WHY

D1.3

Use Case Definition: objectives, scope, variables

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EXECUTIVE SUMMARY

This deliverable includes the definition of the five Use Cases of the WHY project, which capture a wide diversity of contexts from the micro-grid to energy community, national, European, and global level. These Use Cases play a central role in the project, as through their application in diverse situations, the WHY Toolkit and models will be tested and validated. This deliverable aims to provide detailed definition and design for the Use Cases, which will be then operationalized and carried out in WP5 using the WHY Toolkit and Energy System Models (ESMs). In this way, the impacts of WHY modelling enhancements on energy and climate strategies at different jurisdiction levels, from the micro-grid and energy communities to the European and global levels.

The design of all Use Cases has been greatly benefited from the active engagement of stakeholders and end-users, including policy makers, public authorities, and utilities. This has taken various forms, depending on the specificities of each Use Case ranging from the organisation of (online and in-person) workshop to interviews, focus groups on online questionnaires. In all cases, stakeholders helped to define the most important aspects, questions, and policy-relevant insights to be assessed in each Use Case of WHY. An active communication channel with stakeholders has been established and will be extensively used to discuss the results of the Use Cases and identify policy-relevant recommendations.

Various aspects were considered in the definition of each Use Case, including:

a) the types of potential interventions to be assessed (with the support of relevant stakeholders);
b) the external policy and regulatory framework at different jurisdiction levels, including both those already legislated and implemented as well as possible future policies and strategies targeting EE improvements, fostering DR actions, or the electrification of services,
c) the load profiles to be generated and integrated in the different use cases including the number and characteristics of different residential loads and their temporal and spatial scale,
d) The development of the external and internal variables (or aspects) that affect energy consumption (weather, energy prices, energy taxes, socioeconomic developments, incomes, behavior, cultural, grid access, etc.), based on the latest available official or scientific sources,
e) The Sustainability Assessment Model, based on a collection of the most relevant KPIs in each Use Case to measure the technical, economic, environmental, and social sustainability.

The study also includes the relevant information needed for the implementation of the scenarios and policy interventions with the WHY Toolkit and the links with large-scale ESMs (PRIMES, TIAM-ECN, PROMETHEUS), focusing on the European and global Use Cases where the use of ESMs was identified as important.

The deliverable serves as a starting point and as a basis for the analysis in WP5, providing key input assumptions, policy framework, definitions, policy interventions, and KPIs to be used for the actual development of the five Use Cases through scenario implementation, simulations, and policy impact assessment using the WHY Toolkit.

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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 gases emission. Energy System Models (ESM) are tools that help energy analysts, planners, and policy makers 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 for short and long-term household energy consumption modelling with the aim to improve the understanding of what, when, how much, and why energy is consumed at households. The WHY Toolkit builds on the causality chain to model the energy demand, building on associations between measurable variables. The WHY Toolkit will be applied and tested in five Use Cases, capturing a wide diversity of contexts from local micro-grid and energy community to national, European, and global level.

The Use Cases are a key part of WHY project ambition to create an improved and transparent energy modelling framework and improve the understanding for energy consumption in the buildings sector. The Use Cases will serve to test, validate, and demonstrate the WHY Causal modelling toolkit and its links to leading Energy System Models, through the creation of model plug-ins. To ensure consistency and transparency, the data and information required for the definition and design of the five Use cases are presented in detail in this report. The analysis provides details for the Use cases, which demonstrate the relevance and adequacy of the WHY modelling toolkit to enhance the modelling of energy consumption in the residential sector and show the ability of the proposed approach to answer specific questions related to the evolution of the energy consumption at local, national, European, and global levels. The use cases will also act as a real-life proof of concept of the WHY research methodology. Through the five Use Cases, the modelling enhancements and linkages with ESMs will be validated through a comparison of modelling results with previous studies (without the use of WHY Toolkit) to re-assess policy instruments and interventions. The WHY Use cases provide an in-depth analysis on specific topics (e.g., energy community, energy cooperative) and geographical regions (local micro-grid, national), which are important in the current EU energy policy landscape. The use cases are further enhanced and fine-tuned through stakeholder workshops during the course of the project. The actual development of the Use Cases using the WHY Toolkit will be conducted in WP5.

The aim of the report is to define the five Use Cases, considering the following aspects:

a) the types of interventions to be assessed (using information gathered by relevant stakeholders) and their classification in terms of importance,

b) the identification and development of external and internal variables and aspects that affect energy consumption (e.g., energy prices, socio-economic developments, weather, consumer behaviour) based on official and scientific data sources,

c) the external policy framework in place at different jurisdiction levels, including already legislated and implemented as well as possible future policies and strategies targeting energy efficiency, emissions reduction, and electrification,

d) the load profiles to be generated and integrated in different use cases,

e) the sustainability assessment based on a collection of KPIs that measure the four aspects of sustainability (technical, economic, environmental, and social).

The analysis in each Use Case is complemented by stakeholder engagement via appropriate forms, ranging from the organisation of workshops (online or in-person) to interviews, surveys, or focus groups. The information provided by stakeholders is crucial to ensure that the final set of scenarios and interventions assessed with the WHY Toolkit are relevant for each Use

Case. Finally, a first attempt is made to identify how the Use Cases will be actually implemented, i.e., by linking with large ESMs or with direct use of the WHY Toolkit.

The deliverable at hand will lay the foundation for future work in WHY. Together with the output of D1.1 (stakeholder requirement analysis) and D1.2 (state of the art on research for energy system models, policies, legislation, and initiatives), this report will provide the basis for the WHY Use Cases development in WP5. The final set of scenarios and interventions of each Use Case will be co-designed with relevant stakeholders, implemented, and assessed using the WHY Toolkit and its links with large-scale Energy System Models.

The report is structured as follows: Section 2 provides an overview of the five WHY Use Cases and the broad methodology used. Sections 3-7 provide details on various aspects related to the Use Cases (Section 3 focuses on Gniebing microgrid, Section 4 on Energy Cooperative, Section 5 on Energy Communities, Section 6 on the European energy strategy and Section 7 on global energy scenarios). Section 8 concludes.

2. Defining the WHY Use Cases

The modelling enhancements and improvements developed as part of WHY project will be validated in 5 different Use Cases. Every Use Case has a unique combination of geographic scope, temporal framework, technologies, methodologies, and policy objectives. The table below includes a summary of the WHY Use Cases.

Table 1: The WHY Use Cases

Scenarios	Geo.	Temp.	ESM	Objective
Gniebing Microgrid Operation	City	Hourly / Yearly	Load Profile Generator	• Improve load forecasting under normal operation • Create load profiles under black-out operation
Energy Cooperative O&P	Regional	Hourly / Yearly	Own Model	• Improve load forecasting under normal operation • Test the impact of new policies / tariff have on the utility
Energy Community	City	Hourly / Yearly	Load Profile Generator	• Create tool to size the different components and to define the business and governance models • Help designing interventions that increase the participation on the energy community
2030 & 2050 European energy strategy	European	2030 / 2050	PRIMES	• Create different load profile under different interventions to foster EE, DG, DR and ES • Assess the impact of different EE campaigns
Global energy scenario	Worldwide	2100	TIAM-ECN	• Create different load profile under different interventions to foster EE, DG, DR and ES • Project business as usual energy consumption

2.1. Methodology used in the Five Use Cases

The five Use Cases share a similar use context, acting as proof of concept and testing/validating the modelling improvements developed in the WHY project, in particular the WHY Toolkit. Their objective is to assess the impacts that a set of interventions (e.g., policy measures) may have on the energy system development, energy costs and prices and CO_2 emissions using the WHY modelling tools. To support policy decisions, the actor or entity (modeler, researcher, policymaker, utility, energy community or other) will use the WHY toolkit to assess the policy impacts before the policy is implemented.

To start, the modeler, who designs the scenario, defines the geographic and temporal scale, the policy interventions to consider, the household segments that are going to be affected and any other information needed to run the modelling tool (specific to each Use Case). Then, the modeler retrieves all this information and configures both the WHY Toolkit and the relevant Energy System Model (which will be soft-linked with the WHY Toolkit). Finally, the modeler runs the required simulations and gets the results which can then be analysed and delivered to policy makers, industries, citizens, and other relevant stakeholders. The simulations are iterative. First, the energy system model asks the WHY Toolkit for an estimation of the load profile of the residential segments under the set of interventions defined in the scenarios and provides them with a price signal. Then, the WHY Toolkit performs an estimation and gives the ESM a load profile. Next, the ESM performs the simulation of the rest of the energy system and finally, the time step advances, and the process is repeated until the end of the simulation is reached. At this point, the modeler will retrieve the results of the simulations in the form of KPIs for the final and intermediate status of the system.

Due to the large diversity of the WHY Use Cases, different Use Case Manager (UCMs) have been allocated to each Use Case for leading their definition and development. These UCMs come from different WHY partners which have large expertise in the specific Use Case. In addition, the Use-Case Coordinator (Panagiotis Fragkos - E3M) holds the responsibility of managing and coordinating all activities related to the different exploitation possibilities and is the nexus between partners, Use Cases and external stakeholders. The different Use Case Managers are:

- Gniebing Microgrid: Thomas Nacht (4ER)
- Energy Cooperative: Chris Merveille/Leire Astigarraga (Goiener)
- Bilbao: Cruz Borges (UD)
- EU strategy for 2030 and 2050: Panagiotis Fragkos (E3M)
- Global energy scenarios: Francesco Dalla Longa (TNO)

Despite their differences, there are several issues to be considered in all Use Cases. These include: the scope/boundaries of the Use Case under examination, the external policy framework, and types of policy interventions to be assessed, the external and internal variables, the Sustainability Assessment, the limitations of the Use Cases, the expected results, and the design of Use Case implementation in Energy System Models. These are presented in detail in the following sections.

2.2. Description of the WHY Use cases

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 microgrid and city level up to the national, EU and global scale) with and without the WHY Toolkit. The section briefly describes the WHY Use Cases, which will be analysed in subsequent sections. In particular:

Gniebing microgrid operation. The Microgrid Use Case is based on real-life implementation of a Microgrid in the Austrian municipality of Gniebing in south-eastern Styria. The Gniebing Microgrid aims to support a limited number of consumers during a blackout scenario. It consists of two diesel generators and a hydro-plant. No battery storage system has been installed yet and the diesel generators are used for the black-start and act as control reserve of the grid. The Use Case focuses on renewable energy sources that will replace the diesel generators whenever possible to reduce the amount of diesel consumed. The Use Case will conduct a detailed comparison between the current numbers of consumers that could be supplied and a maximized utilization of the generation and grid capacities resulting from the improved energy demand predictions

Energy cooperative Operation and Planning. Energy retailers want to know as precisely as possible how much energy end users will need. This allows them to optimize the purchase of energy, reduce deviations, risks and therefore penalties and secure futures in a more accurate way, which means tariffs that are fitting for the customers. Having an accurate view of consumer demand is also critical for setting the margin in electricity rates, especially when making tighter purchases. Currently consumer demand is estimated based on the existing consumer portfolio (aggregate consumption profile) and extrapolating considering the growth forecast based on indices of previous years, the annual consumption curve, and the weather conditions. With the use of WHY Toolkit, Goiener will be able to perform more accurate demand forecasting by taking into consideration not only climatic factors but other non-climatic factors that are difficult to simulate on a massive scale. This Use Case will assess the improvements of using the WHY Toolkit in the daily operation and on the strategic planning of new incentives, tariffs, actions, or campaigns of Goiener.

Energy Communities. In recent years, energy communities have become a "hot" topic widely discussed at city and community levels, while also attracting attention in energy policy debates held at EU and national levels. However, despite manuals and best practice guidebooks becoming increasingly available[1] there is still a lack of tools to help municipalities in the setup of Energy Communities in line with the Electricity Market Directive and Renewable Energies Directive. This Use Case will develop tools to support municipalities on setting up Energy Communities. The primary objective is the selection of the policy mix that increases the likelihood of achieving an optimal energy community, along with the development of tools that enable the operation of the energy community, i.e., the tariff systems, business model, etc. Using the WHY toolkit, a set of practical recommendations to build and operate energy communities will be developed. The platform allows simulating the energy needs of citizens, the use of appliances and the impact that citizen demand has on different distribution networks.

European energy strategy for 2030 and 2050. Energy efficiency and decarbonization of the European building stock are hailed as key drivers of Europe's transition to climate neutrality by mid-century, as part of the EU Green Deal and Fit for 55 policy package. However, most analyses on emission reduction targets in buildings are based on large-scale models that do not include a granular representation of load profiles of energy consumers and do not model the specificities of different building types. To overcome these challenges, in this Use Case the WHY Toolkit will be soft-linked with the PRIMES modelling suite (especially PRIMES-Buildings module), one of the most widely used and well-established models at EU and Member State level. It has been used to provide quantitative model-based assessment of EU energy and climate policies (Clean Energy for all Europeans- Winter package 2016, Energy Efficiency directive, Fit for 55 package, "Clean Planet for All" strategy). A two-way interlinkage of the WHY Toolkit with the PRIMES model will be carried out based on data interface and a disaggregation of PRIMES results (based on representative households for each country) to capture consumer differences, idiosyncratic behaviours and load profile granularity provided by WHY Toolkit. The Use Case will offer quantitative evidence on different pathways to decarbonize the EU buildings sector by 2050, that promote energy efficiency, electrification, fuel switch, net-zero energy buildings and deep renovations, smart appliances/grids, demand-side management, and co-benefits to achieve climate neutrality by 2050. Based on detailed load modelling and consumer representation, the EU Use Case will re-assess various policy instruments (as identified in the targeted stakeholder workshop[2]) consistent with the revised

1 Caramizaru, A. and Uihlein, A., Energy communities: an overview of energy and social innovation, EUR 30083 EN, Publications Office of the European Union, Luxembourg, 2020,ISBN 978-92-76-10713-2, doi:10.2760/180576, JRC119433
2 Details on this stakeholder workshop for the EU Use Case will be presented below.

Energy Efficiency Directive, the Fit for 55 package and the EU's commitment to turn climate neutral by 2050 as part of the EU Green Deal.

Global energy scenarios. The Paris Agreement signed by almost all countries globally has set the goal of limiting global warming to well below 2ºC and pursuing efforts to bringing it down to 1.5ºC, which requires a substantial drop in global Greenhouse Gas (GHG) emissions. This can be achieved only through large and rapid changes in the energy system leading to net-zero emissions by or slightly after 2050 (Van Soest et al., 2021). Key drivers are the uptake of renewable energy, electrification of end uses, and energy efficiency improvements which are commonly assessed using large-scale energy-economy and Integrated Assessment Models. However, these models typically do not represent in detail energy demand, consumer behaviour and energy efficiency measures. To improve the modelling of energy demand in global mitigation scenarios, the Global Use Case will link the WHY Toolkit with the integrated assessment models TIAM-ECN and PROMETHEUS, which have a global coverage and represent the energy system dynamics disaggregated in more than 20 distinct regions. A comparison will be presented between the outcomes of the global models when a soft link with WHY Toolkit is activated. This Use Case aims to develop a plug-in to soft-link the WHY Toolkit with TIAM-ECN (and other TIMES-based models from the wider TIMES modelling community) and PROMETHEUS and asses the systemic effects of the improved representation of energy demand from the built environment on long-term global energy scenarios, in line with the Paris agreement.

Last, a detailed **Social Impact Assessment for each WHY Use Case** will be developed that will consider not only technical, economic and environment indicators but also the impacts on the society, in particular on reducing energy poverty and social inequality and mitigating the risks of social exclusion. This assessment is conducted based on a methodology developed by the University of Deusto and is described in section 2.3.

2.3. Methodology for Sustainability Assessment Model

Each Use Case will also include a list of Key Performance Indicators (KPIs) to be included in the WHY toolkit. The focus is not only on ensuring that the WHY toolkit includes all relevant techno-economic variables for the Use Case, but also environmental and especially social variables. The objective is to implement as many KPIs as automatic outputs of the WHY toolkit and the ones that cannot be calculated directly, to provide as much information possible to the researchers involved (this is mainly related to the social variables).

To this end, a template with key parameters has been filled by each Use Case responsible. The template consists of the following parameters:

ID: an autonumeric number to uniquely identify the KPI.

Title: a title describing the KPI.

Description: a short summary of the KPI and its importance.

Unit: the physical unit used to measure the KPI.

Type: technical, economic, environmental, or social.

Inputs: Information needed to calculate the KPI. The information from this field will be used in T5.1 to retrieve the information from the Use Case.

Methodology for calculation: description of the methodology proposed to calculate the KPI (including formulas when possible).

Objective: maximise, minimise, threshold or qualitative.

Comments: any relevant comment to help in the implementation of the KPI

The template has been reviewed by social impact experts from within the consortium and a discussion has been held. The objective was not only to achieve a consensus but to foster the discussion around the Use Case from a social impact perspective. The results of this activity will be presented in each Use Case section, while the complete list of KPIs per Use Case are presented in Annex 1 of the deliverable.

3. The Gniebing Use Case

The Gniebing Microgrid use case is based on real-life implementation of a Microgrid in the Austrian municipality of Gniebing aiming to support a limited number of consumers during a blackout scenario.

3.1. Objective and Scope of the Use Case

Gniebing-Weissenbach was formerly an individual municipality in Austria and is now part of the larger municipality of “Neue Stadt Feldbach”. The hamlet of Gniebing itself, which is in the center of Gniebing-Weissenbach is home to 991 inhabitants. Figure 1 shows an aerial view of the region. It can be seen in the figure that most buildings are aligned to the main roads through the hamlet and the hamlet has a rather rural and agricultural structure.

Figure 1: Aerial view of Gniebing

During the last few years, the topic Blackout has gained substantial popularity in the municipality of “Neue Stadt Feldbach”. Different R&D projects and actions backed by local authorities are trying to mitigate the effects of such an event. As a part of these actions, different spots have been defined throughout the region as “light-towers”. These are places that, inhabitants can use when in need of shelter, help, or information. In order for these “light-towers” to work during such an event, they need to be supplied with back-up generators for emergency electricity supply. One of these “light-towers” is also situated at the municipal office of Gniebing.

During the development of the Gniebing “light-tower” the local DSO and energy supplier, called “e-Lugitsch” advanced the idea of providing back-up supply to the local “light-tower” by creating a plan to maintain grid operation in case of a failure of the superior grid. The local grid of Gniebing is operated at 10 kV and low voltage and is connected to the interregional DSO’s grid at a coupling point in the city of Feldbach. Figure 2 shows the grid of e-Lugitsch, which goes beyond the borders of Gniebing.

Figure 2: Grid of the DSO and energy supplier e-Lugitsch

While it is not possible to maintain the operation of the entire grid, the idea is to provide emergency supply to a selected group of consumers within the hamlet of Gniebing. For that purpose, the grid operator is expected to separate the grid of the hamlet of Gniebing from the rest of the 10 kV grid and go into islanding mode (emergency grid operation); and most regular consumers to be switched off. To maintain emergency operation, two 250 kVAr Diesel-generators should act as the main source of energy and maintain a stable 50 Hz grid. Additionally, the option of including the local run-of-river plant (150 kW) is considered as well as local PV generators in the range of 50 kW to 200 kW.

The goal of this emergency supply is to provide the local “light tower” as well as the fire fighters and some other selected critical buildings, including the control room of e-Lugitsch itself with electricity. For the emergency strategy, a very conservative approach has been adopted. The generation capacity available for the emergency supply surpasses the expected consumption values, yet not being familiar with the consumption behaviour of individual households or how this behaviour may change if only limited electric energy is available prevents the DSO and energy supplier from being included in the emergency supply.

The lack of balance between generation capacity and electricity consumption has increased further since, as of lately, the municipality equipped several buildings with individual back-up generators, thus the number of potential users of the emergency grid operation has diminished. This would allow for additional consumers, potentially residential users, to be included in the system.

This defines the main goal of this Use Case, which is to use the WHY-Toolkit to simulate the behavioural change of the residential consumers in the hamlet of Gniebing in order to obtain a deeper knowledge on the load behaviour of these consumers. The load behaviour should be analysed in a regular supply situation and an emergency supply situation.

Furthermore, the DSO and the energy supplier, who is a small player in the Austrian electricity supply system, is looking for new business models to approach its customers. As of lately they have observed limited interest in consumers to adopt new business models, therefore they are looking for ways to assess how consumers would react to new business models.

This defines the sub-goal of this Use Case, which is to use the WHY-Toolkit to simulate how residential consumers would react to new business models for energy supplies, ESCOs or DSOs. The most relevant business model currently in discussion is the founding of energy communities, which is tackled by the Energy Community use case.

3.2. External policy framework and interventions to be assessed

The Gniebing Use Case is, in comparison to the other use cases developed in the WHY project, rather technical and not so much policy oriented. Nevertheless, the local policy makers, especially the mayor of the municipality "Neue Stadt Feldbach" has a very strong drive to advance the topic of "Black-Outs". Therefore, certain policy measures have been taken to induce awareness in the general population of Gniebing. These measures could indirectly affect the consumption behaviour of the residential consumers and thus contribute to the Use Case.

Economic and fiscal instruments: There have been some local approaches to provide consumers with black-out packages (14 day supply rations, plus some equipment), which were sold by local stores. Some of these packages were raffled during one of the many events.

Information and communication instruments: Over the last few years, the municipality has organised and held multiple workshops for their residents, informing them on the effects of black-outs and what actions should be taken to mitigate the effects of a black-out. Furthermore, the municipality has developed leaflets and flyers with practical information for the residents to prepare them for such Black outs.

Aside from the policy interventions, non-policy-driven interventions obviously play a major role in this use case (see WHY Deliverable D1.2) and direct the use case more directly:

Black-Out: A Black-Out is a major disruption of our everyday life and thus will cause a certain behavioural change of consumers. Since until now, no major Black-Out has occurred that has affected the region, there is no experience as to how this intervention will actually affect consumer behaviour. This intervention aims at the general behaviour, for example the decision of going to work or staying at home.

Adapting consumption patterns to minimise consumption: One of the more technical interventions is the necessity of consumers to focus on a reduced energy consumption in order to meet the requirements of an emergency reduced power supply. This intervention aims to assess consumption at a high detail level because it affects consumption behaviour on a device level, for instance the decision of whether a device is actually needed or not.

Turning off or unplugging all non-necessary energy-consuming equipment: Similar to the intervention above, this intervention should induce the behaviour to initially turn off and even unplug devices that are not needed.

Of the interventions mentioned in this chapter, the focus should be set directly on those that are not -policy-driven. The analysis will focus on the Black-Out intervention, which is expected to cause the most relevant effects. While being interesting and indirectly affecting consumption behaviour through a more informed population, the policy-driven interventions are not essential to deliver the analysis of this Use Case. Policy driven interventions are more relevant at national, EU and international levels.

3.3. External and Internal Variables

For the Gniebing Use Case the following variables have been identified:

Weather data: Weather data will be of huge importance due to two factors: 1) they are to a large extent relevant for energy consumption, especially heating and 2) they will affect the renewable generation capacities and production of the power plants in Gniebing.

Social Structure: Social structure will largely define the types of households that will be encountered in this use case. It will also act as a baseline for the technology distribution and possibly the building standards of the buildings encountered. Furthermore, the social structure will be relevant when it comes to the simulation of the decision of the energy consumers.

Degree of knowledge on Black-Out-Mitigation: While it is very likely that this variable needs to be assumed, the information made available to the consumers in the region will increase the knowledge about how to behave in a Black-Out. This will therefore alter the way energy is consumed and how people will react.

- Technology Distribution: This variable defines technologies deployed in the different households which could be used during a Black-Out. The variable considers a wide variety of technologies and energy-consuming equipment ranging from small electronics up to charging points for electric vehicles and electrical heating systems. It should be noted that the analysis includes both these technology types but also other commonly used technologies such as water- or wastewater pumps.
- Building Standards: The building standard itself is relevant for those buildings where electric heating is an option as it affects the energy consumption.
- Grid Data: Since the Gniebing Use Case is a very detailed and technical Use Case, the calculation of the grid strain will play an important role. Thus, the grid data of the emergency grid needs to be considered.
- Fuel availability: It is probable that most of the energy provided for emergency purposes will originate from the two diesel back-up generators. For this it must be assumed how much diesel fuel will be available for emergency operation.

Internal variables (to be assessed in the Gniebing Use Case)

- Heat demand for buildings with electrical heating: Heat demand will play an important role in buildings where heat is generated via electricity as it will increase the potential need for electricity in cases of emergency.
- Household electricity consumption: Load profiles with a resolution of at least 15 minutes need to be calculated and assessed in this Use Case, since these will determine grid strain and whether generation capacities and the grid will be able to maintain emergency operation. The consumption does not need to be available on building resolution, as transformer or grid node resolution will suffice.
- Building electricity consumption: Similar to the household electricity consumption, the building consumption will play an important role in this use case. Building consumption consists of the consumption of the auxiliary devices and equipment in the building such as lighting, lifts, or water- and wastewater pumps. The consumption does not need to be available on building resolution; transformer or grid node resolution will suffice.
- Energy Generation: These variables contain the generation profiles of the generators that feed into the emergency grid. Generation profiles act as a variable for checking whether the required energy can be provided to maintain emergency grid operation.
- Grid Strain: It encompasses the set of variables that describe the current strain of the grid. Grid strain consists of the nodal voltage levels as well as the power flow over the lines and the system losses which need to be compensated by the generator as well.

- Fuel Use: Aside from the energy generation or load profiles to define whether emergency operation can be maintained, one crucial internal variable is the fuel consumption of the diesel generators. This variable will define how long the emergency operation can be maintained.

3.4. Sustainability Assessment

The Gniebing Use Case will provide the following Key Performance Indicators (KPIs) to the Sustainability Assessment:

- Number of consumers that can be supplied during a Black-Out situation. One of the key factors of the emergency supply is the number of residential consumers that the system can support. Since it is not feasible to increase the number of residential consumers one by one –the grid operator will consider the real numbers of residential consumers on each of the transformer or substations.
- Number of days that the system can operate. One of the limiting factors of emergency grid operations will be the diesel fuel. Since the system will rely heavily on the diesel generators to maintain in operation, the amount of diesel available will limit the duration of the emergency operation in a black-out context. With an increasing number of consumers connected to the emergency grid, the duration will decrease, while inefficiencies due to operation of the diesel generators in a non-favourable working point will negatively affect the duration of the system operation.
- Number of timesteps the system needs to reduce power or shut down renewable energy sources to prevent overproduction. The backbone of the emergency system are two diesel generators. Still however renewable generation capacities will also be considered to reduce the amount of diesel required and CO_2 emitted. Since these capacities are not able to operate in islanding mode on their own, they will act as support for the diesel generators. As such there will be times when overproduction occurs and the renewable energy sources will either need to be switched off entirely or their generation reduced (if technically possible).
- Number of timesteps the system needs to reduce power or shut down renewable energy sources in order to prevent overproduction. To prevent a total failure of the emergency system, it might be necessary to shed certain loads from time to time - this will likely happen by automatically disconnecting individual transformers or substations. This KPI quantifies how often this measure of last resort is necessary. The focus of the emergency operation always will be to serve critical infrastructure rather than the residential consumers.
- Ratio of renewable energy in the supplied energy. As mentioned above, renewable energy will act as support for the diesel generators reducing the amount of diesel required to maintain emergency operation and associated emissions. This KPI will concentrate on the actual amount of renewable energy in the energy mix, while the value will never reach 100% in this setting, since the diesel generators are enabling the islanding mode.
- Cost of the system as a function of the number of consumers that can be supplied. It is obvious that operation costs (due to diesel use) of the system will largely depend on the number of consumers that can be supplied. Furthermore, one needs to consider that additional investments in generation capacities might be an option for the DSO.

- Environmental impact of the emergency operation. Since diesel will likely be the main source of energy for maintaining the emergency operation of the grid, the environmental effects of the emergency supply need to be analysed under different conditions (numbers of consumers supplied). This KPI will quantify for instance the CO2 emissions that result from the emergency supply through diesel-fired power generation.

- Robustness of the system under certain critical assumptions. Not all consumers are likely to have the same critical importance to be supplied with electricity during a black out. There might be consumers that need electricity to supply life supporting machines etc. Also, extreme weather situations like extreme heat or cold will render some consumers as more dependent due to cooling or heating needs. This KPI will analyse how resilient the emergency system is in such situations.

3.5. Limitations and Expected Results

There are certain limitations to this Use Case. First, while the load profiles generated by the WHY-Toolkit could technically be at household level, the DSO does not need the data to be in such a high resolution, as data on substation or transformer level are more than sufficient. For this reason, the results will be aggregated on that level.

Second, the simulations will only generate adapted load profiles for residential customers. Non-residential customers will not be considered at all in the simulation or load profiles for consumption during the black-out will be assumed.

Furthermore, the simulations to calculate the strain on the grid will facilitate a single-phase representation of the three phased grid under the assumption of a symmetric load. Additionally, the calculation will only consider the steady state of the system, any dynamics will be neglected.

Given those limitations, the following results are expected from the Gniebing Use Case:

- Aggregated “Black-Out”-consumption load profiles on transformer level. *Load profiles of the simulated residential and assumed non-residential loads on each transformer or substation with a time resolution/granularity of at least 15 Minutes.*

- Required characteristics of power generation capacities to support those load profiles. *Different characteristics such as peak power, changes in power levels between timesteps, overall power generation capacity etc. will be evaluated, to define whether the existing generation capacities can satisfy the energy demand.*

- Grid strain and operational grid parameters. *The grid strain is defined by the power transport on the lines, to monitor if the lines are being overburdened as well as the voltage levels on the different nodes within the grid, to check whether the power quality is within sufficient levels.*

- Diesel consumption for backup generators. *The amount of diesel used during the emergency grid operation to indicate how long the operation can be maintained during a black-out. Since there are only limited amounts of diesel fuel available, it is necessary to know when the diesel runs out in a black-out situation.*

3.6. Designing the implementation in ESM

The Gniebing Use Case is somewhat special due to its small size relative to other WHY Use Cases. As the emergency grid operation will happen in very well defined and small scaled borders, there is no need to employ a full-scale implementation in an Energy System Model (ESM).

4. The Energy Cooperative case

The energy retailers want to know consumer demand with high precision in order to help optimize the purchase of energy, reduce risks and associated penalties. In this Use Case, the Spanish energy cooperative Goiener will perform better estimations and load demand forecasts using the WHY Toolkit, considering not only the climatic factors but also other non-climatic factors that are difficult to simulate on a massive level.

4.1. Objective and Scope of the Use Case

Goiener is a non-profit citizen energy cooperative established in 2012. It is located in the Basque Country, in the north of Spain. Its main activity is the to sell electricity of 100% renewable origin. Given that the field of action (energy) is very broad, the Goiener association was set up in 2015, aiming to build awareness around energy cooperatives, and offer services related with training and development. In 2018, the first generation of renewable energy projects was launched, having as main goal to promote, build and purchase the distributed, local and decentralized renewable energy. Currently, there are 51 workers, 14538 partners and 200 volunteers.

For Goiener, it is necessary to foresee the short-term consumption profile of its members in order to be able to buy energy in a more adjusted way in the daily power market. But it is also critical for Goiener to be able to do precise consumption forecasts in the medium and long term. Based on a good demand forecast, Goiener will be able to know exactly how much energy it will have to acquire in the months or years to come. In this way, Goiener will be in a position to stabilise the prices of customer tariffs.

Moreover, it will allow Goiener to enter into long-term power purchase agreements (PPAs) with small renewable energy producers. Carrying out these PPAs with small producers allows achieving some of the cooperative's strategic objectives. Therefore, it is crucial for Goiener to have mathematical models and tools that project consumer behaviour with high precision.

This defines the main goal of this Use Case, which is to use the WHY-Toolkit to simulate the behaviour of the residential consumers in order to obtain a deeper understanding of their load profile and its response to changes in external conditions. One such key condition is the electric tariff. It is also one of the most powerful interventions that an energy cooperative can do to modify the behaviour of their partners. Goiener is interested in knowing how a change in its tariff structure will:

- Modify the load profile and purchase strategy of its partners (individually and as a group)
- Affect the achievement of long-term goals such as reduction of the energy consumption, increase of distributed renewable generation assets for self-consumption, reduction of energy poverty and increase of community empowerment.

In order to analyse these aspects, Goiener took advantage of the change of electric tariffs that was implemented in Spain on the 1st of June of 2021. The objective of this change of tariff was to shift the load curve from peak hours to flat and valley hours in order to improve the electric system. In this Use Case, we will complement this intervention with a set of information campaigns to see the joint effect of these interventions. This will be further explained in the next section 4.2.

4.2. External policy framework and interventions to be assessed

In the last few years, new energy and climate policies have been implemented in order to reduce emissions, improve energy efficiency, expand the renewable energy generation capacity and improve the electric system overall.

The Goiener Use Case has taken advantage of a recent policy change in Spain. On the 1st of June of 2021, a change of electric tariff was implemented all over the country. Before that time, there were 6 different tariffs (with different amount of power and energy periods) for households. The modification simplifies the tariff structure and now there is just one, which has 2 periods for power access and 3 periods for energy consumption.

The main objective of this policy is to improve the use of the national electric system by shifting the load curve from peak hours to flat and valley hours, reducing the thermal gap[3] to the extent possible.

To measure how much it will affect them, all 14 000 consumer-members of Goiener take part in an experiment. All of them will receive basic advice on moving their loads. Furthermore, each consumer group will receive additional information about the following: environmental impact, extra tips on moving loads, and finally, energy efficiency related advice.

The intervention will last for 6 months. The general message will be sent once a month and the reinforcement messages after 15 days.

The aim of this intervention is to identify which kind of messages have the biggest effect on energy consumption and load shift of Goiener customers.

4.3. External and Internal Variables

For Goiener Use Case, the following **external** variables have been identified:

- **Climate zone**

Climate zone will be of huge importance due to its high relevance for energy consumption, especially for space heating.

- **Social Structure**

Social structure will largely define the types of households that will be encountered in this Use Case. Moreover, the social structure will be relevant when it comes to simulating the decisions of electricity consumers.

- **Level of knowledge about the importance of load shifting**

The information made available to the consumers in the region will increase their knowledge about the relevance of load shifting. This will therefore alter the way energy is consumed.

3 The thermal gap is the amount of power that has to be provided to the energy system by schedulable power plant based on fossil fuels.

- **Building standards**

Building standards are relevant for those buildings where electric heating is an option since it will affect the overall energy consumption.

- **COVID-19**

COVID-19 will be fully taken into account in this Use Case, since it has been seen altering the way energy is consumed in buildings (e.g., through increased remote working at home).

For the Goiener Use Case, the following **internal** variables have been identified:

- **Household electricity consumption**

Load profiles with a resolution of at least 1 hour will be essential to assess in this Use Case, as they will be the key factor to answer to the question of how the different interventions (policy and non-policy) affect the electricity consumption.

- **Heat demand for buildings with electrical heating**

Heat demand will play an important role in buildings where heat is generated through electricity. This will increase the consumption of the household.

- **Potential renewable energy generation**

The contribution of renewable energy in households will have an important impact when shifting the electric load, therefore it will alter the way energy is consumed. Moreover, it will be interesting to analyse if the number of renewable energy installations is growing in households.

- **Degree of the impact of the tariff change**

The type of consumption and habits of each household will result in different degrees of impacts of the tariff change, which, in turn, will alter the way energy is consumed.

- **Previous tariff type**

The previous tariff type contracted by each household will be used as a control variable to see the impact on behavioural change.

- **Contracted power**

The power access contracted by each household will be used as a control variable to see whether the change of tariff has a direct impact on the reduction or increase of electricity consumption.

4.4. Sustainability Assessment

This Use Case will provide the following KPIs to the Sustainability Assessment:

- The percentage of energy that is maintained in the same periods and the percentage of energy moving to different periods. The main objective of the intervention is to shift the loads from peak to flat or valley hours, so this will be one of the most relevant KPIs.
- Change of the amount of kWh purchased by Goiener and its costs for peak, flat and valley hours.
- Change of the kWh penalties associated with the purchase orders made by Goiener and the associated costs in peak, flat and valley hours.

- Difference of kWh consumed in the study compared to the same period of the previous year (2020). With this KPI it will be tested if the interventions induce consumers to behave more energy efficiently or not.
- Number of inquiries about the two power periods in the customer support office. The objective is to observe the number of persons that could be interested in buying (or using) an Electric Vehicle (EV), a heat pump, accumulators, batteries, self-generation or exploit the new tariff on second homes.
- The impact of the new tariff scheme on the electricity bills of the cooperative members.
- The degree of difficulty to move loads by different collectives. A qualitative assessment will be made using a post-intervention survey and a quantitative assessment will use the information included in the contract to segment the consumer partners (geographic location, type of contract, power contracted, etc.). Average Rate of Return (ROI) of a net-zero self-consumption solar PV installation (assuming standard weather conditions from the North of Spain and space availability on the roof).
- Percentage of consumers and partners who have responded (clicked and read the advice) to the treatment (regardless of the results).
- Amount of emission reduction in the Spanish energy system due to the modified consumption patterns of the consumers.

4.5. Limitations and Expected Results

As all experiments and use cases, this set up has certain limitations. The next paragraphs introduce the ones that the researchers are aware of:

- **Bias due to different treatment durations**: consumer partners are not entering into the new regime at the same time, and this could imply a bias in the results. Nevertheless, this bias is expected to be marginal for two reasons. On the one hand, there has been a massive campaign in the media about this change of tariff scheme, so most people are already aware and will change their behaviour even as they have not yet officially joined the new tariff scheme. On the other hand, preliminary information sent by the DSO (the entity responsible of producing the change of tariff) suggests that the majority of consumer members of Goiener will change to the new tariff at the same time.
- **Lack of effect size**: even as the amount of subjects in the experiment is quite significant, the energy consumption has a natural random component due to factors not controlled in the experiment. This has to be controlled and considered as a measurement error in the Use Case. Any result (independent of its statistical significance) based on an effect size smaller than the measurement error should be discarded.
- **Bias for not considering a full season**: it is known that energy consumption has daily, weekly, and annual seasonality. The experiment is not going to consider a full season (year) and this could introduce a bias. Nevertheless, the electrical consumption in the North of Spain does not significantly change with respect to summer as most of the heating systems use gas and not electricity. Moreover, a difference-on-difference experimental set up is going to be taken into consideration, so these biases could be controlled.
- **Bias due to external events changes the behaviours**: at the time of writing this document, a massive increase in the electricity price is happening in Spain (and in

most of Europe) due to a shortage of gas supply that drives upwards gas import prices and a large increase in carbon emission taxes through the EU Emission Trading System (ETS). This has fuelled public discussion around the energy system and the necessity to reduce the energy bill (intervening on the tariff or by energy sufficiency actions). This was not foreseen and could introduce a bias when assessing the differences on energy consumption between years. To this end, controlled and non-controlled cost assessment will be produced and discussed.

- **Bias due to non-random sampling**: an opt-out experimental setup was put in place. The attrition rate is insignificant at the moment, but unfortunately, the consumer-members of Goiener are not a census nor a random sampling of the overall population. This is probably the largest limitation of this experiment. For this reason, extra care should be taken when generalizing the results of this experiment. On the one hand, we will use a multilevel regression with post-stratification in order to control and reduce this bias. On the other hand, we will triangulate our results with the results of the Spahousec III initiative carried out at the moment by the Institute for Diversification and Saving of Energy (IDEA) of the Ministry of Industry, Energy and Tourism. Spahousec III is a much larger and ambitious experiment that will assess the yearly energy consumption of a random sample of 1000 household in Spain.

Given those limitations, the following **results** are expected from the Goiener Use Case:

- Reduce consumption and power in peak hours which creates a financial saving due to the new tariff structure.
- Facilitate and improve the forecast of purchase in the wholesale electricity market. This implies reduction of the penalties associated with misguided energy purchases by the system operator.
- Test if a change in the tariff could significantly change the electrical load profile of a consumer.
- Understand which incentives and policy interventions contribute to increasing investments in each of the sectors that will be analysed in T2.2: building, appliances, mobility, and flexibility.

4.6. Designing the implementation in ESM

In this Use Case, there is no need to employ a full-scale implementation in an Energy System Model (ESM). All quantitative and qualitative assessments will be made using the load profiles directly taken from the billing system and applying advanced statistical algorithms.

5. The Energy Community 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. This multi-level process is incredibly complex and challenging, but it begets numerous opportunities for the European energy transition to embrace alternative ways of governing socio-energy systems[4].

4 Miller, M.A., Richter, J., O'Leary, J., 2015. "Socio-energy systems design: A policy framework for energy transitions." Energy Research & Social Science, 6, 29–40. Energy Research & Social Science. https://dx.doi.org/10.1016/j.erss.2014.11.004

5.1. Objective and Scope of the Use Case

In that context, energy communities can be instrumental in changing the energy landscape[5] and enabling the clean energy transition at the local and citizen level[6]. In the grassroots, 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[7]. Beyond the community-specific lens, energy communities can bring increased flexibility and resilience to the main energy grid[8], and from an economic perspective, they can also be seen as socially innovative enterprises, engaging in economic activity that lowers energy costs while providing financial returns to the local community.

Against this backdrop, energy communities can take many legal, organisational, and financial forms[9], subject to local circumstances and needs, while also dependent on the policy and regulatory support available[10]. From a technical standpoint, traditionally energy communities focused only on energy generation, but this is expanding to also include storage, supply, and energy efficiency, while the system can either be centralised, distributed, or decentralised[11]. From an organisation point of view, energy communities can be created in a top-down or bottom-up approach, with initiatives including communities of place, whose values are shared within a certain landscape, and communities of interest, who come together driven 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. The Clean Energy for All Europeans package (2019) 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.

While it becomes clear that no two community-based energy projects are alike, they can still share common elements, such as technologies, funding sources, and business models. Especially the latter deserves emphasis, since under flexible regulatory frameworks, energy communities have the capability to develop innovative solutions and business models, allowing them to stay true to their core objective of optimising local benefits while investing in the clean energy future. In this way, the diversity of energy communities becomes a unique selling proposition, as their ability to deliver innovative business models makes them eligible to contribute to different objectives, workstreams and actions outlined in the European Green Deal.

In the next sections we will present the different stakeholders involved in energy communities, their objectives and challenges related to energy communities, a short state of the art of the different energy communities found in practice in Europe, and then we will present our own definition of Energy Community in order to set the scope of the use case. Then, we will set our

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5 Reis, I.F.G., Goncalves, I., Lopes, M.A.R., Henggeler Antunes, C., 2021. "Business models for energy communities: A review of key issues and trends." Renewable and Sustainable Energy Reviews 144 (2021). https://doi.org/10.1016/j.rser.2021.111013
6 Caramizaru, A. and Uihlein, A., 2020. Energy communities: an overview of energy and social innovation, EUR 30083 EN, Publications Office of the European Union, Luxembourg. ISBN 978-92-76-10713-2, doi:10.2760/180576, JRC119433.
7 Walker, G., Devine-Wright, P., 2008. "Community renewable energy: What should it mean?" Energy Policy 36, 497-500. doi:10.1016/j.enpol.2007.10.019
8 Salgado, A., Anisie, A., and Boshell, F., with additional contributions and support from Harsh Kanani and Shikhin Mehrotra (KPMG India). IRENA (2020), Innovation landscape brief: Community-ownership models, International Renewable Energy Agency, Abu Dhabi. ISBN 978-92-9260-176-8
9 Hewitt et al, 2019. "Social Innovation in Community Energy in Europe: A Review of the Evidence." Frontiers in Energy Research 7 (2019) 31. https://doi.org/10.3389/fenrg.2019.00031
10 Nolden, C., Barnes, J., & Nicholls, J. O., 2020. "Community energy business model evolution: a review of solar photovoltaic developments in England." Renewable and Sustainable Energy Reviews, 122, https://doi.org/10.1016/j.rser.2020.109722
11 Guia, E.M., MacGill, I., 2017. "Typology of future clean energy communities: An exploratory structure, opportunities, and challenges." Energy Research & Social Sciences. doi:10.1016/j.erss.2017.10.019

objectives, the experiments we wanted to carry on and the data we plan to use. Finally, we present the set of KPIs we plan to use to evaluate the results, the limitations and expected results and the implementation details.

5.2. Legal and policy framework

At the moment, the legal framework is routed in two definitions given by the Clean Energy for all Europeans Package[12]: Renewable Energy Community (REC) which is contained in Directive (EU) 2018/2001 (the recast Renewable Energy Directive) and Citizen Energy Community (CEC) which is contained in Directive (EU) 2019/944 (recast Electricity Directive). Table 1 show the particularities of each definition:

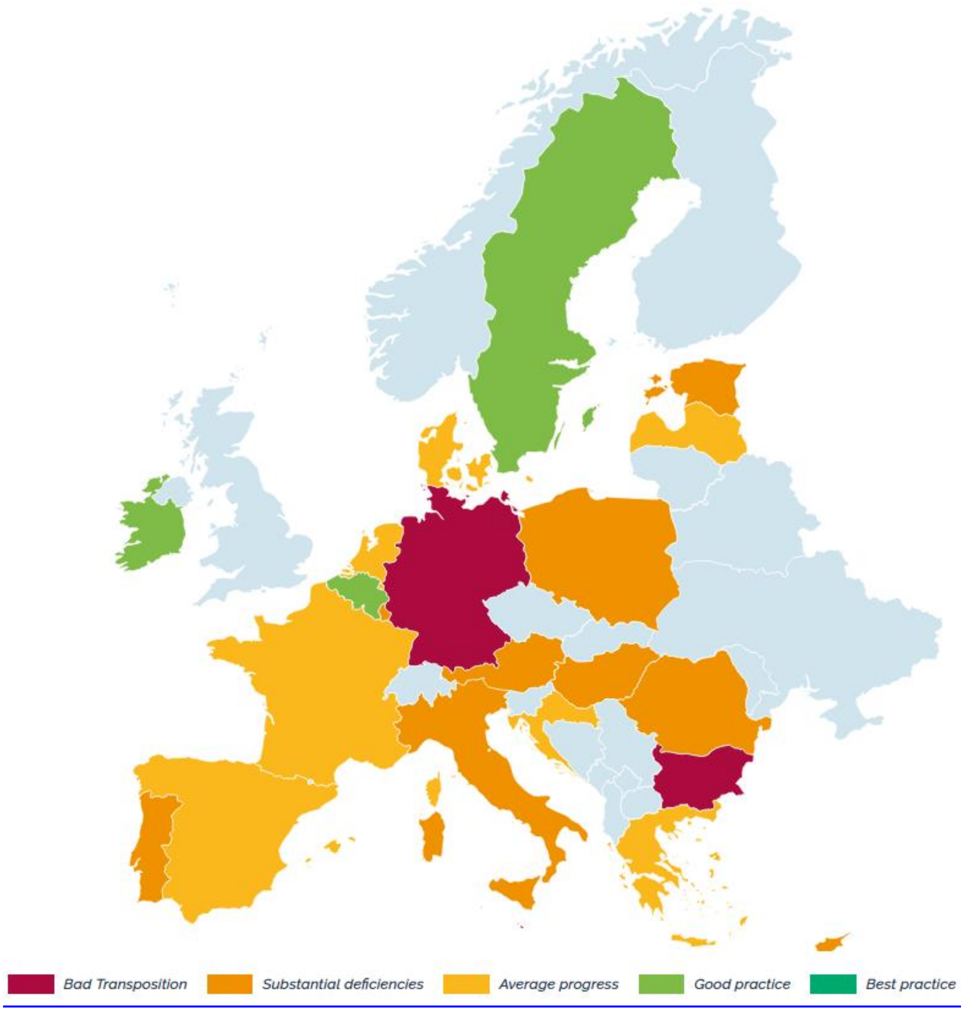
Table 2: Definition of REC and CEC[13]

Article 2(16) Recast Renewable Energy Directive ‘Renewable Energy Community’	Article 2(11) Recast Electricity Directive ‘Citizen Energy Community
A legal entity: a. which, in accordance with the applicable national law, is based on open and voluntary participation, is autonomous, and is effectively controlled by shareholders or members that are located in the proximity of the renewable energy projects that are owned and developed by that legal entity; b. the shareholders or members of which are natural persons, SMEs or local authorities, including municipalities; c. the primary purpose of which is to provide environmental, economic, or social community benefits for its shareholders or members or for the local areas where it operates, rather than financial profits.	A legal entity that: a. is based on voluntary and open participation and is effectively controlled by members or shareholders that are natural persons, local authorities, including municipalities, or small enterprises; b. has for its primary purpose to provide environmental, economic or social community benefits to its members or shareholders or to the local areas where it operates rather than to generate financial profits; and c. may engage in generation, including from renewable sources, distribution, supply, consumption, aggregation, energy storage, energy efficiency services or charging services for electric vehicles or provide other energy services to its members or shareholders;

Having two quite similar definitions of what an Energy Community is included into two Directives, which Member States need to transpose into national legislation, has created confusion and resulted in various different terms. Figure 3 shows a map[14] that depicts the progress of the transposition of the Renewable Energy Community (REC) and Citizen Energy Community (CEC) definitions in the European Member States.

12 https://energy.ec.europa.eu/topics/energy-strategy/clean-energy-all-europeans-package_en
13 https://www.rescoop.eu/toolbox/q-a-what-are-citizen-and-renewable-energy-communities
14 https://www.rescoop.eu/policy#transposition-tracker

Figure 3: Energy Communities Transposition Tracker



Source: REScoop

The current status of Energy Communities in the EU

The energy community concept has been evolving as the definition of community is complex and context-dependent[15]. Using the definition developed by Walker and Devine-Wright[16], and captured in a two-dimensional matrix, "energy community needs to be either, and ideally both, open & participatory and local & collective". The process dimension focuses on who runs the project and the outcome dimension addresses how the outcomes are spatially and socially distributed and who benefits economically and socially from the project. The process dimension presupposes local participation in the design, planning, and implementation, while the outcome dimension is centred around the benefits brought to the community.

An energy community defines the relationship between locally produced energy and the community, which involves stakeholders with different interests and objectives. This is a major

15 Creamer, E., Aiken, G.T., van Veelen, B., Walker, G., Devine-Wright, P., 2019. "Community renewable energy: What does it do? Walker and Devine-Wright (2008) ten years on." Energy Research & Social Science 57 (2019) 10.1016/j.erss.2019.101223
16 Walker, G., Devine-Wright, P., 2008. "Community renewable energy: What should it mean?" Energy Policy 36, 497-500. doi:10.1016/j.enpol.2007.10.019

difference with developer-led large-scale renewable energy projects. The stakeholders involved in community-led energy projects and their interests are described below:

Promoters

Citizens

- Improve local sustainability: use local resources, foster local employment, reduce the local environmental impact.
- Energy cost savings
- Lower levels of energy poverty
- Community bonding and engagement of the local community
- Being part of the energy transition
- Re-think globalisation, remove the dependencies with large utilities / corporations, increase the level of autarky and self-sufficiency

SMEs

- Reduce their energy cost
- Act climate friendly and be recognised as such / corporate social responsibility
- Increase the community bonding and engagement of the local community towards the company
- Marketing activity to get more clients/partners
- Benefit from energy community support schemes

Public authorities

- Provide new services to citizens: electricity, heat, and transport
- New income sources for the municipality renting the spaces, managing the community or taxing the activity
- Act climate-friendly and be recognised as such
- Looking for a way to reduce the energy cost of their citizens
- Increase the community bonding and engagement of the local community
- Improving the local grid to be more robust

Energy cooperatives / energy retailers / ESCOs

- Foster the energy transition
- Their objective is to promote them, help them to grow and later to go away or continue offering services, if requested.
- They will provide services to any stakeholder to:
    - Promote / co-create an energy community
    - Consultancy in the set up
    - Engineering (including software for operation)
    - Marketing to get more clients/partners
    - Financial services or setting-up of new business models

Financial partners: crowdfunding, shareholders, banks, etc.

- New market
- Contribute to the decarbonization of the economy
- Follow the direction set by the EU Taxonomy Compass[17]
- Set-up new business models to foster participation

Participants

Citizens

- Mid-Upper economic class
- Energy poverty

Enterprises

- SMEs
- Industries (provided that they do not hold control of the community)

Public authorities (or other large entities)

- Municipalities (or other large entities) that share spaces (normally large roof) to install part of the components of the energy community
- Managers and technology providers: DSO, cooperative / not for profit association, ESCO / building managers, industries, etc.
- New market

Research entities

- Tool to design technical, legal, and social aspects of an energy community
- Tools to foster the participation of citizens

While individual members of an energy community may have different interests, the common goals of the energy community emerge from sustainable development imperatives, including the production of clean energy and GHG emission reduction, participation in renewables self-consumption and local economy revitalisation through sustainable job creation. The key characteristics that community-led energy projects should possess are: local distribution of profits, local ownership, and democratic governance.

Literature[18]provides insights regarding different enabling frameworks for energy communities: the process framework and the outcome framework. The process framework is a bottom-up approach that focuses on procedural justice, understood as fairness in decision-making and involvement, where the community initiates, plans, develops, and runs the project. The outcome framework is top-down and focuses on distributional justice, namely how local citizens benefit from the project.

There is an interdependence between process and outcome, and the ideal project would incorporate both into an analytical framework for optimal success. The objective of these differentiations is to visualise the two different prioritisation categories that are determined during an energy community project.

17 https://ec.europa.eu/sustainable-finance-taxonomy/

18 Palm, J., (2021). "Energy communities in different national settings – barriers, enablers and best practices." Deliverable D3.3 of the NEWCOMERS.

From the bottom-up process perspective, energy communities should be instruments to alleviate the disproportionate burdens of decarbonisation on the most vulnerable households. However, data shows that traditionally, energy communities are not demographically diverse. For example, in Germany, more than 70% of members were high-income, educated men. In fact, without inclusive requirements, green technologies, like solar PV, and e-mobility remain exclusionary niches for the high-income citizens[19,20]. Knowing that energy communities have the potential to boost energy self-sufficiency for low-income households, there is even more emphasis on addressing justice concerns so that vulnerable households are able to participate and benefit from these projects. Looking forward to a clean energy future, there is the opportunity to create a solid *scheme of schemes* that can truly enable community-led solutions on the ground instead of merely pouring money in different directions. Further democratising renewable energy projects and energy communities to include the most vulnerable citizens and low-income households could potentially be a win-win for just transition to a clean energy future.

From the top-down process perspective, local governing bodies need to unlock innovation across the board, from upgrading their energy systems to meet climate neutrality targets, to ensuring citizens are engaged and there's public buy-in, bearing in mind the specific challenges that energy community development represents in cities as opposed to rural areas.

5.3. Stakeholder Consultation

As explained before, energy communities come in different forms and documenting all of them falls out of the scope of the project. To therefore we developed a stakeholder consultation process to where we ask different stakeholders about:

- What do you understand as an energy community?
- What is your strategy around them?
- What are the main problems you are currently facing to fulfil that strategy?
- What tools will you need to overcome these problems?

An open consultation with the members of Climate Alliance[21] was organised. The cities of Karlsruhe, Frankfurt, Maintal, Kelsterbach, and regions of Essen, Main-Taunus-Kreis (Germany), Plymouth (UK) and Tartu (Estonia) responded to the outreach, yet no conclusive information was provided, the main reason being that some Member States have just or are about to complete the transposition of the Directive and the concept is too new and/or municipalities have not shown interest until now.

In addition, semi-structured interviews were carried out with energy cooperatives from Reescoop[22] and direct contacts of the consortium. These include Goiener (Spain), Coopérnico (Portugal), Bürgerwerke (the largest association of energy cooperatives in Germany) and EWS Municipality of Schönau (the oldest energy community from Europe located in Schönau, Germany). Surprisingly enough, despite the different technological and socio-economic realities, the challenges and needs were quite similar.

Finally, public statements from different stakeholders across Europe where collected and assessed:

19 Radtke, J., Ohlhorst, D., 2021. "Community Energy in Germany – Bowling Alone in Elite Clubs?" Utilities Policy 72 (2021) 101269. https://doi.org/10.1016/j.jup.2021.101269
20 Palm, J., (2021). " Energy communities in different national settings – barriers, enablers and best practices." Deliverable D3.3 of the NEWCOMERS.
21 https://www.climatealliance.org/municipalities/the-network.html
22 https://www.rescoop.eu/network

- Bridge's Energy Communities and self-consumption Task Force "Review of electricity tariffs and business Models"[23]
- Rescoop, Friend of the Earth and Energy-cities "Community Energy: Practical Guide to reclaiming power".[24]
- E-DSO Position Paper "DSOs as facilitators of energy communities".[25]
- ASSET STUDY on "Energy Communities in the European Union"[26].
- JRC Policy Report "Energy communities: an overview of energy and social innovation"[27].
- SOM Energia "Guía práctica para la autoproducción colectiva en bloques de pisos"[28].
- Working paper from IDAE "Guía para el desarrollo de instrumentos de fomento de Comunidades Energéticas Locales"[29].
- Spanish Ministry for the ecological transition and demographic challenge: "Self-consumption roadmap"[30].
- CNMC report on "collective self-consumption sharing schemes"[31].
- Joint policy "Recommendations to strengthen prosumers and energy communities when transposing the Clean Energy Package" from PROSEU, SCORE and EREF H2020 projects and Community Power Coalition and EREF federation[32].

With all the information collected from stakeholders, the following conclusion were found:

- The legislation is unclear at best, very restrictive at worst. There are a lot of best practices working in one Member State that cannot be replicated in others. In particular, the following elements in the different legal regimes pose restrictions to the uptake of energy communities:
    - Imposing a grid tariff to the self-produced energy even when the grid is not used, which reduces the profitability of the community-led intervention.
    - No possibility to organise local or peer-to-peer markets or use the surpluses from self-generation as a source of renewable guaranties of origin to sell to other members of the energy community.
    - No measures to mitigate the investment risks undertaken by promoters;
- There is a lack of tools to:
    - Show potential interested citizens the benefits of participating in the energy community design in ways that they can understand and relate to (e.g., energy costs, self-sufficiency, local sustainability, job creation, energy poverty, etc.). The goal should be to show them realistic numbers while presenting the initiative.

23 https://ec.europa.eu/energy/sites/default/files/documents/bridge_tf_energy_communities_report_2020-2021.pdf
24 https://www.rescoop.eu/toolbox/community-energy-a-practical-guide-to-reclaiming-power
25 https://www.edsoforsmartgrids.eu/dsos-as-facilitators-of-energy-communities/
26 https://asset-ec.eu/home/advanced-system-studies/cluster-4/eu-energy-communities/
27 https://publications.jrc.ec.europa.eu/repository/handle/JRC119433
28 https://blog.somenergia.coop/som-energia/2020/11/publicamos-una-guia-practica-de-autoproduccion-colectiva-en-bloques-de-pisos/
29 http://www.idae.es/publicaciones/guia-para-el-desarrollo-de-instrumentos-de-fomento-de-comunidades-energeticas-locales
30 https://www.miteco.gob.es/es/ministerio/planes-estrategias/hoja-ruta-autoconsumo/default.aspx
31 https://www.cnmc.es/sites/default/files/3586390_3.pdf
32 https://proseu.eu/resource/transposition-guidance-citizen-energy-policies

- Carry on a spatial assessment addressing where the energy community could be deployed.
- Have access to real data from clients or create realistic synthetic data. This makes it difficult to assess what will be the electrical net balance and the potential OPEX of the solution.
- Define what is the best tariff system to share the generated energy (static, hourly or true dynamic coefficients) and the costs (PPP schemes, crowdfunding, shareholding, etc.).
- Perform risk assessment of the community investment.
- Assess the viability of P2P (Internal Flexibility) or participation on flexibility markets (with external agents).
- Make social impact assessments including the impact on energy poverty, local jobs created, social inequalities, rebound effect or the measurement of social concerns and oppositions.

Given the previous points, 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. In particular, we plan to show how the WHY toolkit could be used to plan the setup of an energy community from the technical, economic, environmental, and social perspective providing tools to answer the following questions:

- Who should be involved and how to involve them?
- How to size the different components (generation, storage, control strategy, etc.)?
- What legal entity is the most effective / robust?
- What is the best business model / tariff system to be deployed?
- How to manage new contracts and cancellations after the set up?

5.4. External Policy Framework and Interventions to be assessed

We will carry two assessments:

- **Top - down**: a stakeholder (a public authority or an SME) decides to use some space in their facilities for generating and/or storing distributed renewable energy. In order to increase the profitability of the system (or to fulfil their statutes, their corporate social responsibility activities) the stakeholder decides to sell the energy directly to the neighbourhood instead of selling it to the market. The stakeholders could also be interested in promoting energy efficiency and conservation actions or provide power to heat (district heating) or power to transport (fast charging stations) services over the same infrastructure.
- **Bottom - up**: a group of citizens wants to become an active part of the energy system and the energy transition, so they share their own roof and basements to install some generation (PV, run-of-river hydroelectricity, biomass-based CHP systems, etc.) and storage capacity and share among all the partners the energy generated. On top they can also electrify their space & water heating (install heat pumps) and transport (install charging points for electric vehicles) needs.

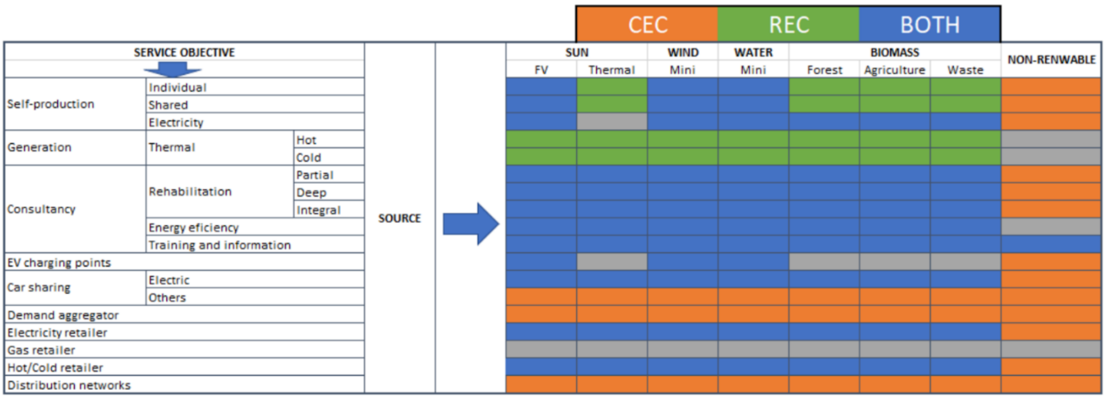
For the first assessment we will use the example of Hernani, a small industrial city situated in the Euskadi region (north of Spain) with around 20 000 inhabitants, where Goiener is proposing to build an energy community that involves the entire municipality including citizens, SME, public authorities and even industries in different types of memberships such as consumers, service providers, collaborators, investors, or workers. Figure 4 shows the different stakeholders with their proposed role in the Hernani Energy Community.

Figure 4: Member of Hernani Energy Community

	Directive	Type of member				
		Consumer	Service provider	Colaborator	Investor	Worker
Type of person	Natural person	√			√	√
	Small company	√	√	√	√	
	Medium company	√	√	√	√	
	Big company			Very limited		
	Public institution (local)	9/2017 LCSP Law		33/2003 PAP Law 2/2004 LRHL RD 7/1985, RBRL Law	33/2003 PAP Law 2/2004 LRHL RD 7/1985, RBRL Law	
	Public institution (not local)			Very limited		
	Organization/Asociation	√				
Example of power %		60%	10%	10%	10%	10%
Example of membership fee		10€	10€	1000€	100€	10€

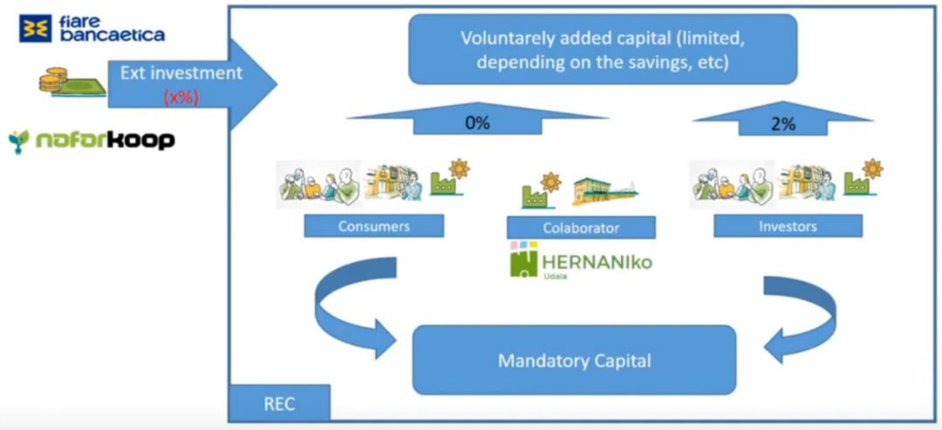
Several different projects will be carried out at Hernani considering not only generation from renewable sources (like solar PV, wind onshore, run-of-river hydroelectricity or with biomass) but also energy efficiency and electric charge installations. Figure 5 shows a list of projects being considered at Hernani Energy Community.

Figure 5 Projects to be carried on Hernani Energy Community



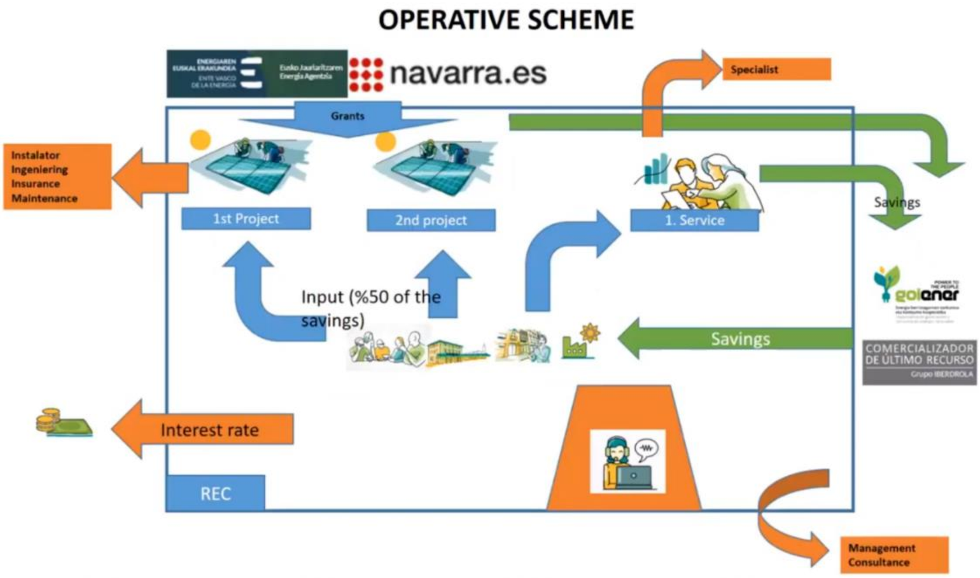
The legal entity proposed for the Hernani Energy Community is the cooperative with one vote per person / entity. The decisions are taken by vote following the one person / entity vote including a weight coefficient on each of the 5 different stakeholder groups that compose the energy community (Consumers, Service providers, Collaborator, Investor and Workers). In any case, the group of consumers will be the group with the biggest power. The investment scheme proposed is composed of a Mandatory Capital fee for all participants plus a Voluntary Capital fee subject to a small repayment interest. Moreover, each stakeholder group has different membership fees. An example of the distribution could be seen in Figure 6.

Figure 6 Investment scheme for the Hernani Energy Community



The operation and management of the Energy Community will follow the 50/50 concept. This way, 50% of the savings made by the participant will be given back as a tax to fund the operation (including insurance, maintenance, services, etc.) and expansion of the Energy Community. Moreover, projects can also be funded by participating on calls in order to secure external investments like the ones provided by the NextGeneration EU funds, regional funding schemes, or Horizon Europe projects. Figure 7 shows a diagram with the proposed operation and management procedures.

Figure 7 Operation and management procedures proposed for Hernani Energy Community



For the second assessment we will use a residential complex that has shown interest in becoming an energy community. The residential complex has the following characteristics:

- Building complex with 27 x 3 = 81 houses (~150 inhabitants).
- Properly insulated (A rating).
- Large façade south oriented without any shade.
- District heating (gas powered).

- DHW supplied by an aerothermal heat pump (9 kW electric ~ 30 kW heat).
- Shared parking space (~200 parking spaces not ready to host electric vehicles).
- 3 swimming pools available to store / use daily energy surpluses
- Main interest of the residents:
- Being able to heat the pool all year (including the installation of a PV pergola).
- Reduce their energy invoice (install PV and change the heating system to a heat pump).
- Interest on installing translucid BIPV panels in part or all of the terraces to be able to use it all year (and increase further the energy efficiency of the houses).

In both cases, the main idea is to use the WHY toolkit to define and foster the implementation of the energy community.

5.5. External and Internal Variables

The information required for each one of the assessments is different. For example, for the residential complex, the information needed is:

- High resolution smart meter data from some houses (potentially all) and all other electrical services of the building (shared lighting and elevators, telecommunication, and swimming pool).
- Individual and overall clean water, heat and DHW consumption for several years.
- Renewable energy generation potential.
- Physical access to survey the building or to interview the different households.
- Blueprints and building materials.
- Energy certification.

On the other hand, for the city of Hernani the information needed is:

- The potential space to include energy generation (building roofs surfaces or waste heat) and storage (location of potential thermal storage or batteries).
- Renewable energy generation potential taking into consideration the potential space to be used.
- The list of potential candidates for electricity consumption following national rules (500 m around the location of the roofs for PV generation). If they are GOIENER customers, real data will be used. For the rest of candidates, realistic synthetic data will be generated using the WHY toolkit.
- Real energy performance certificates or approximations made by models of the potential savings achievable by proper insulation of the candidate buildings.
- Amount of vehicles registered at the candidate buildings and space for electric charging.

In both cases, preliminary access to that information has been granted.

5.6. Sustainability Assessment

The European Green Deal aims toward a climate-neutral, circular economy as part of the just energy transition that 'leaves no one behind'. While the EU's goal of a just energy transition has evolved over the last two decades, up until recently, it was centred around job replacement, workers, and the communities affected by a transition to a low-carbon economy. NGOs broadened this understanding with the component of environmental justice on a citizen level, with discourse built around environmental and social issues. This broader concept of a just transition encompasses issues of energy justice and energy poverty. With that in mind energy communities could be used as a strategic option to tackle energy poverty in an EU-wide context, but this relation has not been addressed in the literature sufficiently.

The assessment of energy communities will be based on the below variables:

- Self-consumption
- autarky rate
- peak power
- maximal hours without access to warm water
- maximal hours with temperature below x-degree (winter)
- maximal hours with temperature above x-degree (summer)
- total costs of investment (CAPEX)
- ROI (return of investment)
- annual savings
- annual costs (OPEX)
- $C0_2$ emissions
- required own effort
- complexity and effort required for installation
- installation time
- required space
- percentage of income needed to be invested
- social opposition to the deployment
- rebound effect
- mean percentage of budget dedicated to energy (energy poverty and social inequalities)
- Easiness to foster citizen participation
- Easiness to implement a transparent administration
- robustness of the legal entity
- robustness of the business model
- risk of technological lock-down

5.7. Expected Results and Limitations

The main expected result is a tool that:

- Allows all participants to understand the benefits of participating in the energy community using data as close to reality as possible.
- Helps define the elements (e.g., PV generation, energy storage, electric vehicles, etc.) that will be part of the energy community (this is particularly relevant in the Hernani assessment).
- Helps size the different components to be installed (e.g., PV panels, storage solution, electric vehicle chargers, etc.) and decide on their suitability.
- Makes it possible to select the best tariff scheme and business model to be implemented in order to share the generation and the investment costs.
- Provides hints about the governance structure that is most suitable for the composition of the energy community (this is particularly relevant in the residential complex).

The main limitation of this Use Case relates to the computational limits for providing fast answers to the modellers/researchers, and promoters of the energy community. In that sense, the tools should be easily deployable “in the field” during a presentation of an energy community and deliver preliminary answers in minutes in order to be useful. It should be noted that these are not engineering tools, so for the final installation in the energy communities designed using the WHY toolkit other specialist tools need to be used, which take into consideration more technical and engineering aspects (like the grid lines, the topography, the local legislation, etc.) that are out of the scope of the WHY project.

5.8. Designing the implementation in ESM

In this Use Case, there is no need to employ a full-scale implementation of energy communities in an Energy System Model (ESM). All quantitative and qualitative assessments will be made using the WHY toolkit directly the following way:

- Use of the causal model to simulate a priori the individual willingness to accept the different infrastructures.
- Use of the causal model to define potential interventions to foster energy efficiency / conservation actions to be carried out and the maximum potential impact.
- Use of the building sizing loop for the best technical solution and to determine the sizing of the different components.
- Run individual simulations to assess the best control strategy and business model for different energy communities.
- Despite computational constraints, the upscale function will be adjusted in order to be potentially used in other WHY use cases in WP5.

6. The European use case

The European Use Case explores the impact of EU-wide and national policies on achieving the EU goals on climate change mitigation and energy efficiency. In this chapter, we first analyse the objective and the scope of the Use Case. We continue expanding on the policy framework and those external and internal variables used in the development of the European

Use Case. Next, we discuss limitations and expected results. Last, we discuss the implementation of the Use Case in the PRIMES model.

6.1. Objective and Scope of the Use Case

The objective of the European Use Case is to provide an improved understanding of the role of energy efficiency (EE) and electrification of buildings towards achieving the ambitious EU emission reduction targets in the medium and longer term. This will be implemented by re-assessing EE policies and measures consistent with the pathway to climate neutrality by 2050, using the improved WHY modelling capabilities. The current goals of the "Clean Energy for All Europeans" package to achieve at least 40% GHG emission reduction, 32% renewable energy share and 32.5% improvement in energy efficiency by 2030 are implemented through eight legislative acts. The recast Renewable Energy Directive (RED II), the amending Directive on the Energy Efficiency (EED)[33] and the Energy Performance of Buildings Directive (EPBD)[34] are central pillars of the package.

The updated "Fit For 55" policy package presented by the European Commission (EC) on 14 July 2021, raises the bar even higher with more ambitious GHG emission reduction targets of at least 55% by 2030 relative to 1990 levels, a 40% renewable energy share in 2030 and an overall reduction of 36-39% for final and primary energy consumption by 2030. To enhance its policy relevance, the European Use Case will explore the impacts of the latest proposed revision of the Energy Efficiency Directive (submitted in 2021) where more ambitious efficiency goals and strategies are set. In addition, the European Use Case will integrate the National Energy and Climate Plants (NECPs) of EU Member States put forward until the end of 2019, together with the current EU energy and climate legislation. The Use Case will analyse these recent EU and national policy proposals for 2030, and also explore their potential upscale towards climate neutrality in 2050, fully considering the socio-economic implications of COVID19. It will also evaluate different policy measures and portfolios to fulfil the strategic EU emission reduction targets for 2030 and 2050, address implementation challenges and barriers, minimize adverse side effects (i.e., high costs for low-income classes) and maximise the socio-economic benefits associated with ambitious climate policies.

In this use case, the WHY Toolkit will be linked with the PRIMES model (especially PRIMES-Buildings module BuiMo), one of the most widely used and well-established models at EU level. PRIMES has been used to provide quantitative model-based assessments to benchmark EU policy impact on energy and climate (e.g., Fit For 55 policy package, 2030 Climate Target Plan, Winter Package 2016, Clean Planet for all strategy). The PRIMES-BuiMo projects into the future the energy demand of buildings of the residential and services sectors. It focuses on the dynamic simulation of the renovation strategies, the choice of technology equipment covering energy end-uses, including space heating, air cooling, cooking, water heating and applications of different electric appliances[35].

The energy model plugins developed as part of the WHY Toolkit will be used to provide a highly segmented load profile to PRIMES model for a series of scenarios examining EE measures and deep decarbonisation strategies and their impacts to various consumer types. These plug-ins will also enable other modelers that work using similar models to also take advantage of the novel insights provided by the WHY toolkit. A two-way interlinkage of the WHY Toolkit with PRIMES model will be developed. In particular, a data interface and a disaggregation of PRIMES results will be carried out to capture consumer idiosyncratic

33 Directive (EU) 2018/2002
34 Directive (EU) 2018/844
35 Fotiou, T.; de Vita, A.; Capros, P. Economic-Engineering Modelling of the Buildings Sector to Study the Transition towards Deep Decarbonisation in the EU. Energies 2019, 12, 2745. https://doi.org/10.3390/en12142745

behaviours and load granularity provided by WHY Toolkit. This Use Case will provide an improved understanding of the role of consumers and energy efficiency. In particular:

- Quantify the systemic implications of WHY interventions, by capturing system interlinkages (energy demand, supply, storage, grids), changes in energy prices, sectoral substitution, fuel mix, investment/costs
- Deepen the demand side-related parameters in existing models widely used at European level (PRIMES-BuiMo) including new aspects (e.g., consumer behaviour, prosumaging) and data sources of high granularity.
- Explore the effects and technical feasibility of climate neutrality on consumer demand, load profiles, energy costs etc. In this way, the pathways to climate neutrality are evaluated based on their feasibility, implementation barriers and challenges when considering high temporal and spatial granularity provided by the WHY Toolkit.

6.2. External policy framework and interventions to be assessed

In the last decades, the EU is actively pursuing and implementing ambitious energy and climate policies, aiming to reduce its GHG emissions, while boosting growth and protecting environmental sustainability. The main pillars of the EU climate policy framework include:

- GHG emission reductions
- Energy efficiency improvement (e.g., in the form of efficiency standards)
- Increase of renewable energy shares in energy consumption
- Carbon pricing through the EU Emission Trading System (ETS)

The EU climate targets have been gradually strengthened in the last decades. Starting from the 20-20-20 targets in 2008, then moving on to a 40% GHG reduction target in 2030 (adopted in 2016), which was revised upwards in 2021 to 55% through the 2030 Climate Target Plan/ Fit For 55 policy package which also calls for energy efficiency and renewable energy uptake.

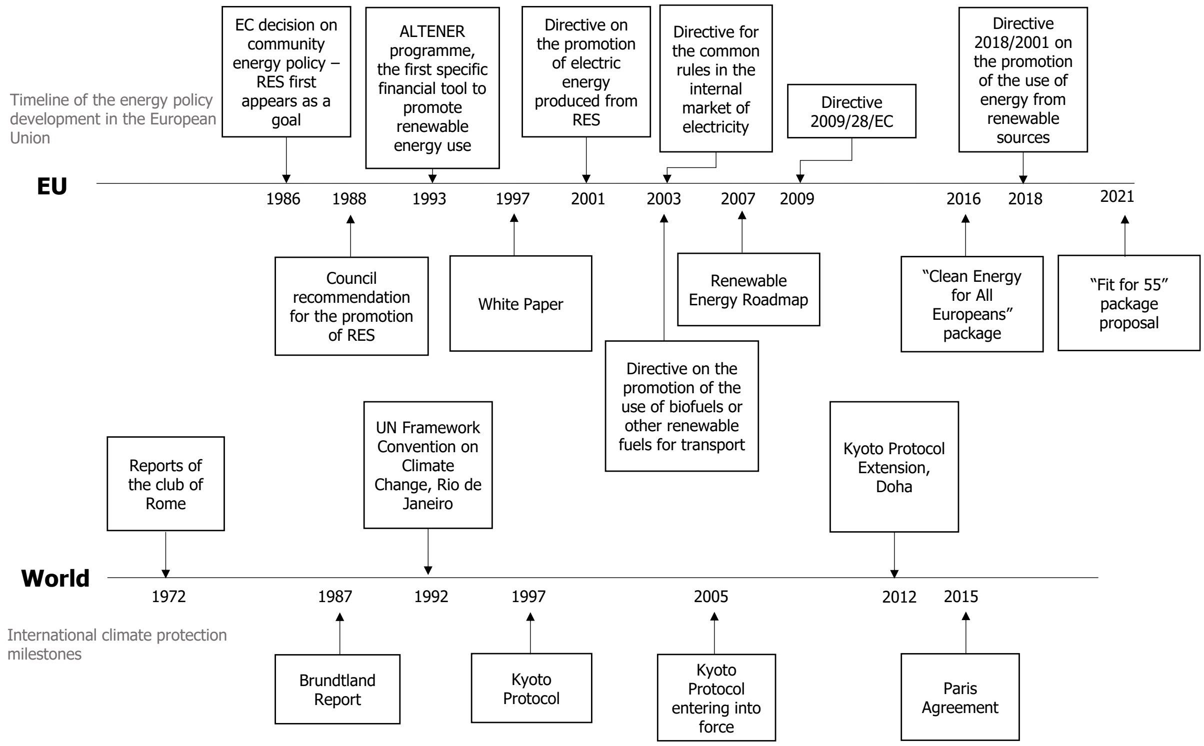
In parallel, the EC explored long-term transformation pathways towards deep decarbonisation. While the EU energy roadmap 2050[36] and the Roadmap to a Low-Carbon economy[37] explored the implications of achieving 80% reduction in EU GHG emissions over 1990-2050, the focus shifted gradually towards more ambitious net-zero targets by mid-century as explored in the Clean Planet for all[38] strategy published in November 2018.The EU Green Deal[39], aims to turn Europe the first climate neutral continent by 2050 by setting in motion the Fit for 55 package.

These medium and long-term targets and strategies are accompanied by specific policy instruments, which are commonly included in EU and national legislation in the form of directives (e.g., EU ETS or Energy Efficiency Directive-EED). Of special relevance to the residential sector is the amended in 2018 EED and its recent (July 2021) proposed update where buildings and the heating and cooling sector are recognized as the sectors with the highest potential for energy savings. In addition, the EC Regulation 2019/2021 laying down eco-design requirements for electronic displays, as reported in the Directive 2009/125/EC, is

36 https://ec.europa.eu/energy/sites/ener/files/documents/2012_energy_roadmap_2050_en_0.pdf
37 https://ec.europa.eu/clima/system/files/2016-11/roadmap_fact_sheet_en.pdf
38 https://ec.europa.eu/clima/eu-action/climate-strategies-targets/2050-long-term-strategy_en
39 https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en

of importance to the white, grey, and black appliances used in households along with consumer preferences for their replacement and choice.

Figure 8 Timeline of EU energy policy developments



Description of Stakeholder workshop[40] to co-define the WHY policy interventions

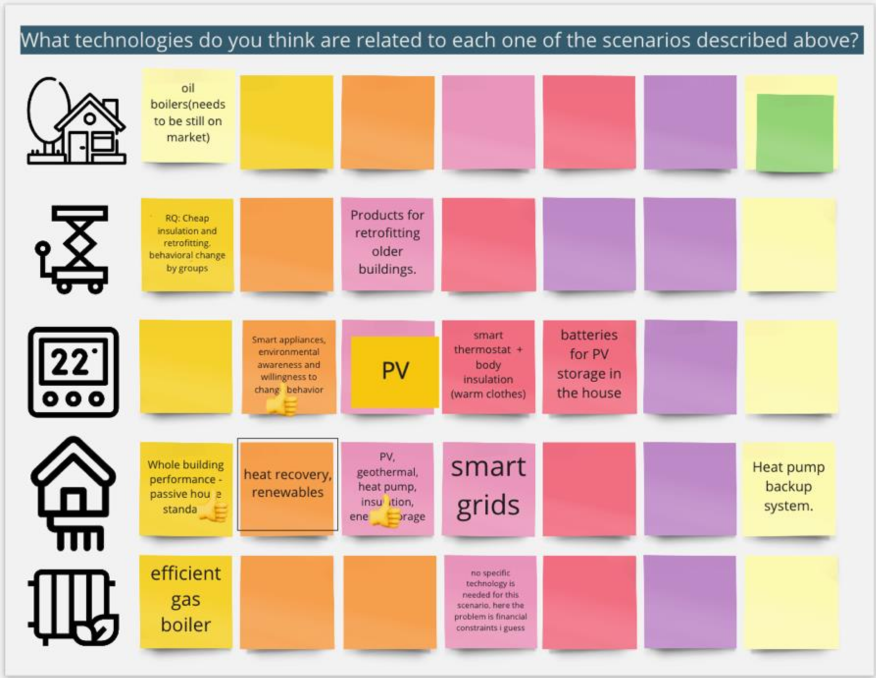
Considering the specific EU energy and climate goals and policies, the WHY consortium sought feedback from a diverse group of stakeholders including EU policy makers, energy associations, research institutes, consumer organizations and more. To actively engage them, we organized an online workshop where the discussion was set up around two main thematic areas: 1) Technical building sector aspects when modelling the energy transition and 2) Policy interventions towards low-carbon transition and their impacts on buildings. This discussion aimed at narrowing down the possible focus areas to be explored by identifying the most important policy interventions for the European building sector. Likewise, the stakeholders were asked, through a creative and interactive process, to prioritize technical solutions and policy interventions relevant for reducing emissions from the built environment.

Regarding technical solutions the stakeholders were asked to focus on building performance, mobility, and flexibility together with smart appliances. Next, the specific developments and focus areas were selected based on five main scenarios of the possible evolution of the building sector based on the EU climate goals by 2050 – the scenarios were rated from baseline to more ambitious. Depending on the scenario, the stakeholders linked technical building solutions to the scenarios (Figure 9**Error! Reference source not found.Error! Reference source not found.**). We observe that the more climate ambitious the scenario, the

40 The detailed results of the EU Use Case workshop are presented in the WHY report, here https://www.why-h2020.eu/fileadmin/user_upload/WHY__The_EU_Use_Case_Workshop_Report-4.pdf. We would like to thank all participating stakeholders for dedicating their time and providing us with important input during the workshop. We are also grateful to WHY partners for the commitment in organising this workshop as well as for their support in writing this report.

more efficient and innovative the technical building system solution. When moving towards more ambitious decarbonisation targets, stakeholders emphasized the need for higher uptake of low- and zero-emission technologies largely based on renewable energy, combined with storage, digitalization, and smart grids, but also with behavioural changes and new business models.

Figure 9 Technologies anticipated by stakeholders as relevant for the first set of the scenarios



The objective of the session on energy and climate policies was to analyse and prioritise the most important policy interventions to drive the transformation of the EU buildings sector. These will be assessed quantitatively in the EU Use Case using the WHY toolkit soft-linked with PRIMES BuiMo. Policy interventions include regulatory, economic, financial, innovation, educational and informative measures related to buildings' energy performance, electrification, flexibility, smart appliances, and socio-economic issues (e.g., energy poverty).

Initially, the WHY consortium provided stakeholders with identified key actions per theme as guidance. For building performance these were: Net Zero Energy Buildings (NZEBs) and Renovations. For electrification, we chose the phasing out of combustion appliances and installing heat pumps in households. The stakeholders provided additional actions and measures based on their expertise. Next to the Energy Performance of Buildings Directive (EPBD) and the Energy Plus building standards, relevant for NZEBs, measures complementing renovations included: Building Renovation Passports, increasing renovation depth, mandatory efficiency standards, targeting renovations for energy poor households, and training schemes for renovation professionals. The stakeholders also addressed the industry knowledge gap, financing schemes, consumer awareness and one-stop-shops, and the split incentives between tenants and owners.

Next, stakeholders analysed the types of interventions for implementing the policy measures as input to the European Use Case. The interventions discussed varied from economic, fiscal, and regulatory to information-based instruments. For example, regarding NZEBs, stakeholders indicated interventions like subsidies or other financial incentives being used to bring down the cost of low- carbon technology; technical support and informational instruments regarding whole life carbon and circular design; and creating stronger building codes standards. The figures below present the actions and interventions proposed by stakeholders to improve the performance of buildings, accelerate electrification, and smart appliances and address socio-economic challenges.

Figure 10 Interventions to Foster Building Performance Implementation

Figure 11 Policy Measures and Instruments for Electrification of Building Sector

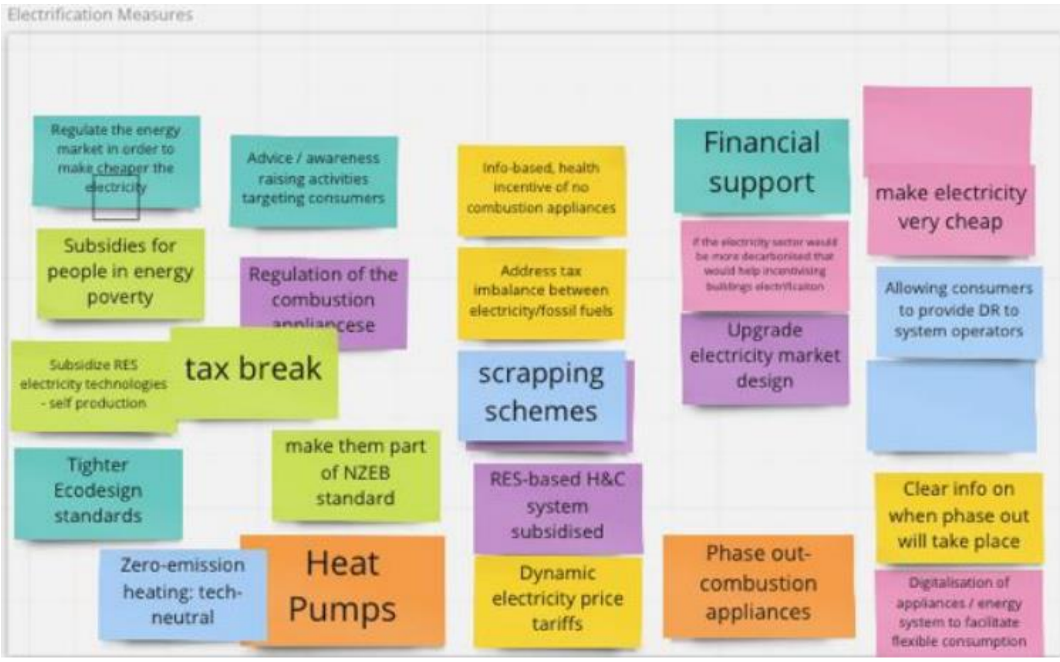


Figure 12 Policy Measures for Flexibility and Smart Appliances

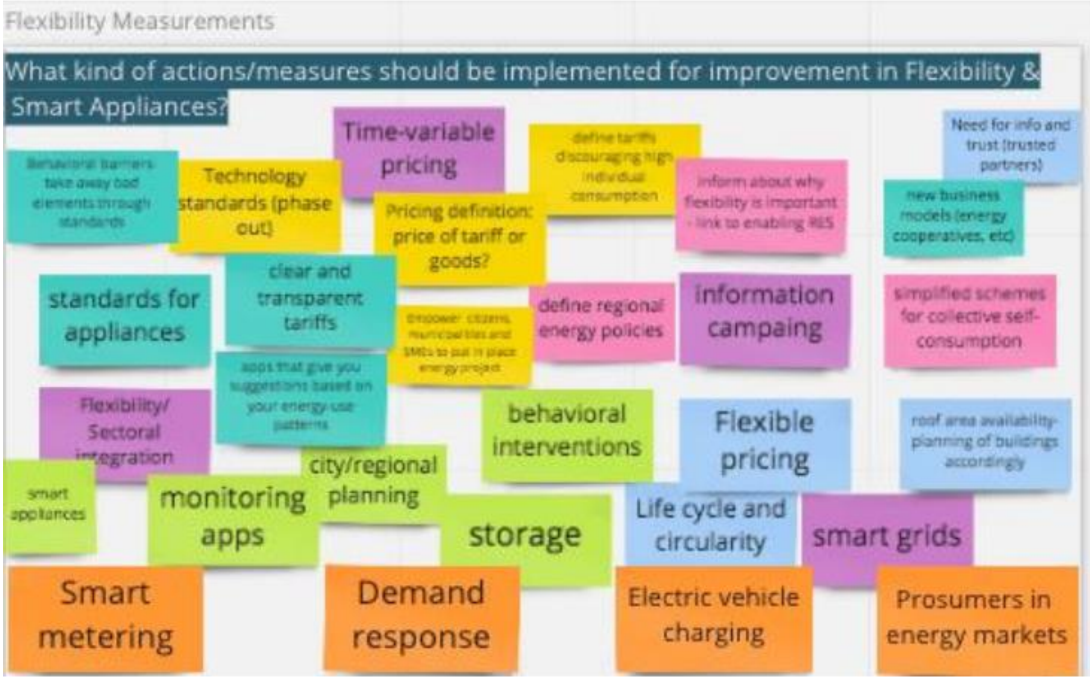


Figure 13 Policy Interventions to address Socio-economic Issues in Building Decarbonisation

Building on these insights, the above policy interventions were discussed and prioritized considering their effectiveness and implementation barriers, related e.g., to social acceptance, political issues, technology availability and potential ramp-up, governance, policy, and institutional barriers (results of prioritization are presented in the Annex of the deliverable). Of the economic interventions, making renovation loans more convenient for consumers through an on-bill repayment scheme was viewed as highly effective and faced less implementation barriers compared to a more complicated and less socially acceptable carbon pricing scheme for buildings. Stakeholders disagreed with the level of implementation barriers that tax breaks entail, since tax breaks were viewed as less effective than many other interventions. In addition to economic-based instruments, the experts mentioned that information resources will play a complementary role, as information campaigns are very effective for reducing energy consumption, but due to the implementation barriers, they need to be paired with other policy instruments.

Regarding electrification, stakeholders mentioned economic, regulatory, and information-based measures, such as dynamic electricity tariffs, energy market regulation, and informational campaigns that educate citizens on the health, socio-economic and climate benefits of replacing combustion appliances with electric heat pumps. The stakeholders focused on subsidies (economic intervention) to reduce electricity prices, address the tax imbalance between electricity and fossil fuels in several EU countries and minimize the distributional effects of energy transition. The regulatory interventions focused on banning combustion appliances and encouraging standards and market design. The information interventions concentrated around public information campaigns and encouraging training and communication regarding new technologies, like heat pumps, and new flexibility market solutions, like demand response, prosumage, and dispersed renewable energy generation.

On the topics of flexibility and smart appliances, the expert group discussed a multitude of economic, technology, regulatory, policy and information interventions, ranging from local planning to energy communities, new business models, information campaigns, time-variable pricing, transparent tariffs, standards for appliances, behavioural considerations, and smart grid integration. The prioritization of flexibility and smart appliances showed the importance of regulatory and information-based interventions. Information campaigns and consumer education were considered as effective interventions that have fewer implementation barriers than energy decentralisation to local authorities or public infrastructure investment. Moreover, combining information measures with subsidies and stricter regulations to create an intervention policy package can be a cost-effective means to reduce energy consumption and emissions from the EU Buildings sector.

Last, stakeholders identified energy poverty and just transition as the most important socio-economic issues related to the decarbonisation of EU buildings. Economic interventions include subsidy support for low-income households, progressive electricity tariffs, and supporting business models focused on low-carbon solutions. Many responses emphasized the importance of targeting the most vulnerable populations to both tackle energy poverty and achieve a just energy transition in line with the EU Green Deal goals. Stakeholders also mentioned different coalition-building techniques, like participatory projects, empowering citizens into energy communities, public-private partnerships with firms, and developing job retraining to raise awareness. Finally, the landlord-tenant dilemma was brought up, as it has large implications on both energy poverty and just transition in many EU member states where there is a high concentration of renters.

To sum up, the stakeholders suggested that economic interventions (e.g., subsidies, low-cost loans) should be combined with information-based interventions towards a policy package to trigger the clean energy transition with high efficiency and limited implementation barriers. Policy interventions based on consumer education and information were typically considered highly effective, as they empower citizens to gain buy-in to the energy transition demonstrating the need for Energy System Models (ESMs) to improve the representation of these aspects.

Identification of the most important policy interventions to be explored in WHY

The discussions at the workshop with the invited stakeholders provided valuable insights for the definition and development of the European Use Case. The workshop design proved to be very effective in getting climate and energy experts and policy makers to acquire an improved understanding of and prioritise the technical and political aspects that should be considered in the modelling of energy demand in the European buildings sector. There are numerous political issues to be included in the energy demand modelling and prioritizing them is not straightforward.

Through the stakeholder workshop and the research expertise of the WHY consortium, we managed to identify the most relevant regulatory, economic, and information-based policy interventions to be assessed in the EU Use Case. The analysis should focus on policy instruments such as subsidies or other financial incentives (e.g., renovation loans) driving down the costs of low carbon technologies. At the same time, the enforcement of stringent building codes and energy performance certificates and their compliance will be assessed together with raised citizen awareness through informational campaigns and improved technical support.

Regarding electrification, the focus is on the role of economic policy instruments to bring electricity prices down in order to address the tax imbalance between electricity and fossil fuels in several EU counties and minimize the distributional effects of the energy transition. 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. Last, the distributional effects of such interventions with a special focus on the most vulnerable populations will be analysed and policy instruments targeting vulnerable households will be examined, including progressive tariffs, low-cost loans, or targeted subsidies for low-income households.

6.3. External and Internal Variables

The European Use Case will consider a large set of external and internal variables that affect the future development of energy consumption in buildings, including socio-economic development, income of households, energy prices and taxes, weather conditions, human behaviour, and more. To ensure the highest policy relevance of the analysis, the evolution of external variables is largely based on the most recent official sources or other sources widely used by the scientific and policy community.

6.3.1 Brief description of PRIMES-BuiMo

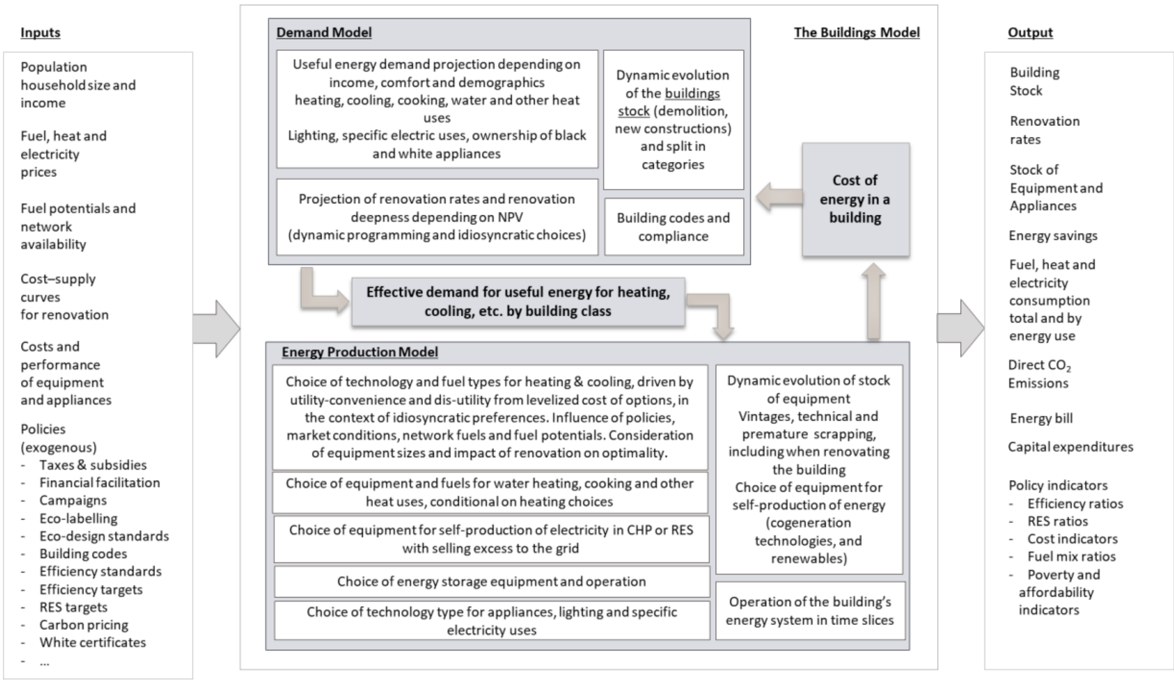
The PRIMES-BuiMo model projects the final energy consumption, fuel mix, CO_2 emissions, renovation rates and depth, equipment choice and replacement rates in the residential and services sectors, under alternative policy and regulatory measures (European Commission 2021; Fotiou, T. et al., 2019). It covers market and non-market barriers; hidden costs and perceptions affecting consumer behaviour and models a variety of policy instruments influencing decisions and possibly removing barriers. The model accounts for behavioural aspects of energy consumers while also respecting engineering and technical constraints and specificities and tapping possibilities for buildings transformation. PRIMES-BuiMo provides projections for residential and service buildings independently and covers EU Member States individually. The model splits the stock of buildings in many categories, namely by geographic locations, age of construction, income classes and service sector sub-sectors. Income classes help simulate the heterogeneity of energy consumers and their idiosyncratic behaviour, which depends (among others) on a multitude of factors, including income, preferences, weather patterns, access to loans, location, and household composition. Instead of a single representative actor, the model includes a variety of actors with distinct behavioural patterns. Discount rates differ by income class with low-income classes typically facing higher discount rates, representing their difficulty to access to low-cost loans. Through the differentiation of the discount rates based on real-world estimates, the model can reproduce consumer decisions (e.g., to purchase a heat pump or improve thermal insulation) capturing the heterogeneity of consumers in each class, thus addressing the drawbacks of the representative consumer assumption.

However, the enhanced representation of energy consumption and energy efficiency requires further modelling improvements especially on how consumer behaviour is represented, which factors influence the decisions of energy consumers, how new markets and business models are integrated (e.g. prosumaging, distributed generation, smart appliances) and how various instruments influence consumer decisions for investment and operation of energy-related equipment (including electric appliances and heating and cooling equipment). The soft-link of PRIMES-BuiMo with the WHY Toolkit will enable an improved assessment of households' energy demand and a better representation of all the above factors while considering the complex interactions of energy demand, supply, fuel prices and investment dynamics as captured by PRIMES.

The modelling of renovation is based on the concept of dynamic discrete choice, where, out of a finite set of dynamic renovation strategies, heterogeneous agents choose the most cost-efficient ones. A dynamic strategy, endogenous to the model, may involve renovation of building envelope, technical building system equipment selection, including self-production equipment for electricity, premature replacement of equipment, and fuel switching. Starting point, based on the renovation strategy by building class, is the calculation of the useful energy demand to be met by the purchase of energy products. This, in turn, is translated to the final energy consumed (through dynamic evolution and keeping track of equipment vintages) by the space heating system. The choice of the space heating strategy depends on the timing and depth of the envelope renovation. Likewise, the dynamic strategy of hot tap water and cooking equipment depends on the space heating system. Keeping track of capital turnover as technology vintages, PRIMES-BuiMo determines the fuel mix for the technical building equipment. As a result, it derives energy consumption by fuel, associated CO_2 emissions, operating costs, and investment expenditures. In addition, PRIMES-BuiMo includes a sub-module projecting electricity use in households, which first determines the energy service to be provided and then chooses the type of technology to purchase to meet the desired level of energy use. The turnover of the stock of appliances is dynamic and endogenous to the model. Policy instruments and specifically eco-design regulations influence the technology types that the market offers to consumers.

Energy labelling and other policies are represented in the model and facilitate the uptake of highly efficient, yet more expensive, technology types through reducing the uncertainty and lack of information. PRIMES-BuiMo can represent various policy instruments including: Taxes for energy products, financial facilitation for renovation and purchase of low-carbon technologies, Information campaigns, eco-labelling of technical equipment, eco-design standards, Building code standards and levels of compliance, Energy efficiency standards, carbon pricing (EU and national), White Certificates and targets for RES heating and cooling.

Figure 14 Flowchart of the PRIMES-BuiMo mod



6.3.2 External Variables

External variables are considered those that are provided as exogenous inputs to the Use Case and their development is based on exogenous assumptions. The future development of external variables influences the projections of internal variables, which are derived using PRIMES-BuiMo. In the EU Use Case, the main external variables can be categorized as below:

a) Socio-economic developments (GDP, population, household income, household size – i.e., persons per dwelling), including the potential effects from COVID-19 pandemic

b) Assumptions on technology costs and performance (e.g., heat pumps, boilers, storage etc.)

c) Prices of energy products and carbon taxes

d) Targets on emission reduction, electrification, efficiency improvement, emergence of low-carbon fuels (e.g., hydrogen), decarbonization of district heating/cooling networks

e) Energy and climate policies (regulatory, fiscal, economic, knowledge, informational)

f) Parameters influencing the adoption of low-carbon technologies (e.g., fuel potentials, network availability, cost-supply curves for renovation, discount factors)

g) Climate related parameters (e.g., Heating and Cooling Degree Days)

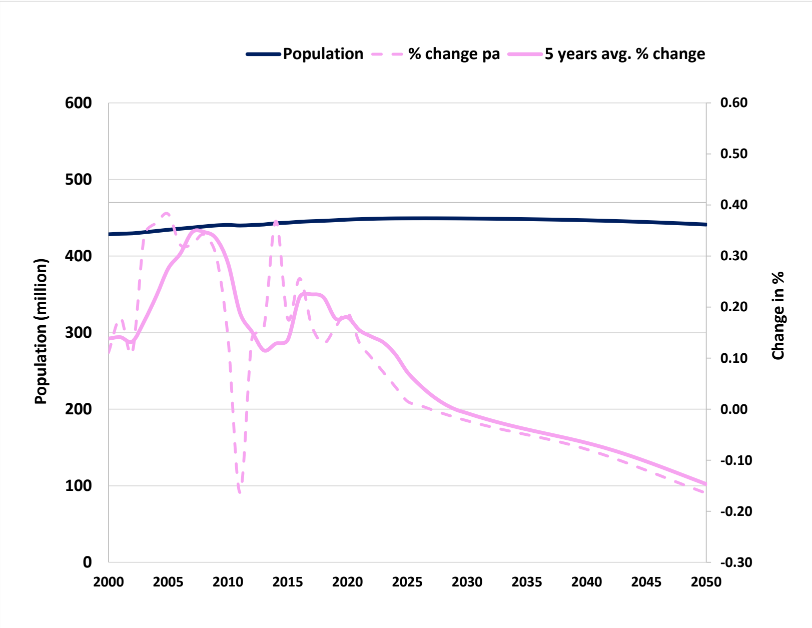
To provide additional insights on the external variables underpinning the Use Case, the section includes the quantitative projections for the main exogenous drivers, which are largely based on the recent EC Reference scenario 2020 (European Commission 2021).

1) Socio-economic developments

Regarding GDP and demographics, which are key input variables for the European Use Case, we use statistical data from Eurostat. The 2021 Ageing Report[41] provides the basis for long-term population and GDP growth trends, while the short- and medium-term GDP growth projections are taken from the Spring 2020 DG ECFIN forecast, which includes the impact of the COVID-19. The historical and recent demographic and economic evolution of EU countries is the starting point for their projection, which are provided by Eurostat and the work of the Economic Policy Committee and the European Commission. The GEM-E3 model is used to simulate the socio-economic developments and sectorial production in each EU Member State by 2050. As a CGE (Computable General Equilibrium) model with high country and sectoral resolution, GEM-E3 ensures that macroeconomic and sectorial projections of the EU economy are consistent with the global economy context. The impacts of the COVID-19 pandemic have been fully reflected in the demographic and macro-economic projections as well as in the sectoral composition of GDP (European Commission 2021).

The EU population is projected to slightly increase until 2030 and then decline in the long term. Still, there are differences between national population trends, as in 11 Member States the population is projected to grow by 2050. Figure 15 shows the population projection in the EU until 2050.

Figure 15 Population evolution and projection in the EU

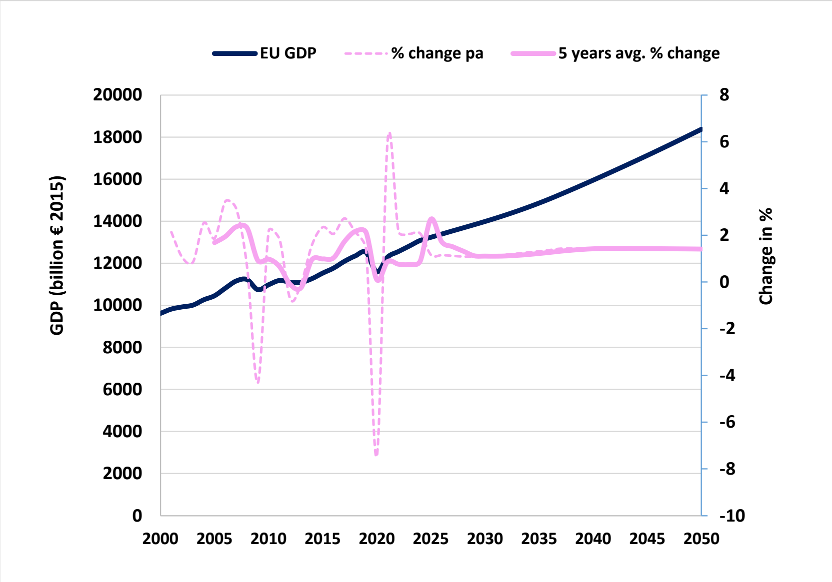


Source: EUROPOP 2019, European Commission 2021

The GDP projection is based on the European Commission's 2021 Ageing Report and the Spring 2020 Economic Forecast (European Commission 2020a and European Commission 2020b). Projections on GDP growth are uncertain due to the effects from COVID-19 pandemic and vary widely across different sectors of the economy with sectors like aviation and tourism suffering the most negative impacts (Figure 16). As a result, the economic growth will highly depend on the duration of the pandemic and on new trends emerging in the post-COVID-19 era regarding among others remote work, fewer business trips and changes in global supply chains (European Commission 2021).

41 "2021 Ageing Report: Underlying Assumptions and Projection Methodologies. European Economy 11/2020", Directorate-General for Economic and Financial Affairs (DG ECFIN)

Figure 16 EU GDP in aggregate terms



Source: European Commission 2021

2) Technology costs for the buildings sector

The cost development of technologies is also provided exogenously, both for electric appliances and heating and cooling equipment, as well as the renovation of buildings' envelope. Consumer decisions related to the purchase of household appliances, space and water heating technologies and technical building system equipment largely depend on total purchasing costs, which are based on acquisition costs, the prices of energy products and efficiency by vintage. The technical and economic characteristics of each technology category are assumed to change over time as a result of learning-by-doing and economies of scale. Techno-economic assumptions have been revised following updated literature research and large-scale stakeholder consultations.

Table 3: Purchasing costs for heat pump technologies

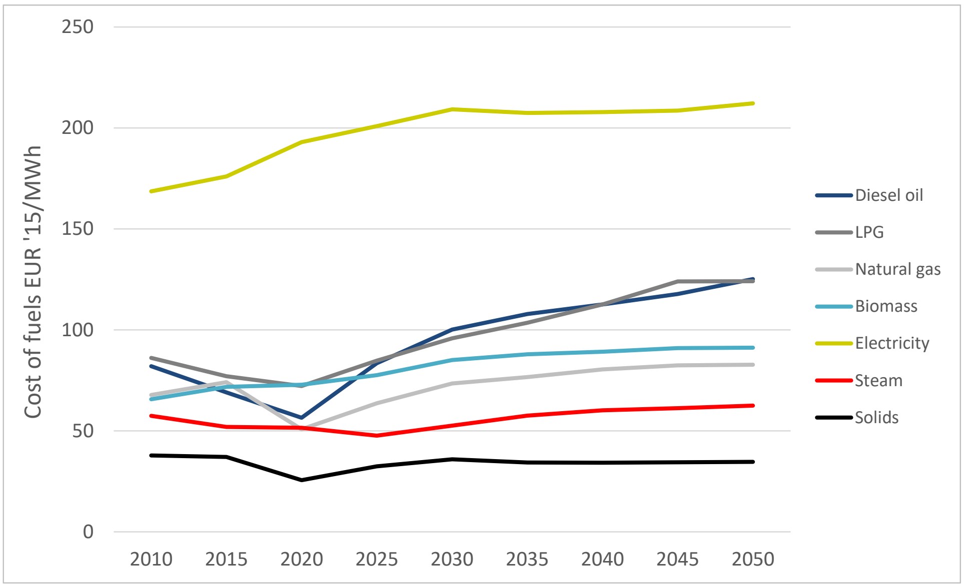
Heat pump technology	**in EUR/kW**						
		2030			Ultimate		
	Current	From		To	From		To
Heat pump air in South Countries in Middle South countries in Middle North countries in North countries	784	603	835	1080	267	673	1030
Heat pump water	1036	847	1104	1428	487	960	1287
Heat pump ground	1695	1385	1805	2335	1203	1570	1774
Heat pump gas	1176	904	1194	1512	400	942	1339

Assumptions on envelope renovation costs depend on the climate zone and depth of such renovation. Here, we consider investment costs which are the energy related expenditures needed to implement an energy renovation of a building envelope – without considering usual renovations performed for other purposes (structure, decoration etc.). The energy savings rate refers to a typical building as in the current stock of existing buildings, not savings in new constructions.

3) Prices of energy products

In PRIMES electricity and fuel prices are calculated in such way that allows recuperating all costs, including those related to RES policies (e.g., feed-in-tariffs), grid costs, charging infrastructure for EVs and investment costs including stranded investments, back-up, and reserve costs as well as profit margin. PRIMES differentiates electricity prices by sector reflecting load profiles, generation, and grid costs. Weighted average electricity prices modestly increase until 2030 in the households' sector, due to the increasing carbon taxes that impacts the costs of fossil-fuel-based electricity producers and the higher grid costs due to infrastructure development to support grid expansion to facilitate expansion of variable RES and new interconnections. Fossil fuel products (e.g., natural gas, diesel oil, LPG) see increasing prices until 2050 driven mostly by increasing international import prices in the absence of strong global climate action, whereas end user prices of steam and biomass slightly increase by 2050. The modelling does not take into account the recent short-term changes in energy prices, especially for gas, electricity, and oil. However, these will be fully considered in the use case analysis in WP5.

Figure 17 Average end user price for fuels in the residential sector



Source: European Commission 2021

4) Discount factors used for the decision in buildings

Private discount rates pertaining to individual agents play an important role in their decision-making as they highly influence their decision to purchase technologies and appliances with different cost structure, e.g., balance between up-front investment costs vs long-term operating and maintenance costs. This is especially the case for a household, or a small enterprise deciding to renovate a building or choose a new type of heating equipment. Agents' economic decisions are usually based on the concept of cost of capital. Depending on the sector, this is either the weighted average cost of capital (for larger firms) or a subjective discount rate (for individuals or smaller firms). In both cases, the rate used to discount future costs and revenues involves a risk premium which reflects business practices, various risk factors or even the cost of lending. In the buildings sector, the discount rate for individuals (households) also reflects an element of risk averseness as consumers tend to prefer technologies with low upfront investment costs (and relatively higher operating costs).

The discount rates vary across sectors. In the European Use Case, we use discount rates of up to 14% for the decision making for buildings renovation of household. Table 4 shows the discount rates for different elements during an energy renovation and the variation by income class. The discount rates are also necessary for annualising capital or investment expenditures (CAPEX) for cost reporting.

Table 4: Discount rates of households

Assumptions for EU Reference Scenario 2020	Discount rates	Modified discount rates due to EE policies[42]
Households for renovation of houses and for heating equipment	14.75%	12%
Households for choice of appliances	13.5%	9.5%
By income class (for the decision on renovation and the choice of equipment)		
Low	14.1%	
Low-Mid	13.6%	
Mid	13.2%	
Mid-High	12.8%	

Source: European Commission 2021

6.3. Internal Variables

Internal variables are those that are endogenously calculated by the PRIMESBuiMo model and its soft linkage with the WHY toolkit. The main internal variables are listed below:

- Useful energy demand for heating and cooling and electricity
- Dynamic evolution of the building stocks
- Envelope renovation strategies (rate and depth of buildings’ renovation)
- Technical building equipment choice and replacement options
- Electric appliances equipment choice and replacement options
- Replacement rates of heating cooling equipment
- Final energy consumption — by country, building type, income group and energy use
- Fuel mix used in residential sector by country, building type and energy use
- Direct CO_2 emissions

42 It is assumed that standard discount rate values are pushed downwards by policies addressing the barriers which caused the high discount rate values in the first place.

- Final energy savings relative to base year or a Business-As-Usual scenario
- Costs and investment for envelope renovation and technical building equipment
- Interlinkages with transport and electricity sectors through PV, EVs, storage
- Scenario impacts on fuel, heat, and electricity prices
- Energy-related expenditure for households
- Policy indicators, e.g., efficiency ratio, RES shares, energy cost and affordability

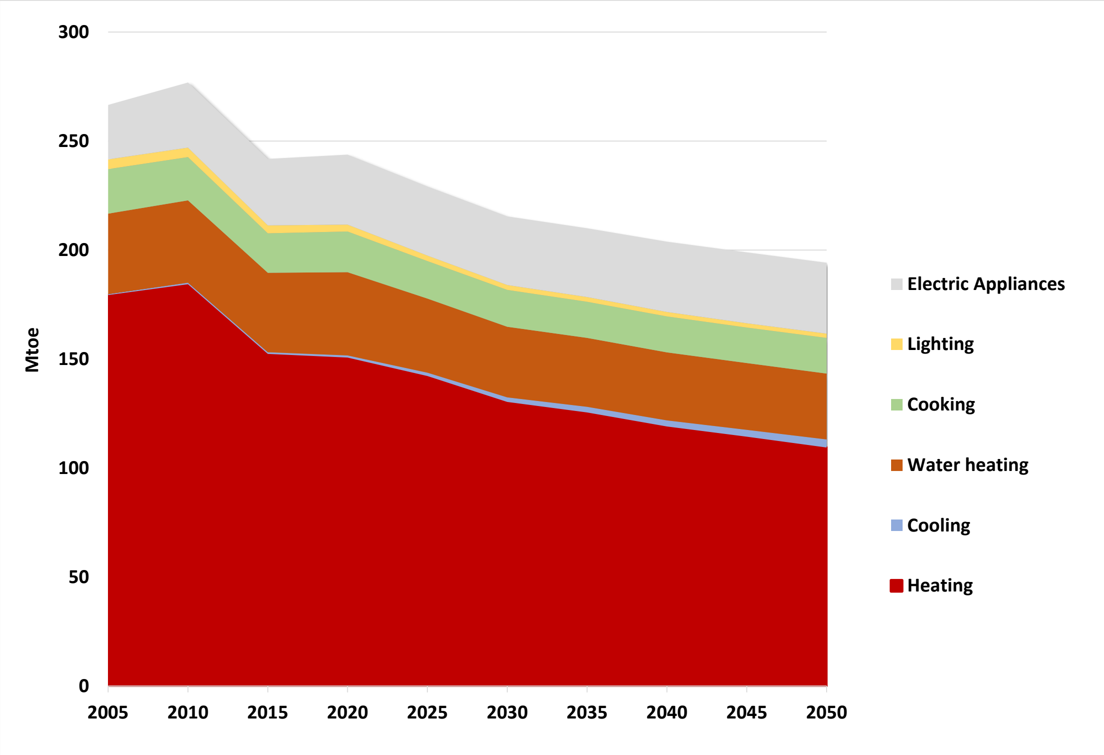
The section below briefly presents the PRIMES-BuiMo projections of the Reference scenario based on the current modelling set-up, i.e., before the modelling enhancements to be realized in WHY. As the focus of the Use Case is the EU, model-based projections are provided for EU27 (excluding the UK). The Reference Scenario is a policy relevant projection on the future developments of the EU economy, energy system, transport and greenhouse gas emissions that acts as a benchmark for future policy initiatives. It reflects policies and market trends used by policymakers as baseline for the design of policies in the mid- and long-term, notably in 2030 and 2050. It includes:

- A core target of at least 40% reduction in domestic GHG emissions in the period 1990-2030
- The share of renewable energy in total gross energy consumption should be at least 32% in 2030 (in line with the EU Renewable Energy Directive)
- Increased energy efficiency improvements to at least 32.5% in 2030 (in line with the EED provisions) making use of the tools foreseen in the Governance Regulation

The scenario reflects the outcomes of adopted EU level policies and considers national contributions and planned policies as well as Member State projections as provided in their NECPs and assumes no intensification of current policies or development of new policies fostering the uptake of renewable energy, energy efficiency and clean fuels beyond 2030. The scenario assumes that regulatory, financial, or enabling measures will not be strengthened after 2030 to support higher climate ambition.

The Reference Scenario projections show a remarkable decoupling of EU energy demand from income growth, much above historical trends, which intensifies in the period 2021-2030 as a result of the Energy Efficiency Directive, national renovation strategies and the policies included in NECPs. These policies have an impact after 2030 as well, causing demand for energy in buildings to further decline, but at a slower pace in the absence of additional policies. Space heating represents the largest share of residential energy demand, which decreases due to efficiency improvements (**Error! Reference source not found.**). Economic growth drives an increase in the stock of electric appliances (black and white). Between 2015 and 2030 the stock of white and black appliances increases on average by 2% per year following historic trends and income growth in EU countries. The growth in Information and communication technologies is about 4.5% per year in that period due to increased digitization of services. Advancements in lighting technologies will continue at a moderate pace resulting in further efficiency improvements. Cooking shares remain rather stable and so does demand for water heating. The increase in useful energy for cooling is associated with increasing cooling degree days (CDD) – driven by higher temperatures and climate extremes due to climate change – and the increase in household income, which together lead to higher penetration of cooling equipment. The drop in the shares of heating is a result of increased renovation and uptake of more efficient space heating equipment.

Figure 18 Residential energy demand by use for EU27

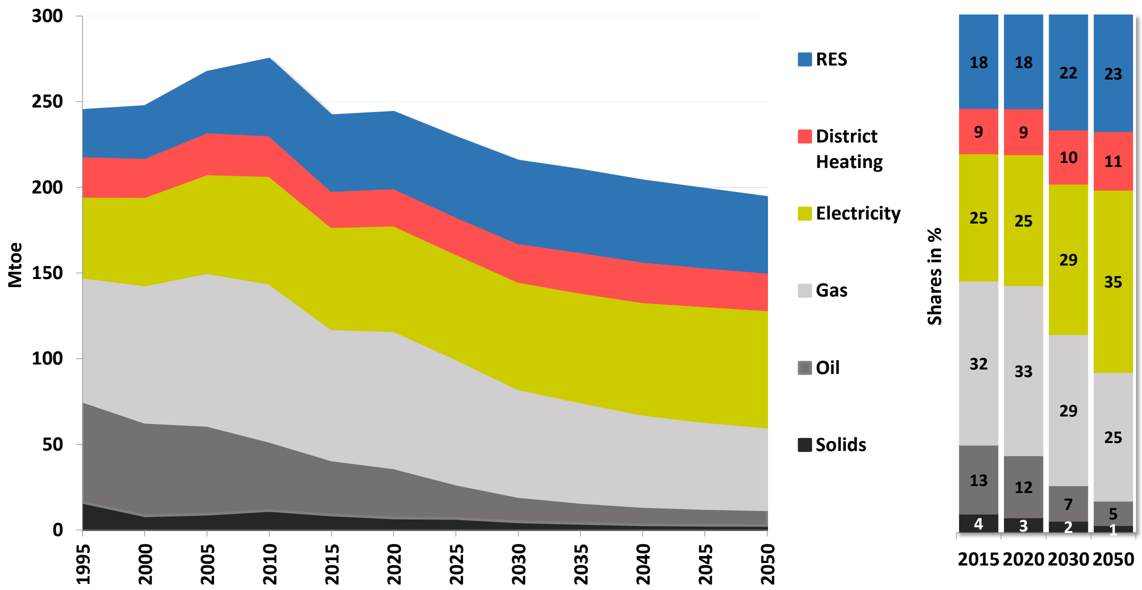


Source: European Commission 2021

The fuel mix used in residential buildings shows a large shift away from the use of solids and oil products, due to policies for air quality, growing electrification of end-uses, increased connection to gas networks and moderate extension of district heating infrastructure where already existent. Gas roughly maintains its market share until 2030, which declines slightly over 2030-2050 (European Commission 2021). In contrast, the share of electricity in residential energy consumption is projected to increase from 25% in 2020 to 29% in 2030 and further to 35% in 2050, driven by the increased use of appliances and the penetration of heat pumps, which is facilitated by technological progress and energy efficiency measures (European Commission 2021). Heat pumps are prioritized in cases where deep renovation is pursued, or where buildings are highly insulated. Renewable shares are projected to increase modestly by 2050, mainly due to support measures for solar thermal and biomass boilers.

Historically, demolition and construction rates are very low in the EU. Thus, renovation of existing buildings is the main option for achieving energy savings. While today most renovations are described as “light” offering limited energy savings, the implementation of the EED and EPBD at national level is expected to increase the depth and rate of renovation. EU’s renovation rates, i.e., the number of houses undergoing renovation over the total stock of houses, have been on average below 0.8% per year. The first stream of energy efficiency policies pushed that rate upwards, and current policies are expected to boost it further towards 2030 to about 1%-1.2% per year over 2020-2030. Despite the slowdown after 2030 due to the lack of new policies, annual renovation rates are projected to remain on average above 0.8% also after 2030, as a result of the inertia of the currently implemented policies.

Figure 19 Residential energy demand by fuel

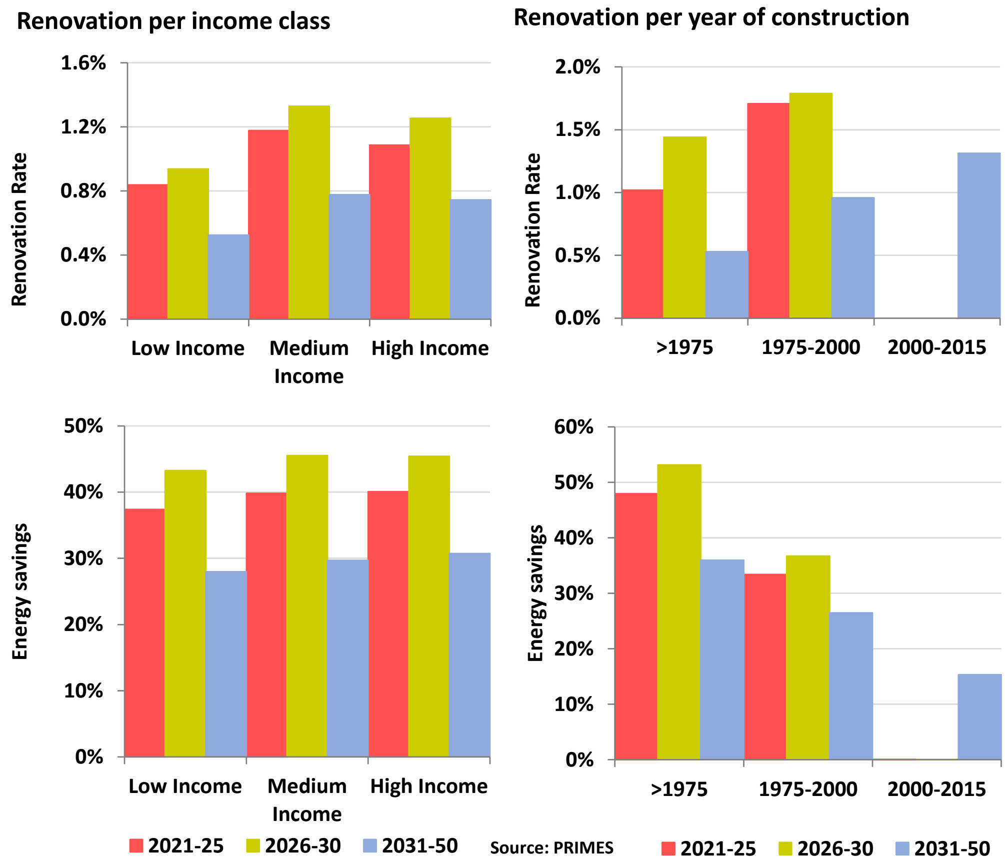


Source: European Commission 2021

Analysing renovation rates from the perspective of income class and age of the building stock, the majority of renovations in the Reference scenario is carried out by medium and high-income classes (Figure 20) as they have better access to funding than low-income households. Limited access to capital forces lower income classes to undertake lighter renovations, which are less capital intensive. In absence of additional policies after 2030, the depth of renovations decreases for all income classes over 2030-2050. The mid-aged buildings have higher average renovation rates compared to older buildings, which are more difficult to renovate for reasons related to unknown structures that may require additional works. At the same time however, the energy savings achieved in mid-aged buildings are lower than those in older houses, since mid-aged buildings have better thermal insulation as building standards are in place since 1975 in most EU countries; still, it is more cost-efficient to perform medium depth renovations in buildings of over 20 years.

Member States have already put in place and are projected to implement policies for overcoming market and non-market barriers to the renovation of buildings. While these policies and measures are expected to lead to substantial fuel switching and energy savings in the residential sector, still the projected savings are found not to be in line with the current EED target – further results of the July 2021 update of the EED remain to be explored. The Reference scenario shows that low-income classes face significant economic obstacles, which cannot be overcome in most Member States with the current national policies. In order to achieve a just transition and reduce energy poverty, additional policies to overcome such barriers are needed both at European and national levels.

Figure 20 Renovation rates by age/income class of residential buildings



Source: European Commission 2021

6.4. Limitations and Expected Results

The scenarios assessed within the EU Use Case will lead to an improved understanding of system-level implications of enhanced energy efficiency and electrification in EU buildings in the context of ambitious targets towards achieving climate neutrality by mid-century. The main outcomes will be a set of medium and long-term projections of key energy-economy-emissions indicators in EU countries that describe the development of the energy system (focusing on the buildings sector). These projections will differ by scenario, which simulates the effects of specific policy instruments that will be co-designed with stakeholders. These indicators include (among others): final energy consumption by building type, energy mix in buildings, CO_2 energy-related emissions, uptake of low-carbon technologies, carbon prices, investment, and energy system costs.

The European Use case will provide new insights into:

- What affects the energy-related choices of individuals in the residential sector and how can these factors improve the modelling and projections of energy consumption?
- What is the effect of different energy policy interventions and incentive systems to reduce energy consumption and unleash the flexibility potentials in the residential sector?
- What is the potential of a future uptake of low-carbon and flexibility solutions in the residential sector, including electric vehicles, decentralised electricity generation etc.?

- What are the system effects of the uptake of energy efficiency and flexibility solutions in the transformation of the EU energy system towards climate neutrality by mid-century?

The main limitation of the approach used in the EU Use Case is that the results of large-scale models like PRIMES do not provide detailed forecasts of how the energy system will develop, as model outcomes are interpreted as possible future realizations (projections) of the energy system based on the current state of knowledge. A more detailed analysis of possible policy-induced requires the use of more detailed, highly granular modelling tools focusing on smaller regions, a shorter time horizon and specific sub-sectors; other WHY use cases (e.g., the Gniebing microgrid or the Energy Community case) are better-placed to provide short-term forecasts of policy impacts on local energy systems. In addition, the modelling tools of the EU Use Case include several simplifications to handle issues that are highly complicated in real-world, e.g., simplified representations of power grids and new options (e.g., demand response, prosumaging), aggregation of individual consumers and buildings into specific “representative” household categories based on their incomes, building type etc. Finally, uncertainties are examined only through developing multiple scenarios and sensitivities to explore the implications of different policy interventions or alternative socio-economic pathways, without properly integrating uncertainty into consumer decisions related to equipment purchasing and operation, while short-term uncertainties (e.g., blackouts) are not considered.

6.5. Sustainability Assessment

The European Use Case will provide the following KPIs to the Sustainability Assessment:

- Emissions reduction achieved in the EU buildings sector by 2030 and 2050
- Energy efficiency improvements in EU residential energy consumption
- Share of renewable energy in EU residential energy consumption
- Electrification rate in buildings in European countries
- Impacts of decarbonization on energy system costs and electricity prices in EU countries
- Optimal building renovation strategies by income class
- Robustness of buildings decarbonization strategies under uncertain assumptions (e.g., about socio-economic developments, technology or policy failures, weather conditions)
- Energy affordability and energy expenditures by income class
- Uptake of low-carbon technologies (e.g., heat pumps) and smart appliances

The use case outcomes on the transformation of the EU buildings sector are strongly linked with several Sustainable Development Goals (SDGs). In particular, the results of the EU use case will be assessed and interpreted in the context of SDG 7 goals, Affordable Energy and Clean Energy. Several of the central themes of SDG 7, such as the expansion of clean energy, energy efficient improvements, and decarbonization of energy supply can be quantified in the Use Case. Additional links are present with many other SDGs, including SDG13 (Climate action), SDG 3 (Good Health and Well-Being), SDG 9 (Industry, Innovation, and Infrastructure) and SDG 10 (Reduced inequalities).

6.6. Designing the implementation in ESM

The modelling of demand at household and services sectors in ESMs has been identified as a potential area of improvement to achieve better projections of future mitigation scenarios (Grubler et al 2018), as most energy system models lack a proper segmentation and temporal resolution in the household sector and often do not consider the effects of policy interventions on energy demand. The PRIMES-BuiMo model includes a detailed representation of energy demand in the residential sector with high technology, policy, building type and country granularity. However, the soft-link of the WHY Toolkit with PRIMES-BuiMo will further improve model properties, in particular for the representation of load profiles and the segmentation of consumer types. The improved modelling framework allows evaluating the implementation barriers, challenges, opportunities and impacts of the revised EED targets with higher granularity and enhanced consistency and realism compared to the conventional Energy System models. It will further enable assessing the impacts of a wide spectrum of policy measures at EU and national level including proposing amendments to the decarbonisation pathways ensuring their compliance with technical and behavioural challenges with high granularity. Finally, it will allow the first time to create spatially and temporally explicit load profiles for new energy services in the buildings sector, considering electro-mobility, prosumaging, etc.

The scenarios of the EU Use Case will be designed to assess various policy interventions as described in sections 6.2 and 6.3. An important element in the scenario implementation is establishing a link between PRIMES-BuiMo and the WHY toolkit. In WP4 a series of model plug-ins will be developed to parse the outcomes of the WHY toolkit into a format that can be used by PRIMES and other large-scale energy models. Flexible routines for the aggregation or disaggregation and averaging of the outcomes of the WHY toolkit will be developed. On the other hand, there are certain modifications that will be carried out in PRIMES to increase its granularity so as to be well-placed to integrate a large range of outcomes from the WHY toolkit (e.g., enhanced load granularity, modelling of prosumers, additional differentiation in the buildings stock to better match the types of buildings described in WHY toolkit).

Different scenarios will be designed and developed with the new modelling framework to assess the implications of alternative policy interventions, which are co-designed with the WHY stakeholders. The exact number of scenarios to be simulated in the European Use case will be decided after discussions with the relevant stakeholders and will be presented in detail in the WHY Deliverables D5.1 and D5.2. These scenarios will consider the latest developments related to the EU energy system, socio-economic developments (including those related to COVID-19), technology progress and energy and climate policies, including the recent Fit for 55 policy package and the revised EU NDC target for 2030. The final assumptions for the EU Use Case about policy interventions, socio-economic developments, technology costs and energy prices, will be presented in detail in Deliverable D5.1, as the final values included in the analysis may change to incorporate the most recent assumptions (e.g., the recent increase in energy prices) taken from a wide and comprehensive evidence review.

7. The global use case

In the global use case, the integrated assessment models (IAMs) TIAM-ECN and PROMETHEUS are employed to assess the impact of energy efficiency and climate change control policies on the global energy system. The scenarios used for the assessment are designed based on interviews conducted with experts in this area, complemented by internal expertise on this type of analysis.

7.1. Objective and Scope of the Use Case

Long-term model scenario analysis at the global level is a tool to assess possible energy futures for the world, used extensively by many international organizations and high-level bodies, such as the Intergovernmental Panel on Climate Change (IPCC) and the International Energy Agency (IEA). With this Use Case we aim at linking to the discourse on global energy and climate scenarios and providing novel insights in this area. Specifically, the objective of the Global Use Case is twofold. First, we intend to investigate using TIAM-ECN and PROMETHEUS models how improving the representation of energy demand from the built environment will affect long-term global energy scenarios. The necessary improvements in the representation of energy demand in the models are provided by the WHY toolkit, developed in the project. The outcomes of the toolkit are integrated in the models via plug-ins, which will also enable (during and after the execution of the WHY project) other modelers who use similar models (in particular those based on the well-established TIMES platform upon which TIAM-ECN is built) to take advantage of the novel insights provided by the WHY toolkit. Second, this Use Case enables us to study the effects of enhanced energy efficiency on demand sectors, globally and for major economies (e.g., Europe, USA, China) and their impacts on pathways towards meeting Paris Agreement goals. The ‘efficiency first’ principle is being proposed in the energy policy discourse as a means to achieve the climate objectives in a lean and efficient way. In this context, the global Use Case uses IAM scenario analysis to assess and contrast the pros and cons 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.

7.2. External policy framework and interventions to be assessed

The main policy dimensions that can meaningfully be assessed in a global study with the two IAMs have been identified through an internal and external expert consultation process:

- Global climate policy;
- Carbon pricing (global or differentiated by region/sector);
- Subsidization of clean heating and cooling technologies;
- Subsidization of electrification (through heat pumps)
- Obligations to meet energy efficiency standards;
- Energy financing for retrofits in the building sector;
- Clean cooking promotion in developing countries;
- Sustainable Development Goals (SDGs), especially those that focus on improved energy access and reduction of energy poverty.

7.3. External and Internal Variables

The internal and external variables that will form the basis of our scenario analysis have also been discussed during the expert consultation process. Among the thousands of variables that constitute the input database of any IAM, there are several that relate directly to the policy dimensions reported in the previous section. These can be varied in a structured way to create scenarios for the global use case. The main variables to be considered in this context are:

- Long-term GDP and population growth (including possible macro-economic effects triggered by the COVID19 pandemic);
- Targets for limiting global temperature increase;
- Energy efficiency improvement objectives in the demand sectors;
- Granularity of the building stock;
- Targets for fuel mix in the buildings or transport sector;
- Average surface temperature (differentiating ‘warm’ and ‘cold’ countries);
- Electrification rate in residential energy consumption;
- Availability and cost of electricity storage;
- Share of decarbonized district heating/cooling networks;
- Penetration of hydrogen and other synthetic fuels;
- Targets on increasing energy access and limiting energy poverty.
- Energy costs and prices by type of consumer
- Investment by consumers to reduce emissions from buildings

The first three variables are the most impactful for an IAM analysis at the global level and will be placed at the heart of the scenario design. Economic and population growth are the main drivers that determine energy demand levels in an IAM. In this study we will start from the well-accepted projections of the Shared Socio-economic Pathways (SSPs) and apply some corrections to account for the expected short-term economic effects of the COVID19 pandemics. Climate control targets in line with the Paris Agreement foresee limiting global temperature increase to ‘well below 2°C’ while the 1.5°C target is also heavily discussed, which requires the transition to net zero energy systems by mid-century. Given the large uncertainty in the relation between global temperature increase and remaining carbon budget, state of the art IAM analyses typically assess a range of carbon budgets that may be in line with the Paris objectives (see e.g., Bertram et al., 2021). We will follow this practice in the global use case scenarios. Regarding energy efficiency improvements, the analysis will contrast the model outcomes of business-as-usual scenarios with those of scenarios in which a strong ‘energy efficiency push’ is applied, either globally or only in a selection of regions and/or sectors. Specific energy efficiency increases will be assumed in several technology categories across all demand sectors to construct these improved efficiency scenarios. The remaining variables will be used to refine the scenario assessment, e.g., by means of sensitivity analyses.

7.4. Limitations and Expected Results

The scenarios assessed within the global use case will lead to an improved understanding of system-level implications of enhanced efficiency under stringent climate policies towards meeting Paris Agreement goals. The main outcomes will be long-term (2050 and beyond) projections of several key indicators that describe the development of the energy and economy system under each scenario. A few examples of typical results are:

- Total energy consumption at global and regional level
- Energy mix at global and regional level, for all major economic sectors

- Power generation mix by technology
- Carbon price
- Additional system costs and investment
- (Regional) emissions.

The main limitation of the IAM approach is that the results do not provide detailed forecasts or predictions of how the energy system will develop and do not capture short-term changes. The model outcomes should rather be interpreted as possible future realizations of the energy system. These can serve as blueprints to design far-reaching high-level policies to e.g., reach global climate control targets. In order to achieve a more detailed description of possible policy-induced changes in the energy system, one needs to reduce the scope of the modelling – e.g., limit the analysis to a smaller region, a shorter time-horizon, a specific economic (sub-sector). Some of these more detailed studies are indeed part of the other WHY use cases.

7.5. Sustainability Assessment

The outcome of IAM analysis is strongly linked with a number of Sustainable Development Goals (SDGs). In particular, the results of the global case study will be assessed and interpreted in the context of the objectives of SDG 7, Affordable Energy and Clean Energy. Several of the central themes of SDG 7, such as energy access, cooking technologies, energy efficient improvements, and decarbonization of energy generation can be quantified through IAM analysis. For example, electricity access in Africa was the subject of a recent study with the TIAM-ECN model (Dalla Longa and van der Zwaan, 2021). Additional links are present with many other SDGs, including SDG 3 (Good Health and Well-Being), SDG 9 (Industry, Innovation, and Infrastructure) and SDG 11 (Sustainable Cities and Communities).

7.6. Designing the implementation in ESM

The modelling scenarios will be designed according to the guidelines presented in sections 7.2 and 7.3. An important element in the scenario implementation is establishing a link between TIAM-ECN (respectively PROMETHEUS) and the WHY toolkit. In WP4 a series of plug-ins will be developed to parse the outcomes of the WHY toolkit into a format that can be read by the IAMs. The type and quantity of data that can be transferred to the IAMs depends on the granularity of the IAMs' input database. For example, since in the two IAMs Europe is modelled as one single region, it will not be possible to feed information at Member State level into the models. This means that flexible routines for the aggregation and averaging of the outcomes of the WHY toolkit should be developed. On the other hand, there are certain modifications that can be carried out in the IAMs to increase their granularity and allow them to accept a larger range of outcomes from the WHY toolkit. For example, additional differentiation in the buildings stock can be implemented in the IAMs, to better match the types of buildings that are described in the WHY toolkit.

8. Way forward and Conclusions

The five Use Cases of WHY project capture a wide diversity of contexts from the micro-grid to energy community, national, European, and global level. Through the application of the WHY tools and models in diverse situations and use cases, the WHY Toolkit will be tested and validated. Therefore, the five Use Cases play a central role for the WHY project, and the objective of this deliverable is to precisely define and design the Use Cases, which will be then operationalized and carried out in WP5 using the WHY Toolkit and Energy System Models. In each Use Case, a reassessment of previous analyses made by partners or stakeholders using the WHY Toolkit will be conducted, and the results will be compared to understand the impacts of WHY modelling enhancements on energy and climate strategies at different jurisdiction levels, from the micro-grid and energy communities to the European and global levels.

The design of all Use Cases has been greatly benefited from the active engagement of stakeholders and end-users, including policy makers, public authorities, and utilities. This has taken various forms, depending on the specificities of each Use Case, ranging from the organisation of high-level workshop (in the European case) to interviews, focus groups on online questionnaires. In all cases, stakeholders helped to define the most important aspects, questions, and policy-relevant insights to be assessed in each Use Case of WHY. An active communication channel between Use Case Managers and stakeholders has been established and will be extensively used later in the project to discuss the interim and final results of the Use Cases and identify policy-relevant recommendations.

Various aspects were considered in the definition of each Use Case, including

f) the types of potential interventions to be assessed (with the support of relevant stakeholders);

g) the external policy and regulatory framework at different jurisdiction levels, including both those already legislated and implemented as well as possible future policies and strategies targeting EE improvements, fostering DR actions, or the electrification of services,

h) the load profiles to be generated and integrated in the different use cases including the number and characteristics of different residential loads and the temporal, spatial and aggregation scale,

i) The development of the external and internal variables (or aspects) that affect energy consumption (weather, energy prices, energy taxes, socioeconomic developments, incomes, behavior, cultural, grid access, etc.), based on the latest available official or scientific sources,

j) The Sustainability Assessment Model, based on a collection of the most relevant KPIs in each Use Case to measure the technical, economic, environmental and social sustainability.

The study also includes the relevant information needed for the creation and pre-processing of load profiles (in combination with WP2) in each Use Case and for the implementation of the scenarios and policy interventions in the large-scale ESMs of the consortium, focusing on the European and global Use Cases where the use of ESMs was identified as important.

The current deliverable provides the definition of the five Use Cases, including the aspects mentioned above. It serves as a starting point and as a basis for the analysis in WP5, providing key input assumptions, policy framework, definitions, policy interventions, and KPIs to be used for the actual development of the Use Cases through scenario implementation, simulations and policy impact assessment using the WHY Toolkit.

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ANNEX 1: Detailed selection of KPIs for the five Use Cases

1) The Gniebing Use Case

ID	Title	Description	Unit	Type	inputs	Methodology for calculation	Objective
KPI_G_1	Number of days the system can be operated (even with planned interruptions if need be)	Number of days the adapted load profiles can be supplied by the generation capacities during emergency grid operation, before either fuel runs out or generation in general fails to meet the consumption requirements	days	technical	Simulation results: - Load Profiles - Generation Profiles	for each quarter hour check whether there is a lack in generation: generation value < consumption value and make the sum of these events for each day. Count the days with such events afterwards.	maximize
KPI_G_2	Number of timesteps the system needs to reduce power or shut down renewable energy sources in order to prevent overproduction	Number of timesteps (15 Minute resolution) in which too much renewable energy is available in comparison to the consumed energy. In such cases generation needs to be reduced or dropped to prevent overproduction	# of 15 Minute Timesteps	technical	Simulation results: - Load Profiles - Generation Profiles	for each timestep check whether there is a surplus in generation: generation value > consumption value and make the sum of these events for each day. Count the number of events with such events afterwards.	minimize
KPI_G_3	Number of timesteps the system needs to shed loads in order to prevent underproduction	Number of timesteps (15 Minute resolution) in which not enough generation is available in comparison to the consumed energy. In such cases loads must be dropped in order to reduce the total consumption and prevent a failure of the system.	# of 15 Minute Timesteps	technical	Simulation results: - Load Profiles - Generation Profiles	for each timestep check whether there is a lack in generation: generation value < consumption value and make the sum of these events for each day. Count the number of events with such events afterwards.	minimize
KPI_G_4	Renewable Ration of the supplied energy	The emergency grid operation foresees the use of diesel operated backup generators. In order to reduce diesel consumption, renewables will be thrown into the mix. The flexibility for power control will be provided by the Diesel generators. This KPI defines how much renewable energy can be used in the supply of the consumers during the blackout situation	%	technical	Simulation results: - Generation profile DIesel generators - Generation profile renewable energy sources	sum of energy provides by RES divided by sum of energy provided by all sources	maximize
KPI_G_5	KPI 1 – System Observability	The KPI describes how well the system can be monitored or observed by the grid operator during actual operation of the system, the KPI considers the information on loads and consumption but also the strain off the grid	score (0 - 100)	technical	Availability of (close to) real time data in the system	-	maximize
KPI_G_6	KPI 2 – System Controllability	The KPI describes how well the system can be controlled by the DSO during emergency operation. This includes information on how well he can adjust the generation capabilities, but also how well he can shed or reduce individual or collective loads	score (0 - 100)	technical	Number of consumers, generators and grid devices with the necessary actuator to be controlled by the DSO	-	maximize
KPI_G_7	Costs of the system as a function of the amount of	Fuel costs for the operation of the back up generator during emergency grid operation.	€	economic	Generation profile of the back up generator Price for diesel that was paid	power output * efficiency factor for fuel consumption * fuel price	minimize

	consumers that can be supplied						
KPI_G_8	Environmental impact of the black-out operation	Yearly CO_2 emissions due to the operation of the installation + Total embodied CO2 emissions of the components installed	kg CO2 eq	environmental	database of average embodied emissions per component, generation, database of emission factors from the grid, database of average emissions factors of "not use phase" for each component, list of components to be installed	\sum_components (embodied emissions(component) * # components) + \sum_{t in year} kWh(t) CO2eq (t)	minimize
KPI_G_9	Person in risk protected	Number of households in risk or in energy poverty and / or with ininterrumpible loads (medical machines, etc.) that are provided service during a blackout or extreme weather (heat and cold weather)	#	social	amount of energy consumed by energy poverty houses, amount of energy consumed by ininterrumpible loads, black-out capacity	black-out capacity / kWh(energy power houses) or blackout capacity / ininterrumpible loads	maximize
KPI_G_10	Number Consumers that can be supplied during a Blackout Situation	The number of consumers that can be supplied during emergency generation is limited. This KPI defines how many residential consumer (which weren't originally planned for emergency supply) can be supplied after the analysation done in WHY	#	social	KPI_G_2 KPI_G_3 in different scenarios of supplied customers	-	maximize

2) The GOIENER Use Case

ID	Title	Description	Unit	Type	inputs	Methodology for calculation	Objective
KPI_GOI_1	% of changes of the energy consumed at the different periods	Differences between the percentage of energy consumed at each of the three time periods defined with the new tariff structure at Spain.	%	technical	individual load profiles	For each time serie, the energy consumed at each period will be calculated during 2020 and 2021. Then, the data will be normalized to get the percentage of energy consumed at each energy period and year. Finally, the difference between the different years will be calculated. The mean and standard deviation of these values will be provided.	maximization
KPI_GOI_2	Difference of kWh consumed in the study compared to the same period of the previous year (2020).	Differences between the total energy consumed. The objective is to test if the interventions induce to behave more energy efficiently or not.	kWh	technical	individual load profiles	For each time serie, the energy consumed during 2020 and 2021 will be recorded. The difference between the different years will be calculated. The mean and standard deviation of these values will be provided.	maximization
KPI_GOI_3	Difference of energy cost in the study compared to the same period of the previous year (2020).	Differences between the total cost of the energy.	€	economic	individual load profiles, cost of energy	For each time serie, the energy consumed during 2020 and 2021 will be recorded and multiplied by its real cost. Given that the costs of the energy have changed substantially, a second version of the KPI using only the standardized cost used during Q2'21 for the two tariff simultaneously will be provided.	minimization
KPI_GOI_4	Average ROI of a net-zero self-	The generation of a PV panel big enough to ensure Net Zero	%	economic	individual load profiles,	A set of time series of amount of energy generation by different amount of PV panels will be	maximization

	consumption PV installation	generation will be simulated assuming standard weather conditions from the North of Spain and enough space is available on the roof. The ROI at 25 years will be estimated assuming the electricity price will not increase during this period of time.			cost of energy, radiation profile, database of technical specification	created. Then, it will be selected the one that is just over Net Zero generation (so it will be slightly positive). Then the following calculation will be made and included as the yearly income of the investment: \sum_{t \in every period of the year} if (kWh_generate (t) > kWh_consumed (t); (kWh_generate (t) - kWh_consumed (t)) * €_sell (t) + kWh_consumed (t) * €_buy (t) ; kWh_consumed (t) - kWh_generate (t) * €_buy (t)) The first year the cost will be the cost of the installation at "standard" rate used.	
KPI_GOI_5	Number of inquiries about the new tariff structure	Number of inquiries at the different customer support channels about the new tariff structure. The objective is to observe the number of persons that could be interested in buying (or using) an EV, a heat pump, accumulators, batteries, self-generation or exploit the new tariff on second homes.	#	social	inquiries log	Direct measure at the costumer support log	maximization
KPI_GOI_6	The degree of difficulty to move loads by different collectives.	A qualitative assessment will be made using a post intervention survey and a quantitative assessment will use the information included in the contract to segment the consumer partners (geographic location, type of contract, power contracted, etc.).	score	social	survey results	Survey to be carried out at the end of the experiment to assess what consumer partner group have had the most difficulties to change their habits	qualitative
KPI_GOI_7	Percentage of participation	Percentage of consumers partners who have responded (clicked and read the advices) to the treatment (regardless of the results).	%	social	access log	Direct measure at the access log	maximization
KPI_GOI_8	Amount of change of kWh purchased by Goiener by period	Differences between the amount of energy buyed by Goiener at each of the three time periods defined with the new tariff structure at Spain.	kWh	technical	purchase orders	The difference between the energy buyed during each one of the periods of 2020 and 2021 will be calculated.	minimization
KPI_GOI_9	Change of the purchase costs for Goiener by period	Differences between the cost of energy buyed by Goiener at each of the three time periods defined	€	economic	purchase orders	The difference between the cost of the energy buyed during each one of the periods of 2020 and 2021 will be calculated.	minimization

		with the new tariff structure at Spain.					
KPI_GOI_10	Change of the amount of penalties associated with the purchase orders made by Goiener per period	Differences between the amount of energy penalized by the market operator due to the forecasting error of Goiener by the three time periods defined with the new tariff structure at Spain.	kWh	technical	penalties log	The different type of penalties will be recorded. The difference between the amount of kWh associated to each penalty will be calculated and presented per type of penalty and per time period.	minimization
KPI_GOI_11	Change of the cost due to the penalties associated with the purchase orders made by Goiener per period	Differences between the cost associated to the penalizations by the market operator due to the forecasting error of Goiener by the three time periods defined with the new tariff structure at Spain.	€	economic	penalties log	The different type of penalties will be recorded. The difference between the cost associated to each penalty will be calculated and presented per type of penalty and per time period.	minimization
KPI_GOI_12	Amount of reduction in the emission of the Spanish energy system due to the modification of the consumption measured in the consumer partners.	Changes on the emissions due to the modification of the behaviour of the consumer partners of Goiener	kg CO2eq	environmental	individual load profiles, national emission profile	For each time serie, the energy consumed at each period will be calculated during 2020 and 2021. Then, the data will be normalized to get the percentage of energy consumed at each energy period and year. Finally, the difference between the different years will be calculated. The mean and standard deviation of these values will be provided.	maximization

3) The Energy Community Use Case

	ID	Title	Description	Unit	Type	inputs	Methodology for calculation	Objective
TARGETS FOR THE OPTIMIZATION ROUTINES (BUILDING SIZING AND INFRASTRUCTURE SIMULATION)	KPI_EC_1	self consumption	Percentage of generation that is self-consumed at the energy community (namely, not sold to the grid) or other energy communities.	%	technical	generation, surplus	(total generation on year - energy injected in the grid on the year)/(total generation on year)	maximization
	KPI_EC_2	autarky rate	Percentage of energy not self-generated	%	technical	generation, consumption	1/(356 · 24 · 4) \sum_{t \in 0}^{356 · 24 · 4} (generation(t) - consumption(t)) / consumption(t) if consumption is 0, if not add 1	maximization
	KPI_EC_3	peak power	Maximum amount of instant power generated and maximum amount of power consumed	kW	technical	load, consumption	max generation (t); max consumption(t)	minimization?
	KPI_EC_4	load factor	Relation between the energy consumed and the maximum power delivered. It is a measure of the shape of the load (near 1 more flat, near 0 more spiky or oversized	%	technical	load, consumption	average daily load during a year / maximum load	maximization

	KPI_EC_5	maximal hours without access to warm water	Number of hours that the system is not able to produce hot water when it is requested by a en user	h	social	request of DHW, actual capacity of DHW capacity	\sum_{t in year} Indicator (temp_DHW(t) < 65ºC ∩ person_has_asked_DHW(t))	0
	KPI_EC_6	maximal hours with temperature below x-degree (winter)	Number of hours the system is not able to heat the house at x temperature when it is requested by an end user	h	social	setpoint, actual indoor temperature	\sum_{t in winter} Indicator (temp_HVAC(t) < xºC ∩ setpoint_HVAC(t))	0
	KPI_EC_7	maximal hours with temperature above x-degree (summer)	Number of hours the system is not able to cool the house at x temperature when it is requested by an end user	h	social	setpoint, actual indoor temperature	\sum_{t in summer} Indicator (temp_HVAC(t) > xºC ∩ setpoint_HVAC(t))	0
	KPI_EC_8	risk of technological lock-down	For each component of the solution, amount of providers in the market and amount of qualified companies able to provide the maintenance service on the use case	scale	social	list of components to be installed, amount of different providers for each technology,	Scale that is 0 if one component only have providers and 1 if all components have more than n providers (interpolated between these values)	minimization
	KPI_EC_9	total costs of investment (CAPEX)	Acquisition and installation cost of each one of the participants / stakeholders	€	economic	database of average costs per component, list of components to be installed, amount of persons that could operate or maintaining the technology	\sum_components (€(component) * # components)	minimization
	KPI_EC_10	ROI (return of investment)	Return on Investment for each one of the participants / stakeholders	%	economic	cost of buying and selling energy, self consumption, surpluses	(y * annual savings - CAPEX) / CAPEX for different y (that should be bigger than Pay Back)	maximization
	KPI_EC_11	Payback period	Payback for each one of the participants / stakeholders	years	economic	cost of buying and selling energy, self consumption, surpluses	lowest y \in N : CAPEX < y * annual savings	minimization
	KPI_EC_12	annual savings	Yearly expected energy savings for each one of the participants	€	economic	cost of buying and selling energy, self consumption, surpluses	\sum_{t in year} if (kWh_generate (t) > kWh_consumed (t); kWh_generate (t) - kWh_consumed (t); 0) * €_sell (t) + if (kWh_generate (t) < kWh_consumed (t); kWh_consumed (t) - kWh_generate (t); 0) * €_buy (t)	maximization
	KPI_EC_13	annual costs (OPEX)	Running cost for each one of the participants / stakeholders	€	economic	database of average maintenance costs per component,	\sum_{t in year} kWh(t) * € (t)	minimization

						cost of buying and selling energy, self consumption, surpluses, list of components to be installed		
	KPI_EC_14	embodied CO2 emissions	Total embodied CO2 emissions of the components installed	kg CO2eq	environmental	database of average embodied emissions per component	\sum_components (embodied emissions(component) * # components)	minimization
	KPI_EC_15	embodied energy	Total embodied energy of the components installed	kWh	environmental	database of average embodied energy per component	\sum_components (embodied energy(component) * # components)	minimization
	KPI_EC_16	annual CO2 emissions	Yearly CO_2 emissions due to the operation of the installation	kg CO2eq	environmental	generation, database of emission factors from the grid, database of average emissions factors of "not use phase" for each component, list of components to be installed	\sum_{t in year} kWh(t) CO2eq (t)	minimization
ADDITIONAL TARGETS FOR BUILDING SIZING	KPI_EC_17	required own effort	Time exped to buy the solution and to understand how it is used	h	social	list of components to be installed, database of own efforts per component	for each component time per unit (at the database)	minimization
	KPI_EC_18	complexity and effort required for installation	Amount of interdependencies between the solutions deployed and "point of failure" of the system	scale	social	list of components to be installed	expert judgement	minimization
	KPI_EC_19	installation time	Amount of time needed to complete the installation using mean values. Assumed sequential time (even as most of the works could be done in parallel)	h	social	database of average installation times per component, list of components to be installed	for each component time per unit (at the database) times number of units	minimization
	KPI_EC_20	required space	Amount of space required by the solution. Mainly PV and batteries. Assume that solutions could not be stacked	m^2	social	database of average space required per component, list of components to be installed	for each component space per unit (at the database) times number of units	minimization

Social Impact	KPI_EC_21	percentage of income needed to be invest on actions	Percentage of the yearly income that each socio-economic profile need to invest to participate in the energy community after all rebates and grants	%	social	income distribution of the target zone, economic KPIs	For each participant: share (participant) * (\sum_{devices} €(devices) * #(devices) - grants) / yearly income (participant)	minimization
	KPI_EC_22	mean percentage of budget dedicated to energy	Yearly percentage of the income used to buy energy used to assess the energy poverty and the distribution of inequalities	%	social	income distribution of the target zone, annual cost (OPEX) economic KPIs	\sum{participant} (energy (participant) * costs / income (participant)) / # participant	minimization
	KPI_EC_23	easiness to foster citizen participation	Composite index that measure the capacity of the energy community to foster the participation of the citizens	scale	social	technical description of the solution, assessment by a panel of experts	Expert assessment of how the technologies, business model and legal framework foster the participation and involvement of citizens	maximization
	KPI_EC_24	easiness to implement a transparent administration	Composite index that measure the easiness to provide information about the technical and financial operation of the energy community to the end-users.	scale	social	technical description of the solution, assessment by a panel of experts	Expert assessment of the amount of devices needed to retrieve the information, the computational power to present it and the technical expertise needed to assess the information that have to be provided	maximization
	KPI_EC_25	robustness of the legal entity	Tolerance of the legal entity to changes in its shareholders or the board of directors or similar decision board without significant management problems	scale	social	technical description of the solution, assessment by a panel of experts	Expert assessment of the amount of the characteristics of the legal entity	maximization
	KPI_EC_26	robustness of the business model	Tolerance of the business model towards sign in and cancellations of consumers without significant problems	scale	social	technical description of the solution, assessment by a panel of experts	Expert assessment of the amount of the characteristics of the business model	maximization
	KPI_EC_27	social opposition to the deployment	Type of opposition that could be found to the deployment of the solutions	scale, qualitative	social	technical description of the solution, database of the probability of be in opposition to a technology given its socio-economic profile	Qualitative description of the reasons for the opposition, # \sum_{technologies} \sum_{socio-economic profiles} persons (socio-economic profile) * opposition (technologies)	qualitative
	KPI_EC_28	rebound effect	Estimation of the rebound effects due to the actions carried out	kWh	social	surveys, technical solution deployed, impacts, socio-economic description of the population	# \sum_{technologies} \sum_{socio-economic profiles} persons (socio-economic profile) * rebound (socio-economic, technologies)	minimization

4) The European Use Case

ID	Title	Description	Unit	Type	inputs	Methodology for calculation	Objective
KPI_EU_1	Emissions reduction achieved in the EU buildings sector by 2030 and 2050 from 2010 levels	Estimate of the reduction in EU emissions from the buildings sector calculated for the different scenarios of the EU Use Case	tCO2eq	environmental	Historical data	Comparison of PRIMES-based scenario projections with 2010 data	minimization
KPI_EU_2	Energy efficiency improvements in EU residential energy consumption (From 2010 levels)	Estimate of energy efficiency improvements from the buildings sector calculated for the different scenarios of the EU Use Case	TWh or mtoe	technical	Historical data	Comparison of PRIMES-based scenario projections with 2010 data	maximization
KPI_EU_3	Share of renewable energy in EU gross final energy consumption	Estimate the share of renewable energy in EU gross final energy consumption calculated for the different scenarios of the EU Use Case	%	technical	no	Directly estimated from PRIMES scenarios	maximization
KPI_EU_4	Electrification rate in buildings in European countries	Estimate the share of electricity in EU buildings' final energy consumptions calculated for the different scenarios of the EU Use Case	%	technical	no	Directly estimated from PRIMES scenarios	maximization
KPI_EU_5	Impacts of decarbonization on energy system costs and electricity prices in EU countries	Estimate the energy system costs and electricity prices in the different scenarios of the EU Use Case	€	economic	no	Directly estimated from PRIMES scenarios	minimization
KPI_EU_6	Optimal building renovation strategies by income class	Calculate optimal building renovation strategies to meet specific energy efficiency goals (e.g. the recent 36%-39% efficiency target included in the Fit For 55 policy package)	% savings	technical-economic	no	Directly estimated from PRIMES scenarios	maximization of energy savings/cost-optimality
KPI_EU_7	Uptake of low-carbon fuels (i.e. hydrogen, electricity) in the transport sector	Amount of low-carbon fuels used in the transport sectors (mainly green hydrogen(-based fuels) and electricity).	TWh	technical / social	no	Directly estimated from PRIMES scenarios	maximize
KPI_EU_8	Energy affordability and energy expenditures by income class	Estimate the energy expenditure for the different scenarios of the EU Use Case	EUR/toe consumed in buildings	social/economic	no	Directly estimated from PRIMES scenarios	minimization
KPI_EU_9	Uptake of low-carbon technologies (e.g. heat pumps) and smart appliances	Estimate the share of heat pumps for the different scenarios of the EU Use Case	% share	technical	Historical data	Directly estimated from PRIMES scenarios	maximisation

5) The Global Use Case

ID	Title	Description	Unit	Type	inputs	Methodology for calculation	Objective

KPI_GLO_1	Emissions reduction achieved globally in the buildings sector by 2030 and 2050 under different scenario assumptions	Estimate of the reduction in global emissions from the buildings sector calculated for the different scenarios of the Global Case	tCO2eq	environmental		IAM analysis	maximize
KPI_GLO_2	Energy efficiency improvements in global residential energy consumption	Reduction in energy consumption in the building sector as a result of enhanced energy efficiency	TWh	technical / social		IAM analysis	maximize
KPI_GLO_3	Share of renewable energy in global residential energy consumption	Amount of energy used in the residential sector that is produced via renewable sources, expressed as a share of total residential energy consumed in this sector.	%	technical		IAM analysis	maximize
KPI_GLO_4	Global electrification rate in buildings	Share of electricity in the energy consumption mix in the built environment	%	technical / social		IAM analysis	maximize
KPI_GLO_5	Impacts of enhanced energy efficiency on energy system costs	Cost differential between scenarios that are built on different assumptions with regard to energy efficiency	$	economic		IAM analysis	minimize
KPI_GLO_6	Impacts of enhanced energy efficiency on global carbon price	Difference in global carbon price values between scenarios that are built on different assumptions with regard to energy efficiency	$	economic / social		IAM analysis	minimize
KPI_GLO_7	Uptake of low-carbon technologies (e.g. heat pumps) in buildings	Amount of energy used in buildings that is produced with low-carbon technologies, such as heat pumps, green hydrogen(-based fuels), geothermal energy.	TWh	technical / social		IAM analysis	maximize
KPI_GLO_8	Uptake of low-carbon fuels (i.e. hydrogen, electricity) in the transport sector	Amount of low-carbon fuels used in the transport sectors (mainly green hydrogen(-based fuels) and electricity).	TWh	technical / social		IAM analysis	maximize
KPI_GLO_9	Need for deployment of carbon removal technologies under different energy efficiency assumptions	Amount of carbon that needs to be removed from the atmosphere in order to reach the global climate mitigation targets (that will change depending on the scenario assumptions regarding energy efficiency)	tCO2eq	technical / social		IAM analysis	minimize

ANNEX 2: EU Use Case stakeholder workshop- Prioritization of policies

The annex presents the detailed results of the prioritization of policy instruments conducted by the stakeholders in European Use Case workshop. The results are discussed in the main report.

Figure 21 Prioritisation of policy interventions for the performance of Buildings

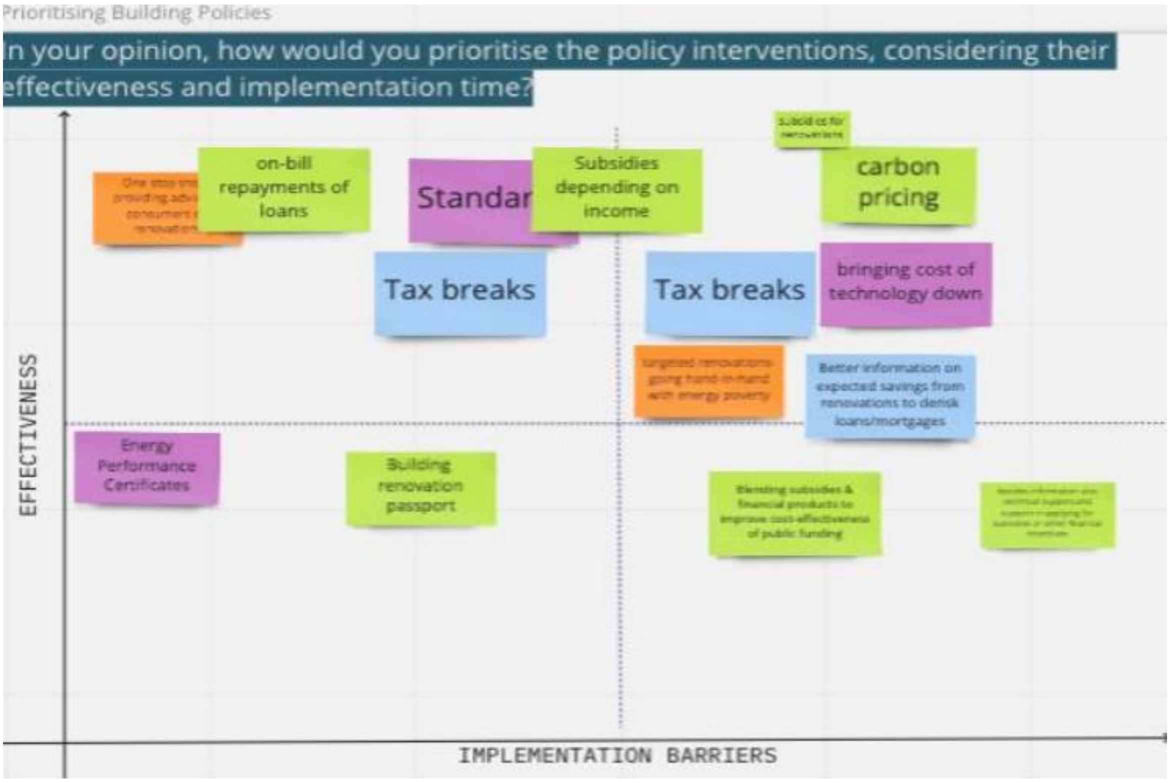

Figure 22 Prioritisation of policy interventions for Electrification of buildings

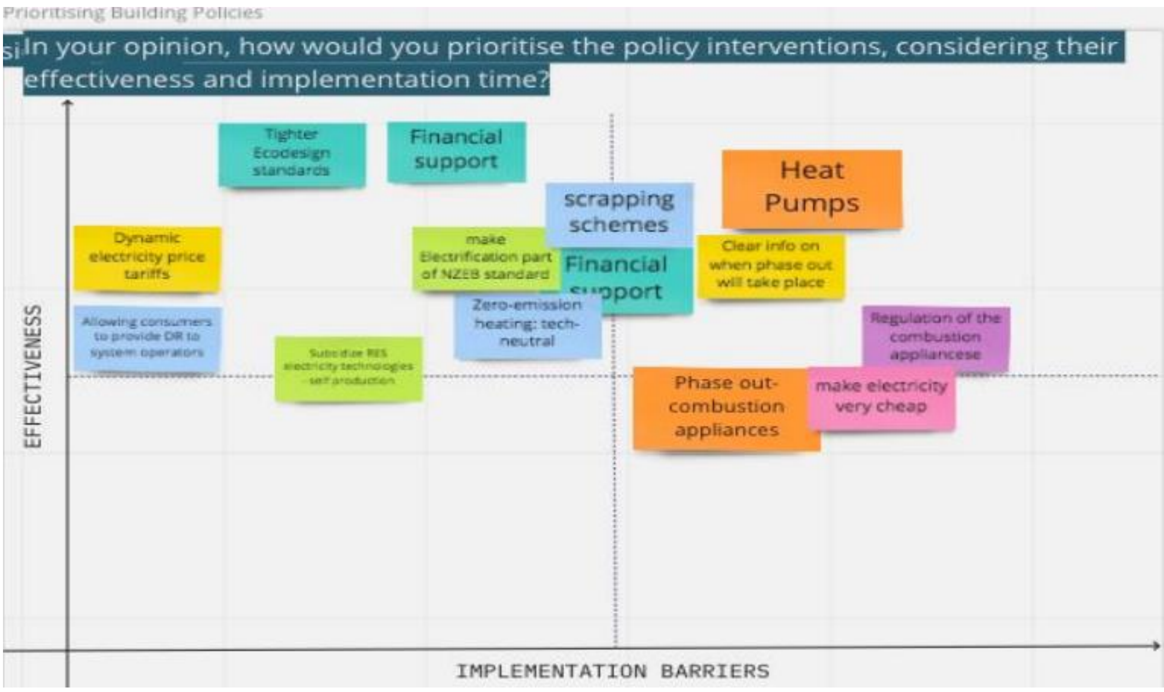

Figure 23 Prioritisation of policy interventions for Flexibility and Smart Appliances