh<0.5	Rural	1					
CDD <20	ha/hh<0.5	Suburban	1					
CDD <20	ha/hh<0.5	Urban			1		1	
20<CDD<50	>1ha/hh	Rural				1	1	
20<CDD<50	>1ha/hh	Suburban	1					
20<CDD<50	>1ha/hh	Urban			1		1	
20<CDD<50	0.5<ha/hh<1	Rural	0.5			0.5		
20<CDD<50	0.5<ha/hh<1	Suburban	1					
20<CDD<50	0.5<ha/hh<1	Urban			1		1	
20<CDD<50	ha/hh<0.5	Rural	1					
20<CDD<50	ha/hh<0.5	Suburban	1					
20<CDD<50	ha/hh<0.5	Urban			1		1	
CDD>50	>1ha/hh	Rural				1	1	
CDD>50	>1ha/hh	Suburban	1					
CDD>50	>1ha/hh	Urban	1					
CDD>50	0.5<ha/hh<1	Rural	1					
CDD>50	0.5<ha/hh<1	Suburban	1					
CDD>50	0.5<ha/hh<1	Urban	1					
CDD>50	ha/hh<0.5	Rural	1					
CDD>50	ha/hh<0.5	Suburban	1					
CDD>50	ha/hh<0.5	Urban	1					

Table 85 Matrix choice heating technologies collective prosumers,

Climate zone	Woodland	Population density	Heat pump	Thermal energy storage	District heating	Biomass boiler	Solar thermal	CHP
CDD <20	>1ha/hh	Rural					1	1
CDD <20	>1ha/hh	Suburban	1					
CDD <20	>1ha/hh	Urban			1		1	
CDD <20	0.5<ha/hh<1	Rural					1	1
CDD <20	0.5<ha/hh<1	Suburban	1					
CDD <20	0.5<ha/hh<1	Urban			1		1	
CDD <20	ha/hh<0.5	Rural	1					
CDD <20	ha/hh<0.5	Suburban	1					

CDD <20	ha/hh<0.5	Urban			1		1	
20<CDD<50	>1ha/hh	Rural					1	1
20<CDD<50	>1ha/hh	Suburban	1					
20<CDD<50	>1ha/hh	Urban			1		1	
20<CDD<50	0.5<ha/hh<1	Rural					1	1
20<CDD<50	0.5<ha/hh<1	Suburban	1					
20<CDD<50	0.5<ha/hh<1	Urban			1		1	
20<CDD<50	ha/hh<0.5	Rural	1					
20<CDD<50	ha/hh<0.5	Suburban	1					
20<CDD<50	ha/hh<0.5	Urban			1		1	
CDD>50	>1ha/hh	Rural					1	1
CDD>50	>1ha/hh	Suburban	1	1				
CDD>50	>1ha/hh	Urban	1					
CDD>50	0.5<ha/hh<1	Rural					1	1
CDD>50	0.5<ha/hh<1	Suburban	1	1				
CDD>50	0.5<ha/hh<1	Urban	1					
CDD>50	ha/hh<0.5	Rural	1					
CDD>50	ha/hh<0.5	Suburban	1	1				
CDD>50	ha/hh<0.5	Urban	1					

Table 86 Matrix choice heating technologies tertiary sector,

Climate zone	Woodland	Population density	Heat pump	Thermal energy storage	District heating	Biomass boiler	Solar thermal	CHP
CDD <20	>1ha/hh	Rural					1	1
CDD <20	>1ha/hh	Suburban	1					
CDD <20	>1ha/hh	Urban			1		1	
CDD <20	0.5<ha/hh<1	Rural					1	1
CDD <20	0.5<ha/hh<1	Suburban	1					
CDD <20	0.5<ha/hh<1	Urban			1		1	
CDD <20	ha/hh<0.5	Rural	1					
CDD <20	ha/hh<0.5	Suburban	1					
CDD <20	ha/hh<0.5	Urban			1		1	
20<CDD<50	>1ha/hh	Rural					1	1
20<CDD<50	>1ha/hh	Suburban	1	1				
20<CDD<50	>1ha/hh	Urban	1					
20<CDD<50	0.5<ha/hh<1	Rural					1	1
20<CDD<50	0.5<ha/hh<1	Suburban	1	1				
20<CDD<50	0.5<ha/hh<1	Urban	1					
20<CDD<50	ha/hh<0.5	Rural	1					
20<CDD<50	ha/hh<0.5	Suburban	1	1				
20<CDD<50	ha/hh<0.5	Urban	1					
CDD>50	>1ha/hh	Rural					1	1
CDD>50	>1ha/hh	Suburban	1	1				
CDD>50	>1ha/hh	Urban	1					
CDD>50	0.5<ha/hh<1	Rural					1	1
CDD>50	0.5<ha/hh<1	Suburban	1	1				
CDD>50	0.5<ha/hh<1	Urban	1					
CDD>50	ha/hh<0.5	Rural	1					
CDD>50	ha/hh<0.5	Suburban	1	1				
CDD>50	ha/hh<0.5	Urban	1					

9.2 Overview results

9.2.1 Results graphs

Table 87 Annual electricity demand in different scenarios and different reference years (in TWh),

Member state	Reference 2015	Reference 2030	Renewables/ Autarky 2030	Reference 2050	Renewables/ Autarky 2050
Austria	32	38	42	39	49
Belgium	49	60	69	67	89
Bulgaria	11	15	17	17	22
Croatia	9	11	13	12	16
Cyprus	2	3	6	4	11
Czech Republic	34	41	46	43	53
Denmark	24	29	33	31	41
Estonia	5	6	6	6	7
Finland	30	36	39	40	46
France	246	282	331	305	420
Germany	312	347	426	348	526
Greece	22	25	36	27	52
Hungary	29	34	40	33	47
Ireland	14	17	19	19	23
Italy	174	216	280	237	385
Latvia	7	8	8	8	9
Lithuania	7	8	8	7	9
Luxembourg	4	5	6	7	9
Malta	1	1	2	2	4
Netherlands	81	90	99	93	115
Poland	106	134	146	132	158
Portugal	16	21	26	24	35
Romania	32	40	44	40	51
Slovakia	14	18	20	19	23
Slovenia	6	7	8	8	10
Spain	98	115	145	129	196
Sweden	40	50	53	57	66
United Kingdom	196	236	262	261	325
Total	**1,601**	**1,892**	**2,230**	**2,016**	**2,798**

Table 88 Electricity production with prosumer technologies relative to total demand residential and tertiary sector (in TWh),

Member state	Reference 2015	Reference 2030	Renewables/ Autarky 2030	Reference 2050	Renewables/ Autarky 2050	Demand 2050 Autarky
Austria	2	5	13	8	29	49
Belgium	3	5	20	6	43	89
Bulgaria	0	1	7	1	15	22
Croatia	0	1	4	2	10	16
Cyprus	0	0	4	1	8	11
Czech Republic	0	0	13	1	31	53
Denmark	3	5	13	6	26	41
Estonia	0	0	2	1	5	7
Finland	1	1	10	2	22	46
France	6	26	124	51	281	419
Germany	22	40	137	56	291	526
Greece	2	5	17	8	38	52
Hungary	0	0	13	1	29	47
Ireland	1	1	7	2	16	23
Italy	9	15	111	35	247	385
Latvia	0	0	2	0	5	9
Lithuania	0	0	2	0	6	9
Luxembourg	0	0	1	0	3	9
Malta	0	0	1	0	1	4
Netherlands	2	6	25	8	57	115
Poland	1	2	39	5	89	158
Portugal	1	3	12	4	25	35
Romania	1	1	17	2	38	51
Slovakia	0	0	5	1	12	23
Slovenia	0	0	3	0	7	10
Spain	6	12	60	22	131	196
Sweden	2	3	17	4	37	66
United Kingdom	4	9	81	11	183	325
Total	**68**	**143**	**761**	**238**	**1,686**	**2,797**

Table 89 Electricity production of prosumer technologies relative to total demand residential and tertiary sector in Renewables/Autarky scenario in 2050 (in TWh),

Member state	Solar PV	Wind	Hydro (small scale)	CHP	Demand
Austria	20	8	0	1	49
Belgium	30	13	0	0	89
Bulgaria	14	1	0	0	22
Croatia	7	2	0	0	16
Cyprus	8	0	0	0	11
Czech Republic	16	14	0	1	53
Denmark	12	14	0	0	41
Estonia	2	2	1	0	7
Finland	11	10	0	1	46
France	182	95	0	5	419
Germany	159	132	0	0	526
Greece	25	12	0	0	52
Hungary	22	6	1	1	47
Ireland	7	9	0	0	23
Italy	183	63	0	0	385
Latvia	2	3	0	0	9
Lithuania	2	2	1	0	9
Luxembourg	2	1	0	0	9
Malta	1	0	0	0	4
Netherlands	36	20	0	0	115
Poland	52	33	0	3	158
Portugal	22	3	0	0	35
Romania	19	18	0	1	51
Slovakia	7	4	0	0	23
Slovenia	4	2	0	0	10
Spain	105	25	0	2	196
Sweden	20	15	0	1	66
United Kingdom	119	64	0	0	325
Total	**1,090**	**572**	**8**	**17**	**2,797**

Table 90 Heating and cooling demand residential and tertiary sector (in TWh),

Member state	Heating demand			Cooling demand		
	2015	2030	2050	2015	2030	2050
Austria	64	56	52	1	2	2
Belgium	89	78	73	2	3	3
Bulgaria	19	16	15	2	3	4
Croatia	19	17	16	1	1	2
Cyprus	2	2	2	6	11	19
Czech Republic	65	57	53	1	1	1
Denmark	45	40	37	0	0	1
Estonia	9	8	8	0	0	0
Finland	62	55	51	0	1	1
France	414	366	343	16	26	33
Germany	660	574	537	6	10	11
Greece	32	29	28	19	34	53
Hungary	58	51	47	1	2	3
Ireland	29	25	24	0	0	0
Italy	349	310	291	61	104	153
Latvia	13	11	10	0	0	0
Lithuania	12	11	10	0	0	0
Luxembourg	7	6	6	0	0	0
Malta	1	1	1	2	3	5
Netherlands	116	101	95	2	3	3
Poland	180	160	150	2	3	4
Portugal	16	14	13	6	9	13
Romania	51	45	42	2	4	6
Slovakia	26	23	21	0	0	0
Slovenia	11	9	9	1	1	1
Spain	126	110	103	46	77	104
Sweden	81	70	66	1	2	2
United Kingdom	369	325	306	6	9	9
Total	**2,924**	**2,570**	**2,408**	**185**	**310**	**434**

Table 91 Energy carriers used to cover the energy demand for heating and cooling in residential buildings in the Renewables/Autarky scenario in 2050

Member state	Electricity	Derived heat	Biomass	Solar heat
Austria	30	8	14	1
Belgium	62	12	0	1
Bulgaria	13	0	6	1
Croatia	12	0	6	0
Cyprus	21	0	0	0
Czech Republic	30	10	13	1
Denmark	27	10	0	1
Estonia	2	3	3	0
Finland	17	18	16	1
France	346	0	28	2
Germany	548	0	0	0
Greece	79	0	1	0
Hungary	46	0	5	0
Ireland	14	10	0	1
Italy	444	0	0	0
Latvia	3	3	4	0
Lithuania	2	3	6	1
Luxembourg	5	0	0	0
Malta	6	0	0	0
Netherlands	64	31	0	2
Poland	75	32	43	3
Portugal	25	0	1	0
Romania	28	0	18	1
Slovakia	12	0	9	1
Slovenia	6	0	4	0
Spain	196	0	10	2
Sweden	29	23	13	3
United Kingdom	142	157	0	16
Total	**2,284**	**319**	**200**	**40**

Table 92 Electricity storage capacity in the Autarky scenario in 2050 (in GWh)

Member state	Electricity storage capacity	
	Battery storage	EV
Austria	136	94
Belgium	174	129
Bulgaria	69	45
Croatia	46	24
Cyprus	26	10
Czech Republic	181	94
Denmark	110	47
Estonia	33	10
Finland	139	64
France	1,085	633
Germany	1,561	720
Greece	141	76
Hungary	162	53
Ireland	77	38
Italy	985	737
Latvia	27	9
Lithuania	34	14
Luxembourg	15	12
Malta	2	5
Netherlands	256	146
Poland	562	335
Portugal	75	71
Romania	204	83
Slovakia	63	32
Slovenia	42	19
Spain	402	385
Sweden	201	104
United Kingdom	905	629
Total	**7,712**	**4,621**

Table 93 Annual amount of thermal energy stored (in GWh)

Member state	Heat/cold stored				
	2015 Reference	2030 Reference	2030 Autarky	2050 Reference	2050 Autarky
Austria	-	-	-	-	-
Belgium	19	20	229	23	511
Bulgaria	-	-	-	-	-
Croatia	-	-	25	-	58
Cyprus	-	-	-	-	-
Czech Republic	-	-	-	-	-
Denmark	34	36	36	38	38
Estonia	-	-	1	-	1
Finland	-	-	-	-	-
France	-	-	500	-	1,167
Germany	2	2	546	2	1,270
Greece	-	-	-	-	-
Hungary	-	-	20	-	47
Ireland	-	-	-	-	-
Italy	-	-	-	-	-
Latvia	-	-	1	-	2
Lithuania	-	-	0	-	1
Luxembourg	-	-	6	-	14
Malta	-	-	-	-	-
Netherlands	1,553	1,591	1,563	1,577	1,577
Poland	-	-	100	-	234
Portugal	-	-	-	-	-
Romania	-	-	-	-	-
Slovakia	-	-	6	-	14
Slovenia	-	-	-	-	-
Spain	-	-	-	-	-
Sweden	137	148	150	168	168
United Kingdom	7	8	8	9	9
Total	**1,752**	**1,806**	**3,190**	**1,816**	**5,108**

9.2.2 Other results

Table 94 Distribution electricity demand different application in Renewables/Autarky 2050 scenario (in TWh),

Member state	Electricity demand lightning and devices		Electricity demand EV	Electricity demand heating and cooling		Total electricity demand	
	Residential	Tertiary	Residential	Residential	Tertiary	Residential	Tertiary
Austria	13	19	10	5	3	28	22
Belgium	21	36	15	11	6	48	41
Bulgaria	5	7	6	2	1	13	8
Croatia	4	6	3	2	1	9	7
Cyprus	1	2	1	6	1	8	3
Czech Republic	14	23	8	6	2	28	25
Denmark	9	17	7	6	2	22	19
Estonia	2	3	1	0	0	4	4
Finland	11	22	8	3	1	23	24
France	76	164	89	72	18	237	182
Germany	116	164	97	106	43	319	207
Greece	7	13	10	18	5	35	17
Hungary	11	18	6	9	3	26	21
Ireland	7	9	4	3	1	13	10
Italy	65	109	82	92	36	240	145
Latvia	3	4	1	0	0	4	5
Lithuania	3	4	2	0	0	5	4
Luxembourg	2	5	2	1	1	4	5
Malta	0	1	1	2	0	2	1
Netherlands	23	58	19	9	7	51	65
Poland	47	71	21	14	5	82	76
Portugal	6	12	9	5	2	20	14
Romania	18	15	11	5	2	34	17
Slovakia	5	12	4	2	1	11	12
Slovenia	2	3	3	1	0	6	4
Spain	31	73	36	37	19	104	92
Sweden	14	30	14	5	2	33	32
United Kingdom	91	112	85	58	16	235	128
Total	**607**	**1,013**	**554**	**483**	**177**	**1,644**	**1,190**

Table 95 Installed capacity electricity generation Renewables/Autarky 2050 scenario (in GW),

	Installed capacity				
Member state	**Solar PV**	**Wind**	**Hydro (small scale)**	**CHP**	**Total**
Austria	16	4	0	8	27
Belgium	27	4	0	-	32
Bulgaria	10	0	0	4	14
Croatia	5	1	0	2	8
Cyprus	4	0	0	0	4
Czech Republic	17	6	0	5	28
Denmark	13	4	0	-	17
Estonia	3	1	0	5	8
Finland	14	4	0	6	23
France	106	32	0	53	191
Germany	165	58	0	-	223
Greece	14	4	0	1	19
Hungary	21	3	0	5	29
Ireland	8	3	0	-	11
Italy	118	26	0	-	145
Latvia	2	1	0	1	4
Lithuania	3	1	0	2	6
Luxembourg	2	0	0	-	2
Malta	1	0	0	-	1
Netherlands	39	7	0	-	46
Poland	60	14	0	23	98
Portugal	11	1	0	5	16
Romania	14	8	0	5	27
Slovakia	6	2	0	2	10
Slovenia	4	1	0	2	7
Spain	48	9	0	20	78
Sweden	23	6	0	6	35
United Kingdom	142	20	0	-	162
Total	**893**	**222**	**3**	**156**	**1,274**

Table 96 Potential production prosumers without cap by technique in Renewables/Autarky 2050 scenario (in TWh),

	Potential production prosumers (TWh)				
Member state	**Solar PV**	**Wind**	**Hydro (small scale)**	**CHP**	**Total**
Austria	51	24	0	1	76
Belgium	30	15	0	0	45
Bulgaria	24	62	0	0	86
Croatia	11	43	0	0	55
Cyprus	20	1	0	0	21
Czech Republic	18	141	0	1	160
Denmark	15	120	0	0	135
Estonia	5	59	1	0	65
Finland	20	57	0	1	78
France	283	1,757	0	5	2,045
Germany	159	176	0	0	335
Greece	55	396	0	0	452
Hungary	35	79	1	1	116
Ireland	10	549	0	0	559
Italy	228	240	0	0	468
Latvia	5	170	0	0	175
Lithuania	5	268	1	0	274
Luxembourg	2	1	0	0	3
Malta	1	0	0	0	1
Netherlands	36	50	0	0	86
Poland	69	199	0	3	272
Portugal	61	67	0	0	128
Romania	29	294	0	1	324
Slovakia	9	52	0	0	62
Slovenia	5	4	0	0	9
Spain	499	1,150	0	2	1,651
Sweden	87	245	0	1	333
United Kingdom	121	325	0	0	446
Total	**1,893**	**6,542**	**8**	**17**	**8,459**

Table 97 Potential production prosumers without cap compared to demand in Renewables/Autarky 2050 scenario (in TWh),

Member state	Residential			Tertiary		
	Potential production	Demand	Production relative to demand	Potential production	Demand	Production relative to demand
Austria	71	28	255%	5	22	24%
Belgium	40	48	83%	6	41	13%
Bulgaria	84	13	632%	2	8	28%
Croatia	53	9	597%	1	7	16%
Cyprus	21	8	267%	0	3	15%
Czech Republic	157	28	557%	3	25	11%
Denmark	130	22	599%	5	19	25%
Estonia	63	4	1751%	2	4	64%
Finland	74	23	330%	3	24	14%
France	2,000	237	844%	44	182	24%
Germany	284	319	89%	51	207	25%
Greece	449	35	1274%	3	17	16%
Hungary	112	26	427%	3	21	15%
Ireland	556	13	4159%	3	10	28%
Italy	449	240	187%	19	145	13%
Latvia	175	4	4183%	1	5	12%
Lithuania	273	5	5836%	1	4	22%
Luxembourg	3	4	64%	0	5	7%
Malta	1	2	40%	0	1	11%
Netherlands	74	51	146%	12	65	19%
Poland	259	82	316%	13	76	17%
Portugal	123	20	613%	5	14	37%
Romania	320	34	941%	4	17	24%
Slovakia	61	11	550%	1	12	9%
Slovenia	8	6	132%	1	4	22%
Spain	1,624	104	1556%	27	92	29%
Sweden	327	33	976%	6	32	20%
United Kingdom	848	235	361%	45	128	35%
Total	**8,638**	**1,644**	**525%**	**268**	**1,190**	**22%**

Table 98 Heating and cooling demand divided by residential and tertiary sector in Renewables/Autarky scenario 2050 (in TWh)

Member state	Heating demand		Cooling demand	
	Residential	Tertiary	Residential	Tertiary
Austria	38	14	0,3	2
Belgium	54	19	0,1	3
Bulgaria	12	3	1,1	3
Croatia	14	2	0,8	1
Cyprus	2	0	15,9	3
Czech Republic	41	12	0,2	1
Denmark	29	8	0,1	0
Estonia	6	2	0,0	0
Finland	38	13	0,0	1
France	267	76	11,2	22
Germany	384	153	0,7	10
Greece	25	3	35,8	17
Hungary	35	12	0,9	2
Ireland	18	6	0,0	0
Italy	235	56	89,9	63
Latvia	8	3	0,0	0
Lithuania	8	2	0,0	0
Luxembourg	4	2	0,0	0
Malta	0	0	4,3	1
Netherlands	69	25	0,1	3
Poland	120	29	0,3	3
Portugal	9	4	7,1	6
Romania	33	9	2,9	3
Slovakia	16	6	0,1	0
Slovenia	7	2	0,1	1
Spain	79	24	47,8	57
Sweden	47	19	0,0	2
United Kingdom	242	63	0,3	9
Total	**1,841**	**568**	**220**	**214**

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