D5.2

Use Case Simulation Methodology

LEGAL DISCLAIMER

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Scope of the document according to the DoA	Public report and open data repository delivered at the end of M37. The report will include the description of the methodology followed to perform the simulations needed for the assessment of the Use Cases, the data collected and the RAW results. The database will be published in an open-access database (ensuring full compliance with the FAIR principles) to be reused by the stakeholders and the research community. This deliverable will be peer reviewed by scientific experts.

EXECUTIVE SUMMARY

This deliverable includes the results of five use cases capturing a wide diversity of contexts from local and energy community to national, European and global level. The goal is to provide an improved and transparent energy modelling framework focusing on the household sector and to address specific questions related to the evolution of the energy consumption at local, national, European, and global levels. The raw data from the five Use Cases of the WHY project can be found online in open access: https://zenodo.org/doi/10.5281/zenodo.7382923. The design of all Use Cases has been greatly benefited from the active engagement of stakeholders and end-users, including policy makers, public authorities, businesses, and utilities. In all cases, stakeholders helped to define the most important aspects, questions, and policy interventions to be assessed in each Use Case from the local up to the European and global ones.

The Positive Energy District Use Case in Maintal is discussed in Chapter 2 of this report. This case study aims to assess the impacts of interventions in a positive energy district using the WHY Toolkit. The goal is to inform policy decisions (and energy system planning) related to energy consumption, fuel mix, technology investment, energy costs and CO2 emissions at the local level in case of blackout. The WHY Toolkit was applied to simulate 131 households applying 3 different archetypes (Single Family Home, Detached and Terraced Home and Apartment Building). This involved utilizing the toolkit's capabilities to model and analyse different scenarios, considering factors such as energy demand, water consumption as well as electrical and thermal load profiles, the so-called inner heat gains, renewable energy generation and potential policy measures. Stakeholder engagement is integral to refining the Use Case and validating the methodology. The Maintal use Case showcased the practical application of the WHY Toolkit in a local setting and its results contributed to the understanding of how interventions can shape energy outcomes at the community level.

The Energy Cooperative Use Case (Chapter 3) demonstrated the WHY Toolkit's efficacy in understanding and influencing residential energy consumption behavior tested in an energy cooperative. Goiner, a non-profit citizen energy cooperative in the Basque country, used the WHY Toolkit to simulate residential consumers' behaviour. Goiner aimed to understand how changes in its tariff structure would impact load profiles, purchasing strategies, and long-term goals, such as reducing energy consumption and alleviating energy poverty. The findings of the analysis showed that behavioural changes such as load shifting, and energy reduction actions are influenced by tariff complexity and perceived barriers.

The Energy Community Use Case (Chapter 4) explores the role of local and citizen led engagement in clean energy transition. Specifically, this use case showcases how new energy community-based business models can contribute to making cities climate neutral by 2030. In this direction, the study employs a comprehensive methodology combining survey results from community partners and stakeholders. The study evaluates key drivers such as the state of play, business models, value sharing governance structures, replicability, scalability, and future projections. This use case provides a comprehensive understanding of the energy community landscape, emphasizing the diverse structures, services, financial tools, and challenges faced and how the WHY toolkit can be used to address them.

The European Use Case in Chapter 5 delves into the impact of energy and climate policies on achieving EU goals for climate change mitigation and energy efficiency. By soft-linking the PRIMES-BuiMo buildings model with the WHY Toolkit, this use case explores the role of energy consumers in decarbonizing European buildings. The soft-linking bridges the gap between cost-optimality in Energy System Models (ESMs) and the dynamics of everyday behavioral decisions by energy consumers. The model-based analysis shows that the EU's

transition towards climate neutrality required significant investment in energy efficiency of buildings combined with decarbonization of the fuel mix, mostly through the uptake of electric heat pumps replacing the use of fossil fuels. The Use Case also demonstrates that targeted policy interventions considering the national context and specificities are required to ensure an efficient and sustainable transition to zero-emission buildings.

The Global Use Case (Chapter 6) explores the implications of ambitious climate policies and energy efficiency measures on the global energy mix, with a specific focus on the future development of the buildings sector. Employing two well established Integrated Assessment Models TIAM-ECN and PROMETHEUS, linked with the WHY Toolkit, this use case aim to enhance the model simulation properties for a more accurate representation of decarbonization in the buildings sector. The overarching goal is to bring a global perspective to the project, demonstrating how tools developed in WHY can benefit global energy and climate modelling studies. The Global Use Case provides essential insights into the potential risks and complexities associated with specific policy measures for the buildings sector emphasizing the need for comprehensive analysis and informed decision making in the pursuit of global decarbonization goals.

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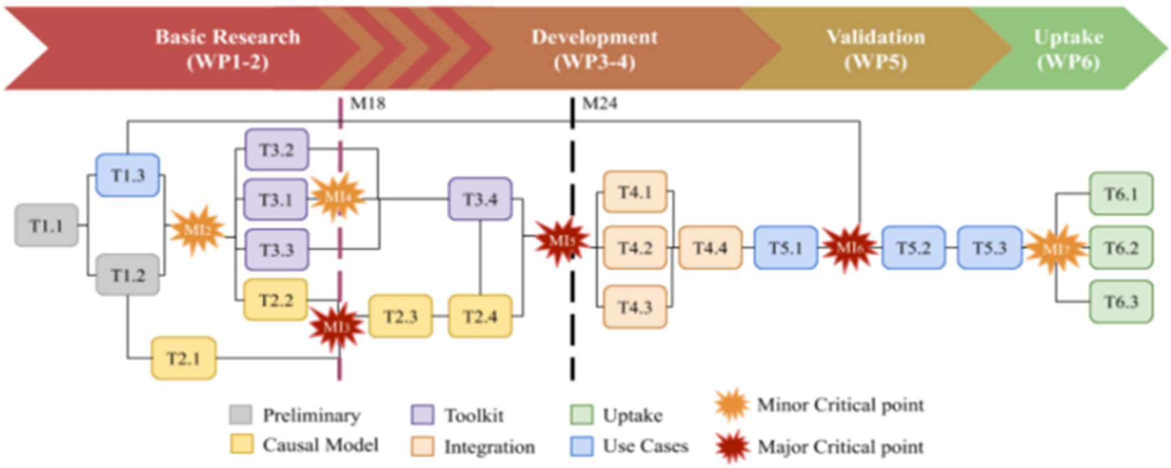
LIST OF ACRONYMS AND ABBREVIATIONS

Acronym	Long text
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
EU	European Union
EC	European Commission
EV	Electric Vehicle
CO2	Carbon Dioxide
EE	Energy Efficiency
DR	Demand Response
ESM	Energy System Model
UCM	Use Case Manager
IDEA	Institute for Diversification and Saving of Energy
REC	Renewable Energy Community
CEC	Citizen Energy Community
KPI	Key Performance Indicator

1. Introduction

To mitigate climate change effects, urgent action is required in all sectors of the economy to significantly reduce greenhouse gas emissions and improve energy efficiency. Energy System Models (ESM) are tools that help energy analysts, planners, and policymakers to rationally describe energy systems and systematically evaluate the impacts of long-term scenarios and policy instruments. The WHY project develops innovative methodologies and a toolkit to describe household energy consumption aiming to improve the understanding of what, when, how much, and why energy is consumed in households. The WHY Toolkit is applied and tested in five Use Cases, capturing a wide diversity of contexts from local and energy community to national, European, and global level.

The Use Cases are a key part of the WHY project ambition to create an improved and transparent energy modelling framework especially in the household's sector. The Use Cases will serve to test, validate, and demonstrate the WHY toolkit and its links to leading Energy System Models (the technical process of developing the WHY Toolkit and the model plug-ins has been described in other project deliverables, in particular in D3.1, D4.1 and D4.2). The current deliverable describes the application of the WHY methodology to the five use cases and presents the main results aiming to demonstrate the relevance and adequacy of the WHY toolkit to enhance the modelling of energy consumption in the residential sector and to address specific questions related to the evolution of the energy consumption at local, national, European, and global levels. The use cases act as a real-life proof of concept of the WHY research methodology, validated through a comparison with previous studies (without the use of WHY Toolkit) to re-assess policy instruments and interventions. The use cases are further enhanced and fine-tuned through stakeholder engagement and codesign workshops for each use case.



As part of this deliverable, the modelling enhancements and improvements developed in the WHY project are validated in five different Use Cases. Every case has a unique combination of geographic scope, temporal framework, technologies, methodologies, and policy objectives. The five Use Cases act as proof of concept and testing/validating the modelling improvements developed in the WHY project, in particular the WHY Toolkit and its soft linkage with ESMs. Their objective is to assess the impacts that a set of interventions (e.g., policy measures) may have on the energy demand, fuel mix, technology investment, energy costs and prices and CO_2 emissions. To support policy decisions, the actor or entity (policymaker, utility, energy community, energy cooperative, researcher or other) will use the WHY toolkit to assess the policy impacts before the policy is implemented. The WHY model toolkit will be validated by comparing the techno-economic decisions and policy recommendations made in the 5 Use Cases in a multitude of contexts (from the local and city level up to the national, EU and global scale) with and without the WHY Toolkit.

The report is structured as follows: Section 2 describes the results for the Use Case about the positive energy district in Maintal, while Sections 3 and 4 describe the Energy Cooperative and Energy Community use cases respectively. Section 5 presents the main findings from the EU Use Case, while the global use case is presented in section 6. Section 7 concludes the report.

2. The Positive Energy District Use Case in Maintal

This use case is based on the assessment of the positive energy district in Maintal.

2.1. Objective and Scope of the Use Case

The city of Maintal is currently developing a new positive energy district "Am Berghof" with a mixed allocation of the available space within the buildings (companies, households, etc.). The district will be planned by a technical bureau (Alpha IC GmbH), which will also have to address the topic of energy consumption and energy provision within the district. Normally the planner will rely on standardised values (average consumption values for energy demand per m²) for energy consumption and generation, both for thermal and electrical energy, which would result in reduced and uncertain effectiveness of energy planning. Planners mostly work with annual values for energy generation and consumption and do not look into the details of high-resolution load profiles in specific local contexts, e.g. energy districts. Thus, if the energy generation is greater than the annual consumption, the plus energy criterion is fulfilled. But it gives no indication of whether the generated energy is actually used by the consumers at the time needed.

The WHY-project helps to reduce the uncertainty by providing more detailed information on the energy consumption and consumption profiles of the households in specific local contexts. For that purpose, the planners will provide the WHY consortium with the general data on the potential occupants of the buildings in the Maintal district "Am Berghof".

During the detailed planning phase of the positive energy district, the planners will decide on what heating technology to implement for the entire district. During that phase the WHY Building Sizer, a model library which is part of the WHY-Toolkit and responsible for sizing components, see Deliverable 3.2, was used to optimise the setup and provide the planners with the means to validate their results.

Additionally emergency energy supply is a topic that is not part of the planning process but is addressed by the WHY consortium.

The Use case is separated into two phases:

- **Draft planning phase:** During this phase the WHY consortium used the WHY-Toolkit to generate individual load profiles for types of households which will inhabit the positive energy district. The number of households was provided by the technical bureau Alpha IC. The input data on the occupancy of the households and the technical parameters was initially planned to be provided by the technical bureau but was later defined by the WHY consortium. As a result the Maintal planners have received household load profiles with a temporal resolution of 15 minutes for their calculations.
- **Post planning phase:** During the post planning phase, when everything was defined, the technical Bureau used the data for thermal energy demand from WHY and compared them with the results of the standardised approach. Furthermore a Blackout-Simulation was conducted by WHY and a comparison of the results of the standardised approach and the results of the WHY-Toolkit was made.

2.2. Methodology to perform the simulations to assess the Use Case

As mentioned in Section 2.1, the plan was to have two phases:

In the first phase, the WHY Toolkit was used to simulate the domestic hot water, electricity and heat consumption of the positive energy district “Am Berghof”. For that purpose, the technical bureau defined the buildings and their specific use, as shown in Figure 1. The information provided to the WHY consortium included the type of buildings, the gross floor area, the net floor area as well as the number of households of the specific types (i.e. single-family houses, terraced houses, apartment buildings or semi-detached houses), as shown in Table 1.

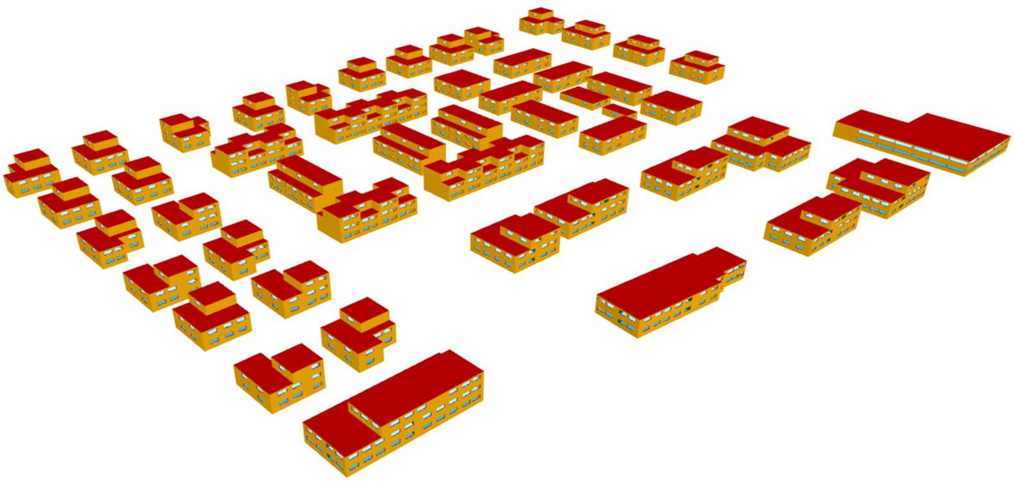


Figure 1: 3D Rendering of the Buildings in the district “Am Berghof”. Source: Alpha IC

Type	Number of Buildings	Number of Households	Gross Floor Area [m²]	Nt Floor Area [m²]
Semi-detached house	3	6	1.140	969
Retirement Living	10	18	1.615	1.373
Terraced houses	29	29	4.640	3.944
Single Family Houses	20	20	6.100	5.185
Apartment buildings	8	58	6.025	5.121

Table 1: Building Information of the Positive Energy District “Am Berghof”. Source: Alpha IC

Building on these data, the WHY consortium provided the technical bureau with a set of different building setups and configurations of inhabitants (=archetypes) to distribute amongst the buildings defined by them. This approach was scrapped because the technical bureau could not provide the necessary data and instead the WHY consortium calculated the occupancy of the buildings based on data from a German Statistical Data base[1], and assigned each household to an individual archetype, which matched predefined household types of the Load Profile Generator (LPG) (Pflugradt et al.2022) which is described in detail in the WHY Deliverable D3.2. The LPG is one of the core components of the WHY-Toolkit and responsible for calculating water- and energy consumption.

[1] https://www.destatis.de/DE/Themen/Gesellschaft-Umwelt/Wohnen/Publikationen/Downloads-Wohnen/wohnen-in-deutschland-5122125189005.html
5122125189005.html&sa=D&source=docs&ust=1703229408069122&usg=AOvVaw1X581f94j5kPRz9pBrug7N

A total of 131 households were simulated (matching the number of households in *positive Energy District "Am Berghof")* applying 3 different archetypes, which described the occupancy of the household. For the simulation of the buildings the following building codes from the Tabula Dataset[2] were used:

- Single Family Home: DE.N.SFH.12.Gen
- Detached and Terraced Home: DE.N.TH.12.Gen
- Apartment Building: DE.N.MFH.12.Gen

Simulations of households of the same archetype had different results, as the Universal Time Series Provider (UTSP) in combination with the HiSIM creates slight deviations in the simulation of the behaviour of the inhabitants to generate different results for the same archetypes. The UTSP and HiSIM are described in Deliverable D3.2. The simulations provided data on water consumption as well as electrical and thermal load profiles and the so-called inner heat gains, which consist of the heat gains from people and devices within the building, for each of the households in the district with a temporal resolution of 15 Minutes.

The data was provided to the technical bureau (Alpha IC GmbH) in the form of a ".csv" file, which was then implemented manually in their simulation Software Thermal Analysis Tool (TAS[3]). For their simulations only the inner heat gains were used in TAS. A direct comparison of total heat demand was not done, as WHY uses a different building database. Due to the requirements of using standardised approaches for the definition of the electrical and thermal loads, the technical bureau then compared the results of the standardised approach for thermal energy with the customised approach of the WHY Toolkit.

In the **Post Planning Phase,** the results of the technical bureau were compared with those of the WHY-Toolkit, based on the technologies planned by the technical bureau. Furthermore, a simulation of a Black-Out Scenario had been concluded.

For the blackout simulation the data on solar PV generation in the "central heat supply" scenario of the technical bureau has been used, where PV generators are installed solely on the multi-family homes. The corresponding PV-Data is provided in *Table 2*.

Building	Useable Roof-Area [m²]	# of PV Modules	Installed Capacity [kWp]
Apartment Building 1	120	71	28
Apartment Building 2	120	71	28
Apartment Building 3	84	49	20
Apartment Building 4	84	49	20
Apartment Building 5	84	49	20
Apartment Building 6	76	45	18
Apartment Building 7	336	198	79
Apartment Building 8	180	106	42

Table 2: Considered PV-Capacity for the simulations (Alpha IC)

[2]https://webtool.building-typology.eu/%23bm&sa=D&source=docs&ust=1703229408062950&usg=AOvVaw3adRuOFM7koCvpj8qxHyJe
[3] https://www.ifes-koeln.de/leistungen/simulation/tas-software-und-hotline.html&sa=D&source=docs&ust=1703229408069686&usg=AOvVaw3dKVy9W6Vre06U45tOeQ34

Global Irradiation Data was taken from the German Weather Service[4] for the year 2021 and the region Berghof, Maintal, to simulate PV generation. The buildings were modelled in the same way using the Tabula Dataset in HiSIM. The electrical load profiles were generated with the LPG using the same archetypes provided to the technical bureau in the first project phase. For electric vehicles and charging necessity the movement data was provided by the LPG the charging data by HiSIM.

For the black out simulation heating and warm water generation was required, as even in a case of disruption of power, thermal energy should be provided to keep people warm. As such a scenario with a decentralised heat generation was implemented. The energy report is the final report of the technical bureau AlphaIC Gmbh for the city of Maintal. For that purpose, each building will be fitted with a heat pump to provide space heating. The scaling of the heat pump for spatial heating will be done in HiSim and adapted, if it deviates from the data used by the technical bureau. Warm water will be generated using electrical boilers.

The input generated in HiSIM and the LPG will be fed into a Blackout Simulator programmed using Python. The Blackout Simulator is a single time step simulation where for each time step a comparison of available energy supply and occurring demand is made. If surpluses exist, they will be fed into a battery storage (if available), if that is not an option, curtailment of energy generation will occur. If the energy demand is not met, energy is provided by the battery storage system. If that is not an option, curtailment of individual power supply services will be made. Data on which services will be curtailed, is taken from a survey (see Annex 3 and Deliverable D5.3). In this survey it has been asked to a sample of citizens about which energy services should continue working under different types of blackouts. The results indicate that the most relevant services where:

- Ensure that drinking water is available in my home.
- Allow me to cook.
- Allow me to heat / cool my house.
- Allow me to keep the food refrigerated.
- Allow me to generate hot water for showering and cleaning.

For the analysis, an entire year is simulated with a blackout starting every 6 hours and lasting for 168 hours. In the simulation, 131 consumers and 8 generators were considered. Each simulation had 672 timesteps, which resulted in 88 032 possible supply situations (1 per quarter hour and consumer) and 5376 possible generation situations (1 per generator and quarter hour) in which a curtailment could potentially happen. For each of the blackout cases the amount and duration of load and generation curtailment is analysed. Two different types of battery storage were added to the district, a 115 kW / 229.5 kWh version and a 141 kW / 382.5 kWh version to buffer excess generation and changes in demand.

2.3. Co-design process with stakeholders

The Kick-Off for the co-design process was held on the 26th of April in 2023, when the WHY consortium was invited to Maintal to discuss the project with the local authorities, energy provider, regional planners and the members of the technical bureau. During the Kick-Off the expectations of the different stakeholders were discussed. Interest in the WHY project

[4] https://www.dwd.de/EN/Home/home_node.html

was high, as were the expectations in the cooperation between the technical bureau and the WHY consortium.

On May 3rd, an online meeting took place between the members of the technical bureau and the 4ward Energy Research (4ER) team. The agenda included discussions on the methodology for data exchange and the development of a preliminary work plan. One pivotal issue addressed was the definition of household occupancy. Initially, it was determined that the WHY Consortium would furnish a list of archetypes for household occupancy. This list was intended to be distributed among the buildings by the technical bureau members. However, this approach was later abandoned, because the technical bureau did not have the capacity at the time to make the distribution, in favour of utilising statistical data, a decision implemented by 4ER.

On the 22nd of June, 4ER provided the list of household occupancies, which was subsequently deliberated among the members of the technical bureau. A second opinion was sought from the city of Maintal, and upon receiving their final approval, the decision was made to proceed with the defined data.

On the 3rd of August 2023, the coordination meeting transpired, focusing on the deliberation of a set of test data. The primary focus of this discussion was to conclude the refinement of the interface connecting the WHY Toolkit and the technical bureau's software, TAS. While the general approach was a subject of discourse, a consensus emerged that, despite time constraints becoming apparent, the initially selected approach should be adhered to.

On the 18th of August, the technical bureau received profiles detailing inner heat gains and electricity consumption. Shortly thereafter, on the 16th of September, a meeting was convened where the technical bureau revised its stance. Initially, the technical bureau had thought that water consumption within households was not relevant to their work. However, in contrast to their earlier opinion, they now expressed the need for this information. This shift in perspective was communicated during the meeting. The water consumption profiles were provided on the 6th of October, but were sadly, due to time constraints not used in the final report of the technical bureau.

2.4. Data collected

During the development and analysis of the Use Case the following data have been collected or were generated in the process:

Data from the Maintal positive energy district "Am Berghof"

- Maintal building data (collected): This dataset contains the relevant building data for each of the buildings in the positive energy district "Am Berghof". The data was provided as an Excel file containing the following information:
    - Building Type (Semi-detached house, retirement living, terraced house, single family house, apartment building).
    - Abbreviation for the building type
    - A picture as reference to the map of the district
    - Area of the full storey in m²

    - Number of storeys
    - Area of the partial storey in m²
    - Number of partial storeys
    - Gross floor area in m²
    - Net floor area in m²
    - Number of households in the building
    - Net floor area per household in m²
    - Total number of buildings of that type
    - Total number of households in buildings of that type
    - Total gross floor area in m²
    - Total net floor area in m²
- Alpha IC heat demand (collected):
    - Name of the building
    - Annual thermal energy demand in kWh/a
    - Maximum thermal power in W
    - Specific thermal energy demand per m² in kWh/ a m²
    - Specific maximum thermal power per m² in W/m²
    - 97% Quantile of the specific thermal power per m² in W/m²
- Statistical Distribution of occupancy (generated): This data set provides the input for the distribution of the inhabitants of the buildings for the positive energy district "Am Berghof" in Maintal. The data provides the information for each "Type of Occupancy":
    - Total number of occurrence in the district
    - Share in the total number of occupancies

  For each building type in Maintal the following data was generated:

    - Share of a specific type of occupancy in that type of building
    - Number of households per type of occupancy in that type of building
- Maintal Building Distribution (generated): The dataset contains the exact allocation of the household templates to the buildings within the positive energy district of Maintal. The data contains:
    - Name of building
    - Name of the category of occupants
    - LPG Household Template
    - Number of electric vehicles
    - Unique Identifier

General data for the simulation runs

- Simulation Matrix for each building (generated): .CSV file containing the simulation parameters for each building in the Maintal positive Energy District. For each building within the dataset the following data are defined:
    - Identificator containing the type of building
    - Name
    - Net floor area in m²
    - Gross floor area in m²
    - Number of households
    - Installed PV-capacity in kW

    - LPG-Template to be used for the building
    - Description of the LPG-Template
    - Building Archetype
    - House number
    - Identifier for LPG runs
- Simulation Matrix for each household (generated): .CSV file containing the simulation parameters for each household in the Maintal positive Energy District. For each household within the dataset the following data are defined:
    - Identificator containing the type of building
    - Identification containing the type of building and type of household
    - Type of house
    - Type of household
    - LPG-Template to be used for the building
    - Description of the LPG-Template
    - Number of electric vehicles
    - Building Archetype
    - Identifier for LPG runs

Load Profile Generator: All data generated in this category is generated once per household according to the "*Identification containing the type of building and type of household*"

- Bodily Activity Level: This JSON file contains heat emanating from the occupants within the building in W with a temporal resolution of 1 Minute and 15 Minutes. For that purpose, two different JSON files are generated.
- Information on electric vehicles: For the simulation of the electric vehicles three different JSON files were generated. Each includes a timestamp with a resolution of one minute. The first file contains the information on the current position of the electric vehicle, which is relevant for calculating the charging behaviour. The second file contains the distance driven by the car which defines the energy needed to recharge once it comes to a charging station. The third file contains the state of charge of the battery of the car.
- Electricity demand on device level: The .CSV file contains the electricity demand for each time step of each device considered in simulation. Electricity Consumption is provided in kWh. The temporal resolution is 15 minutes.
- Water demand on device level: The .CSV file contains the water demand for each time step of each water consuming device considered in simulation. Consumption is provided in litres. The temporal resolution is 15 minutes.
- Heat gains on device level: The .CSV file contains the sum of heat gains for each time step from all devices considered in simulation. The gains are provided in kWh. The temporal resolution is 1 minute.
- Warmwater demand: The .CSV file contains the sum of thermal energy demand for warm water for each time step from all devices considered in simulation. Demand is provided in kWh. The temporal resolution is 15 minutes.
- Total electricity demand of the household: The .CSV file contains the sum of the electricity demand for each time step of all devices considered in simulation. Consumption is provided in kWh. The temporal resolution is 1 minute.

HiSIM Runs:

- HiSim-Simulation Results (generated): The data is provided as a zip-archive consisting of one folder for each building considered in the simulation. Each of the folders contains the following datasets:
    - Information on the use of electric vehicles:
        - Timestamp (hourly resolution)
        - Charging power in W
    - Information of the electricity demand:
        - Timestamp (hourly resolution)
        - Electricity demand in W
    - Inner heat gains from devices
        - Timestamp (hourly resolution)
        - Thermal power from inner heat gains from devices in W
    - Inner heat gains from Occupants
        - Timestamp (hourly resolution)
        - Thermal power from inner heat gains from occupants in W
- Building configuration in HiSIM (generated): JSON-file containing the information on the technical setup of the building used as input data for the HISIM run.

Data for the black-out simulation:

- Black-Out-Simulation Input: Consumer List Devices (generated): This .CSV file contains the information on which devices are active during a disruption of the power supply. Information whether the device is active is represented by a 0 (off) and a 1 (on). For each household represented by the *"Identification containing the type of building and type of household"*.
- Power generation of PV-Generators (generated): The .CSV file contains the PV generation values in kWh for each timestep of the black-out simulation and for each of the PV generators in the simulation setup.
- Probabilities of device use during a black-out (gathered): The .CSV file contains the information of the usage probability of the different device categories, which will be applied to the LPG, during a black-out.
- Consumption values during a black-out (generated): The .CSV file contains the load values in kWh per household, described by the *"Identification containing the type of building and type of household"* for each timestep of the black-out simulation. The consumption values represent the reduced consumption resulting from a reduced use of devices.
- Consumption values under normal conditions (generated): The .CSV file contains the load values in kWh per household, described by the *"Identification containing the type of building and type of household"* for each timestep of the black-out simulation. The consumption values result from a regular behaviour of the occupants of the buildings.
- Simulation results for two different battery storage systems (BSS): The .CSV file contains the results of the relevant KPIs for each black-out simulation run. Each black-out-case is described by a unique identifier. For each case the following data is generated:
    - Starting time of the Case
    - End time of the Case
    - State of Charge of the battery resulting from regular operation at the start of the Case in kWh

- State of Charge of the battery resulting from black-out operation at the end of the Case in kWh
- Sum of the total number of deactivations of individual consumers, each consumer that is deactivated during each time step increases the count by 1
- Longest disruption of supply for consumers
- Mean duration of disruption for all consumers in that case
- Amount of consumption that can be supplied during black-out case
- Total amount of energy supplied to the consumers in kWh
- Total amount of energy shed in kWh
- Sum of the total number of deactivations of generators, each generator that is deactivated during each time step increases the count by 1
- Longest disruption of infeed from generators
- Mean duration of disruption of infeed from in that case
- Share of the total generation that can be supplied to black-out case
- Total amount of energy generated by the generator kWh
- Total amount of energy curtailed in kWh

2.5. Analysis of Results

The technical bureau used the results of the WHY Toolkit in a comparison of the annual thermal energy demand of the district. For their calculations a standardised approach is used, whereas WHY was using detailed simulations to obtain the results. The following table (*Table 3*) shows the comparison of the results on thermal energy demand of the WHY Toolkit with the results of the standardised approach. It needs to be mentioned that the warm water demand was the same for both analyses, as the results of WHY could not be considered due to time constraints.

Building	Thermal Energy Demand using inner heat gains from WHY [kWh]	Thermal Power using inner heat gains from WHY [kW]	Thermal Energy Demand according to the standardised approach [kWh]	Thermal Power according to the standardised approach [kW]	Difference Energy Demand in %	Difference thermal power in %
3 Semi-detached houses	27 668	13	31 426	14	-12%	-7%
10 units for Retirement Living	93 041	35	99 461	37	-6%	-5%
29 Terraced houses	99 163	47	123 807	55	-20%	-15%
20 Single Family Houses	194 497	75	182 904	78	6%	-4%
8 Apartment buildings	140 695	55	142 373	64	-1%	-14%

Table 3: Comparison of energy demands and thermal power requirements for the two different approaches used by the technical bureau. Source: AlphaIC.

The total thermal energy consumption can be differentiated between Heating and Hot Water Provision, as is shown in Figure 2.

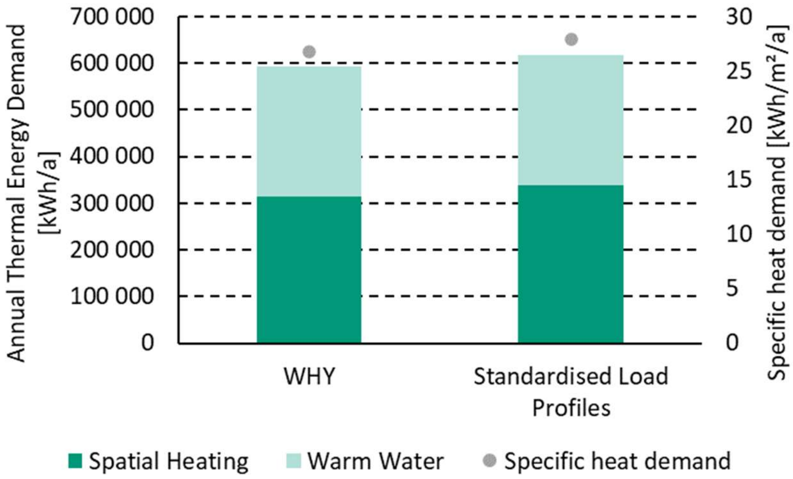


Figure 2: Comparison of the results for the thermal energy demands from WHY and the standardised approach. Source: AlphaIC

The results show that using WHY's inner thermal loads results in relatively lower thermal energy demands and lower power requirements than the standardised approach. The result comes as no surprise, as the standardised approach is somewhat conservative and does not reflect the behaviour of the inhabitants. On average the thermal energy demand for heating is 7.5% lower when using the results of the WHY toolkit compared to the standardised load profiles. The biggest deviation occurs for Terraced Houses where the WHY toolkit generates a heating demand that is 20 % lower than that of the standardised approach. Interestingly enough the heating demand for single family homes is higher (+6%) when using the WHY toolkit.

When comparing the electricity demand with the results from the standardised approach a similar result can be reached, see *Table 4*. The deviations between the standardised approach and the WHY-approach are not particularly high. A total deviation of -10% can be reached, meaning, that WHY estimates a lower electricity demand than the standardised approach. The biggest deviation occurs for Terraced houses, with a value of -20% with the WHY toolkit strongly underestimating the electricity demand of that building type.

Building	Electricity Demand according to WHY [kWh]	Electricity Demand according to the standardised approach [kWh]	Difference in Electricity Demand in %
3 Semi-detached houses	14 153	14 874	-5%
10 units for Retirement Living	40 005	42 758	-6%
29 Terraced houses	75 279	94 292	-20%
20 Single Family Houses	54 954	55 443	-1%
8 Apartment buildings	112 024	123 429	-9%

Table 4: Comparison of the electricity demand of the WHY Toolkit with the standardised approach of AlphaIC

When looking at the detailed results for these 29 Terraced Houses the conclusion can be drawn that the chosen occupancy of these buildings did not match the assumptions made for the standardised values. The occupancy shows a high quantity of single people staying at home. Thus, the inner heat gains from people inside the building is higher and electricity consumption is lower than in households with multiple people.

For the Positive Energy District “Am Berghof '' a simulation of blackout was conducted to gain insights on how well the district would perform given a situation with a disruption of power supply and the technical options to work as an isolated part of the grid. *Table 5*shows the results of the simulations with the two different storages, the table shows the average values of the relevant KPIs for each simulated black out case.

KPI	Battery Storage System: 115 kW / 229.5 kWh	Battery Storage System: 141 kW / 382.5 kWh
Mean Duration without power supply	290 Minutes	250 Minutes
Mean Duration with power supply	9 790 Minutes	9 830 Minutes
Number of timesteps the system needs shutdown generation	168 Timesteps	159 Timesteps
Amount of energy lacking	4 506 kWh	3 700 kWh
Amount of excess energy	16 751 kWh	15 827 kWh
Average Number of users that would need to be switched off in order to maintain operation.	48 Users	32 Users
Average Number Consumers that can be fully supplied during a Blackout Situation	83 Users	98 Users
Number of timesteps the system needs to shed loads in order to prevent underproduction	244 Timesteps	167 Timesteps

Table 5: Average values for KPIs for the 1433 simulations of the blackout simulations of the Positive Energy District Use Case

The results indicate that while the system can provide energy during a large amount of occurring situations, there still are situations when a (partial) shut down is necessary but the amount of system shutdowns was reduced by the increased storage capacity. On average the system can operate for a very long duration of time, but the results vary a lot depending on the starting time of the simulation. As can be seen in Figure 3 for the share of situations, where the system can be fully supplied.

The figure clearly indicates that the winter months are challenging for a black out case, as one would expect given the reduced PV-generation. During the summer months, given a large enough BSS-capacity, the simulations indicate that the consumption can be met to a large extent. Nevertheless, even during the summer months some of the simulations showed that the supply cannot be guaranteed at all times.

The results clearly show that increasing the battery capacity will lead to an improvement in the supply situation.

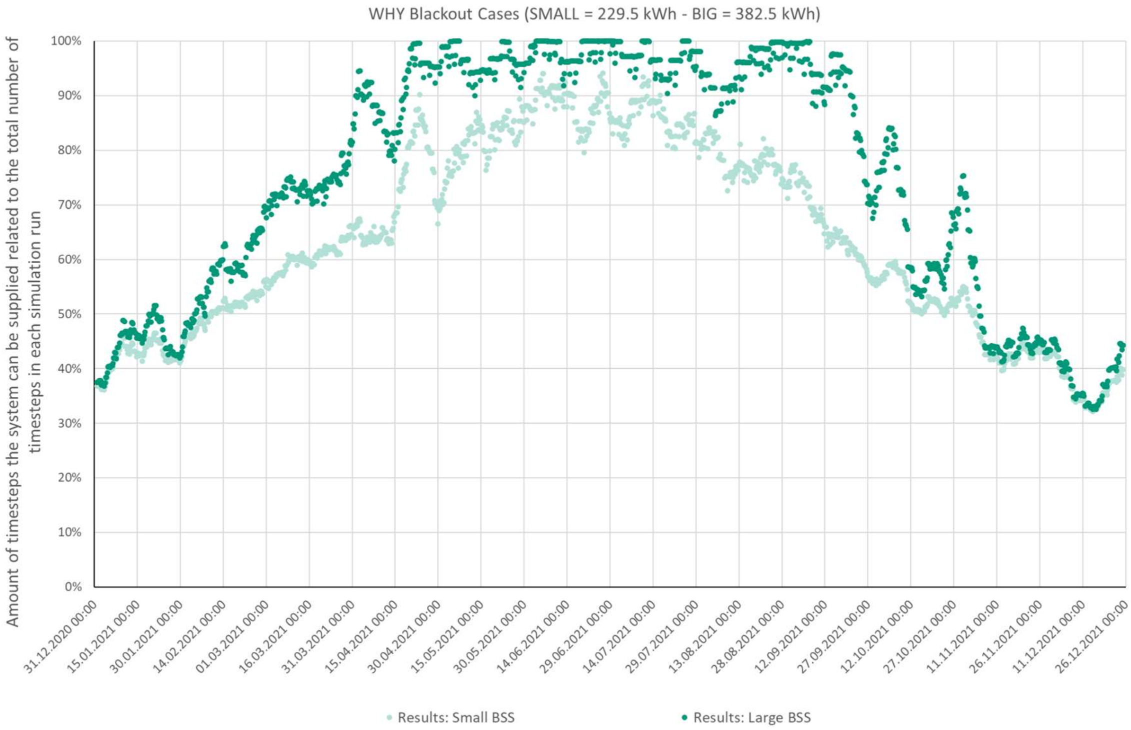


Figure 3: Comparison of the amount of timesteps the system can be supplied related to the total number of timesteps in each simulation run for different battery storage system capacities

2.6. Brief Summary/Main findings

The cooperation with the technical bureau Alpha IC went very well and showed the potential of using detailed simulations of buildings developed in the WHY project rather than standardised approaches. Firstly, the results indicate that the standardised approach overestimates the thermal energy demand, a result that was also validated by the members of the technical bureau. In addition, the WHY toolkit provides the means to do additional simulations, such as the black out simulation which has shown that a primary factor for the duration during which a black out supply can be provided is the battery power and capacity. Furthermore, the results clearly indicate that a supply during a blackout situation would be technically possible, especially during the summer months, given a large enough storage system. During the winter months the situation is a bit more critical as not enough generation is met by a higher demand.

However, certain considerations must be taken into account. Firstly, employing a standardised approach implies using a tried-and-tested method that has been repeatedly validated within the industry. If detailed simulations were to replace this established approach, they would need to undergo similar rigorous testing and validation using field data from diverse local contexts. Failure to meet these standards could result in non-acceptance within the industry, leading to limited usage.

Moreover, it is crucial to recognize that, at least in Germany, planners are legally obligated to adhere to standardised approaches in their work. Should they opt for alternative methods, such as utilising a detailed simulation tool like the WHY-Toolkit, corresponding norms and laws would necessitate adaptation to accommodate these novel approaches.

Another challenge that arose was the absence of a standardised interface. While the results were delivered in a ".csv" file format through the use of the UTSP, there was inconsistency in the nomenclature of the data across various results. Consequently, an extra effort was required to rename the datasets for implementation. Addressing this issue becomes imperative if the WHY-Toolkit is to be employed on a larger scale.

Given that this use case marked the inaugural application of the WHY toolkit beyond a scientific setting, it was anticipated that a significant effort would be needed to integrate the data supplied by WHY into the TAS software. The members of the technical bureau acknowledged this and deduced that standardising the process would significantly reduce the complexity of the task. This insight holds substantial importance for the future evolution and use of the WHY-Toolkit and HiSIM.

Another valuable insight derived from the Maintal Use Case pertained to the future utilisation of the WHY-Toolkit in such a context. While the options of presenting the WHY-Toolkit as a software solution for technical bureaus or delivering data as a service—where the technical bureau requests specific data simulated by a service provider—seemed enticing, both avenues appeared impractical. This was primarily due to time constraints on the technical bureau's part.

The conclusion drawn was that a more viable approach would involve providing technical bureaus with a repository of pre-simulated households (a database of representative household data). From this repository, they could then procure individual household profiles, which could be utilised repeatedly. This approach would minimise the effort required to integrate these profiles into their respective software solutions.

Another finding indicates that a notable drawback of the WHY-Toolkit lies in its restriction to the residential sector, highlighting the potential value gained through its extension to include the services sector, including offices and public/municipal sectors.

3. The Energy Cooperative case

3.1. Objective and Scope of the Use Case

Goiener is a non-profit citizen energy cooperative founded in 2012 in the Basque Country, in the north of Spain. It primarily sells 100% renewable origin electricity. To broaden its impact in the energy sector, the Goiener association was established in 2015, focusing on raising awareness about energy cooperatives and providing related training and development services. In 2018, the first round of renewable energy projects was initiated, emphasising the promotion and acquisition of distributed, local, and decentralised renewable energy. With 51 employees, 14,538 partners, and 200 volunteers, Goiener aims to forecast short-term and long-term energy consumption patterns to optimise energy purchases, stabilise customer tariffs, and enter into long-term power purchase agreements (PPAs) with small renewable producers.

The main goal of this Use Case is to utilise the WHY-Toolkit to simulate the behaviour of residential consumers, gaining a deeper understanding of their load profiles and responses to external changes. Electric tariffs play a crucial role in this analysis, serving as a powerful tool for modifying consumers' behaviour. Goiener is particularly interested in assessing how changes in its tariff structure will impact the load profiles and purchasing strategies of its partners, both individually and collectively. Additionally, the cooperative aims to understand how these tariff changes will influence its long-term goals, such as reducing energy consumption, increasing distributed renewable generation for self-consumption, alleviating energy poverty, and enhancing community empowerment.

To analyse these aspects, Goiener leveraged the tariff changes implemented in Spain on June 1st, 2021. The objective of this tariff adjustment was to shift the load curve from peak hours to flat and valley hours to enhance the overall resilience of the electric system. In this sense, this tariff presents a Time of Use (ToU) schema where the price of the energy is different depending on the hour of the day it is consumed. In this Use Case, Goiener complemented this tariff intervention with a series of information campaigns to observe the combined effects of these interventions.

Moreover, on May 13rd 2022 the Royal Decree- Lay 10/2022 was adopted, establishing a temporary mechanism for adjusting production costs for the reduction of electricity prices on the wholesale market. As a result, the energy periods were completely changed, with the lowest tariffs during the central hours of the day mostly due to solar PV uptake. So, this use case has also analysed the effect that this mechanism had in the consumption behaviour of the Goiener partners.

Additionally, the gas cap induced a discernible price signal (PS), namely, the price of the energy for each hour of the next day is fixed the afternoon of the day before and could change substantially from past prices. The temporal modifications were not arbitrary; rather, they underwent hourly shifts every day of the year, dependent on the prevailing gas prices in the spot market and the quantity of energy produced by gas turbines. This dynamic pricing structure was reflective of real-time market conditions and played a pivotal role in shaping the consumption behaviour of Goiener partners. The gas cap's influence on the PS introduced an added layer of complexity to the analysis of how these policy measures affected the energy landscape.

3.2. Methodology to perform the simulations

As mentioned in section 3.1 two different interventions have been carried out.

In the first intervention, the change of tariff implemented on the 1st of June of 2021 was used to analyse the energy consumption behaviour of the partners. In July 2019, the CNMC (National Markets and Competition Commission) in Spain proposed a new methodology for calculating electricity transport and distribution tolls, based on time-of-use rates. Initially planned for implementation on January 1st, 2020, the process faced delays and modifications (partly due to the COVID-19 outbreak), and the new rates eventually took effect on June 1st, 2021. This change in rates led to significant modifications in the billing of electricity consumption.

To assess the impact of these modifications, a large-scale research action was initiated aimed at benefiting both the consumer-members of Goiener and the cooperative itself as an electricity retailer. To quantitatively measure the impact, a Randomised Controlled Trial (RCT) involved the participation of all consumer-members (except those who declined). Periodic messages offering advice on reducing energy consumption or adapting behaviour to the new electricity rates were sent to experimental groups. Through this trial and the energy consumption data of over 12,000 electricity consumers recorded by Smart Meters over six months, the necessary quantitative information was obtained.

For the qualitative analysis, a questionnaire was distributed to all participants in January 2022, and 691 consumer-members responded. The questionnaire aimed to assess:

- Knowledge about the new rates and opportunities for members.
- The degree of adherence to suggested behaviour changes and barriers encountered among different experimental groups.
- The type of energy consumer.
- The Socio-economic profile of consumers.

In the second intervention, the aim was to analyse the effect of the Gas Cap implemented on May 13rd of 2022. In response to the surging prices in European energy markets, Royal Decree-Law 10/2022, enacted on May 13rd, introduced a temporary mechanism on the Spanish market. This mechanism aims to adjust production costs temporarily to alleviate the impact of rising electricity prices on the wholesale market.

The Royal Decree-Law addresses the influence of escalating natural gas prices on the wholesale electricity market, given its marginalist design. This design dictates that the price of all electricity is determined by the last power generation unit needed to meet demand each hour, with natural gas often acting as the marginal technology. The mechanism acts as a cost-adjustment tool for fossil technology production, reducing their market offers and subsequently lowering the market clearing price. The consumers benefiting from this reduction finance the adjustment, resulting in a final price lower than it would be without the measure. This mechanism was planned to be effective for a 12-month period but has been extended.

This intervention is effectively a PS and leads to changes in energy periods (peak, off-peak, valley), with the least expensive hours often occurring during the central hours of the day.

To communicate these changes to partners, the cooperative undertook various measures. An explanatory email was sent to all partners and a Telegram channel was created where the electricity prices for the next day are shared, enabling partners to consume energy during the most cost-effective hours. To assess the impact of these changes on consumption habits, a comparison is made between September to December in 2022 and the same months in 2021. Monthly statistics will be calculated to determine whether the shift in energy price periods has influenced energy consumption behaviour among partners. For the qualitative analysis, a questionnaire was distributed to all participants in January 2023, and 699 consumer-members responded.

This comprehensive approach provided insights into both the quantitative and qualitative aspects of the impact of the new electricity rates and the Gas Cap on consumer-members, helping Goiener tailor its strategies and services accordingly.

3.3. Co-design process with the stakeholders

Several meetings were held with the Spanish Institute for the Diversification of Energy Supply and Energy Savings (IDAE) both before, during, and after the interventions. In the initial phase, the discussions primarily centred around preparing the survey, allowing us to incorporate the perspectives and insights of IDAE into the survey design. Subsequent meetings shifted their focus to the analysis and interpretation of the survey results. This collaborative approach ensures a comprehensive and well-informed understanding of the outcomes, enriching the overall assessment with the expertise and perspectives of IDAE. Moreover, collaborations with other projects under the same funding initiative, such as NewTrends, have been carried out. This collaborative effort will expand the scope to include more countries and diversify the types of assessments conducted.

3.4. Data collected

The data collected to analyse the quantitative part has been obtained from smart meters, which are metering devices installed at customer supply points for processing electrical measurements. The dataset consists of anonymized hourly electricity demand data from 25 559 electricity supply points. These supply points come from the customer database of Goiener. The original raw dataset provided by Goiener consists of 71 048 files containing diverse information related to consumers consumption, generation, contracted power, pricing and other relevant information. The supply points recorded cover a wide range of locations, including mainly households, but also offices, SMEs, industrial buildings and public facilities. The data collected spans from the end of 2014 to June 2023, with a significant increase following the widespread deployment of smart meters in January 2018. This data was used to track changes over time and to profile different types of energy consumers. Over the course of the project, behavioural changes were observed in response to unexpected interventions or events.

As for the qualitative part, two different surveys were sent to Goiener partners. The aim of the first survey was to analyse the qualitative effect of the tariff change implemented in 2021. The survey was administered to all participants in January 2022, with a total of 691 consumer-members providing responses. To assess the impact of the Gas Cap introduced in May 2022, a subsequent survey was distributed to all participants in January 2023, receiving feedback from 699 consumer-members. This follow-up survey aimed to analyse and understand how the Gas Cap has influenced the experiences and perspectives of the participants since its implementation.

This holistic approach allowed for a thorough examination of both the numerical and experiential dimensions concerning the effects of the new electricity rates and the Gas Cap on consumer-members. The findings obtained from this analysis are instrumental in guiding Goiener to customise its strategies and services to better align with the needs and preferences of its members.

3.5. Analysis of Results

The next sections present a summary of the qualitative and quantitative results of the actions carried out in the energy community use case. The raw information is deposited in Zenodo[5] and tables with the main results in numerical form could be found in Annex 2.

3.5.1. Qualitative assessment of the results

In this section we will assess the qualitative results of the survey. We will focus on self-perception indicators above the different tariff schemes implemented and we will assess the differences between the two tariffs. The first relevant indicator is the comparison between the understanding of the different tariffs. A PS is clearly more complex than a ToU tariff and this is reflected in the results where the median score of the understanding of the ToU (Figure 4) is a 6 (just above the pass threshold) while the median of the PS is just a 4 (just below the pass threshold). In any case, the distributions of the scores are clearly different which suggests that there is clearly a problem understanding, and obviously following, a PS by humans.

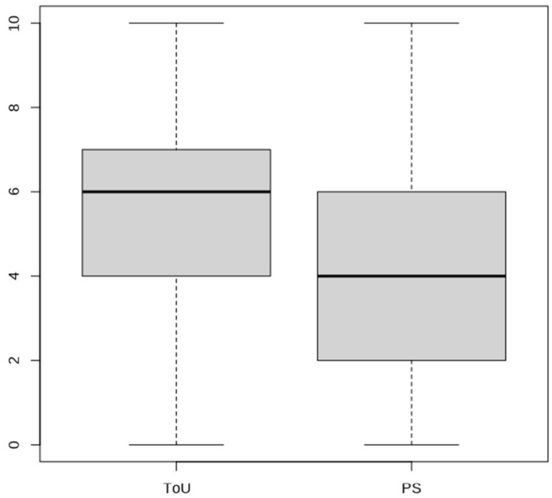


Figure 4: Comparison between the knowledge about the two different tariff systems

The second indicator we wanted to focus on is the knowledge on the actions Goiener put into place to help understand / foster the adoption of the different tariff. As we present on Section 3.2, a set of emails were sent to explain the motivations to implement and to foster

5 https://zenodo.org/doi/10.5281/zenodo.7382923

the adoption of a ToU tariff. On the other hand, an email explaining the reasons to implement the PS and how this will help bounding the price of the energy was sent and an app was used to help following the PS. The results (Figure 5) shows again a completely different distribution of answers between the ToU and the PS tariff. On the one hand, the knowledge and usefulness of the interventions carried out by GoiEner for the ToU were far more successful than the ones for the PS. In fact, most of the people were unaware of the app and this could have hindered their capability to actually follow the PS.

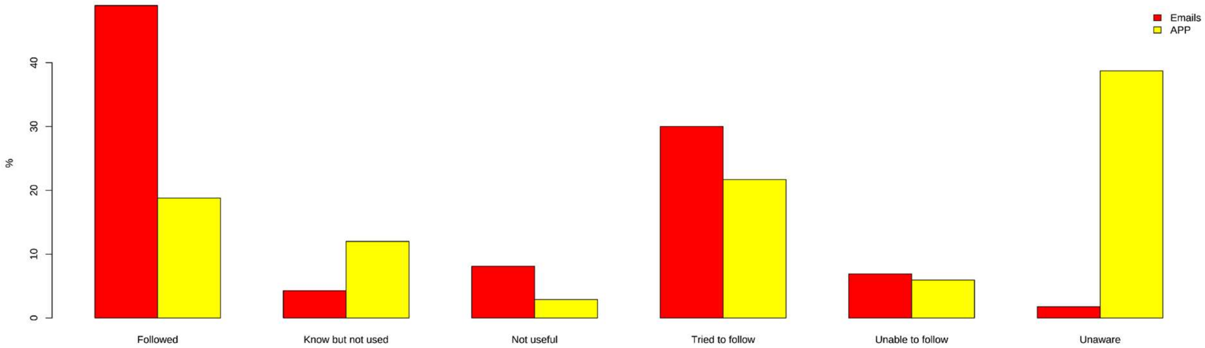


Figure 5: Degree of knowledge of the interventions carried out by GoiEner to foster the adoption of the different tariff structures.

There are multiple reasons for this result. On the one hand, the change to a ToU tariff was used by the political opposition to try to wear down the government. There was a lot of coverage on the news and the government did not implement a very good communication campaign. Goiener understood that this could be a problem and implemented a carefully planned communication campaign which was successful. On the other hand, during the introduction of the PS, even as the opposition tried to follow the same strategy, in this case both the news and the social media did not follow the approach most probably for a combination of lack of understanding and approval of the gas cap.

Goiener, in this case, tried to repeat the same communication strategy augmented with the introduction of an app but it seems like this time it was not so successful. The reasons most probably were that the focus was on the massive increase (due to the war in Ukraine) on the energy price that was the main reason to introduce the intervention. This probably, plus the lack of noise in the media, explain not only the lack of knowledge on the interventions but also the differences in opinion on the suitability of the measure. In particular, as can be seen inFigure 6, the general opinion about the ToU tariff was bad or sceptic (probably biassed by the press coverage) while for the PS the most repeated answer was the “other” category suggesting the lack of understanding.

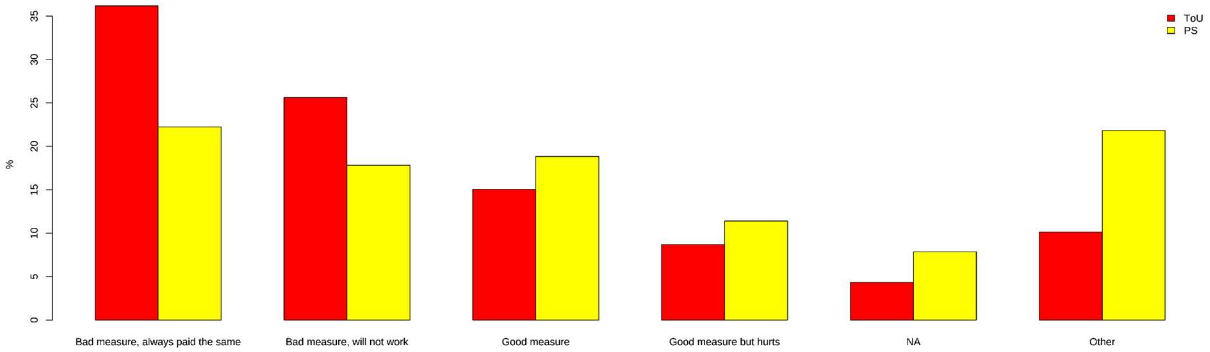


Figure 6: Reported opinion about the change of the tariff

With respect to the actions carried out, both tariffs show (Figure 7) that they are able to trigger both energy reduction and load shifting actions, but they have some relevant differences. In particular, it could be seen that the ToU tariff induces more people to carry out actions related to load shifting like changing the ToU of appliances or the laundry while the PS triggers a large sample of population to reduce the use of appliances, activate the eco program or adjusting the thermostat. All of these actions are more related to the reduction of energy use than load shifting. Our main explanation for this difference is probably due to the uncontrolled increase of the energy price. Given that the PS was a reaction to the large increase in energy prices, it is next to impossible to separate both components only using the data collected. Finally, it is important to mention the "same as before" and "none" results. Please take into consideration that the introduction of the PS was carried out after the ToU, so a substantial learning effect is expected.

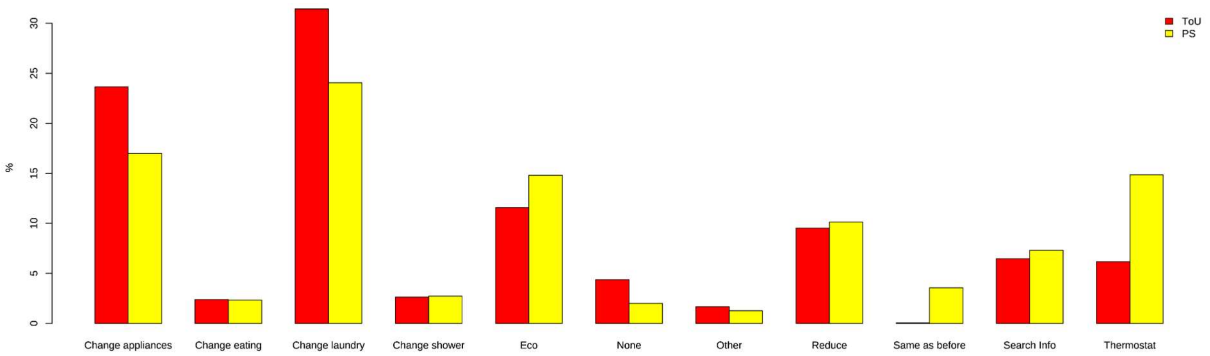


Figure 7: Self-described behavioural changes induced by the tariff

Finally, we take a look at the self-reported barriers found to carry out actions to foster the consumption of energy in the cheapest periods. As before, we need to take into account the potential learning effect that increases the "none" column for the PS. Removing that, what we found is that both tariffs have very similar distributions of barriers. In particular, the family schedules or routines are the most cited buried followed by comfort oriented answers.

Nevertheless, a bit of caution should be taken before concluding that both tariffs have the same barriers. As we have seen from the first point in this section, PSs are significantly more complex and worse understood by the population. This was further confirmed by a free text question where we ask for any potential other barrier found. While for the ToU no significant comments were made, for the PS several comments mentioning that it was impossible to follow the constant change of habits suggested by the PS. Nevertheless, even as this was reflected in (Figure 8), we have the hypothesis that a large part of the persons that have answered “none” most probably have not completely understood the PS at all.

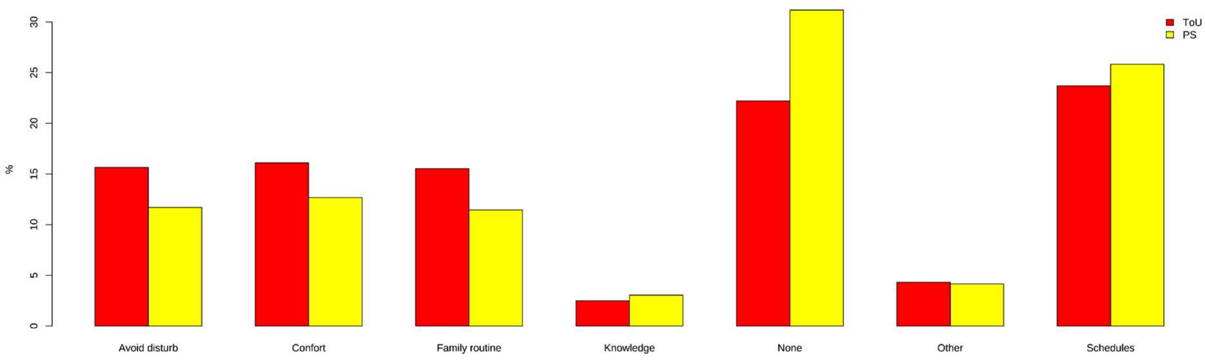


Figure 8: Barriers found to change behaviour

3.5.2. Quantitative assessment of the results

In this section, we will assess the quantitative results of the survey. In particular, we will present the results of indicators captured directly from smart meter data that show the objective impact that the two different tariff schemes implemented have produced in different collectives. For the qualitative assessment we have followed a “differences in differences” approach using the data from March 2019 to February 2020 as baseline. Please note that the gap between the start of the implementation of the actions and the baseline is required in order to remove the impact of the interventions to reduce the impact of COVID in the population (lockdowns) that completely change the behaviour of the population.

The first relevant indicator is overall reduction in energy consumption triggered by both tariffs. Figure 9shows that both tariffs have triggered significant reductions in the overall energy consumption of the sample: 1.1 % in the case of the ToU and 6.9 % in the case of the PS. A small reduction in the energy consumption was expected to be triggered by any changes of tariff and this was the case for the ToU. Nevertheless, the rather impressive result obtained by the PS is to be taken with precaution as there is a confounding element that could also explain and that was in fact the reason to issue the intervention: the large increase of price of the energy due to the war in Ukraine.

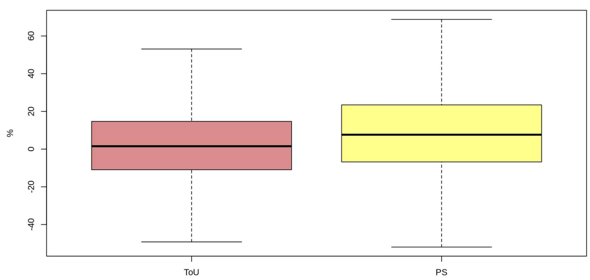


Figure 9: Percentage of reduction in the energy consumption triggered by each change of tariffs. Positive values means reductions in energy consumptions while negative values means increase in the energy consumption.

Figure 10includes the desegregation by the different stratas of the sample. A description of each strata and the numerical results could be consulted in Annex 2. As can be seen, in both cases the distribution follows a classical logistic shape with a group of stratas with very low or very high changes and the rest of them following a linear trend. The trend is more clearly appreciated on the PS than in the ToU. The stratas in the 10% of stratas that have reduced the most their energy consumption at both interventions are:

- "Behaviour objective - 19" (which corresponds with houses with electric heating)
- "Collectives at risk of poverty - Old living alone"
- "Saving capacity - <1"

Similarly, the stratas in the 10% of stratas that have reduced less (or even increase) they energy consumption at both interventions are:

- "Contracted power - >5kW"
- "Total surface - >120"
- "Collectives at risk of poverty - Single parent families"

As can be seen, there are significant differences between the socio-economic position of the stratas that have reduced or not the overall energy consumption in both tariffs. While the people in vulnerable households[6] have reduced significantly its energy consumption, the people who live in large households or with large, contracted power have reduced less. The most probable explanation for this behaviour is the necessity. While the first group have found this an opportunity (or a survival strategy) to adapt reducing its energy consumption to the change, the second group could simply ignore the change and continue using the energy as they are used to just paying a small amount of price.

Single parent households require a larger explanation as it does not fit the previous explanation. The key point here is that we could be conflating two different stratas. Due to the structure of the survey, we cannot separate "single parent families" (namely, one parent with one or more children) with "households with couples where one person is working and one person has just retired". The latter case[7] most probably have already paid for their house, do not have to support other members of the family and continue having significant incomes. Namely, it fits perfectly into the other two stratas (as in all cases most probably the socio-economic condition of the households are very good). Nevertheless, in the former case (the "single parent family"), even as they should be in the first group these strata have a completely different set of problems. The most significant one is probably its inability to adapt its schedules that clearly leads to a compromised capability to reduce its energy consumption or to shift it.

[6] Please note that persons have problems saving any significant amount of money, are persons in risk of isolation or the equipment they possess are correlated with low socio-economic status.

[7] At least in Spain, where the survey has been issued.

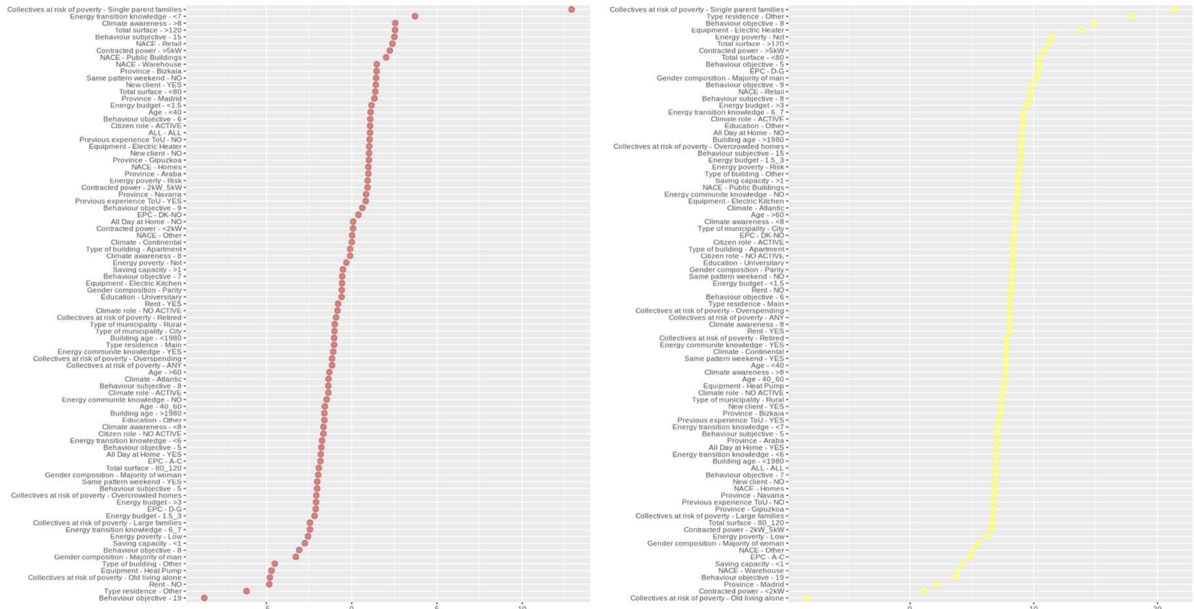


Figure 10: Percentage of reduction in the energy consumption triggered by each change of tariffs per the different stratas. Left panel shows the results for the ToU and the right panel the results for the PS. Positive values means reductions in energy consumption

Another assessment that can be carried out over the data summarised in Figure 10is to check which stratas have been affected by just one of the interventions. To assess that, Figure 11shows the differences between the percentage of reduction achieved for each strata at both interventions. The group of stratas that have not changed its behaviours are composed by:

- Buildings that cannot change its consumption patterns like the "NACE - Warehouse" or "NACE - Other".
- Contracts with little energy consumption like the ones with "Contracted power - <2kW".
- People that have already reduced their energy consumption like the "Collectives at risk of poverty - Old living alone", "Climate awareness - >8" or "Province - Madrid"[8].
- People with lack of knowledge or experience like "Energy transition knowledge - <7" or "Previous experience ToU - NO"

Please note that "Contracted power - 2kW_5kW" is probably a spurious result as it is already quite close to the mean result (denoted by "ALL - ALL").

On the other hand, the group of stratas that have been affected differently by the different tariffs schemes are:

- Households with equipment very sensitive to differences in the energy price like "Equipment - Heat Pump", "Equipment - Electric Heater", "Behaviour objective - 8" (houses with electric DHW) or "Behaviour objective - 19" (which as we have discussed before corresponds with houses with electric heating). It is worth noting that "EPC -

[8] GoiEner has a small number of clients in Madrid. These clients are primarily activists from a twin cooperative "La Corriente" which probably are part of the "Climate awareness - >8" strata.

D-G" probably also fits this group as inefficient houses tend to be heated by electric heaters and also include large inefficient systems.

- Stratas that are very sensitive to changes to the price like "Type of building - Other" (single family houses), "Rent - NO" (as this is basically the previous one). "Type residence - Other" (secondary residences and shops). In these strata a change of tariff that does not modify the overall price probably triggers little behaviour change but they are very sensitive to a change in the overall price.
- Stratas that have large opportunities for reducing its energy consumption like "Behaviour objective - 5" (all day at home) or "Gender composition - Majority of man". The last one is particularly interesting as they seem to have ignored the ToU tariff but have reacted to the price signal. We do not have a clear hypothesis about this behaviour but the use of innovative ICT technologies (like the app) could have fostered the participation of more men households.

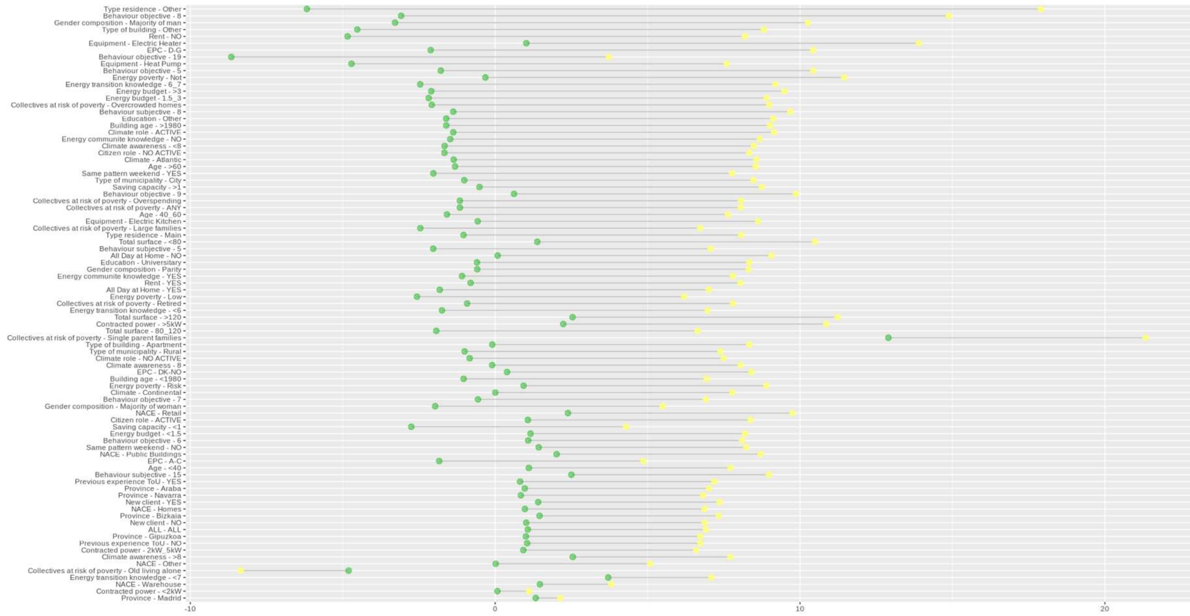


Figure 11: Comparison between the reduction in the energy consumption triggered by each change of tariffs per the different stratas. Green dots represent the results from the ToU intervention, while the yellow ones denote the energy reduction achieved by the PS.

With respect to the amount of demand response obtained, in order to estimate this qualitatively, we have decided to compare the percentage of reduction (or increase) on peak and valley periods. Figure 12shows the variation of the energy consumed in each period. As can be seen, both tariffs have triggered the same effect. Most of the energy austerity measures carried out have been taken to change activities from the peak periods (a reduction of 9.4% and 15.4%, respectively) to flat periods (-3.2% and 1.2%, respectively) instead of valley periods (0.6% and 6.3%, respectively).

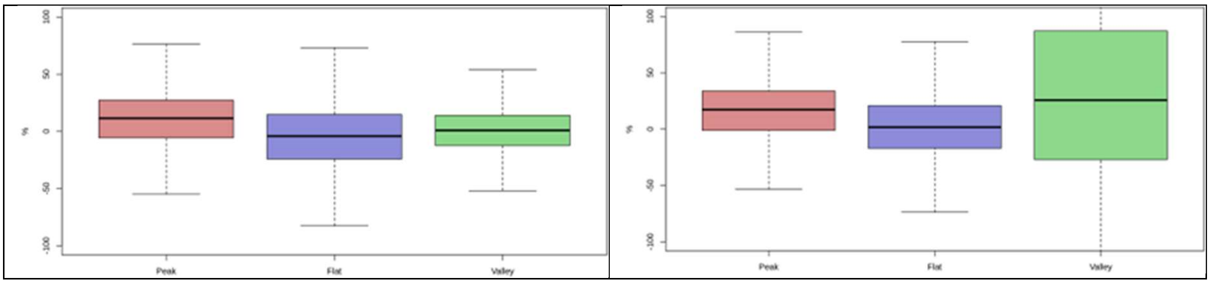


Figure 12: Percentage of reduction in the energy consumption in each period (peak, flat and valley period) triggered by each change of tariffs. Left panel shows the results for the ToU while the right shows the results for the PS. Positive values means reduction

Figure 13shows the same results but per stratas. We have omitted the information from the flat period to increase the visibility of the diagram. The stratas that have changed most significantly their behaviour with both interventions are:

- Different stratas at risk of poverty like “Old living alone”, “Overcrowded homes” or “Single parent families”. These households have probably used this opportunity to cut costs or at least reduce any potential impact that the change of price could bring.
- Households with large consumptions at one or both of the peak periods. "Behaviour objective - 9" (workers) and "Behaviour objective - 5" (all day at home) are the most important stratas. These stratas have the largest opportunities to make changes as any actions would involve a reduction in the peak period and increase in one of the valley or flat periods.

Finally, the stratas that have barely carried out any new demand response are:

- Non households like "NACE - Warehouse", "NACE - Public Buildings" and "NACE - Other". The energy consumption of these stratas are strongly correlated with their public schedule that hardly ever can react to changes in the energy price.
- Stratas that probably were already have moved their energy consumption to valley or flat periods. Here we found stratas like "Energy transition knowledge - >7" (the one with the highest scores) and "Behaviour objective - 8" (house with electric DHW).

Figure 13: Percentage of load shifting detected by each change of tariffs per the different stratas. Left panel shows the results for the ToU and the right panel the results for the PS. Positive values means reductions in energy consumptions while negative values

3.6. Brief Summary/Main findings

In the context of gas consumption, there is a widespread lack of understanding among the public and energy consumers. Divergent opinions and knowledge levels exist regarding gas tariffs. Behavioural changes have been observed due to the introduction of different tariffs, and these changes encounter similar obstacles.

Interestingly, individuals seem to adapt more readily to Time-of-Use (ToU) tariffs compared to PSs, even when supportive tools are provided. Both ToU and PSs have proven effective in promoting energy reduction (especially at peak hours) and fostering flexibility. However, it is noteworthy that the gas tariff appears to induce a greater degree of flexibility, though caution is advised to account for potential confounding factors.

Furthermore, the impact of these tariff changes appears to be consistent across various social groups, indicating a similar influence irrespective of socio-economic differences.

4. The Energy Community use case

4.1. Objective and Scope of the Use Case

The European Union aims to become climate neutral by 2050. All parts of society and economic sectors will play an important role in achieving this goal. While this objective has been defined at the global level (EU or Member State level), its implementation will take place locally, involving all European cities, villages, communities and citizens.

In that context, energy communities can be instrumental in changing the energy landscape and enabling the clean energy transition at the local and citizen level. Community-based energy projects have rapidly gained momentum with the help of public investment and support schemes, and the awareness of sustainable advantages for local populations. Energy communities have encouraged democratic decision-making and self-sufficiency, social innovation, and collaborative social transformation. Beyond the community-specific lens, energy communities can bring increased flexibility and resilience to the main energy grid, and from an economic perspective, they can be also seen as socially innovative enterprises, engaging in economic activity that lowers energy costs while providing financial returns to the local community. Therefore, they will activate the local economy.

Against this backdrop, energy communities can take many diverse legal, organizational, and financial forms, subject to local circumstances and needs, while also dependent on the available policy and regulatory support. From a technical standpoint, energy communities traditionally focused on only energy generation, but this is growing dynamically to include storage, supply, and energy efficiency, while the system can either be centralized, distributed, or decentralized. Organizationally, they can be created either in a top-down or a bottom-up approach, with initiatives including communities of place, whose values are shared within a landscape, and communities of interest, who come together by their shared principles, financial position, and problems. Spatially, energy communities are present in both rural and urban areas, even forming collaborative partnerships. This multidimensional potential has been acknowledged by the European Union that already via the Clean Energy for All Europeans package has sought to empower citizens and communities to become active participants in the energy transition, promoting prosumers involved in energy generation, consumption and trading in energy markets.

The main objective of this use case is to show how new energy community-based business models can make the energy communities 'better' and lead to climate neutral cities by 2030.

4.2. Methodology to perform the simulations

This use case comprises the results of the survey with the community partners and the process of semi-structured interviews conducted with experts and selected stakeholders to evaluate concepts related with communities. Namely:

- the state of the play,
- the business models,
- the value sharing,
- governance structures,
- replicability and scalability of the actions and
- activities, conundrum and future projections

In this context, a brief literature review of these concepts is considered to envision the relevance of including these drivers. The inclusion of the state of the play and the business models allows to arrange a valuable reflection in terms of the consideration of alternative models to the prevailing cooperative structures. In the case of the value sharing and governance structures inclusion, it intends to approach these options between members of the community in terms of engagement and governance structures, along with questions under the umbrella of the fairness and responsibility, ethical aspects and social aspects from the point of view of the global outcomes as an element to tackle the social side of the energy transitions and the community.

In the case of the governance structures, they are very relevant for considering the transformative potential of the initiatives. From the literature review (Wittmayer et al, 2022), the inclusion of socio material configuration elements in governance decisions coming from the social innovation approaches can be considered applied to renewable energy prosumerism. In this vein, socio material configurations, social interactions and social manifestations governance typologies can be considered for this case study.

Regarding Socio material configurations, this approach considers the inclusion of drivers, objects and actions for vertebrate structures. Drivers are based on *narratives, rules, knowledge and expectations*; the objects are related to technologies, infrastructures or natural resources and actions are related to practices, routines and behavior.

In the case of social interaction approach, is based in the relations or interactions between actors considering the paradigms of *"Cooperation"* coming from the members of an energy cooperative work towards the shared goal; *"Exchange"* concerning to the trade of tangible or intangible benefit (e.g. a subsidy where a community energy initiative receives money); *"Competition"* in terms of a struggle over scarce resources and *"Conflict"* in terms for example issues coming from activities that generating unfair and directly impair results.

Social manifestations in contrast, is based in the inclusion of social innovation new ways of doing, thinking and/or organising that can be distinguish in terms of Doing: such as energy production, consumption or storage; Organising: 'governance and organisational structures' within initiatives, such as deliberative principles, or structures for networking and knowledge exchange and Thinking: 'forms of knowledge and normative framings including values and perceptions'.

This approach has been considered in the case of cooperatives, taking 'cooperative energy provision' as an example of a socio-material configuration, that includes ideas about the possibility to organise energy provision in a decentral, small-scale, and community-owned manner with actions including attending to energy generators, and producing/distributing energy. Moreover, the four types of social interaction in EC are not mutually exclusive but exist next to each other. For example, social interactions in cooperatives are based on exchange (e.g. between producers and consumers of energy) or on competition (e.g. between producers in the energy market), but we also see cooperation (e.g. between grid operators and energy producers) and conflict (e.g. between governments and citizens regarding the choice for certain energy sources).

This distinction between the four types of interaction allows us to describe certain socio-material configurations (e.g. energy cooperative) along the types of interaction that are characteristic of them (e.g. cooperation) and think through changes of social relations and their characteristics in energy transitions (e.g. changes between neighbors, with new roles for energy cooperatives vis-`a-vis grid operators or municipalities).

In the case of replicability and scalability options, this inclusion, intends to analyse (among other considerations) the inclusion of disruptive models and narratives coming from the social innovation field and in the case if the case of activities, conundrum and future projections, this inclusion allows to envision the diversity of activities considered in the communities and the assumption of the new roles such as prosumers agents and institutional roles.

The semi-structured interviews are considered in order to deepen certain elements, especially the inclusion of alternative business models, the transformation and assessment of the governance structures and the future projections. Both processes have been considered as complementaries with elements coming from the surveillance process that are contrasted in the semi-structures and vice versa.

4.3. Co-design process with the stakeholders

The Goiener Taldea community provides a unique opportunity for a robust co-design process involving active participation from stakeholders. This collaborative journey draws insights from survey results obtained from community partners and semi-structured interviews with experts and selected stakeholders.

As the process of surveillance and interviews progresses, the intervention underscores a commitment to inclusivity, transparency, and sustainability. In this co-design effort, stakeholders play a pivotal role in shaping immediate outcomes and leaving a lasting impact on the community's energy landscape. This approach ensures that the initiative is not merely an assessment but a dynamic and collective endeavor to build a future that reflects the aspirations and wisdom of the community.

4.4. Data collected

In the dedicated pursuit of a comprehensive quantitative analysis of the energy community use case, an intricately designed survey was meticulously prepared and set into motion. The primary objective of this survey was to discern and measure the depth of knowledge held by participants regarding energy communities. This strategic initiative unfolded by extending the survey to encompass all members of Goiener, resulting in a robust response from 1096 consumer-members during the month of December 2023.

Embedded within the survey were inquiries tailored to unravel insights into the participants' comprehension of energy communities, with a specific focus on future services, perceived limitations, associated risks, and financial considerations. By probing into these multifaceted dimensions, the survey sought not only to quantify the level of awareness but also to explore the nuanced perspectives and expectations harboured by the Goiener community in these pivotal areas.

In the case of the semi structured interviews, still in process, the interviews were based in a script and in a conversation recorded and transcribed. The transcriptions were analysed using a content analysis matrix.

4.5. Analysis of Results

The survey results on renewable energy communities provide a detailed insight into participant involvement and perceptions. Regarding participant profiles, nearly half (49.8%) are self-owned domestic consumers, while 32% are domestic consumers. Local businesses or small consumers account for 5.8%, public service consumers for 5.8%, and industrial consumers for 0.4%. In terms of gender, 63.2% are male, 35.9% are female, and 0.9% identify with another gender. This gender gap aligns with historical trends in the energy sector, which has traditionally been male-dominated due to perceived technical complexities. The modest representation of women, although increasing, underscores the persistent challenges of breaking down gender-based barriers in the industry. The data reflects an ongoing need for targeted initiatives to promote inclusivity, challenge stereotypes, and encourage diverse participation, fostering a more equitable landscape within renewable energy communities and the broader energy sector.

Concerning participation in renewable energy communities, 22.7% are members, and 26.1% participate in some governance structure. Energy communities break down into 41.4% cooperatives, 25.5% associations, 21.7% non-profit organisations, and 9.4% small or medium-sized enterprises (Figure 14).

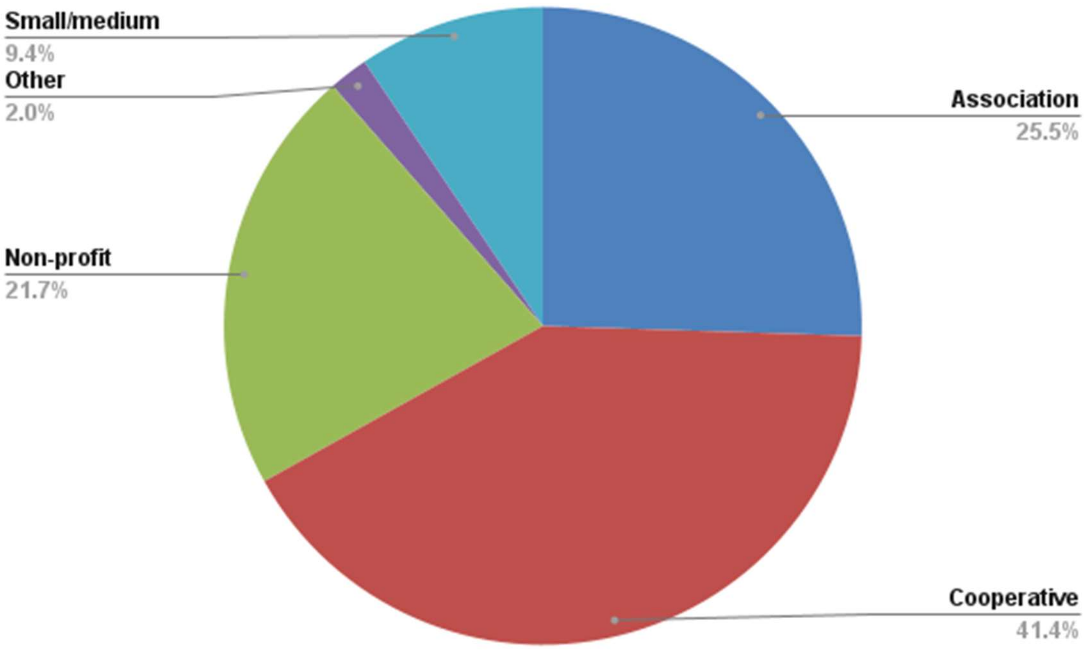


Figure 14: Energy communities break down

The text highlights the most common services offered by renewable energy communities, with the top three being the production and consumption of renewable energy (39.5%), energy sharing (26.3%), and renewable heat production (9.6%). These services are crucial components of sustainable energy practices, emphasizing the community's commitment to environmentally friendly initiatives.

In terms of financial tools, participants in these communities utilize various sources, with primary investment by participants themselves being the most significant (36.1%). Additionally, national or state aid (31.9%) and EU aid (29.1%) play pivotal roles in supporting the financial aspects of these community projects. This indicates a diversified approach to funding, leveraging both individual contributions and external financial support to drive the success of renewable energy initiatives.

Exploring the risks associated with these communities, primary concerns include financial issues, governance matters, and the low maturity of operational and business models. Financial challenges may stem from the diverse funding sources and the need for sustained financial stability. The low maturity of operational and business models implies the need for further development and refinement to ensure the long-term viability of renewable energy community projects.

Regarding limitations in choosing the community model, the most mentioned response is providing environmental, economic, or social benefits. This suggests that participants acknowledge the complexity of balancing these three dimensions when implementing renewable energy community projects. Striking a harmonious equilibrium among environmental, economic, and social aspects is crucial for the overall success and acceptance of these initiatives.

Looking ahead, participants express expectations for renewable energy communities, emphasizing self-generation and self-consumption (14.9%). This underscores the desire for communities to be self-reliant in producing and utilizing renewable energy. Furthermore, ownership and democratization of energy systems and services (11.7%) indicate a push for more inclusive and participatory approaches in managing energy resources. Lastly, the importance of energy education (10.6%) highlights a commitment to fostering awareness and understanding of sustainable energy practices within these communities.

Governance matters underscore the importance of effective leadership and decision-making structures within these communities. In this vein, the fact that the community is considering expanding rights and duties as seen in the above results about expectations and future services reinforces the idea that governance structures need to be reviewed, expanded and also being certainly considered as a useful tool by the memberships. It is important to point out that the expressed concerns, expectation and envisions which are very present in most of the questions, contrasts with the low participation in the available governance structures, with a 73,9 % reporting not taking part in the existing structures.

To date, the most relevant questions that are being contrasted in the semi structured interviews, which is still in process have been the followings:

- Policy and legislations: Covering concerns about how the legislation and in most of the occasion the lack of it, as well as the issues related with the national and regional translation of EU directives often stops the development of such initiatives and steers them towards non-diverse models with less viability and adaptability.
- Business model assessment: Covering mainly revision of the cooperative model and the so-called reflection around the cooperative models, since although the cooperative model is the prevailing one, the cooperative spirit has been lost among the members and the fact that it is used as a tool rather than as a business philosophy.
- Sustainability: Covering the replicability and scalability of the actions and project, the necessity of rescaling the activities.

- Governance: Covering the idea that governance structures need to be reviewed, expanded and also being certainly considered as a useful tool by the memberships.
- Future projections: Covering the assumption of new roles, the necessity of acknowledging the role of communities as transition agents and solidarity and justice schemes concerns.

4.6. Brief Summary/Main findings

The text outlines key findings related to renewable energy communities, highlighting their common services, financial tools, associated risks, limitations, and future expectations. The primary services offered by these communities include the production and consumption of renewable energy, energy sharing, and renewable heat production. Financially, participants rely on a mix of primary investment, national or state aid, and EU aid. Risks identified involve financial issues, governance matters, and the underdeveloped nature of operational and business models. The main limitation in choosing the community model revolves around the challenge of balancing environmental, economic, and social benefits. Looking ahead, participants envision self-generation and self-consumption, ownership and democratization of energy systems, and emphasis on energy education as essential components for the success of renewable energy communities. Overall, the findings underscore the complexity and dynamism of these initiatives, reflecting a commitment to sustainable energy practices.

Regarding the elements contrasted in the semi structured interviews, in the case of Policy and legislations, the absence of clear and dynamic frameworks for the communities and the issues related with the national and regional translation of EU directives is considered as a barrier for the deployment of these initiatives. The hands tied perception with regard to regulatory aspects is frequent, as well as consideration of being stocked in a horizon of uncertainty and inequalities between autonomous communities, regions and countries.

The critical revision of the business model and the so-called reflection around the cooperative models, has produced two important conclusions: on the one hand, there is agreement that the cooperative model suits perfectly to the communities, but on the other hand, a critical revision arises, since although the cooperative model is the prevailing one, the consideration that the cooperative spirit has been lost among the members and the fact that it is used as a tool rather than as a business philosophy prevails.

Within sustainability and scalability, the necessity of rescaling the activities emerges along with ideas associated with Degrowth/postgrowth paradigms. In the case of the future projections, the assumption of new roles is seeing as an opportunity highlighting the cases of the communities assuming the social services management along with the municipalities, in the case for example of the energy poverty situations or the consolidation of the self-consumption managing /agency and the necessity of acknowledging the role of communities as transition agents and solidarity and justice schemes concerns.

As mentioned, governance matters underscore the importance of considering effective leadership and decision-making structures. In this vein, the necessity of providing the communities with the useful and reviewed governance structures and the necessity of reinforcing the participation in the existing structures is an important finding. The experts are self-critical when the ratios of participation structures are considered.

The inclusion of socio material configuration elements in governance decisions, as an alternative, coming from the social innovation approaches, is still under study , but the preliminary findings show that this is an issue that is related with the idea of revisiting the constituency purpose , mission and values and focusing on solidarity schemes.

In general, it is observed that the attitude in this respect is more reactive than proactive, with tools being used when situations of vulnerability or poverty are observed, but with a lack of contingency plans to deal with these cases in advance and with absence of specific projects.

Moreover, the necessity of resignify the terms cooperation has been considered in terms, not only within the members, but as an attitude outwards and a commitment to continuous improvement to offer better solutions and to be sustainable as well as replicable.

Finally, the imbalance that can occur in the case of diverse members in terms of motivations, size, importance, has been seen as a concern for both the governance structures and the viability of the communities.

In this sense, the need to balance the influence of unequal actors (e.g. a prosumer, municipality, association or an SME company) in the prevailing one member-one vote governance structures, on both projects proposals and governance structures is reported.

In this vein, the socio-material configurations can be considered an option for vertebrate this imbalance and its consequences, as it will be developed in the next deliverable.

5. The European use case

The European Use Case explores the impact of energy and climate policies on achieving the EU goals on climate change mitigation and energy efficiency. This Use Case provides an improved understanding of the role of energy consumers towards decarbonization by exploring the effects and feasibility of climate neutrality in European buildings with unprecedented temporal and spatial granularity, while capturing system interlinkages between energy demand, supply, and prices.

5.1. Objective and Scope of the Use Case

In this use case, the PRIMES-BuiMo buildings model, which is one of the most widely used and well-established models at EU and Member state level (Fotiou et al 2019), is soft-linked with the WHY Toolkit. To capture consumer differences, idiosyncratic behaviours and load profile granularity, a two-way interlinkage of the WHY Toolkit with the PRIMES-BuiMo model has been implemented. This linkage has been based on data interface and disaggregation of PRIMES-BuiMo results, which is described in detail in the WHY Deliverable 4.2. The Use Case offers quantitative evidence on different pathways to decarbonise the EU buildings sector by 2050. Figure 15illustrates the requirements to achieve climate neutrality in the EU buildings sector by 2050 based on the Use Case analysis.

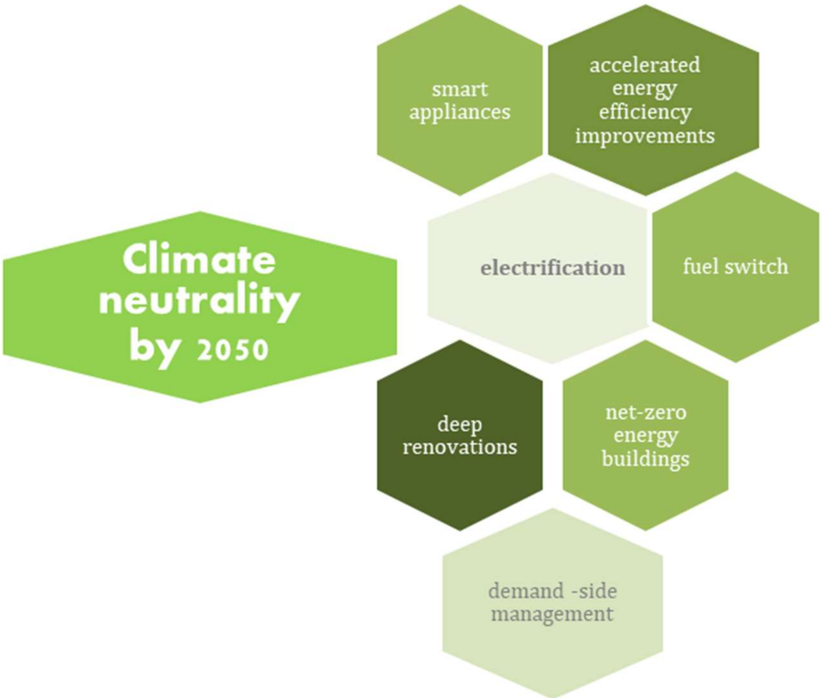


Figure 15: The foundation on achieving climate neutrality by 2050 in the buildings sector

The integration of the WHY Toolkit into a large-scale Energy System Model (ESM) like PRIMES-Buildings is very challenging as it requires a careful selection process to decide what elements should be included while modelling the residential sector. It concerns the technical aspects of energy transition as well as behavioural elements of energy consumers and specific policy interventions, which will determine energy demand, fuel mix and clean technology uptake in the medium- and long-term. To address this challenge, we organised a participatory online workshop “Improving Demand-side Modelling to Inform Ambitious Climate Policies in the European Union” in May 2022. We invited several stakeholders dealing with the European Union's climate and energy policies to investigate what issues, in their opinion, should be considered when modelling the energy demand and what policy measures are the most important to drive the transition in the EU buildings sector. By engaging external stakeholders, we wanted not only to learn about current trends and challenges from the practitioners' perspective, but also to increase the transparency and outreach of our research. The key findings from the workshop, based on the knowledge and expertise of the participating climate and energy experts, are presented in the WHY project report available online[9]. In this workshop, various energy and climate policies were identified as important for the transformation of EU buildings, building on recent regulations including the revised Energy efficiency Directive, the Fit for 55 package and the EU's commitment to become climate neutral by 2050 as part of the EU Green Deal.

5.2. Methodology to perform the simulations

PRIMES-BUIMO brief description

The PRIMES-BuiMo model simulates the future development of the buildings sector in the EU Member States, projecting energy consumption, fuel mix, equipment choice, renovation rates, investment and CO2 emissions under alternative policy scenarios. It dynamically simulates renovation decisions, investment, technology and fuel choices considering market and non-market barriers (Fotiou, T. et al., 2019). The model represents diverse actors (energy consumers) with distinct behavioural patterns based on their income, preferences, weather, location, and household composition. In this way, it addresses the drawbacks of the representative consumer assumption by differentiating discount rates. The model dynamically estimates useful energy demand by building type, tracks technology vintages, and determines fuel mix, CO2 emissions, operating costs, and investments. It incorporates policies such as energy labelling, regulatory instruments, taxes, and subsidies. Notably, it addresses market and non-market barriers in the residential sector to bridge the "energy efficiency gap." PRIMES-BuiMo combines the detailed representation of economic behaviours with engineering aspects and technical constraints embedded in the integrated model-based decision framework (Figure 16). A detailed model description can be found in (Fotiou et al, 2019).

The main strengths of PRIMES-BuiMo that are explored in WHY project are:

- the high-resolution segmentation of consumers into many classes considering key factors influencing the decisions of individuals, including income, geographic, and other dimensions, as well as the classification of buildings by age and other criteria.
- the representation of market and non-market barriers hampering energy efficiency investment, through specific parameters; market barriers are related to "true" costs (that are actually paid by consumers), and issues related to the access to capital resources, whereas non-market barriers refer to elements that do not have a direct payable or "true" cost and are often termed as "perceived costs (Fotiou et al 2019).
- the rich representation of policies to remove the various market and non-market barriers and facilitate energy efficiency investment. PRIMES-BuiMo can simulate a wide variety of policies and measures for the buildings sector, ranging from financial incentives (subsidies for building retrofits, loans) to institutional incentives that act

[9] https://www.why-h2020.eu/fileadmin/Inhalte/Dokumente/WHY__The_EU_Use_Case_Workshop_Report.pdf

as facilitators of investment, and even hard regulatory instruments (minimum efficiency standards, building codes).

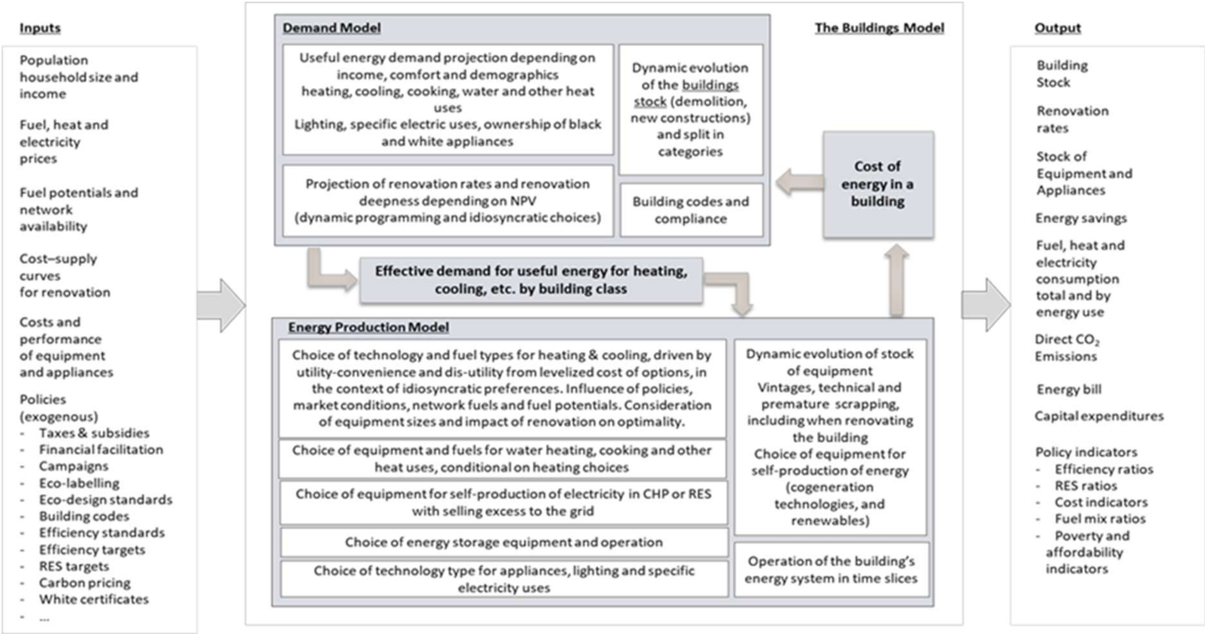


Figure 16: Flowchart of the PRIMES-BuiMo model

Linking PRIMES-Buildings with the WHY Toolkit

Energy System Models (ESMs) are tools that project how energy systems will look in the long term under alternative socioeconomic, policy or technology assumptions. ESMs use detailed information about energy production, end-use and conversion processes on both demand and supply sides, based on specific policy and technology assumptions. While cost-optimality is useful for simulating rational decisions (and thus it is largely used in ESMs), it does not fully capture the dynamics of everyday decisions of energy consumers, especially in households, which are driven by other factors (e.g. social, behavioural, financial) in addition to pure cost calculations.

The WHY toolkit was developed to bridge this gap. It utilises advanced algorithms to estimate household energy consumption with high spatial and temporal granularity, covering various dimensions like energy carriers, building types, socio-economic characteristics and policy interventions. A detailed description of the WHY Toolkit can be found in the WHY Deliverable 3.1[10] and 3.2[11] (both available online).

The toolkit's output needs to align with the level of detail in ESMs. For this purpose, plug-ins were designed and developed with the goal of being easy to use, and applicable (with minimum adaptations) to the vast majority of modern ESMs. For this purpose, a number of criteria were defined that the plug-ins need to satisfy as presented in Figure 17.

[10] https://www.why-h2020.eu/materials/articles-and-reports/technical-documentation-of-the-why-toolkit-d31
[11] https://www.why-h2020.eu/materials/articles-and-reports/why-toolkit-libraries-d32

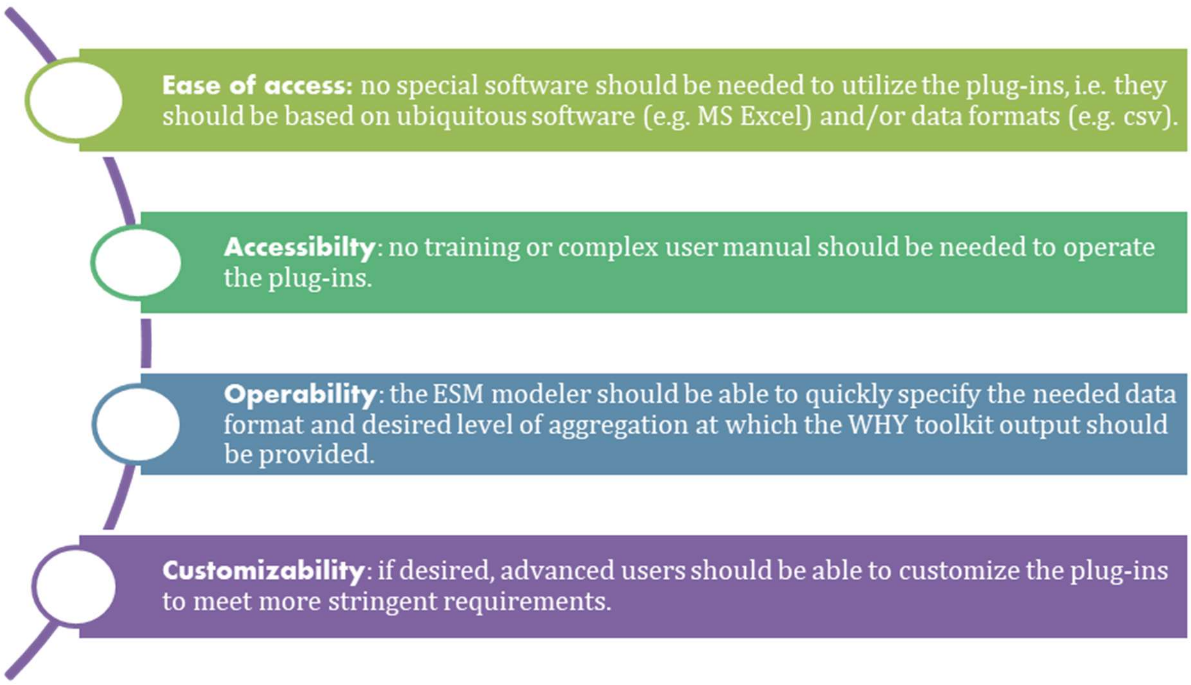


Figure 17: Criteria that the plug-ins need to satisfy

The plug-ins are represented as data exchange tables in an MS Excel template to allow ESM modellers to specify aggregation levels easily (and are described in detail in the WHY Deliverable 4.2). The tables provide the necessary dimensions for energy conversion and demand in residential buildings. The toolkit operator translates the specifications into a query for the toolkit, generating the desired output. The ESM modellers then convert this output into the needed ESM input format. The use of exchange tables ensures that the plug-ins are intuitive and fit seamlessly into the workflow of ESM modellers using widely deployed tools like MS Excel or Python.

PRIMES-Buildings distinguishes four types of energy services in households that can make use of multiple energy carriers, as well as several household appliances based exclusively on electricity. In the columns of the exchange table, PRIMES considers three types of households (low, medium and high income). The buildings are categorised according to their typology (multi- vs single-family) and their age group. PRIMES specifies energy consumption between 2010 and 2050 (though, for the current plug-in implementation it has been decided to only provide input data for historic years, while letting the model create scenario-based projections for future years). Figure 18summarises how the column headers are built. The soft-linked modelling suite focuses on: space heating, water heating (both of which can be provided by multiple fuels as shown in table below), and services that can be provided only by electricity (e.g. lighting, black and white electric appliances, etc).

PRIMES			
Energy Services	*Energy Carriers*	*Energy Services*	*Energy Carriers*
Space heating	Coal	Air cooling	Distributed gas
	Diesel		Distributed Steam
	Distributed gas		Electricity
	LPG	Cooking	Distributed gas
	Distributed Steam		LPG
	Solar		Biosolids
	Geothermal		Electricity
	Biosolids	Refrigeration	Electricity
	Electricity	Freezing	Electricity
Water heating	Coal	Dish Washers	Electricity
	Diesel	Washing Machines	Electricity
	Distributed gas	Dryers	Electricity
	LPG	Lighting	Electricity
	Distributed Steam	Information and communication	Electricity
	Solar	Entertainment	Electricity
	Geothermal	Vacuum Cleaners	Electricity
	Biosolids	Ironing	Electricity
	Electricity	Small Appliances	Electricity

Figure 18: Row headers for the PRIMES plug-in.

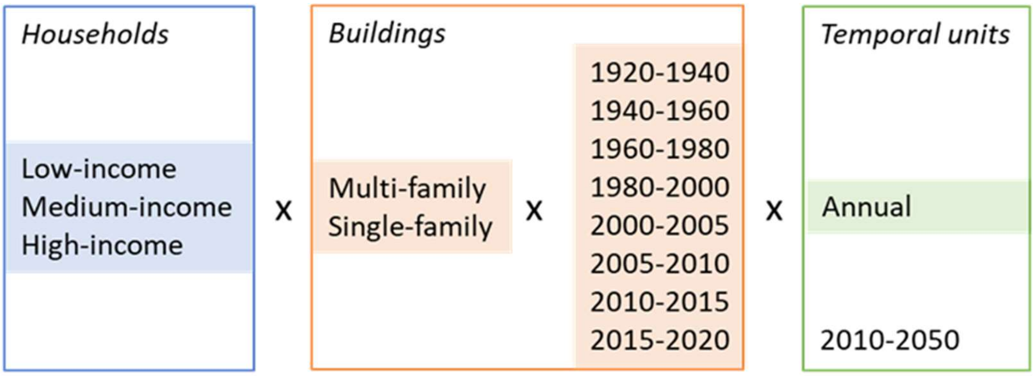


Figure 19: Column headers for the PRIMES plug-in.

The WHY toolkit was queried so as to provide separate estimates for 20 distinct European countries, namely: Austria, Belgium, Bulgaria, Cyprus, Czech Republic, Germany, Denmark, Spain, France, UK, Greece, Hungary, Ireland, Italy, The Netherlands, Norway, Poland, Serbia, Sweden and Slovenia (all of which belong to the EU, except Serbia and the UK).

For each service-carrier combination, the data delivered by the WHY toolkit represent the amount of carrier (in terms of kWh input) that would be needed if this carrier were to fulfil the whole service demand for each combination of building type and construction period. The outputs of the WHY toolkit are expressed as energy per building. Since PRIMES requires energy per household, a further processing step is needed to transfer the data from the WHY toolkit into the models. To that end, the data from the WHY toolkit that represents energy consumption per building type (i.e. terraced houses, multi-family houses, apartment buildings) was translated into energy consumption on a per household basis, using assumptions about the number of households per building. The energy consumption of single-family households provided by the database was used as a basis for that, as they provide an estimation of a household's energy consumption and how this may differentiate among countries based on their macroeconomic and climatic conditions.

5.3. Co-design process with the stakeholders

The stakeholder workshop aimed to co-design policy-relevant scenarios for the transformation of the EU buildings sector. It involved a diverse group of stakeholders including policymakers, business associations, research institutes and consumer organisations. The workshop gathered feedback on policy interventions and technology options to guide the building sector towards climate neutrality. The discussions highlighted that energy efficiency and electrification, especially through increased heat pump adoption and phasing out combustion appliances, are crucial in the EU buildings' transformation.

The key policies discussed included the Energy Performance of Buildings Directive (EPBD), Energy Plus buildings standards, efficiency standards and initiatives targeting renovations for energy-poor households. The industry knowledge gaps, financing schemes, consumer awareness and the challenges of split incentives between tenants and owners were also addressed by the stakeholders. Effectiveness and implementation barriers were considered by the stakeholders to prioritise interventions including social acceptance, technology availability, potential ramp-up governance, policy, and institutional barriers. The consensus emphasised the need for combining economic interventions (subsidies, carbon pricing) with information based and educational strategies to effectively engage citizens in the transition.

The discussions at the workshop with the invited stakeholders provided valuable insights for the definition and development of the European Use Case with energy and climate experts and policy makers developing an improved understanding and prioritising the energy policy aspects to be considered in the European Use Case. There are numerous political issues to be included in the energy demand modelling and prioritising them is a challenging task, where also the modelling capabilities should be considered. Through the stakeholder workshop and our research expertise, we identified the most relevant regulatory, economic, and information-based interventions to be assessed in the EU Use Case. Policy instruments such as subsidies or other financial incentives (e.g., low-cost renovation loans) should be examined together with the enforcement of stringent building codes and energy performance certificates as well as measures to raise citizen awareness through informational campaigns and improved technical support.

Regarding electrification, the focus is on the potential uptake of heat pumps to electrify heating demand, while the tax imbalance between electricity and fossil fuels in several EU counties should also be addressed. On top of that, regulatory interventions for the gradual phase out of combustion appliances, uptake of heat pumps and the further encouragement of efficiency standards will be assessed. The complementary nature of information-based policy instruments will be added to the interventions studied, while the transition impacts on the most vulnerable population groups will also be considered, through targeted policy instruments.

Based on the stakeholder feedback and interactions, we designed alternative policy scenarios to analyse the EU buildings transformation towards climate neutrality. The detailed description of these scenarios and model-based scenario projections using PRIMES-Buimo (soft-linked with the WHY Toolkit) can be found in the sections below.

5.4. Data collected and Scenario design

In analysing potential transformations of the EU buildings sector, robust data inputs and a meticulously designed scenario framework play pivotal roles. These external and internal variables are presented in *Table 6*and are instrumental in shaping the projections and insights that form the basis for informed decision-making and policy formulation.

External Variables	• Socio-economic developments (including GDP and population projections, household income) • Technology cost assumptions • Evolution of international energy prices • Climate-related parameters and policies • Energy demand patterns, consumer habits etc • Energy resource potentials
Internal Variables	• Energy demand by sector • Energy efficiency improvements • Fuel mix by sector • Rate and depth of renovations • Adoption of efficient heating and appliances • Energy supply mix • Energy costs, prices, investment • CO2 emissions from fossil fuel combustion

Table 6: List of external and internal variable included in the EU Use Case

To co-design policy-relevant scenarios for the EU buildings sector transformation, a diverse group of stakeholders was engaged as described in the section 5.3. The dedicated workshop collected valuable information on prioritising policy interventions and transition options, particularly focusing on energy efficiency and electrification through increased heat pump usage and efficiency improvements and phase-out of combustion technologies.

The designed scenarios are analysed to validate model behaviour under alternative policy and technology assumptions. The PRIMES-Buildings Model (PRIMES-BuiMo) serves as a comprehensive tool for assessing energy efficiency and electrification in the EU residential and services sectors. The model's strength lies in its detailed representation of market and non-market barriers as well as its capability to simulate a wide array of policies and measures, from financial incentives to hard regulatory instruments.

To explore PRIMES-BuiMo capabilities and assess its behaviour under changing exogenous assumptions, six scenarios have been designed and developed within the EU use case. The scenarios aim to showcase the potential and demonstrate the added value of the soft-linkage of PRIMES-Buimo model with the WHY Toolkit to enhance the modelling of the transformation dynamics of the EU Buildings sector. The main outcomes of this scenario exercise are a set of medium and long-term projections of key energy-economy-emissions indicators that describe the future development of the EU buildings sector under alternative scenarios. These indicators include (among others): final energy consumption, energy mix in the EU buildings sector, CO2 emissions, uptake of low-carbon technologies, renovation rates, energy and carbon prices, investment requirements and energy costs.

The EU use case explores two different levels of climate policy ambition that are presented in the (*Table 7*).

Existing Framework Context	• Low energy efficiency ambition reflecting the EU Reference scenario assumptions[12], aligning with the National Energy and Climate Plans (NECPs) of the EU Member States • Assumes achievement of national climate targets for 2030, but no climate policy intensification after 2030
Decarbonisation Context	• Aligns with the Fit for 55 policy package with the aim of 55% GHG emission reduction by 2030 and achieves climate neutrality by 2050 • Assumes increased ambition of energy efficiency and renewable energy policies

Table 7: Climate policy scenarios

Within the policy contexts ('existing framework' and 'Decarbonisation') in the EU use case, three scenarios are developed (**¡Error! No se encuentra el origen de la referencia.**).

Energy Efficiency and Electrification Policies	• Focuses on specific policies for enhancing energy efficiency and electrification. • Includes institutional and informational measures to address non-market barriers, encouraging investment in deep refurbishment and heat pumps
Carbon Pricing Extension	• Assumes an extension of carbon pricing in non-ETS sectors (e.g. buildings) • A linear increase in carbon price to USD 450 by 2050 complementing bottom-up renewables and energy efficiency policies
Energy Crisis Impact	• Reflects the current energy crisis, with a drastic reduction in Russian gas imports • International energy prices increase significantly in 2025 and moderately in 2030 relative to "existing framework" assumptions

Table 8: Scenarios developed within the EU use case

By combining the two climate policy contexts (termed as "Base" and "Decarb") with the above cases, we designed six scenarios (*Table 8*) analysed in the EU Use Case.

[12] Available at: https://energy.ec.europa.eu/data-and-analysis/energy-modelling /eu-reference-scenario-2020_en

Base	Reflects the existing framework scenario based on NECPs and Reference scenario assumptions[13]
Base_CP	Extends EU ETS scope to include the buildings sector with the carbon price to increase linearly
Base_HP_CP	Extends EU ETS scope to include buildings with increased international energy prices due to energy crisis
Decarb	Reflects the 'Decarbonisation' scenario with regulatory and institutional measures that align with the Fit For 55 policy package (achieving the EU's 55% GHG emission reduction target by 2030 and climate neutrality by 2050)
Decarb_CP	Aligns with the Fit For 55 policy package extending EU ETS scope to include the buildings sector with a linearly increasing carbon price
Decarb_HP_CP	Aligns with the Fit For 55 policy package, extending EU ETS scope to include buildings with increased international energy prices due to the current energy crisis

Table 8: Scenarios analysed in the EU Use Case

5.5. Analysis of Results

The analysis of policy scenarios provides insights into the medium and long-term projections of key indicators for the EU buildings sector. In the 'baseline' scenarios, final energy demand remains consistently higher than in the 'decarbonisation' scenarios, with larger differences in 2050 due to the EU's climate neutrality ambition. The emergence of Carbon prices and the increased energy import prices contribute to further reductions in final energy consumption, particularly pronounced in the 'decarbonisation' context. Energy efficiency indicators based on PRIMES-BuiMo modelling results soft-linked with the WHY Toolkit highlight a significant reduction in average energy consumption per household in the decarbonisation scenarios, reaching about 50% by 2050 compared to 2015 levels.

The data provided from the WHY Toolkit to feed the ESMs involved a large database for 20 Member States (MSs) that included the end-use energy consumption on a building's basis (in kWh/building) for numerous building categories (as it has been described in detail in D4.2 "Linking the WHY toolkit to large-scale Energy System Models"). More precisely, the databases were prepared for three electricity price schemes: a baseline, which involved "normal" electricity prices and two schemes that involved changes in the prices of electricity (relative to the baseline). The first one represented the implementation of a ToU tariff (ToU) and the second one represented the impact of increased international gas prices on electricity prices. The objective of applying these two price schemes was to change consumption patterns during the day and not to reduce the energy consumption and effectively the changes in prices were such that consuming energy during the midday was far more expensive than consuming energy at nights (but on an annual weighted average the prices were the same as in the baseline). The end-use energy consumption that has been affected by the different energy prices was only the energy consumption for specific electricity uses (i.e. for electrical appliances and lighting) and the differences involved load

[13] Available at: https://energy.ec.europa.eu/data-and-analysis/energy-modelling /eu-reference-scenario-2020_en

shifting between night and day in the different seasons (i.e. summer, winter and intermediate).

To derive useful information from the databases for the PRIMES model first an elaboration of the data took place. More precisely, and taking into account that PRIMES Buildings model operates on an annual basis and does not have hourly or seasonal resolution, the price elasticities of demand for the different seasons/hours (i.e. summer-day, summer-night, winter-day, winter-night, intermediate-day, intermediate night) have been calculated, as the effect of the increased price regimes in the WHY Toolkit involved only load shifting and not load change. The price elasticities of demand were calculated for all MS and all building types and they were found to be relatively similar for all cases (MSs and/or buildings) except for between single and multi-family households. It has been decided to use this indicator (i.e. the price elasticities of demand) as a means of integrating the data from the WHY toolkit into the PRIMES Buildings Model because price elasticity of demand represents behaviours regarding energy consumption. As the data from the WHY toolkit stem from actual data of energy consumption, it would be beneficial for PRIMES buildings model to update its behavioural parameters so as to better reflect the actual consumer behaviours. The calculated price elasticities of demand are handled qualitatively for integration in the PRIMES Buildings model. The graph below (Figure 20) summarizes the information retrieved from the WHY Toolkit. As can be seen from the graph, there is indeed a shift of electricity consumption for electrical appliances from day to night. This is the case for all seasons, but this behaviour is more pronounced during the summertime. A possible reasoning behind it could be that other electricity loads during the summertime, like for example the use of air conditioning (AC), also occur during daytime and such loads cannot be shifted. This is not the case during winter as space heating is usually covered by other fuels like oil or gas and also it is during nighttime that heating demand is at its highest. Intermediate season's behaviour lies in between the two, which is also plausible. As it may be seen from the graph, single-family households are more elastic in changing their demand due to changes in electricity prices than multi-family households, and this is something that has been identified in literature already [Trotta et al, 2022].

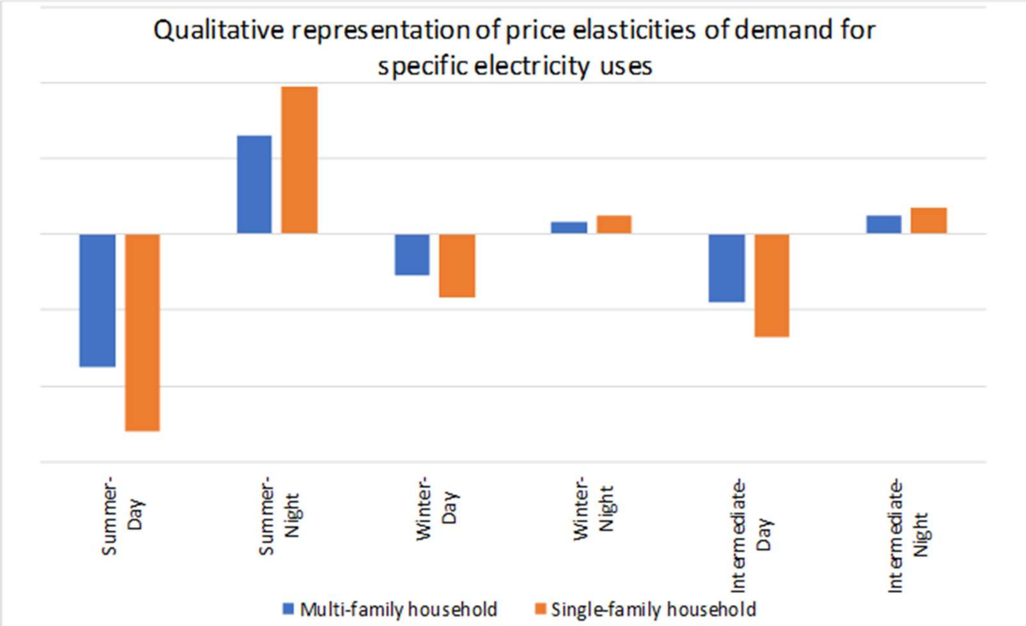


Figure 20: Qualitative representation of price elasticities of demand for specific electricity uses as they have been calculated from the data of the WHY Toolkit

In D5.1. "Report on the integration of the WHY Toolkit with the energy models" the PRIMES Buildings model has developed six scenarios that combined two policy contexts (i.e. "existing framework" and "Decarbonisation") and three price cases (about international prices and/or carbon prices). In other words, there were for each policy context two extreme price cases (i.e. a baseline and a high price, including the extension of ETS in the buildings sector). The scenario details are also presented in the section above.

For the purposes of the current deliverable, the first step was to calculate the price elasticity of demand by end-use and building type in the two policy contexts using the figures of energy consumption and prices of the two extreme price cases from the WHY Toolkit. The aim was to compare the model's behaviour (as it derived from the model runs prepared in the context of D5.1) with the actual behaviour of consumers (as it is represented through the calculated price elasticities of demand from the WHY Toolkit). Then, specific modelling parameters that represent consumers' behaviour regarding energy consumption (or in other words the modelling parameters that represent non-market barriers related to energy consumption behaviour, like for example lack of knowledge, lack of information) were adjusted in such a way that the PRIMES buildings model can reproduce the price elasticities of demand (or their relative differentiation among the different building types) that have been calculated using the data from the WHY Toolkit. Finally, the PRIMES Buildings model has re-run for the same scenarios and results are presented below on a more granular level than in D5.1.

Figure 21shows the price elasticity of demand for specific electricity uses in both the baseline and the decarbonization context. As it is expected, the elasticities are higher in the decarbonization context than in the baseline, as the existence of ambitious policies in the decarbonization scenarios (e.g. to remove market and non-market barriers for energy efficiency) facilitate the uptake of investments in more efficient technologies (thus decreasing the impacts of increased energy prices). Therefore, energy consumption decreases more in the decarbonization context than in the baseline context for the same increase in energy prices, as in the baseline context it is rather a different usage of equipment that is the result of increased energy prices than investments in more efficient technologies. Comparing the behaviour between the different building types, single family households are more elastic than multi-family ones, as it is the case in the WHY toolkit, but the effects of increased energy prices seem less pronounced than in the WHY toolkit (i.e. elasticities in the baseline context are lower than in the WHY toolkit).

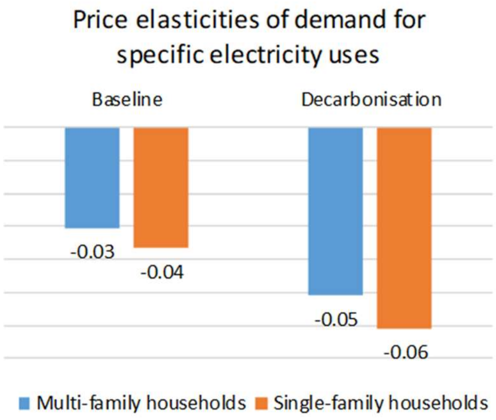


Figure 21: Price elasticities of demand by building type (multi-family households vs single-family households) for specific electricity uses calculated from the results of the diagnostic scenarios ran with the PRIMES Buildings model in the context of D5.1.

Considering that the interpretation of behaviours for specific electricity uses as it derives from the data of the WHY Toolkit could be possibly extended to other uses as well, additional analysis is performed. Figure 22shows the price elasticities of demand, as they are calculated from the D5.1. runs of PRIMES Buildings model, for the rest of the energy uses and the different building types. The elasticities are again higher in the decarbonization context, and when it comes to heating and cooling, they are higher the older the age of the building. This is also plausible, as the older the building is, the worse is its energy performance (if in original state), therefore higher are the energy needs which effectively means higher are the energy costs. Therefore, when energy prices increase the most affected are the older constructions. The difference in behaviour between single and multi-family households is also in this case as in the WHY toolkit, namely single-family households are more elastic than multi-family ones in changes in electricity prices. What could possibly improve in terms of modelling parameters is to assume (similarly to the behaviours related to electrical appliances) that the behaviours differentiate more between single and multi-family households.

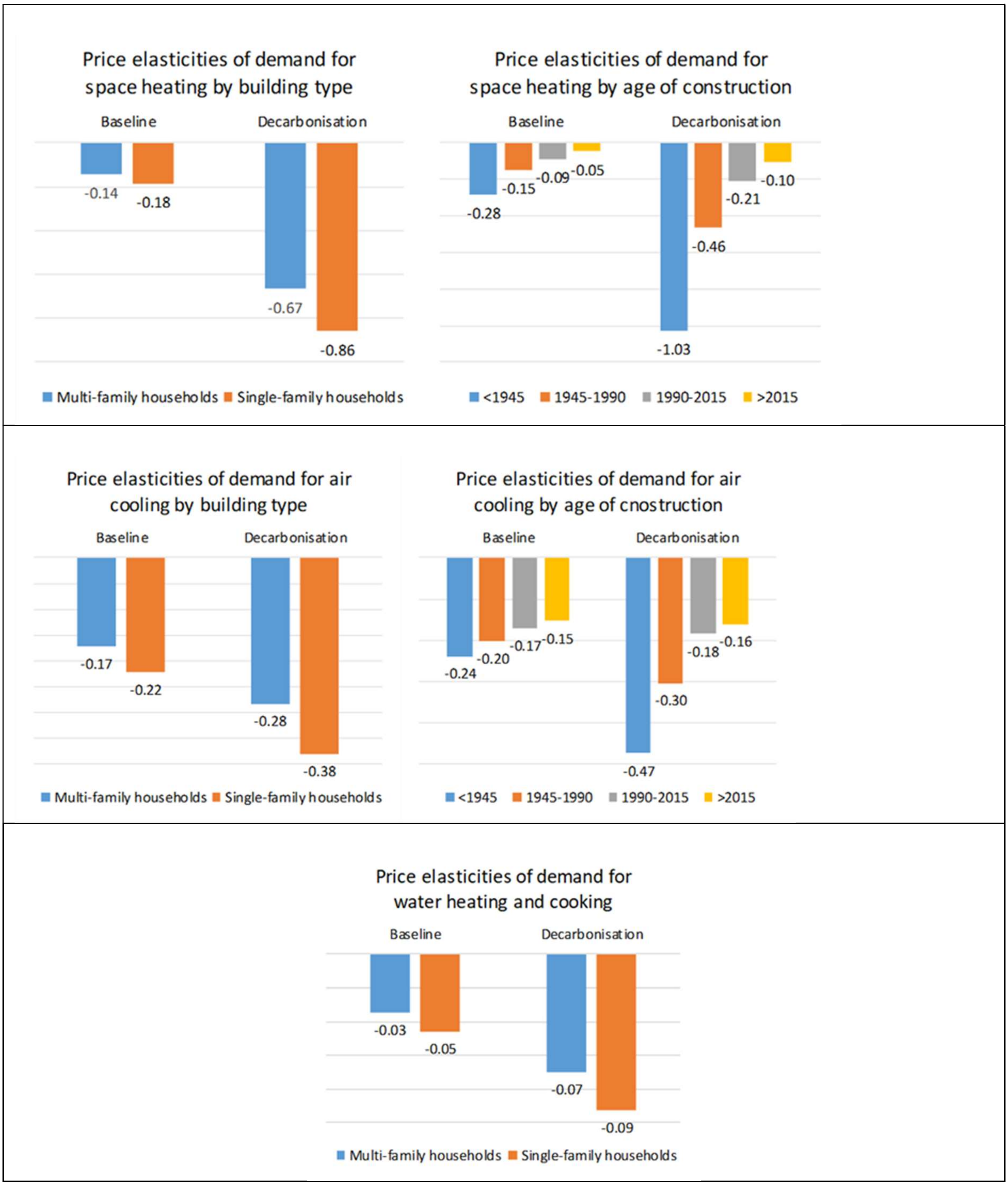


Figure 22: Price elasticities of demand by building type (multi-family households vs single-family households) and age for heating and cooling calculated from the results of the diagnostic scenarios ran with the PRIMES Buildings model in the context of D5.1.

Based on the above, the modelling parameters have been adjusted in order to obtain the following behaviours or relative behaviours:

1. All building types to be more elastic in changes in electricity prices when it comes to the consumption of electrical appliances.

2. Single family households to be more elastic to changes in energy prices than multi family households

The below figures (Figure 23) show the new price elasticities of demand by end-use and building type after the changes in the modelling parameters as per the above aim. The new price elasticities of demand derived from the re-run of PRIMES Buildings Model, for the four "extreme" scenarios, namely for the Base, Base_HP_CP, Decarb and Decarb_HP_CP (for details about the scenario descriptions, please refer to D5.1).

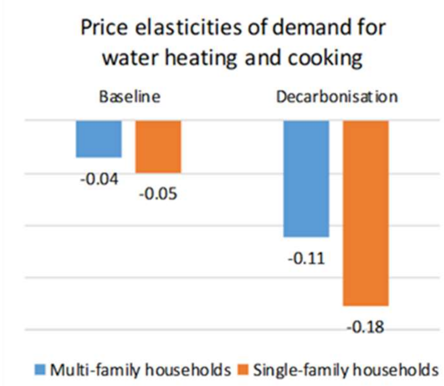
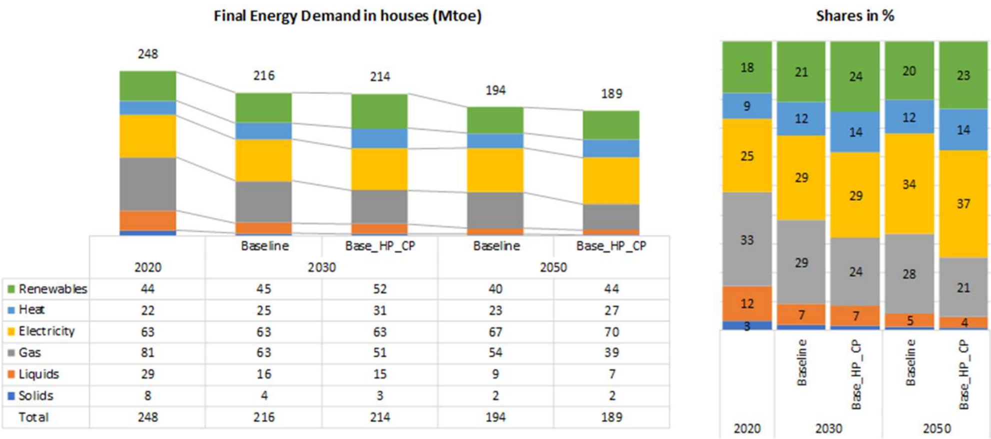


Figure 23: Price elasticities of demand by building type (multi-family households vs single-family households) and age for all end-uses calculated from the results of the re-run of the diagnostic scenarios with the PRIMES Buildings model.

To showcase the effects of the above changes in transformation pathways, the Figures 24-26 present the development of energy consumption and fuel mix in the buildings sector as well as the emissions for the EU27. Comparing the results with the respective graphs of D5.1, the changes are found to be minimal in both the short term and the longer term (see Figure 27, that show the deltas of the new runs compared to previous ones for both the final energy consumption and emissions outlooks). Also, the differences in behaviors between the scenarios remain: In the 'baseline' scenarios, final energy demand remains consistently higher than in the 'decarbonisation' scenarios, with larger differences in 2050 due to the EU's climate neutrality ambition. The emergence of Carbon prices and the increased energy import prices contribute to further reductions in final energy consumption, particularly pronounced in the 'decarbonisation' context. Energy-related CO2 emissions in decarbonisation scenarios become zero by 2050 which aligns with the EU's climate neutrality goals. The fuel mix in the buildings sector shifts towards increased electrification, with electricity representing more than half of total energy consumption in decarbonisation scenarios.



	2020	2030 Baseline	2030 Base_HP_CP	2050 Baseline	2050 Base_HP_CP
Renewables	44	45	52	40	44
Heat	22	25	31	23	27
Electricity	63	63	63	67	70
Gas	81	63	51	54	39
Liquids	29	16	15	9	7
Solids	8	4	3	2	2
Total	248	216	214	194	189

Figure 24: Fuel mix and final energy consumption outlook in the "Baseline" scenarios for EU27 in the residential sector

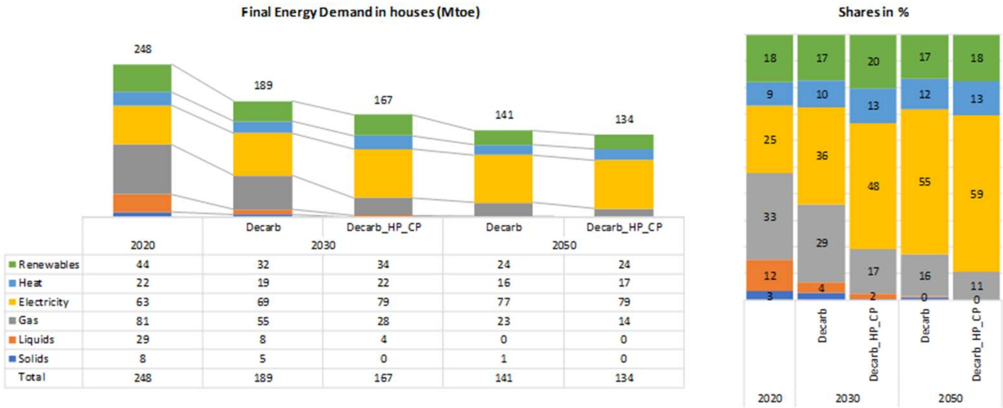


Figure 25: Fuel mix and final energy consumption outlook in the "Decarbonisation" scenarios for EU27 in the residential sector

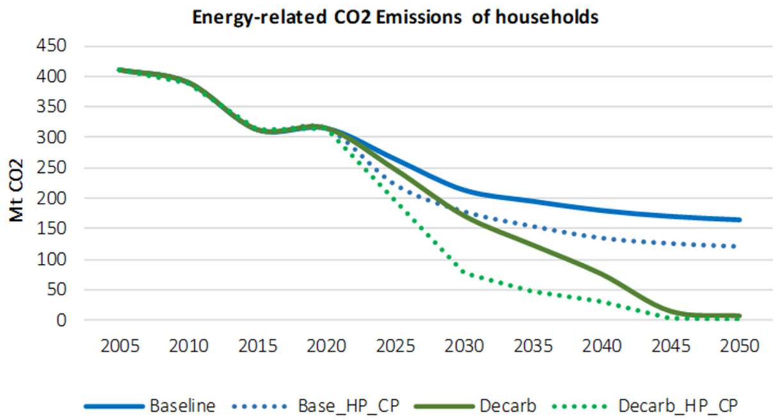
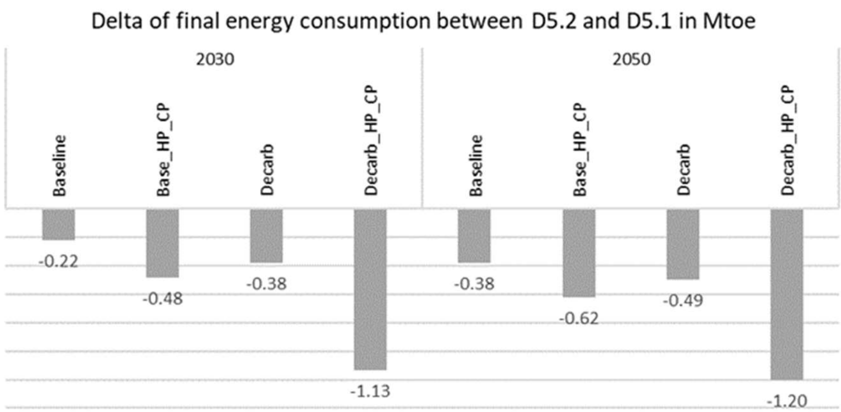


Figure 26: Energy-related CO2 emissions of households' outlook



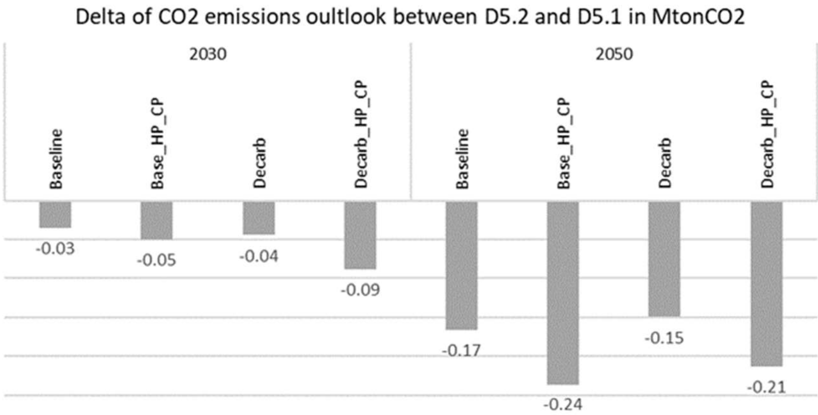


Figure 27: Deltas of the new runs (included in current deliverable - D5.2) compared to old ones (included in previous deliverable - D5.1) both the final energy consumption and emissions outlooks

The rest of this section focuses on representative country specific results and zooms into the behaviour of different building types, to show how the different policy contexts affect the different building and consumer classes. This is important from a policy perspective and also in order to highlight that a common policy context does not necessarily have the same impact in the different MSs and building types, because the macroeconomic as well as the climatic conditions interact with the ambition and effectiveness of energy policies.

The section below compares the model results for Sweden and Greece. These two MSs are considered as extreme cases, but still representative of the differences among EU Member States in terms of climatic conditions (and as a result their heating and cooling needs) but also households' private income (on a per capita basis). What is more the building stock (or the characteristics thereof) differ between the two countries: Sweden has a relatively newer building stock compared to Greece and already today Sweden's households are largely equipped with heat pumps, which are being used as the main heating system, whereas households in Greece use mostly oil and gas boilers to meet their heating needs.

Figure 28presents energy consumption in houses for heating and cooling, in the two MSs and different scenarios modelled with PRIMES-BuiMo. Energy needs in Sweden are much larger compared to Greece throughout the projection period, and this is to be expected as the space heating needs, that make up for most of the heating and cooling needs in both countries, are larger in Sweden because of the longer and colder winters. The fact that households in Sweden have a higher private income compared to households in Greece, explain the fact that the energy consumption in the Baseline scenarios decreases more, relative to 2020 levels in Sweden compared to Greece. In both MSs the ambitious energy efficiency policies as well as the institutional measures included in the decarbonization scenarios induce larger energy consumption reductions compared to the baseline scenarios. The climate neutrality objective for 2050 in the decarbonization scenarios result in both MSs in a reduction of energy consumption for heating and cooling that is as high as 60% relative to the 2020 energy consumption, and this is irrespective of the price scheme and other assumptions included in the two decarbonization variants.

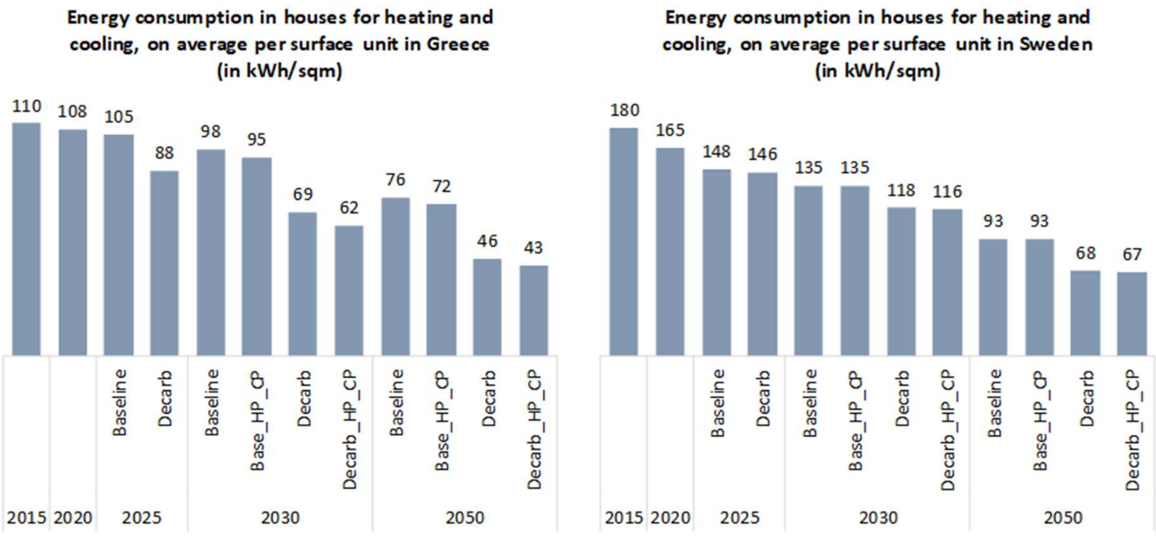
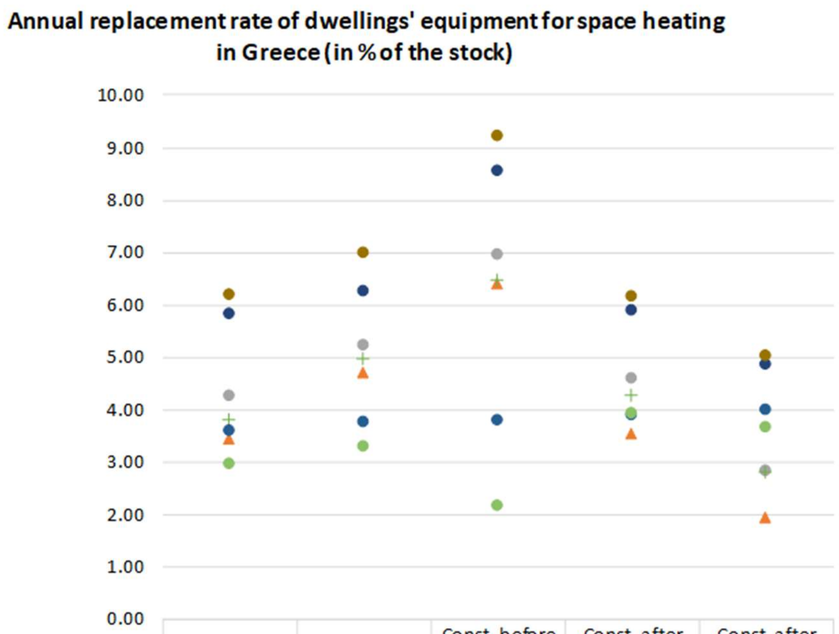


Figure 28: Energy consumption in houses for heating and cooling, on average per surface unit (in kWh/sqm) in Greece (left) and Sweden (right)

Figure 29represents the annual renovation/replacement rates for Greece and Sweden. The developments of these rates throughout the projection period in the different scenarios explain in more detail the development of energy consumption for heating and cooling presented in Figure 28. Both renovation and equipment replacement rates are higher in the decarbonization scenarios compared to the respective baseline scenarios in both MSs, driven by the ambitious energy efficiency and net-zero policies. The newer building stock in Sweden (and therefore the better energy performing one) explains the fact that the annual renovation rate of the building envelope is closer to the historic one (i.e. the one that takes place even without the existence of additional energy efficiency policy) in the short term in the baseline variants compared to Greece. In other words, there are less buildings that are being renovated in Sweden in the baseline scenarios compared to Greece. However, the depth of renovations is projected to be higher in Sweden (driven mainly by the higher private income of households), which is also depicted in the larger reduction of energy consumption for heating and cooling in the respective variants. The ambitious energy efficiency policies of the decarbonization scenarios together with the enabling conditions that represent the institutional measures in these contexts enable a larger replacement rate of space heating equipment in Greece compared to Sweden. This is driven by the fact that almost one third of the current building stock in Sweden is equipped with heat pumps, therefore replacements of heating equipment involve mostly replacements due to the end of the equipment's life and probably with more efficient ones, and not equipment change, which is the case in Greece. The extension of ETS in the building sector, regardless of the policy context, is therefore more effective in Greece compared to Sweden, as in the former heating is mostly covered by fossil fuels while in Sweden heat pumps already dominate so the relative impact of the policy is lower in magnitude.

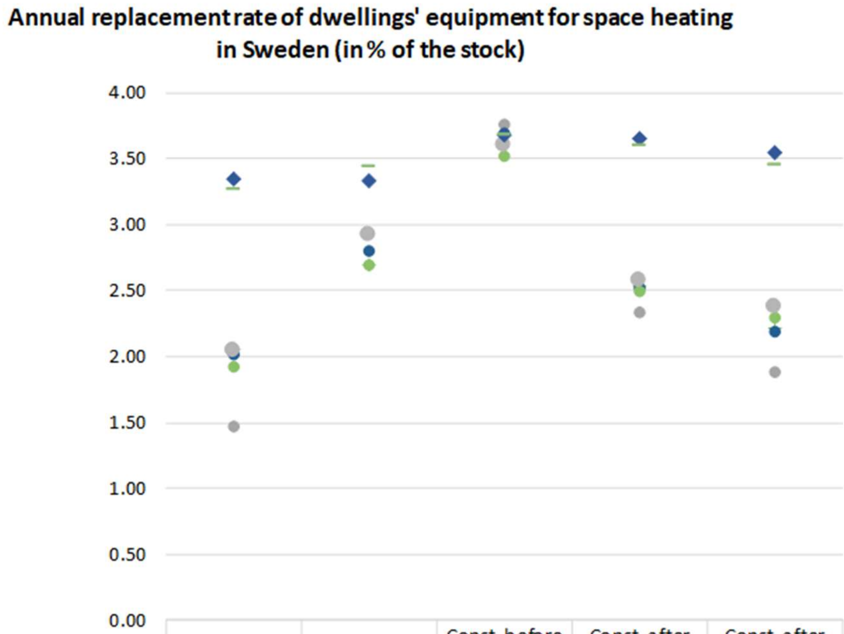
Figure 29: Projection of renovation rates in houses in Greece (top) and Sweden (bottom)

Figure 30and Figure 31present the annual replacement rate of dwellings' equipment for space heating in Greece and Sweden respectively for different building types. In both MSs and irrespective of the scenario, the replacement rates are higher in single-family households compared to multi-family ones. This is logical as multi-family households may be usually equipped with central heating systems that serve many dwellings in one building. In these cases it may be hard to reach an agreement on changing the central heating system with an individual one, and this may well explain the lower replacement rates in multi-family buildings. Comparing the replacement rates of the increased price variants with the respective rates of the "normal" price variants, increased prices drive replacement rates upwards in both EU countries, and this is more pronounced in the single-family households. This is driven by the updates of the modelling parameters (as explained above) that reflect consumer behaviours regarding energy consumption considering the data from the WHY toolkit. The projected rates of replacement differ based on the age of the building, with older constructions having higher rates compared to more recent ones in both MSs. The model-based analysis shows that energy efficiency and climate policies have a larger impact in the replacement of the heating equipment in Greece compared to Sweden, as it was shown in Figure 28, which effectively means that replacement rates in decarbonization scenarios are larger than in the baseline scenarios, in Greece compared to Sweden.



	Multi	Single	Const. before 1975	Const. after 1975	Const. after 2000
2016-2020	3.46	4.72	6.42	3.54	1.97
2026-2030 Baseline	4.28	5.26	7.00	4.63	2.87
2026-2030 Base_HP_CP	3.83	4.97	6.50	4.29	2.83
2026-2030 Decarb	5.85	6.30	8.58	5.91	4.88
2026-2030 Decarb_HP_CP	6.21	7.03	9.24	6.18	5.06
2031-2050 Baseline	3.64	3.80	3.81	3.92	4.01
2031-2050 Decarb_HP_CP	3.00	3.32	2.20	3.95	3.68

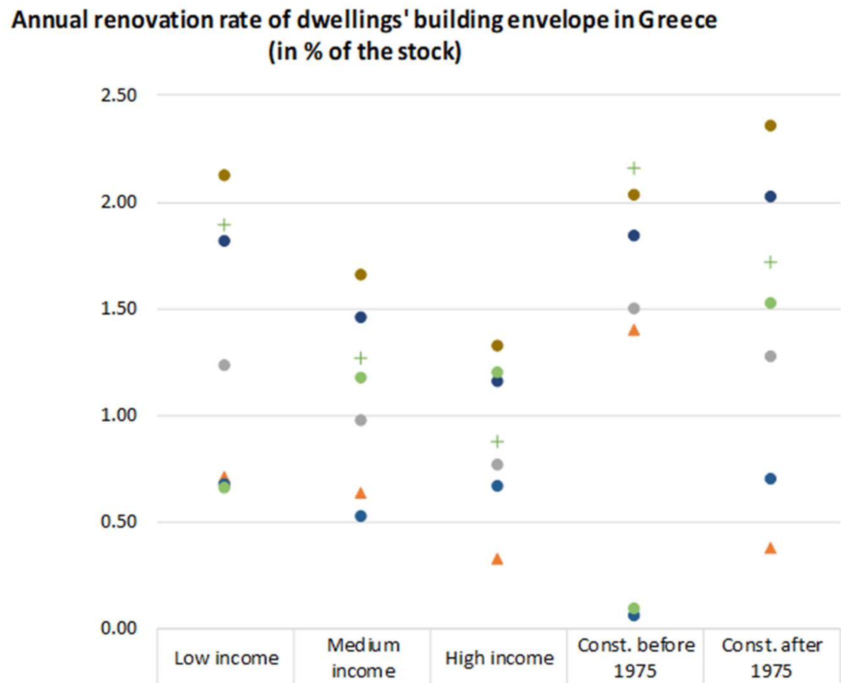
Figure 30: Annual replacement rate of dwellings' equipment for space heating by building type and building age in Greece



	Multi	Single	Const. before 1975	Const. after 1975	Const. after 2000
2016-2020	1.47	2.93	3.76	2.33	1.87
2026-2030 Baseline	2.05	2.69	3.68	2.53	2.21
2026-2030 Base_HP_CP	2.01	2.79	3.69	2.52	2.18
2026-2030 Decarb	1.93	2.69	3.51	2.49	2.29
2026-2030 Decarb_HP_CP	2.04	2.93	3.60	2.58	2.37
2031-2050 Baseline	3.35	3.33	3.67	3.66	3.55
2031-2050 Decarb_HP_CP	3.27	3.43	3.68	3.60	3.45

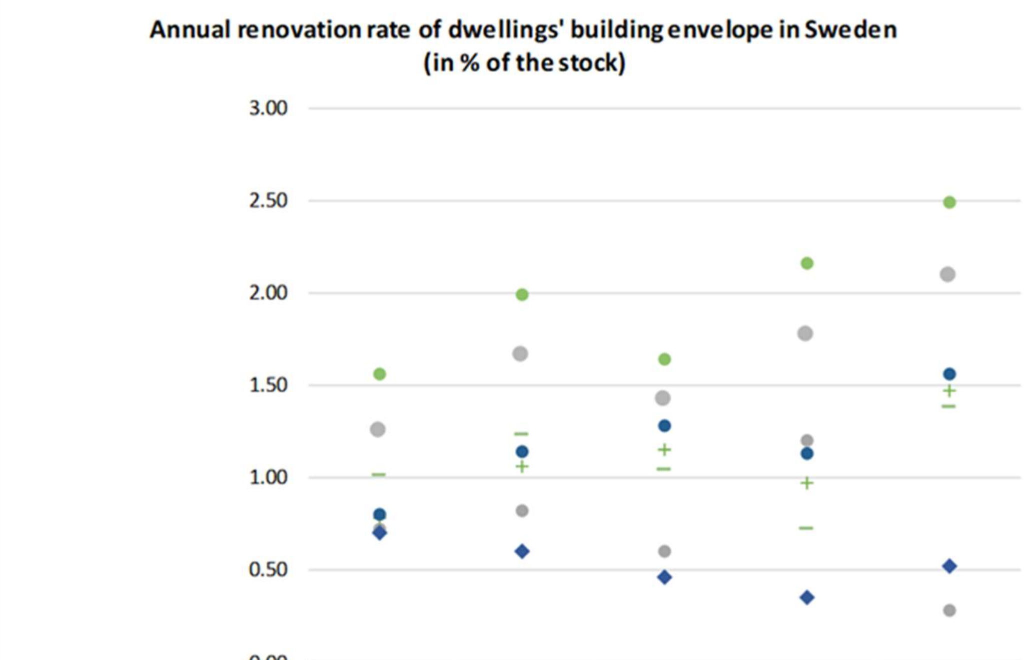
Figure 31: Annual replacement rate of dwellings' equipment for space heating by building type and building age in Sweden

Figure 32and Figure 33show the annual renovation rate of the building envelope in Greece and Sweden respectively differentiated by building and consumer type. In both MS the ambitious energy efficiency policies in the decarbonization scenarios drive renovation rates upwards compared to the respective baseline scenarios. Also, older constructions (and therefore worse performing ones) have a higher rate compared to more recent ones, at least in the short term. Towards the end of the projection period, when the older construction would most probably have already been renovated once, it is the more recent constructions that are being renovated. This explains the fact that the annual renovation rates of the more recent constructions are higher in this period compared to those of the older ones. The two MSs differ regarding the performance of the different income classes: in Greece the lower income consumers show the higher renovation rates in all contexts, whereas in Sweden the medium income consumers show the higher rates. This however relates to the distribution of ages of constructions in the different income groups: in Greece the largest part of the very old constructions commonly belongs to low income families and this is why the annual renovation rates of these categories (i.e. low-income and constructions before 1975) show a similar performance in all contexts and periods. In contrast, in Sweden, the medium income families live in the oldest constructions, and this is why the performance of these two categories is similar in all contexts and time periods.



	Low income	Medium income	High income	Const. before 1975	Const. after 1975
2016-2020	0.72	0.64	0.33	1.41	0.39
2026-2030 Baseline	1.24	0.98	0.77	1.51	1.28
2026-2030 Base_HP_CP	1.90	1.27	0.88	2.16	1.72
2026-2030 Decarb	1.82	1.46	1.17	1.85	2.03
2026-2030 Decarb_HP_CP	2.13	1.66	1.33	2.04	2.36
2031-2050 Baseline	0.68	0.53	0.67	0.07	0.71
2031-2050 Decarb_HP_CP	0.66	1.18	1.20	0.10	1.53

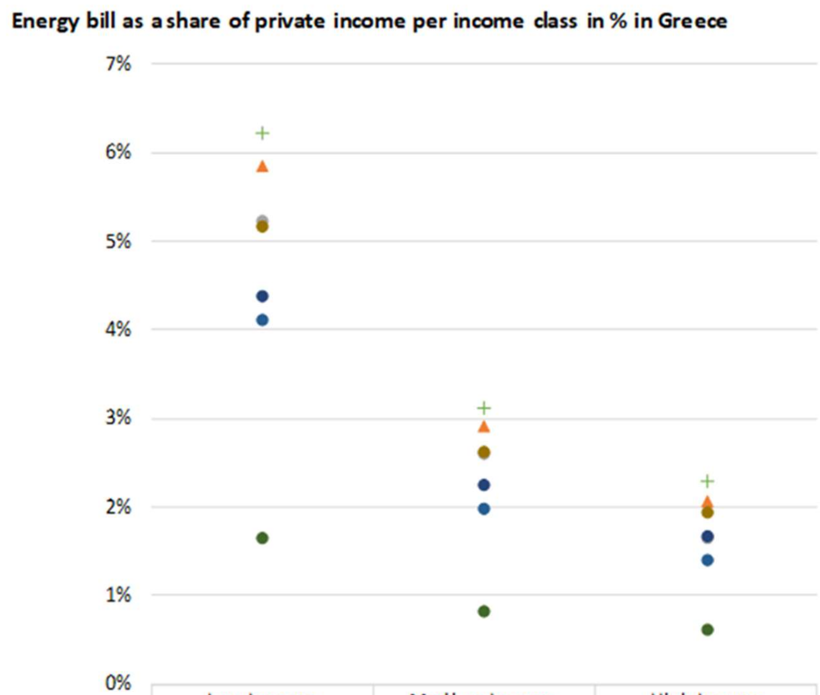
Figure 32: Annual renovation rate of dwellings' building envelope by income class and building's age in Greece



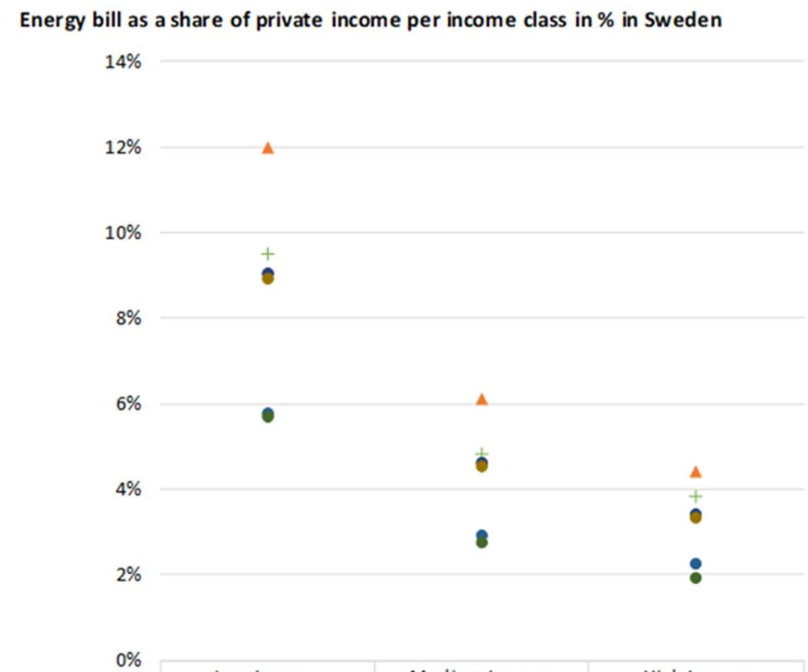
	Low income	Medium income	High income	Const. before 1975	Const. after 1975
2016-2020	0.72	0.82	0.60	1.20	0.28
2026-2030 Baseline	0.78	1.06	1.15	0.97	1.47
2026-2030 Base_HP_CP	0.80	1.14	1.28	1.13	1.56
2026-2030 Decarb	1.56	1.99	1.64	2.16	2.49
2026-2030 Decarb_HP_CP	1.26	1.66	1.42	1.77	2.09
2031-2050 Baseline	0.70	0.60	0.46	0.36	0.52
2031-2050 Decarb_HP_CP	1.01	1.23	1.04	0.72	1.38

Figure 33: Annual renovation rate of dwellings' building envelope by income class and building's age in Sweden

Finally, Figure 34shows the energy bill as a share of private income per income class in Greece and Sweden. In both MSs low-income consumers need to always spend a higher share of their income for energy purchases compared to medium and high-income ones irrespective of the policy or price context, pointing towards higher risks of energy poverty. The investments in energy efficiency in the decarbonization scenarios decrease the share of income that all consumer classes need to spend for energy purchases, but low-income consumers are more affected, in the sense that the share for them decreases more than for the other consumers. The shares in Sweden are always higher than in Greece but this is to be expected as energy consumption per capita as well as energy prices in Sweden are higher than in Greece.



	Low Income	Medium Income	High Income
2020	5.84%	2.91%	2.06%
2030 Baseline	5.22%	2.60%	1.65%
2030 Base_HP_CP	6.22%	3.12%	2.29%
2030 Decarb	4.38%	2.25%	1.66%
2030 Decarb_HP_CP	5.16%	2.62%	1.94%
2050 Baseline	4.10%	1.98%	1.41%
2050 Decarb_HP_CP	1.66%	0.82%	0.60%



	Low Income	Medium Income	High Income
2020	12.01%	6.12%	4.41%
2030 Baseline	9.06%	4.61%	3.40%
2030 Base_HP_CP	9.49%	4.83%	3.82%
2030 Decarb	9.06%	4.62%	3.43%
2030 Decarb_HP_CP	8.91%	4.53%	3.36%
2050 Baseline	5.79%	2.91%	2.26%
2050 Decarb_HP_CP	5.70%	2.76%	1.95%

Figure 34: Energy bill as a share of private income per income class by scenario in Greece (top) and Sweden (bottom)

Based on the analysis conducted above, comparing the results for two MSs and different building types, we conclude that there are some similarities in the model-based projections (and in consumers' behaviours) or alternatively in the effectiveness of the different policies. However, certain differences exist that relate to the macroeconomic, climatic and building age factors that are specific to each MS. The latter boils down to the fact that although all MSs need to make efforts to meet certain climate and energy efficiency targets on an EU and national level, the stringency and ambition of policies, or even the type of policy instrument should not be horizontal and should take into account the specificities of each EU MS. Also, in case the policies need to also have a social dimension (e.g. to alleviate energy poverty), such specificities need to be taken into consideration.

5.6. Brief Summary / Main findings

The EU Use case, enriched with insights from the WHY Toolkit, provides a comprehensive analysis of system-level implications and alternative policy interventions for achieving climate neutrality in EU buildings by mid-century. The EU Use case provides new insights for key energy, emissions and cost indicators in the building sector.

The integration of the data from the WHY Toolkit into PRIMES BuiMo helped to improve the model's representation of consumer behaviours regarding energy consumption based on real data. This is important for models like PRIMES BuiMo that can be used to realistically assess the impact and effectiveness of energy efficiency and climate policies based on real-world data, increasing their relevance for policy making. The model-based analysis showed that even before the integration of data from the WHY Toolkit, PRIMES-BuiMo showed a behaviour very similar to the one that was inferred by the kit (as the modelling parameters were based on data available in the scientific literature); however, the integration of data from the WHY Toolkit increased the model's integrity and transparency.

From a policy perspective, the Use Case showed that the deep decarbonisation of buildings in the EU is technically and economically feasible, and it can be achieved through the deep renovation of the building's envelope accompanied by the electrification of heat uses. The extension of ETS in the buildings sector incites the energy transition, but this needs to go hand in hand with bottom-up policies like for example subsidisation policies to promote the energy upgrade of the building envelope and the purchase of heat pumps by consumers.

Comparing the model results on a MS level, it is obvious that the stringency and ambition of climate policies, or even the type of policy instruments that should be used to reduce emissions, should not be horizontal and should take into account the specificities of each EU Member State. In addition, policies need to also have a social dimension (e.g. to alleviate energy poverty risks), so such national specificities need to be taken into consideration.

Insights into factors that influence the energy-related choices in the residential sector are explored and the EU Use Case offers a nuanced understanding of how these factors can be integrated into large-scale models. Detailed assessments of the potential for adopting low and zero-carbon solutions in the residential sector have been conducted considering system effects and broader implications. The model-based analysis provides several indicators related to the Sustainability Assessment, including the development of emission trajectories by 2050, energy efficiency improvements in EU households, uptake of electrification and building renovation strategies, as well as their impacts on energy costs and prices for households by income class reflecting energy affordability and energy poverty risks. The consistent integration of PRIMES-BuiMo with data from the WHY Toolkit leads to a more comprehensive assessment that incorporates diverse indicators and aligns with metrics for Sustainable Development Goals. The co-design of scenarios with the stakeholders has also ensured a more inclusive and informed approach to policy interventions, enhancing the relevance and effectiveness of the EU Use case.

6. The global use case

The global use case investigates the impact of ambitious climate policies and energy efficiency measures on the global energy mix and in particular in the future development of the buildings sector. For this use case, two well-established integrated assessment models (IAMs), TIAM-ECN and PROMETHEUS, are employed and linked with the WHY toolkit aiming to improve their simulation properties in the representation of decarbonization of the buildings sector. Scenario design and the selection of input data and output indicators are based on stakeholders' consultation, extensive literature research and internal expertise of the two modelling teams.

6.1. Objective and Scope of the Use Case

Climate change is a phenomenon that affects the world as a whole. While its effects are local – and should be tackled by national and subnational policies – its scope and scale can only be grasped from a global perspective. As such, international cooperation should be the foundation on which to base local and national policies. This use case aims at explicitly bringing the global dimension into the WHY project, and showcasing how global energy and climate modelling scenario studies can benefit from the tools developed in the WHY project. Using the TIAM-ECN model, we make a connection with well-known long-term IAM scenario analyses at the global level by many high-level bodies, such as the Intergovernmental Panel on Climate Change (IPCC) and the International Energy Agency (IEA).

Specifically, the Global Use Case has two main objectives. First, we contribute to the scientific literature on global energy scenario studies, by analyzing the effects of enhanced energy efficiency in the demand sectors on the global energy mix and CO2 emissions (as well as that of major economic regions), in the context of stringent decarbonization policies towards achieving the Paris Agreement goals. We achieved this objective in the course of the WHY project through two studies with the IAMs PROMETHEUS and TIAM-ECN, in which we assess the implications of pushing energy efficiency versus employing other means to reduce emissions, such as promoting renewable energy sources or deploying Carbon Capture, Storage and Utilization (CCSU) solutions (Dalla Longa et al., 2021; Fragkos et al., 2023). Second, we aim at investigating how the novel insights provided by the WHY toolkit can inform, shape and improve IAM analysis. In this deliverable we report specifically our findings in relation to this objective. We create a link between the WHY toolkit and TIAM-ECN (which is described in detail in D4.2), running the model under a stringent decarbonization policy scenario with and without the implementation of the WHY toolkit, and analyze the difference in model-based outcomes. By showcasing and documenting how the WHY toolkit can be used in the context of global energy and climate modelling (and more in general with large-scale models) we provide a useful example for other modelers (especially those working with TIMES-based models, similar to TIAM-ECN).

6.2. Methodology and scenario design

A stakeholder consultation process with international experts on global energy scenarios and climate policies has been conducted in the spring of 2022, by means of written questionnaires and online interviews. This process was complemented with an internal evaluation of the responses received. The main policy dimensions identified through this process for the global case study can be summarized as:

- Global climate policy;
- Carbon pricing;
- Subsidization of clean heating and cooling technologies;
- Obligations to meet energy efficiency standards in buildings;
- Energy financing for retrofits in the building sector;
- Clean cooking promotion in developing countries;
- SDGs, especially those that focus on improved energy access and reduction of poverty.

The IAM studies carried out during the course of the WHY project have explored most of these dimensions through a series of scenario runs and multi-model analyses, the results of which are summarized in two comprehensive journal articles: Dalla Longa et al. (2021) and Fragkos et al. (2023). Carbon pricing was identified in these studies as one of the main levers to drive deep decarbonization, hence in the final stage of the WHY project, we focus for this deliverable on a stringent carbon price scenario and analyze the effect of linking an ESM (TIAM-ECN) with the WHY toolkit. This scenario, named C400-lin, assumes a global carbon market mechanism with the global CO_2-price growing linearly from 130 to 580 $/t$CO_2$-eq between 2025 and 2050.

We consider two variants of this scenario: a baseline variant (C400-Lin), and one in which we employ the WHY toolkit to estimate the effects (at global scale) of increasing power prices in the residential sector, as a policy measure to stimulate more efficient use of electricity (C400-Lin-WHY). The price increases differ per model-timeslice, as detailed in Table 9.

	Price increase €/kWh	
	Day	Night
Summer (PS)	0.44554	0.36310
Winter (PS)	0.20124	0.18102
Intermediate (PS)	0	0.18803

Table 9: Price increases in the C400-lin-WHY scenario

The WHY toolkit reveals that the simulated price increases result in a shift of the consumption of electricity used for powering electric appliances from day to night hours in all seasons, as shown in Figure 6.1. The shifts are relatively small, i.e. only about 4% of electric appliances use shifts from day to night hours. The slight difference in day-hours demand reduction vs night-hours demand increase - the latter being larger than the former

- indicates that there is a net reduction of the overall demand, which is in line with the fact that the prices have increased in all time-slices. The outcomes of the WHY toolkit are implemented in TIAM-ECN by increasing/decreasing the demand for electric appliances in all model regions according to the values in Figure 35.

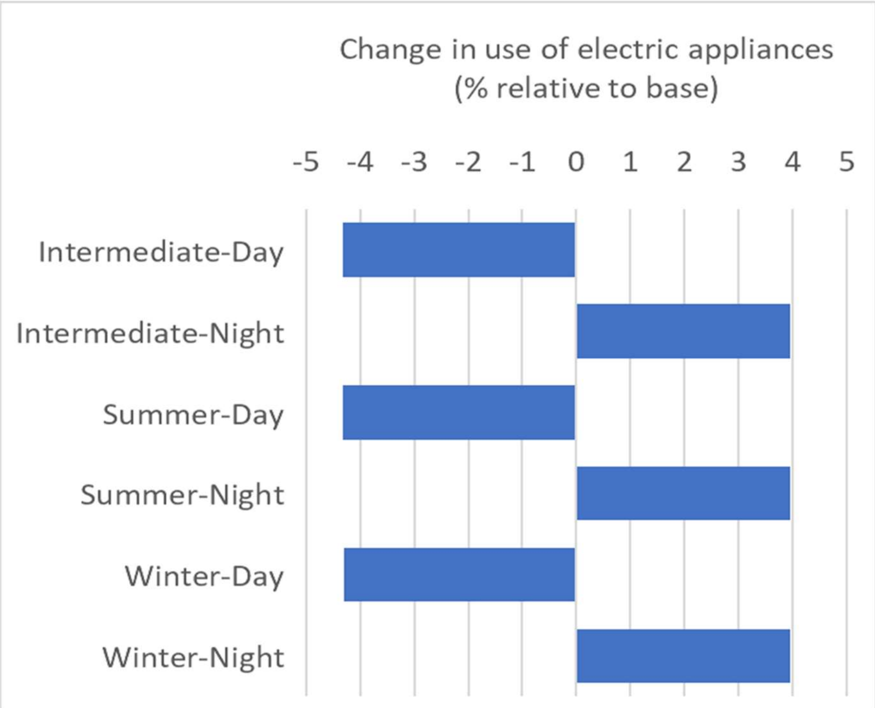


Figure 35: Change in electric appliances use in the C400-lin-WHY scenario variant

6.3. Analysis of Results

Figure 36shows the carbon price (left panel) and resulting global CO_2 emissions projections in the TIAM-ECN run for the C400-Lin scenario. The price increase reflects the scenario assumption but is shown here in €/tCO_2 and displays a slight variation from linearity, due to the fact that the model still retains some freedom in applying slight variations to prices to simulate the effects of price-elasticity of demand. Global CO2 emissions decrease sharply in this scenario, reaching near-zero emissions in 2050. The corresponding plots for scenario C400-Lin-WHY are not shown, as the differences would be too small to be seen in the graphs.

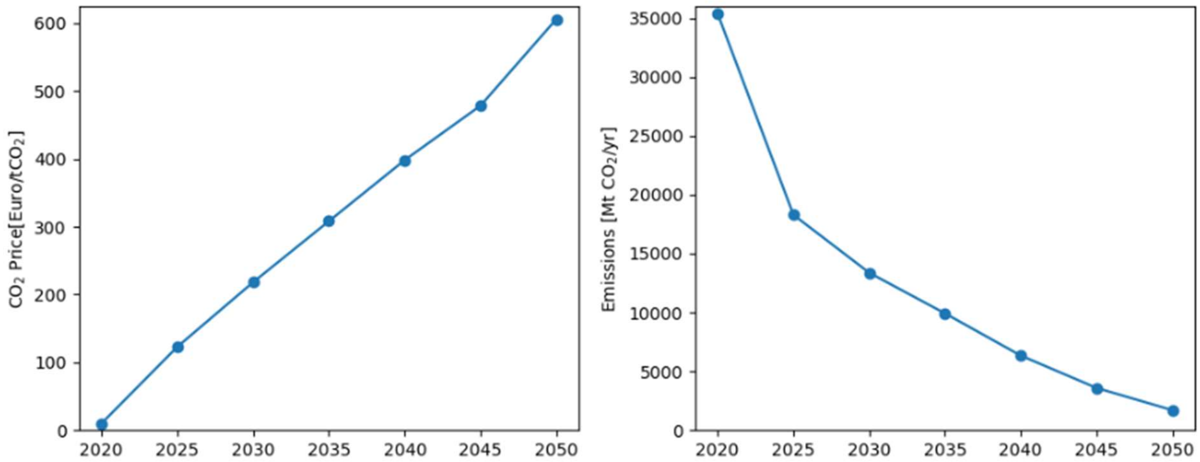


Figure 36: Carbon price and global CO2 emissions

The main differences between the base and the WHY scenario variants are expected in the residential sector. Figure 37shows emissions (left panel) and final energy consumption (right panel) in this sector for both the C400-Lin and the C400-Ln-WHY scenarios. We observe that residential emissions start to significantly decrease only after 2035. The residential sector does not completely decarbonize even by 2050, with global emissions from the sector dropping to about 1700 Mt CO2 by 2050. However, the reduction is quite sharp, especially considering that overall residential energy consumption increases from 94 to 104 EJ/yr at the same time-span. This is in line with the improvements in efficiency analyzed in our previous studies (Dalla Longa, 2021; Fragkos, 2023). The two scenario variants display only very small differences, the two lines almost perfectly overlapping in both plots. A more careful examination reveals that in the WHY scenario variant emissions from the residential sector are higher, while final energy consumption is generally lower than in the base variant.

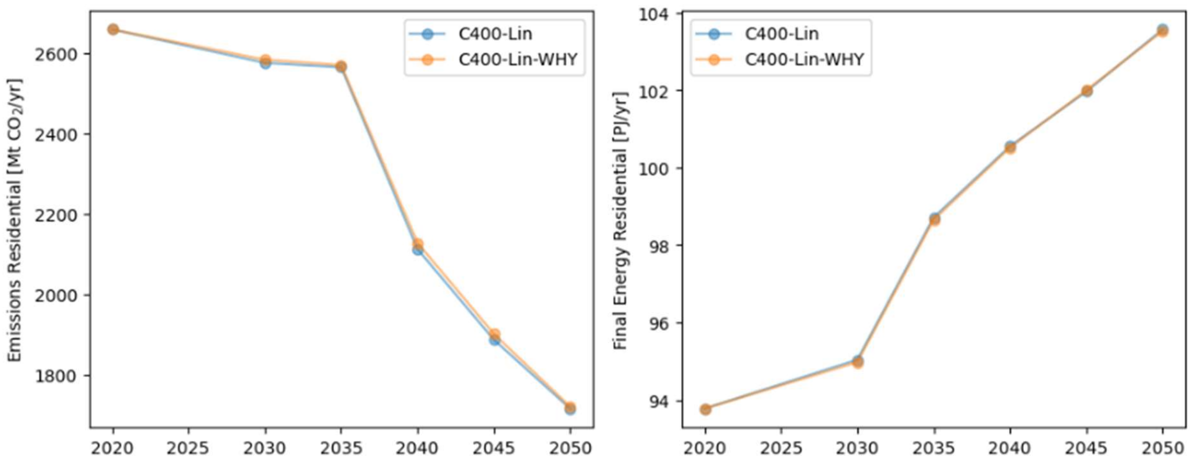


Figure 37: CO2 emissions and final energy consumption in the residential sector

In Figure 38we explore in greater detail the final residential energy consumption in our two scenario variants, C400-Lin and C400-Lin-WHY. The left panel presents a break-down of final energy consumption in the residential sector per type of energy carrier from 2030 onwards. The overall residential energy mix remains substantially the same in the two scenario variants as this is mostly driven by the high carbon pricing, though some small differences can be observed. These are shown in the right panel of Figure 6.4, which displays the changes in final residential energy consumption per carrier in the WHY scenario variant with respect to the base variant (the white dots representing the net difference between the two variants). While the differences are generally very small in magnitude, the WHY variant is characterized by a larger deployment of gas, liquid fuels and district heat, and a lower use of solid fuels, hydrogen and electricity (which is triggered by the increased electricity prices).

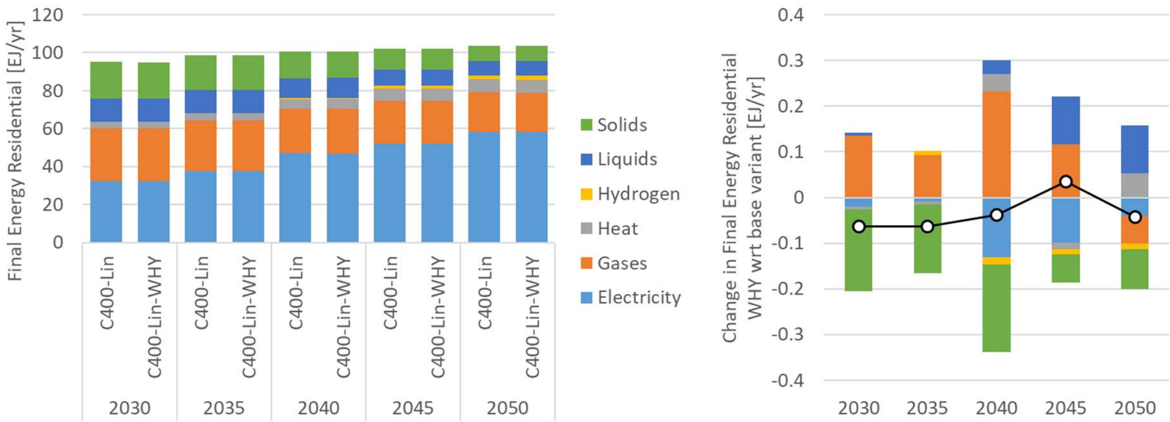


Figure 38: Final Residential Energy consumption, absolute values (left) and difference between WHY and base variants (right)

6.4. Discussion

The price variations introduced in the WHY scenario variant can be interpreted as simulating a policy measure geared towards the reduction of household energy consumption, as well as the displacement of consumption from daytime to night hours to align better with electricity supply. These goals are of course in line with the overarching objective of decarbonizing the energy system to meet the Paris goals. Additionally, the reduction of consumption and (especially) its displacement to other times of the day can help to reduce congestion problems and thereby maintain electricity prices at more affordable levels. The results obtained with the TIAM-ECN model, however, reveal that there are inherent risks in applying such policy measures without considering all their potential consequences. The WHY variant displays an overall reduction in residential energy consumption and a displacement towards night hours, in line with the increased tariffs. At the same time, however, in this scenario we observe a shift to more gas and liquid fuel use in the residential sector, which causes an overall increase in CO_2 emissions.

While the observed effects are rather small in magnitude, and would require a more detailed, region-specific analysis, the results obtained by coupling the WHY toolkit and the TIAM-ECN model still allow us to draw some important policy messages. First, a simple tariff change, as simulated in the scenarios analyzed in this document, can have unwanted consequences if not designed properly. While the tariff change does reduce residential electricity consumption and shift it to night-hours as expected, it also leads to increased CO_2 emissions from the residential sector, which are counterproductive for the ultimate objective of decarbonizing the energy system. Second, when evaluating a policy measure ex-ante, it is important to rely on a set of tools that allows us to consider different perspectives and angles. Third, the analysis presented here highlights the benefits of coupling the WHY toolkit with ESMs and IAMs, as the combination of these two modelling frameworks enables us to investigate the consequences of policy interventions in greater detail than by using any of them in stand-alone mode. The WHY toolkit can accurately estimate subtle changes in residential electricity demand induced by changes in tariffs, while their implementation in TIAM-ECN reveals their broader consequences in the context of stringent decarbonization scenarios.

7. Conclusions

The five Use Cases of the WHY project collectively underscore the adaptability and robustness of the WHY Toolkit, showcasing its effectiveness across various scales (from the local to the national and European levels) for informed decision-making in energy policy and sustainability. The goal is to provide an improved and transparent energy modelling framework focusing on the household sector and to address specific questions related to the evolution of the energy consumption at local, national, European, and global levels. The design of all Use Cases has been benefited from the active engagement of stakeholders and end-users, including policy makers, public authorities, businesses, and utilities. Stakeholders helped to define the most important aspects, questions, and policy interventions to be assessed in each Use from the local up to the European and global levels.

Notably, within the Positive Energy District in Maintal, the WHY Toolkit demonstrated its capability in assessing the impacts of interventions at the local level. The cooperation with the local technical bureau Alpha IC went very well and showed the potential of using detailed simulations of buildings developed in the WHY project rather than standardised approaches. Firstly, the results indicate that the standardised approach overestimates the thermal energy demand, a result that was also validated by the members of the technical bureau. In addition, the WHY toolkit provides the means to do additional simulations, such as the black out simulation which has shown that a primary factor for the duration during which a black out supply can be provided is the battery power and capacity. Furthermore, the results clearly indicate that a supply during a blackout situation would be technically possible, especially during the summer months, given a large enough storage system. During the winter months the situation is a bit more critical as not enough generation is met by a higher demand. However, certain challenges need to be considered. First, if the WHY Toolkit simulations were to replace the established approach, they would need to undergo rigorous testing and validation using field data from diverse local contexts. Failure to meet these standards could result in non-acceptance within the industry, leading to limited usage, especially as corresponding norms and laws for energy system planning would need to be adapted to accommodate these novel approaches. The absence of standardised interface with the toolkit created additional challenges that should be overcome to employ the WHY toolkit on a larger scale.

Another valuable insight derived from the Maintal Use Case pertained to the future utilisation of the WHY-Toolkit in such a context. While the options of presenting the WHY-Toolkit as a software solution for technical bureaus or delivering data as a service—where the technical bureau requests specific data simulated by a service provider—seemed enticing, both avenues appeared challenging. This was primarily due to time constraints on the technical bureau's part. The conclusion drawn was that a more viable approach would involve providing technical bureaus with a repository of pre-simulated households (a database of representative household data). From this repository, they could then procure individual household profiles, which could be utilised repeatedly. This approach would minimise the effort required to integrate these profiles into their respective software solutions. Another finding indicates that a notable drawback of the WHY-Toolkit lies in its restriction to the residential sector, highlighting the potential value gained through its extension to include the services sector, including offices and public/municipal sectors.

The Energy Cooperative Use Case demonstrated WHY Toolkit's efficacy in understanding and influencing residential energy consumption behavior tested in Goiner, a non-profit citizen energy cooperative in the Basque country, to simulate residential consumers' behaviour. Goiner aimed to understand how changes in its tariff structure would impact load profiles, purchasing strategies, and long-term goals, such as reducing energy consumption and alleviating energy poverty. The findings of the analysis showed that behavioural changes such as load shifting, and energy reduction actions are influenced by tariff complexity and perceived barriers. Interestingly, individuals seem to adapt more readily to Time-of-Use (ToU) tariffs compared to price signals (PSs), even when supportive tools are provided. Both ToU and PSs have proven effective in promoting energy reduction (especially at peak hours) and fostering flexibility. However, it is noteworthy that the gas tariff appears to induce a greater degree of flexibility, though caution is advised to account for potential confounding factors. Finally, the impact of these tariff changes appears to be consistent across various social groups, indicating a similar influence irrespective of socio-economic differences.

The Energy Community Use Case explores the role of local and citizen led engagement in clean energy transition. Specifically, this use case showcases how new energy community-based business models can contribute to making cities climate neutral by 2030. In this direction, the study employs a comprehensive methodology combining survey results from community partners and stakeholders. The study evaluates key drivers such as the state of play, business models, value sharing governance structures, replicability, scalability, and future projections. This use case provides a comprehensive understanding of the energy community landscape, emphasizing the diverse structures, services, financial tools, and challenges faced and how the WHY toolkit can be used to address them. The primary services offered by the renewable energy communities include the production and consumption of renewable energy, energy sharing, and renewable heat production. Financially, participants rely on a mix of primary investment, national or state aid, and EU aid. Risks identified involve financial issues, governance matters, and the underdeveloped nature of operational and business models. The main limitation in choosing the community model revolves around the challenge of balancing environmental, economic, and social benefits. Looking ahead, the Use Case indicates self-generation and self-consumption, ownership and democratization of energy systems, and emphasis on energy education as essential components for the success of renewable energy communities. Overall, the findings underscore the complexity and dynamism of these initiatives, reflecting a commitment to sustainable energy practices. The main challenges and barriers for the uptake of energy communities are also identified. These include the absence of clear and dynamic frameworks for the communities and issues related with the national and regional translation of EU directives. The hands tied perception with regard to regulatory aspects is frequent, as well as the consideration of being stocked in uncertainty and inequalities between autonomous communities, regions and countries.

The critical revision of the business model and the reflection around the cooperative models, has produced two important conclusions: on the one hand, there is agreement that the cooperative model suits perfectly to the communities, but on the other hand, a critical revision arises, since although the cooperative model is the prevailing one, the consideration that the cooperative spirit has been lost among the members and the fact that it is used as a tool rather than as a business philosophy prevails. In addition, the assumption of new roles by the energy communities (e.g. social services management, solidarity, alleviation of energy poverty, just transition agent) is an emerging opportunity. The necessity of providing the communities with the useful and reviewed governance structures and the necessity of reinforcing the participation in the existing structures is an important finding. The inclusion of socio material configuration elements in governance decisions, as an alternative, coming from the social innovation approaches, is still under study , but the preliminary findings show that this issue is related with the idea of revisiting the constituency purpose , mission and values and focusing on solidarity schemes. In general, the attitude in this respect is more reactive than proactive, with tools being used when situations of vulnerability or poverty are observed, but with a lack of contingency plans to deal with these cases in advance and with absence of specific projects. Finally, the imbalance that can occur in the case of diverse community members in terms of motivations, size, importance, has been seen as a concern for both the governance structures and the viability of the communities. In this sense, the need to balance the influence of unequal actors (e.g. a prosumer, municipality, association or an SME company) in the prevailing one member-one vote governance structures on governance structures is reported.

The EU Use case, enriched with insights from the WHY Toolkit, provides a comprehensive analysis of system-level implications and alternative policy interventions for achieving climate neutrality in EU buildings by mid-century. The integration of the data from the WHY Toolkit into PRIMES BuiMo helped to improve the model's representation of consumer behaviours regarding energy consumption, increasing their relevance for policy making. The analysis showed that even before the integration of data from the WHY Toolkit, PRIMES-BuiMo showed a behaviour similar to the one that was inferred by the kit (as the modelling parameters were based on data available in scientific literature); however, the integration of data from WHY Toolkit increased the model's integrity and transparency. The consistent integration of WHY Toolkit data into PRIMES-BuiMo leads to a comprehensive assessment that incorporates diverse indicators aligning with Sustainable Development Goals. The co-design of scenarios with stakeholders ensured a more inclusive and informed approach to policy interventions, enhancing the relevance and effectiveness of the EU Use case.

From a policy perspective, the Use Case showed that the deep decarbonisation of buildings in the EU is technically and economically feasible, and it can be achieved through the deep renovation of the building's envelope accompanied by the electrification of heat uses. The extension of ETS in the buildings sector incites the energy transition, but this needs to go hand in hand with bottom-up policies like for example subsidisation policies to promote the energy upgrade of the building envelope and the purchase of heat pumps by consumers. Comparing the model results on a MS level, it is obvious that the stringency and ambition of climate policies, or even the type of policy instruments that should be used to reduce emissions, should not be horizontal and should take into account the specificities of each EU Member State. In addition, policies need to also have a social dimension (e.g. to alleviate energy poverty risks), so such national specificities need to be taken into consideration. Insights into factors that influence the energy-related choices in the residential sector are explored and the EU Use Case offers a nuanced understanding of how these factors can be integrated into large-scale models. Detailed assessments of the potential for adopting energy efficient as well as low and zero-carbon solutions in the residential sector are conducted considering system effects and broader implications.

The Global Use Case focused on introducing price variations from the WHY toolkit into the global TIAM model, simulating a policy measure geared towards the reduction of household energy consumption, as well as the displacement of consumption from daytime to night hours to align better with electricity supply and effectively meet the Paris goals. The reduction of consumption and (especially) its displacement to other times of the day can help to reduce congestion problems and maintain electricity prices at more affordable levels. The results obtained with the TIAM-ECN model, however, reveal that there are inherent risks and challenges in applying such policy. The model-based analysis shows an overall reduction in residential energy consumption and a displacement towards night hours, in line with the increased tariffs. At the same time, however, a shift to more gas and liquid fuel use is observed in buildings, which causes an overall increase in CO2 emissions.

While the observed effects are rather small in magnitude, and would require a more detailed analysis, important policy messages are drawn from the coupling the WHY toolkit and the TIAM-ECN model. First, a simple tariff change, can have unwanted consequences if not designed properly, as it may lead to rising CO2 emissions due to increased use of fossil fuels in the residential sector, which of course are not in line with the Paris Agreement goals. Second, when evaluating a policy measure ex-ante, it is important to rely on a set of tools that allows us to consider different perspectives and angles. Third, the analysis highlights the benefits of coupling the WHY toolkit with Integrated Assessment Models, as their combination enables us to investigate the consequences of policy interventions in greater detail. The WHY toolkit can accurately estimate subtle changes in residential electricity demand induced by changes in tariffs, while their implementation in TIAM-ECN reveals their broader system-wide consequences in the context of deep decarbonization scenarios.

Overall, the study highlights the complex interplay of technical, socio-economic and policy factors in the energy domain, paving the way for more targeted and effective interventions in the future considering the local, national and sectoral specificities. The WHY Toolkit proves to be a valuable tool in this pursuit, offering adaptability and reliability across diverse use cases in highly differentiated contexts in the context of the clean energy transition.

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ANNEX 1: EXPLANATORY EMAIL OF THE GAS MECHANISM

Dear Partner,

You will already be informed that the adjustment mechanism or "gas cap" entered into force on 15 June 2022, published in Royal Decree-Law 10/2022 of 13 May. This RDL establishes a temporary mechanism to limit the influence of rising natural gas prices on the wholesale electricity market. If you want more information, here is the link to our website.

This new mechanism puts a new cost on the electricity supply bill depending on the type of contract each consumer has.

Currently your contract is exempt from this adjustment because it is subject to a fixed price with a certain permanence, so the energy you consume is acquired in advance.

This exemption shall end with the renewal of prices or the extension of the contract.

Neither the Royal Decree Law nor the National Commission on Markets and Competition (CNMC) has clearly indicated how the adjustment of the new mechanism will affect the invoice. Goiener has decided that the most transparent way to do so is to add a new line on the invoice with the cost associated with the consumption of his contract.

Best regards,

ANNEX 2: Results of the two tariff interventions in the Energy Cooperative use case

The table included in this annex contains detailed results of the impact assessment of two changes of tariff. In each cell of the table we present the reduction of energy consumption in % over the baseline period (March 2019 - February 2020). Positive values means actual reduction and correspondingly, negative values means increase in the energy consumptions. The column Overall shows the total reduction on energy consumption while Peak, Flat and Valley columns show the total energy reduction on the particular hours of the day defined by the different tariff structures. In particular, what is expected is a minor positive value on Overall and Flat columns, a strong positive value on Peak and a strong negative value on Valley.

Condition	Group	Time of Use				Price Signal			
		Overall	Peak	Flat	Valley	Overall	Peak	Flat	Valley
ALL	ALL	1.1	9.4	-3.2	0.6	6.9	15.4	1.2	6.3
Previous experience ToU	YES	0.8	12.0	-2.7	0.0	7.2	17.0	2.1	6.9
Previous experience ToU	NO	1.0	9.1	-3.6	0.6	6.7	15.1	1.0	6.1
New client	YES	1.4	7.9	-0.9	1.3	7.4	14.9	2.3	6.5
New client	NO	1.0	9.6	-3.4	0.5	6.9	15.5	1.1	6.3
Contracted power	<2kW	0.1	6.3	-0.3	0.1	1.1	8.0	0.1	0.9
Contracted power	2kW_5kW	0.9	10.2	-4.7	0.3	6.6	16.0	0.6	5.9
Contracted power	>5kW	2.2	6.0	2.7	2.5	10.9	12.8	8.4	10.7
Province	Araba	1.0	11.0	-4.0	0.1	7.0	16.7	1.1	6.1
Province	Bizkaia	1.5	8.9	-2.3	0.9	7.3	15.6	2.2	6.6
Province	Gipuzkoa	1.0	9.6	-3.9	0.5	6.7	15.4	0.7	6.5
Province	Madrid	1.3	7.9	-1.7	0.9	2.1	7.8	0.1	4.5
Province	Navarra	0.8	9.6	-3.5	1.0	6.8	14.6	1.4	5.8
Climate	Atlantic	-1.4	9.9	-8.8	-1.3	8.6	20.5	0.4	7.0
Climate	Continental	0.0	7.5	-5.9	-0.3	7.8	17.5	1.9	7.0
NACE	Homes	1.0	10.1	-4.2	0.4	6.9	16.1	0.9	6.2
NACE	Public Buildings	2.0	5.6	-0.3	2.6	8.7	10.8	1.9	8.9
NACE	Warehouse	1.5	1.8	0.3	1.6	3.8	5.8	2.1	3.1
NACE	Retail	2.4	-0.1	8.9	3.9	9.7	4.2	10.1	10.5
NACE	Other	0.0	-0.3	0.8	0.0	5.1	0.5	5.1	4.4
Equipment	Electric Heater	1.0	8.2	0.4	0.4	13.9	24.0	5.7	13.3
Equipment	Electric Kitchen	-0.6	12.5	-9.4	-1.4	8.6	19.5	-0.8	7.7
Equipment	Heat Pump	-4.7	3.1	1.7	-3.2	7.6	14.8	6.1	5.5
Type residence	Main	-1.0	10.6	-8.9	-0.9	8.1	18.8	0.8	6.7
Type residence	Other	-6.2	0.6	5.6	-5.8	17.9	9.9	-1.7	22.6
All Day at Home	YES	-1.8	7.0	-10.6	-0.8	7.0	19.6	-2.6	6.5
All Day at Home	NO	0.1	10.6	-6.3	-1.8	9.1	18.2	3.9	6.8
Same pattern weekend	YES	-2.0	7.4	-11.3	-1.6	7.8	19.6	-1.0	6.7

Condition	Group	Time of Use				Price Signal			
		Overall	Peak	Flat	Valley	Overall	Peak	Flat	Valley
Same pattern weekend	NO	1.4	12.1	-3.0	-0.1	8.2	19.8	4.3	6.5
Type of building	Apartment	-0.1	9.6	-8.4	-0.3	8.3	19.2	-0.3	7.5
Type of building	Other	-4.5	9.5	-7.9	-4.1	8.8	26.1	3.6	4.3
Rent	YES	-0.8	10.7	-8.8	-0.9	8.1	19.1	0.9	6.6
Rent	NO	-4.8	5.0	-6.7	-3.1	8.2	10.1	-7.4	7.3
Building age	>1980	-1.6	10.3	-8.3	-1.0	9.0	18.9	3.2	8.0
Building age	<1980	-1.0	8.8	-8.9	-1.2	6.9	18.4	-0.3	5.3
EPC	A-C	-1.8	7.2	-14.1	-2.7	4.9	24.1	-5.7	3.7
EPC	D-G	-2.1	8.0	-10.1	-2.0	10.4	26.0	-1.8	12.3
EPC	DK-NO	0.4	10.7	-5.2	0.0	8.4	17.9	3.2	6.5
Type of municipality	City	-1.0	8.9	-7.2	-0.7	8.5	19.6	0.9	7.1
Type of municipality	Rural	-1.0	11.0	-8.9	-2.3	7.4	18.5	0.6	6.1
Saving capacity	>1	-0.5	8.7	-9.3	-0.7	8.7	18.5	0.6	7.1
Saving capacity	<1	-2.8	12.0	-4.8	-3.9	4.3	18.5	4.8	2.9
Education	Universitary	-0.6	8.9	-8.5	-1.2	8.3	19.1	1.9	6.6
Education	Other	-1.6	11.7	-9.7	-1.5	9.1	16.0	-2.7	6.7
Total surface	<80	1.4	13.2	-10.3	0.9	10.5	22.1	-2.9	8.8
Total surface	80_120	-1.9	7.2	-8.5	-2.3	6.6	17.1	1.5	5.3
Total surface	>120	2.5	14.2	-5.5	1.0	11.2	23.1	7.2	9.7
Climate awareness	<8	-1.7	12.0	-8.0	-2.2	8.5	20.6	2.8	8.1
Climate awareness	8	-0.1	6.4	-9.2	-0.7	8.1	18.2	-0.9	5.6
Climate awareness	>8	2.5	8.6	-9.2	1.0	7.7	17.4	2.0	6.9
Energy transition knowledge	<6	-1.7	13.9	-9.4	-2.6	7.0	20.9	-2.6	3.8
Energy transition knowledge	6_7	-2.5	8.4	-10.0	-2.5	9.2	19.0	0.8	7.2
Energy transition knowledge	<7	3.7	6.9	-2.0	5.1	7.1	14.4	5.6	8.1
Energy community knowledge	YES	-1.1	7.8	-7.1	-0.3	7.8	20.0	3.7	6.1
Energy community knowledge	NO	-1.5	13.6	-9.5	-2.1	8.7	20.2	-2.1	7.9
Citizen role	ACTIVE	1.1	10.1	-6.5	0.3	8.4	19.6	5.0	7.6
Citizen role	NO ACTIVE	-1.7	10.8	-10.8	-2.3	8.3	18.0	-1.8	6.8
Climate role	ACTIVE	-1.4	12.1	-8.9	-1.4	9.1	20.3	2.8	8.2
Climate role	NO ACTIVE	-0.8	8.3	-8.6	-0.9	7.5	18.4	-0.1	6.5
Energy budget	<1.5	1.2	7.8	-4.4	0.2	8.2	15.8	3.7	7.3
Energy budget	1.5_3	-2.2	9.9	-10.1	-2.3	8.9	21.4	3.3	7.5
Energy budget	>3	-2.1	10.0	-9.0	-1.1	9.5	21.3	-1.0	8.0
Energy poverty	Risk	0.9	8.6	-12.3	-0.6	8.9	23.8	0.6	8.2
Energy poverty	Low	-2.6	9.2	-8.2	-2.1	6.2	17.1	-1.2	4.8
Energy poverty	Not	-0.3	13.5	-7.1	0.4	11.5	20.8	4.4	11.0
Gender composition	Majority of woman	-2.0	8.5	-11.1	-2.9	5.5	18.9	-2.9	4.0

Condition	Group	Time of Use				Price Signal			
		Overall	Peak	Flat	Valley	Overall	Peak	Flat	Valley
Gender composition	Parity	-0.6	11.9	-8.2	-1.4	8.3	20.0	2.3	7.5
Gender composition	Majority of man	-3.3	4.1	-5.3	0.1	10.3	19.3	6.1	8.4
Age	<40	1.1	10.4	-4.3	4.2	7.7	15.8	0.2	6.3
Age	40_60	-1.6	9.7	-11.6	-1.7	7.6	20.9	-3.3	6.8
Age	>60	-1.3	9.9	-2.6	-2.1	8.5	17.4	9.3	8.1
Collectives at risk of poverty	Single parent families	12.9	32.9	-8.3	9.6	21.3	37.3	5.0	15.2
Collectives at risk of poverty	Large families	-2.5	10.8	-9.5	-2.7	6.7	21.2	-6.3	5.5
Collectives at risk of poverty	Retired	-0.9	8.4	5.0	-1.7	7.8	13.4	9.4	6.3
Collectives at risk of poverty	Old living alone	-4.8	9.1	-4.8	-7.1	-8.3	15.3	-6.0	-9.4
Collectives at risk of poverty	Overcrowded homes	-2.1	13.2	-13.2	-3.9	9.0	24.8	-15.6	1.6
Collectives at risk of poverty	Overspending	-1.2	10.1	-8.8	-1.2	8.1	18.5	0.8	6.7
Behaviour subjective	5	-2.0	5.9	-4.9	0.0	7.1	16.7	1.3	4.5
Behaviour subjective	8	-1.4	10.2	-11.6	-1.5	9.7	21.7	-2.1	8.5
Behaviour subjective	15	2.5	18.1	-5.0	-0.6	9.0	21.3	2.1	7.6
Behaviour objective	5	-1.8	19.6	-6.6	-0.5	10.4	25.8	8.4	7.3
Behaviour objective	6	1.1	9.2	-10.4	-1.7	8.1	16.3	-2.5	6.7
Behaviour objective	7	-0.6	5.7	-8.9	-1.8	6.9	14.4	2.5	5.5
Behaviour objective	8	-3.1	-0.7	-24.9	1.7	14.9	19.6	13.7	15.8
Behaviour objective	9	0.6	17.9	-19.4	1.3	9.9	24.6	-13.1	6.9
Behaviour objective	19	-8.7	1.2	-2.2	-9.2	3.7	10.7	-1.5	4.7

ANNEX 3: Results of the blackout energy services prioritisation

The table included in this annex contains the scores provided by the samples taken in Spain and Latin America to the question. The Power Outage columns provide the scores answered to the following question:

> "Assume that the supply of electricity suffers frequent but short interruptions in your neighbourhood due to a bad grid infrastructure. This way, only a small number of houses are affected and the general communication and service infrastructure is still working. The utility provider has a partial solution to temporarily provide a limited local electricity supply that cannot support all the normal loads. So they are asking which services you would prefer in order to estimate the resulting loads. Please, rank the following energy services from 0 to 10 stars where 0 stars means it is extremely low priority for you and 10 stars is absolutely needed for you:"

On the other hand, columns labelled Blackout answered the following question:

> "Assume that full black-outs could occur in your region. This means **the entire region** (and possibly even beyond) **is without electricity supply for at least a day or two**. Please note that in this situation **several services are not working or working** only in a very limited way (like cellular network, internet, television, etc.). The utility provider has a partial solution to provide limited local electricity supply but cannot support the electricity supply all the normal loads so they are asking which loads they should prioritise. Please, rank the following energy services from 0 to 10 stars where 0 stars means it is extremely low priority for you and 10 stars is absolutely needed for you: "

Finally, the columns labelled diff provide the difference between the two scores provided by the different samples.

	Blackout			Power Outage		
	LATAM	SPAIN	DIFF	LATAM	SPAIN	DIFF
Clean	5.68	3.26	2.42	6.76	4.06	2.7
Communications	6.57	5.55	1.01	7.49	6.02	1.47
Cook	7.65	7.7	-0.04	8.01	7.79	0.22
Cool	5.29	1.78	3.51	6.01	2.16	3.86
DHW	7.48	6.51	0.97	8.12	6.94	1.18
EMS	5.77	3.22	2.55	7.02	4.6	2.42
Entertainment	5.58	4.24	1.34	6.56	4.6	1.96
Fridge	8.68	7.38	1.3	9.15	7.64	1.51
Heat	5.74	6.55	-0.82	6.46	6.83	-0.37
Hot water	4.64	3.23	1.4	5.85	4	1.85

	Blackout			Power Outage		
	LATAM	SPAIN	DIFF	LATAM	SPAIN	DIFF
Light	7.49	6.06	1.43	8.18	6.43	1.75
Logistics	4.19	2.6	1.59	4.97	2.99	1.97
Security	5.99	1.72	4.27	6.99	2.12	4.87
Smart	2.94	1.51	1.43	3.92	1.84	2.08
Telework	7.13	3.94	3.2	7.78	4.41	3.37
Travel	3.99	1.98	2.01	5.04	2.49	2.55
Ventilation	4.86	1.5	3.35	5.85	1.89	3.96
Water	9.31	8.91	0.4	9.49	8.83	0.66
White	5.33	4.61	0.72	6.66	5.25	1.41

ANNEX 4: Exploring Model-Based Decarbonization and Energy Efficiency Scenarios with PROMETHEUS and TIAM-ECN

The annex includes the link to the already published paper in the peer-reviewed scientific journal "Energies". The reference can be found here: P Fragkos, F Dalla Longa, E Zisarou, B van der Zwaan, A. Giannousakis, A Fattahi, Exploring Model-Based Decarbonization and Energy Efficiency Scenarios with PROMETHEUS and TIAM-ECN, Energies 2023, 16(18), 6421; https://doi.org/10.3390/en16186421