ENPOWER

POWER IN OUR HANDS

D3.1 | Interactive tool for consumers 'activation' and energy community planning

CARTIF

July 2024

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Energy Activated Citizens and Data-Driven Energy-Secure Communities for a Consumer-Centric Energy System

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Preface

ENPOWER designs, develops, and demonstrates SSH-driven methodologies, interactive and closed-loop tools, and data-driven services for energy-activated citizens and energy-secure cross-sector communities towards a citizen-centric energy system. By combining leading-edge ICTs with social/behavioural dimensions and with sharing economy and value stacking business models the project aims to deploy: 1) a Social Science Framework for energy citizens activation and innovative multidimensional incentives for citizens' participation in energy markets; 2) AI-based consumers clustering and segmentation algorithms; 3) interactive tools and facilitation services for energy community planning; 4) Energy Data Space adaptation to support community-level data-driven activation and interoperable automated privacy and sovereignty-preserving Demand Response (DR); 5) P2P DLT/Blockchain digital marketplace for tokenized energy and non-energy assets reciprocal compensation; 6) data-driven services and apps for energy efficiency and activation performance management; 7) ICT services and Digital Twins for community-level energy optimization and aggregated flexibility management to trade off local self-consumption against grid service provisioning, while boosting a beyond-energy community social welfare; 8) Edge monitoring hubs for automated DR; 9) Business Sandbox for novel sharing economy and social innovation-based business models; 10) methodologies for evaluating different energy community setups, upscaling and replication. ENPOWER framework will be validated along 4 Front Runners energy communities' pilots and further replicated in 2 Early Adopters, covering different levels of maturity of communities, to demonstrate increased RES local self-consumption and consumers participation to the energy markets, while nurturing increased local security of supply. ENPOWER Leadership Programme and blueprints will support EU-wide replication and advice regulatory bodies on communities-friendly enabling frameworks.

Who we are.

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1	National Technical University of Athens	NTUA	GR	Coordinator
2	Design Strategy Technology S.r.l	Dst	IT	Technology providers
3	INESC TEC - Institute for Systems and Computer Engineering, Technology and Science	INESC TEC	PT	
4	Fundación CARTIF (CARTIF Technology Center)	CARTIF	ES	
5	COMSENSUS D.O.O.	COMS	SL	
6	European Dynamics Luxembourg SA	ED	LU	
7	Audencia Business School	AUDENCIA	FR	Business modelling
8	Regulatory Assistance Project	RAP	BE	Regulatory assistance
9	ICLEI Europasekretariat GmbH	ICLEI	DE	Policy & capacity
10	University of Basel*(associated partner)*	UNIBAS	CH	Social framework
11	Blueprint Energy Solutions GMBH	BLUEPRINT	AT	Pilot 1 - Austria (Front runners)
12	OurPower Energiegenossenschaft SCE	OurPower	AT	
13	Cooperativa de Desenvolvimento Sustentável, CRL	COOPERNICO	PT	Pilot 2 - Portugal (Front runners)
14	WATT-IS SA	WATT-IS	PT	
15	Cooperativa Eléctrica do Vale D'Este CRL	CEVE	PT	
16	Energy Community of Chalki‘Chalkion’	ChalkiON	GR	Pilot 3 - Greece (Front runners)
17	Hellenic Association for Energy Economics	HAEE	GR	
18	Green Energy Aggregator Services SA	GEARS	GR	
19	Parity Platform P.C.	PARITY	GR	

20	Electric Power Research Institute Europe DAC	EEU	IE	Pilot 4 - Ireland (Front runners)
21	University College Cork (MaREI Centre for Energy, Climate and Marine, Environmental Research Institute)	UCC	IE	
22	DC Six Technologies Limited	DCSix	IE	
23	MOL TEIC - Dingle Hub	DINGLE HUB	IE	
24	ESB Innovation ROI Limited	ESB	IE	
25	Békéscsaba Energia ESCO Kft.	BCS	HU	Pilot 5 - Hungary (Early adopters)
26	Enasco Cleantech Alliance LLC.	ENASCO	HU	
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28	VERGY COMMUNITY S.L. *(affiliated partner)*	VER	ES	

Executive Summary

The widespread adoption of distributed Renewable Energy Sources (RES) is transforming the energy system and electricity markets towards a more consumer-centric structure. The center of this transformation are energy communities, as they can offer economic advantages, environmental benefits, and foster social cohesion among members. Energy modelling tools can help to assist the decision making of energy communities in their planning, even though traditional ones are highly technical and require specialized expertise, making them inaccessible to average community members. Open-source models, though promising, often lack user-friendly interfaces and comprehensive documentation. ENPOWER addresses this gap by developing an interactive decision support tool (KER3), designed to:

1. Assist communities and citizens in decision-making, optimizing RES technologies.
2. Provide valuable information to stakeholders, encouraging investment and business opportunities.
3. Serve as an information exchange hub for prosumers, communities, and stakeholders.

The interactive decision support tool or Planning Tool allows visualizing current energy status (baseline), calculating and comparing different future scenarios based on the user preferences and objectives and providing relevant information to help communities make informed decisions. It has three main modules:

- Sizing module for electrical assets: Optimizes electrical assets like PV panels and batteries based on energy profiles and operational impact.
- Optimisation module for thermal networks and heating and cooling assets: Focuses on District Heating Networks (DHNs) and heating/cooling assets, sizing local energy systems and providing interaction with other power grid assets such as PV.
- Key Performance Indicators (KPI) Module: Evaluates scenarios with standalone sub-modules for energy demand, scenario creation, and KPI calculation.

By integrating various Key Performance Indicators (KPIs), the project ensures a thorough evaluation of technical, social, economic, and regulatory aspects, providing a holistic view of the energy community's performance. Section 3 shows the methodology followed to define the comprehensive KPI framework of ENPOWER project. These KPIs cover a wide range of dimensions, including technical, social, economic, environmental, data and regulatory aspects. Technical KPIs focus on metrics like energy performance, self-consumption ratios, and the efficiency of demand response services. Social KPIs measure aspects such as data transparency, community reinvestment from earnings, and the level of citizen engagement in energy activities. Economic KPIs assess financial indicators such as energy bill reductions, operational cost avoidance, and the overall return on investment for energy community projects. Environmental KPIs evaluate the performance in terms of GHG emissions, air quality index, and land use of energy. Data KPIs cover topics related to meters and use of data. Legal KPIs evaluate the extent to which local and national laws support the development and operation of energy communities. The integration of these KPIs into the KPI module enables a comprehensive analysis of various energy community configurations, providing valuable insights for joining an energy community.

Three main modules will be developed in WP3 in ENPOWER project. The document serves as a basis for the next months, covering the current status of the modules, the different inputs and outputs, and developments done so far. The heating and cooling assets and networks module builds on existing tools from REWARDHeat and LocalRES projects. Similarly, the electric assets module of INESC TEC is dedicated to the management and optimization of electricity generation, storage, and consumption, ensuring efficient use of renewable resources. The existing status of these models and future developments are explained in the report.

Furthermore, the tool will feature two main views, one for citizens and one for stakeholders. The citizen-oriented view is tailored to make it accessible, fitting the energy community's targets, geographical, regulatory, and technical factors. On the other hand, the value chain stakeholder-oriented view provides useful information to technical experts, fostering networking and investment opportunities. A grey literature review and a traditional literature review were conducted to assess the requirements for designing the user interfaces. These reviews aimed to identify best practices and lessons learned from previous projects, like those used in ENPOWER, to determine a dual focus. This dual focus is essential for catering to both non-technical users, who may require more intuitive and accessible interfaces, and professionals in the energy sector, who need detailed technical functionalities. From these reviews, a need for developing different views for different users is found addressing both non-technical users (the citizen view) and professionals in the energy sector (the stakeholder view). More in detail, this review benchmarks existing tools to evaluate how well they support energy community planning, highlighting areas for improvement. One-stop shops are also reviewed to streamline the creation of the stakeholder-view. This view should be designed in a way that allows enhancing accessibility, creating greater trust, and delivering better results tailored to users.

Tool inputs include the location of the community, building details and the associated energy consumption profiles. These can be provided by the user through the tool interface or inferred databases. Once the energy community data model is created, it can be enriched with energy systems and technical parameters for each asset, a well as creating scenarios for assessing future designs of the energy community. Tool outputs will include 1) Optimized energy system configurations and operational recommendations, 2) Scenario analysis including energy demand, savings potential, and environmental impact, 3) KPIs to evaluate efficiency, cost-effectiveness, and sustainability of the energy community.

The development of the decision support tool (which constitutes TE-1, *Interactive decision support tool for energy community planning*, within ENPOWER project) is a significant milestone in the project. It will be designed to be user-friendly and accessible, with two distinct views catering to both citizens/consumers and value chain energy stakeholders. D3.1 outcome is the definition of KPIs that will be programmed in later stages, the preliminary results from the modules, and the requirements that will be considered to develop the user interface in the decision support tool. To do that, the present report, D3.1, analyses the gaps from existing tools, defines a robust framework for the tool development and constitutes the starting point of the different modules that will be integrated in the TE-1. The modification of the current CARTIF's databases, the development of the modules (with new features) and the organization of workshops are emphasized as next steps for WP3. All in all, ENPOWER planning tool will be designed for energy communities, offering user-friendly, interactive features to simplify complex energy planning processes. It will empower citizens and stakeholders alike, assisting in the transformation of passive consumers towards energy-activated citizens and prosumers.

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List of acronyms

AI	Artificial Intelligence
CAPEX	CAPital EXpenditure
CEA	CityEnergyAnalyst
CEC	Citizen Energy Community
DES	Decentralized Energy Sources
DHN	District Heating Network
DHW	Domestic Hot Water
DLT	Distributed Ledger Technology
DR	Demand Response
EC	European Commission
ESCO	Energy Service Company
EV	Electric Vehicles
GDPR	General Data Protection Regulation
ICT	Information and Communication Technologies
IoT	Internet of Things
KER	Key Exploitable Result
KPI	Key Performance Indicator
MILP	Mixed-Integer Linear Problem
NPV	Net Present Value
OSM	OpenStreetMap
OSS	One-Stop Shop
PED	Positive Energy District
PV	Photovoltaics
REC	Renewable Energy Community
RES	Renewable Energy Source
STC	Solar Thermal Collector
UI	User Interface
WP	Work Package

1. Introduction

This document, developed under the Task 2.1, along with all the other tasks under Work Package (WP) 2, provides the foundation for citizen engagement and multilevel knowledge creation within energy-secure communities to facilitate a consumer-centric energy system in Europe.

Wide-scale deployment of distributed Renewable Energy Sources (RES) is posing significant challenges to the energy system operation along with electricity market. The latter is being transformed from a centralised supplier-centric structure towards a more decentralised, consumer-centric structure. Energy communities are intended to be key in this transformation. Energy communities are understood in this report as organized structure of people who join forces to produce and manage their own energy. The economic and environmental benefits that come with energy communities can increase citizens' involvement and engagement. In addition, energy community projects tend to increase cooperation and social cohesion and ultimately foster a sense of community among the members because of the common goals these aim at accomplishing [1].

The overall vision of ENPOWER is to design, develop and demonstrate SSH-driven methodologies, interactive and closed-loop tools and services for energy activated citizens and data-driven energy-secure communities towards a consumer-centric energy market. ENPOWER combines leading-edge ICTs technologies [Internet of Things (IoT), Artificial Intelligence (AI), big data, DLT/Blockchains] with social / behavioural dimension, and with sharing economy and value stacking governance and business models.

Thus, the aim of the project is twofold:

1. Transform traditional passive energy citizens into active ones ("energy-activated citizens"
2. Convert energy consumers and/or communities into digitally enhanced entities.

To support the former aim, the project will develop an interactive decision support tool, referred to in this document as 'Planning tool,' which will provide citizens with information and data from a multi-carrier energy perspective. However, the current market lacks user-friendly tools that cater to non-technical users. Most existing innovative tools, such as LEAP [2], Energy Plan [3], Homer [4], OsEMOSYS [5], TRNSYS [6], and TIMES [7] are highly technical, often requiring the use of multiple models and specialized expertise. Although open-source models like openENTRANCE [8] and OEMOF [9] have emerged in recent years, they often lack intuitive user interfaces and comprehensive documentation. This complexity and the need for coding skills make these tools less accessible to the average member of an energy community [10].

Innovative tools for assessing the level of readiness of a citizen or community and the ideal sizing of local communities, while at the same time assessing the implications of joining an energy community, can significantly enhance decision-making. However, offering a comprehensive simulation capability and at the same time a user experience adapted to different levels of knowledge is challenging. To bridge this gap, the objective of the Planning tool in ENPOWER project is to support energy communities in the planning and design phases of their energy system, showing the technical and non-technical benefits of joining an energy community compared to what would be achieved if the same actions were taken individually. Its design will be user-centric, emphasising intuitive and interactive features that simplify complex data and processes.

To promote citizen engagement (including new and existing cooperative members) in various community types and facilitate new service provision, WP3 will provide a Planning tool (KER3) that will:

1. Assist communities/citizens in the decision-making process of creating an energy community, offering tailored sizing and optimization of RES technologies.
2. Provide stakeholders (e.g., ESCOs, retailers) with valuable information to trigger investments and business opportunities in communities.
3. Serve as an information exchange hub for prosumers, communities, and stakeholders.

Therefore, the Planning tool aims to:

- Visualize their current status (baseline)
- Calculate and compare different future scenarios to improve their energy system
- Provide related-energy communities' information about their countries to learn and make informed decisions

1.1 Relation with other tasks

To achieve these objectives, synergies identified during project development, mainly with WP2, include:

- Use cases (Blueprint): Use cases defined by Blueprint can be included in the database to provide insights for users in the information hub.
- Regulatory framework (RAP): Country-specific regulations analysed by RAP can be added to the database to inform users and define system restrictions in the modelling phase.
- Member/consumer segmentation in energy communities (UNIBAS, UCC): Segmentation data can enhance the User Experience (UX) of the Planning tool.
- Incentive mechanisms (WP2): Defining KPIs related to monetary and non-monetary incentives.
- Business models (AUDENCIA): Including feasible business models in energy community assessments or informing users about potential models.

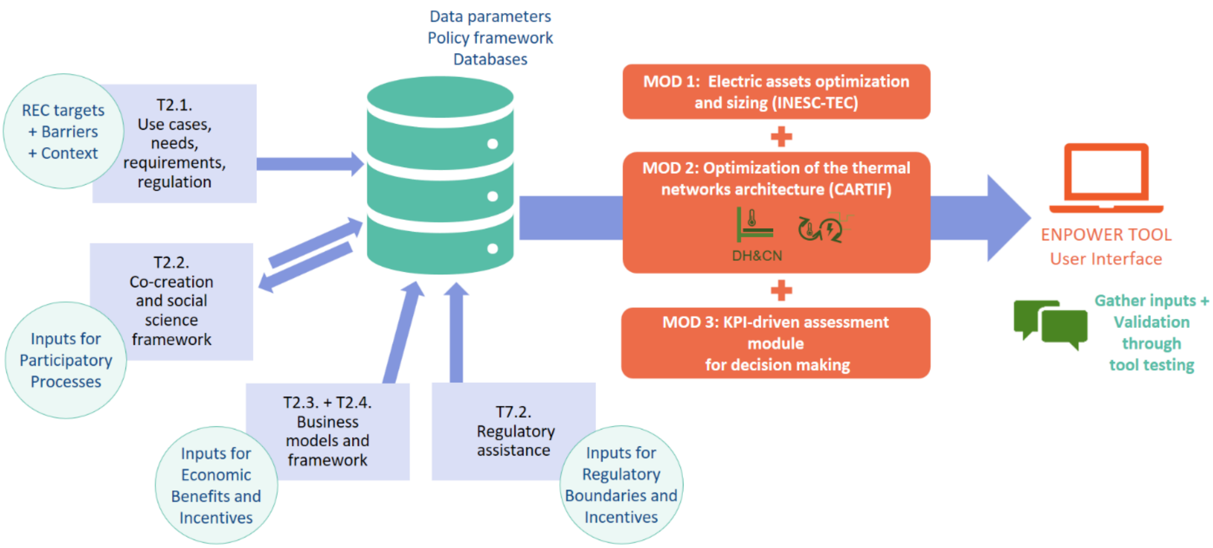

Figure 1. Relationships among tasks (from WP3 perspective).

1.2 Structure of the document

This deliverable is structured as follows:

- In this first section, ***Introduction*** the document sets the stage by explaining the overall vision and objectives of the ENPOWER project, emphasizing the development of interactive tools and methodologies to engage citizens and enhance energy security within communities.
- Section 2, ***Planning tool requirements***, outlines the requirements for the planning tool, detailing the user types, architecture, interactions and relationships, data management, and scalability considerations. This section provides the foundational elements necessary for understanding the tool's design and its functional aspects.
- Section 3, ***KPIs identification and prioritisation for energy-communities***, presents the methodology for identifying and refining Key Performance Indicators (KPIs) crucial for energy communities. Through extensive literature reviews and workshops, this section covers the social, technical, financial, environmental, and legal aspects of KPIs, ensuring a comprehensive approach to measuring the progress and impact of energy communities.
- Section 4, ***Computation open-source modules for RES-based scenario generation and sizing***, describes the development and status of modules designed for electrical and thermal assets: KPI module, heating and cooling assets and networks module, and electrical module. This section includes details on the initial and current status of these modules, the integration of new assets, input and output data descriptions, illustrative examples, and plans for further developments, providing a thorough overview of the computational tools being developed.
- Section 5, ***Decision support tool for energy community planning***, focuses on the design and implementation of a user-friendly interface for the planning tool. This section reviews existing tools and one-stop shops, ultimately guiding the creation of an interface tailored to both citizens and stakeholders. The aim is to enhance engagement and functionality, making the planning tool accessible and useful for various user groups.
- Section 6, ***Conclusions***, summarizes the findings and progress made throughout the document, highlighting key achievements and future steps.

The **appendices**, at the end of the document, include a glossary, a preliminary list of KPIs, detailed tables for the KPI framework, and specific sections on electric and thermal assets, including descriptions of input data and results. These appendices offer additional context and detailed information supporting the main chapters.

2. Planning tool requirements (inputs from WP2)

Energy communities can be involved in different activities depending on the directive definition. The Clean Energy Package, adopted in 2019, introduced two formal definitions of energy communities: Citizen Energy Community (CEC), which is included in the revised Internal Electricity Market Directive (EU) 2019/944 [11] and Renewable Energy Community (REC), which is included in the revised Renewable Energy Directive (EU) 2018/2001 [12]. CECs are focused on the electricity sector and can be involved in activities such as offering flexibility to the grid or acting as aggregators. Following its definition, a REC can potentially rely on any type of renewable energy systems in the electricity and heating sectors and restrict the control of the community to only members that are located in the proximity of the RES projects, while CECs widens the boundaries (virtual boundaries).

The requirements to become an energy community are typically:

- Legal entity status (cooperative, association, etc.)
- Primary purposes are beyond the economic profit
- Inclusion of several stakeholders is optional (except, large companies in RECs)
- Principles of open, voluntary and non-discriminatory participation
- Democratic and governance ownership, with limits to control of assets in RECs (to members located proximate to RES projects), and in CECs there are limitations to large energy companies

Furthermore, the JRC collected a list of possible activities [13] that energy communities can provide or can be involved in, such as generation of energy through renewable energy sources (RES) for self-consumption or for market-sale, aggregation of RES generation, management of local networks, energy services provision (building retrofitting, audits, etc.) or e-mobility services.

JRC requirements, as well as local regulation will need to be considered when designing the Planning tool.

2.1 User type

Users can be preliminary categorised into two groups regarding their role within the community:

- Civic society: citizens who are members of the energy community. They may or may not have an active role and may or may not have knowledge and awareness on energy or environmental topics.
- Practitioners: stakeholders that have a role or provide a service to the community (e.g. legal service, energy experts, etc.).

For instance, Municipalities can act as members of the energy community (investing on RES on public buildings) or as facilitators, i.e. providing the administrative, educational, regulatory, and financial means to create an energy community.

Another categorisation of the Planning tool users depends on their level of involvement in the community modelling process and the main action they want to carry out:

- Administrator of the community: can add or associate new members to the community created in the Planning tool. They may also contribute actively to the model of the community and the generation of scenarios. The administrator of the community can be a member itself (bottom-up initiative) or a promotor or technical partner that act as a facilitator to use the tool.
- Motivated member: can interact and “play around” with their community or with their own building in the Planning tool and perform several scenarios (that later could be shared with the community).
- Visualiser: can only visualize results from their own community or other communities (if the data have been made publicly available), give feedback on the proposed alternatives and take part in the decision-making process.
- Learner: uses the Planning tool to learn about energy and environmental matters.

2.2 Planning tool architecture

This section refers to the overall structure, design and organization of the modules and tool’s components and how they interact with each other.

The main modules (on the back-end) of the Planning tool are:

- Sizing module for electrical assets (PV panels, batteries, etc.) of the energy community members, according to their optimal operation, their energy profiles and the impact of other relevant assets on their energy behaviour (e.g. thermal storage, etc.). This module is being developed in the national Digital CER Portuguese P2020 project.
- Optimisation module for thermal networks and heating and cooling assets for the different community scenarios, exploiting the opportunities and flexibilities offered by the digitalisation of the local energy systems. An open-source simulation engine will be considered to run the scenarios.
- KPI module to evaluate the different scenarios offered to prosumers and energy communities. The module is divided into sub-modules that can be standalone. For example, for the calculation of energy demand, creation of new scenarios or calculation of KPIs.

Furthermore, a user interface will be developed for the Planning tool, including two different views:

- **Citizens/consumers-oriented view**, that will rely on: (i) the targets and interests of the energy communities, (ii) the environment boundaries of the energy community (e.g. resources, energy infrastructures in the community, etc.) and (iii) the services that the community would like to offer. The geographical area selected, specific market regulations, technical restrictions and financing possibilities will be considered to filter the different technology scenarios that could be studied and shown to the user as potential alternatives to build the community. A personal space could be provided to allow users to share information about their household so that the tool can compute the impact of the different scenarios for their particular situation. Gamification strategies will be explored to promote the use of the tool, promoting an easy-to-use tool and user-friendly experience.
- **Value chain energy stakeholders-oriented view**, which will provide value chain energy stakeholders (e.g. ESCOs, retailers, etc.) with useful information for triggering investment and business opportunities in energy communities. This view will foster networking among different stakeholders, facilitate the creation of connections between

stakeholders, prosumers and communities, support the exchange of best practices and provide technical assistance and guidance to foster capacity building and engagement activities.

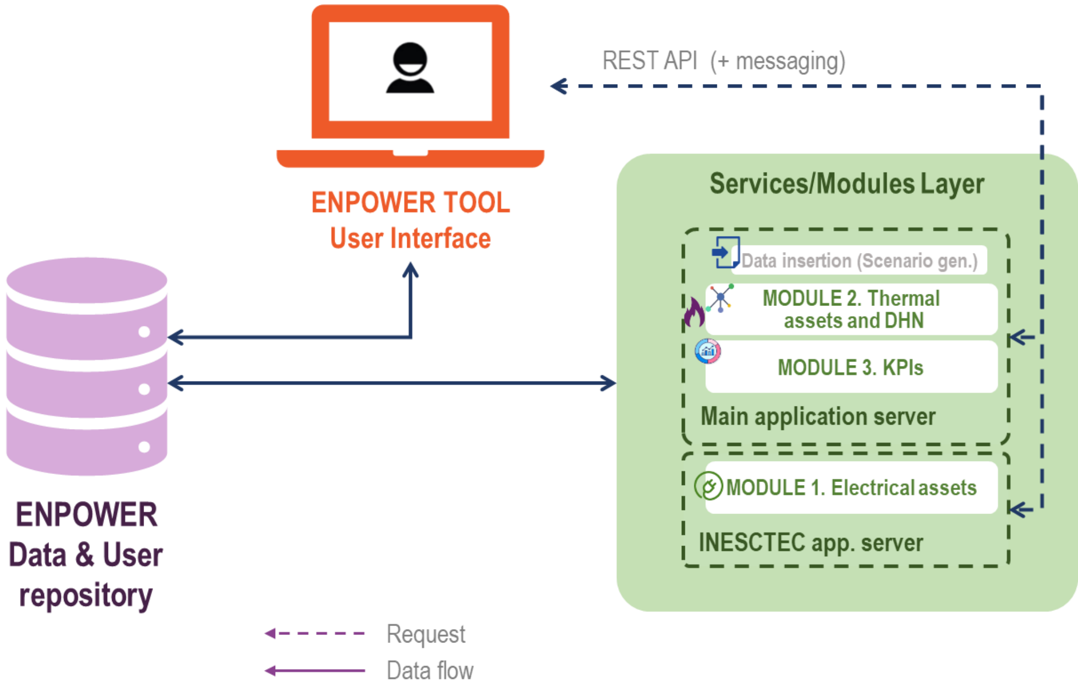

Figure 2. Technical architecture of the Planning tool.

2.3 Interactions and relationships

The modules will interact with the tool's database and user repository hosted on CARTIF servers.

In general terms, the expected inputs of the Planning tool are:

- User provides location, number of buildings. When there is data available, user can introduce data per building, such as number of occupants or building year.
- Energy consumption profiles are generated from the database for each community.
- Energy systems are assigned per building and assumed from the database, unless the user provides specific details.
- Technical parameters include specifications of energy assets, operational constraints, and performance metrics, are assigned to each energy system.
- Scenario parameters could include community's geographical boundaries, market regulations, technical restrictions, financing options, and user preferences for the generation of new scenarios, which will lead to new assets assignations to each building.

The outputs are:

- Optimized energy system configurations including recommendations for the optimal sizing and operation of electrical and thermal assets.
- Scenarios: which includes detailed analysis of different community scenarios, including energy demand, potential savings, and environmental impact. Key Performance

Indicators evaluating the efficiency, cost-effectiveness, and sustainability of different scenarios.

Each interaction has been defined among the partners in detail in each module's section. Figure 3 provides an overview through a sequence diagram that represents the sequence of processes, connections and data flows among each module of the tool. This diagram aims to achieve a common understanding among those involved in the represented system. The diagram describes how modules and components interact in the design of this system, emphasizing the order of events from top to bottom.

Figure 3 is made up of seven main elements represented by rectangles at the top of the diagram:

- User - user actions.
- Application Server containing UI (User Interface) - a server that provides an environment for installing and running applications, centralizing and eliminating installation on client computers.
- Database - the availability of the dataset.
- Scenario recommendation - a module for setting up automatically the scenarios to study in the energy community.
- Module 1. INESCTEC / comp. module - a module dedicated to electrical assets.
- Module 3. KPIs - a module dedicated to Key Performance Indicators (KPIs).
- Module 2. Thermal Assets and DHN - a module dedicated to thermal assets and the District Heating Networks (DHNs).

These elements are connected by their respective vertical lines (lifelines) and vertical rectangular bars that indicate their existence during interactions, in the period in which a process is being executed or awaiting execution, and the activations of these periods are initiated by incoming messages. The horizontal arrows illustrate the exchange of messages between the vertical bars to perform each operation. The dashed arrows represent return messages, indicating that the control is being returned to the calling element after the operation has been performed. Each of these arrows is labelled by the communication that they represent.

The process in this structure starts by "User" action, which interacts directly with the "Application Server containing UI" and the "Database", being present until the last sequence of the diagram. The "Scenario recommendation", "KPI Module", "Thermal Assets and DHN" and "Electric Module INESC TEC" interact exclusively with the database, in isolated processes, but are dependent on the defined sequence.

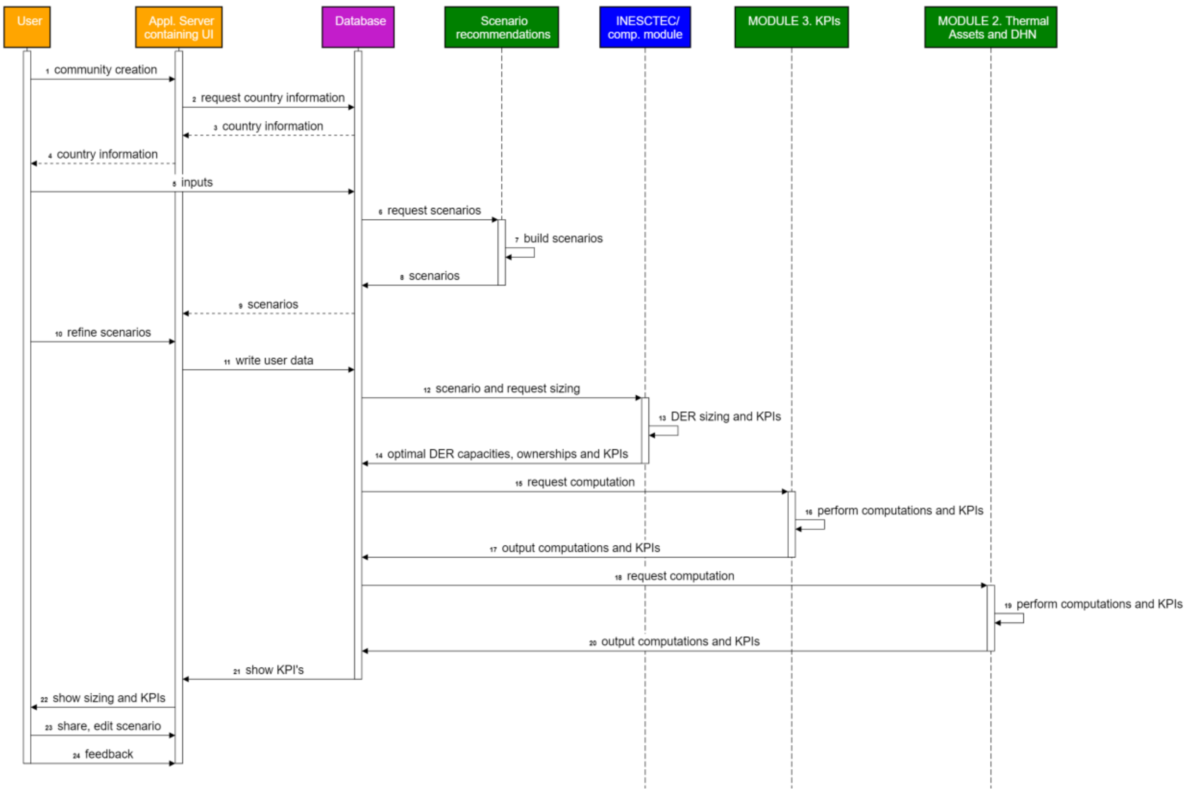

Figure 3. Sequence Diagram of the Planning tool.

2.4 Data management

The following user data management and data security issues will be considered in the design of the Planning tool:

- Secure sign-up process for users.
- Access management by community administrators for members of the community (either activated citizens or consumers).
- Capability for users to update their household information, energy consumption data, preferences, and data sharing options at any time.
- Role-based access control to ensure appropriate permissions for different user types (e.g., citizens, community managers, technical experts).
- Implementation of encryption protocols for data at rest and in transit to protect user information and simulation data.
- Multi-factor authentication to verify user identities and safeguard access to the platform.
- Compliance with GDPR (General Data Protection Regulation) and other relevant data protection regulations to ensure user data privacy.
- Regular security audits and vulnerability assessments to maintain data integrity and security.

2.5 Scalability

Initially, the tool may encounter constraints on the number of users and scenarios it can handle simultaneously due to computational and resource limitations. The user interface is expected to support a predefined number of concurrent users, with the capability to scale based on demand

and resource availability. Furthermore, the number of scenarios per run may be limited to ensure optimal performance and prevent system overload.

The system architecture will be designed to support scaling by incorporating additional computational resources (e.g., cloud-based solutions) to manage increased load effectively. The server infrastructure at CARTIF is engineered to scale up, accommodating a growing number of buildings and complex scenarios, with potential enhancements to support thousands of buildings and numerous scenarios per run.

The tool will be built with a modular architecture, facilitating the seamless addition of new features and modules without disrupting existing functionalities.

3. KPIs identification and prioritisation for energy- communities

A range of studies have proposed KPIs and tools for assessing energy communities. Indicators such as perception[1], attitude[2] and community potential[3] are identified by [11]. [12] introduced KPIs for technical and environmental evaluation, such as electrical self-consumption and avoided carbon dioxide due to changes in the energy systems of the community. However, [13] further emphasized the need for easily understood KPIs. This issue is identified as a gap and addressed by the ENPOWER project.

KPIs provide a means to measure the progress, benefits, and success in achieving the goals for energy-secure communities. By establishing indicators, the tool and the ENPOWER project can track the performance over time and evaluate the effectiveness of certain actions, as well as assess future actions that the scenarios performed in the Planning Tool might be studied by the energy community. Thus, KPIs guide decision-making, highlighting the actions that most benefit the community and identifying areas for improvement. Furthermore, KPIs promote transparency and accountability within the community and can be shared with external stakeholders to engage them in future investments. KPIs also allow for benchmarking different energy communities and identifying best practices.

A framework is established in this section, providing indicators to assess social, technical, financial and environmental impacts. This framework encourages a culture of continuous improvement (*Kaizen*) and will be reviewed in each deliverable.

3.1 Methodology

Figure 4 shows the workflow followed to carry out Task 3.1. The methodology begins with an extensive literature review of technical papers, including peer-reviewed ones, and the indicators frameworks developed in other EU projects. The ENPOWER Grant Agreement was also analysed to incorporate indicators aligned with the project's overall vision. This resulted in the first preliminary KPI list, including 96 indicators measuring the technical, environmental, financial and social benefits that could derive from joining energy communities. Some examples are the variation in primary energy consumed by citizens, the reduction in GHG emissions and energy bills, and the level of acceptance of newly installed RES in the community.

This list was then shared with all partners involved in Task 3.1 for them to review and provide additional inputs. Their feedback was collected, and led to what is referred to here as the "Refined KPIs list". A dedicated workshop was held by CARTIF in the ENPOWER 1st General Assembly to gather inputs on how to assess citizen engagement in RECs and the factors and motivations that could encourage different citizen profiles to join them. A final list, referred to as "Citizen Journey Indicators" was produced and is included here. This will serve as the basis for developing the KPIs computation module as part of the work from Task 3.2.

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[1] *Perception of the situation of energy in the community, and realise the importance of renewable energy, the plans of the community and knowledge about the context and resources.*

[2] *The willingness to use renewable energy or to have a conscious use to use energy worthily.*

[3] People in the community ready to invest in renewable energy.

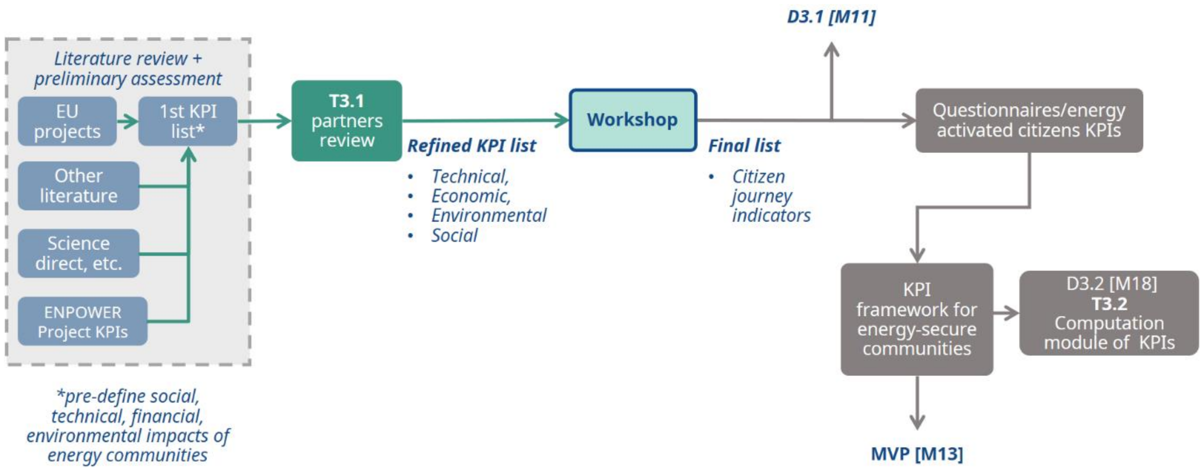


Figure 4. Methodology followed in Task 3.1.

3.2 Literature review

The Key Performance Indicators frameworks of five EU projects were reviewed to integrate and adapt some of the indicators to align with the ENPOWER vision. This review was conducted considering the tool's foreseen capabilities and the overarching goal, which is to guide and support citizens in their journey of energy activation.

Table 1: Literature review from EU projects.

Project	Relevance	KPIs included
CITYKeys	Indicators for smart city projects and smart cities.	Capital expenditure (CAPEX), Net Present Value (NPV), ...
SunHorizon	Retrofitting technology packages for decarbonising the building sector using solar.	Primary energy consumption, renewable energy ratio, thermal comfort level...
LIGHTNESS	Empowering citizens in CECs. Indicators categorization similar to the one expected from ENPOWER.	RES penetration for thermal use, energy curtailment of RES/DES, suitability of the legal framework on EC, collective self-consumption, among others.
LocalRES	Similar thematic to ENPOWER. Focus on citizen involvement in energy communities and energy justice.	Citizen indicators and many technical indicators ranging from e-mobility to blackout and congestion management to P2P trading.
X-FLEX	Integration of Renewable Energy Sources and flexibility systems into stable and sustainable smart grids.	Satisfaction and ease of use of the ENPOWER tool.

The CITYKeys project [14] aimed at defining an indicator framework for the development and assessment of smart cities from environmental, economic, and social perspectives. For ENPOWER, indicators were extracted to evaluate the economic benefits generated from the development of REC projects, even though CITYKeys does not focus on energy communities. For this reason, the economic KPIs are of general interest, as they include the quantitative evaluation of NPV, CAPEX, maintenance costs, and other metrics of the equipment installed in the community for a specific scenario.

The SunHorizon project [15] focuses on the demonstration of coupled solar and heat pump technology solutions, including the optimal design and monitoring of these solutions and the development of a comprehensive KPI framework to assess them at both component and system levels. For ENPOWER, KPIs are extracted to evaluate the variation in primary energy consumption after establishing the community, the extent to which this energy comes from renewables, the economic benefit of joining the community (in the form of costs avoidance), and the level of thermal comfort maintained in the community facilities in both heating and cooling seasons.

The LIGHTNESS project [16] aims to empower citizens in CECs, encouraging them to produce and sell renewable energy within these structures. Due to the strong alignment between the objectives and missions of LIGHTNESS and ENPOWER, the indicators are adapted from the project assessment framework. Special care is needed when retrieving legal indicators, as LIGHTNESS specifically focuses on CECs and may not be as general as required for the ENPOWER pilot contexts.

For the LocalRES project, given the thematic and the objectives alignment ENPOWER, various indicators are easily applicable. A large group of the KPIs retrieved fall into the technical subgroup, such as the amount of thermal storage capacity installed in the community or the penetration of EV infrastructure. Other indicators aim at translating energy information into a more accessible format for common citizens and community members, such as the number of hours of streaming equivalent to the energy savings generated by the REC project [17] [18] [19].

The X-FLEX project [20] focuses on the development of tools to guide the integration of decentralized Renewable Energy Sources into the European energy system, particularly emphasizing flexibility and extreme weather conditions. Each indicator from X-FLEX is associated with one or more project products (i.e., developed tool). Some social indicators are retrieved for ENPOWER to measure user satisfaction with the tool and its ease of use.

The review of technical and peer-reviewed papers helped in both defining new indicators but also set the methodology to follow and understand which are the main concerns, requirements, impacts, benefits in the evaluation of RECs project with a KPIs framework.

Four papers were specifically reviewed to understand the impact that energy communities can have on citizens and on the environment rather than for actual retrieval of indicators.

- Energy security in community energy systems: An agent-based modelling approach (Javanshir Fouladvand) [21]. This study focuses on the impact of energy communities on energy security, specifically as far as heating is concerned. An agent-based modelling approach takes into consideration factors like energy prices and environmental impacts. The main finding is that subsidies and natural gas prices have a greater impact on energy security levels rather than CO_2 taxes.
- Growing community energy initiatives from the bottom up: Simulating the role of behavioural attitudes and leadership in the Netherlands (Amineh Ghorbani) [22]. This study focuses on the social and behaviour implications that come with energy communities. In particular, it provides insights on the importance of social networks and opinion dynamics in fostering energy communities' initiatives. Leadership is found to be a key factor in the establishment of the community and the citizen engagement process.
- Indicators and criteria for assessing achievement of renewable energy utilization in communities, (Nuttiya Tantranont) [11]. This study focuses on the methodology and associated criteria needed to evaluate the renewable energy usage within RECs. These include citizen perception, attitude/motivation, learning, community potential, leadership, participation from community members, problem solving capabilities and finally the effectiveness of the internal and external networks intended as connection and

collaboration within community members or with external agents like government bodies, academic and research institution, funding entities etc. A scoring system in the range 0 to 100, categorized as Excellent, Good, Fair and Poor is provided. The key finding is that the community and external organization participation and cooperation are fundamental to sustain renewable energy use.

- Performance Metrics for Renewable Energy Communities (Emilio Ghiani) [13]. The study analyses some of the performance metrics to evaluate the effectiveness of RECs initiatives, especially in the context of Positive Energy Districts (PEDs) from the social, economic and environmental perspective. These include net present value, internal rate of return, self-sufficiency rate, and CO_2 emissions savings, among others. It also discusses the integration of various technologies like solar PV systems, battery systems, and electric vehicles (EVs) to enhance self-sufficiency and in general the energy performance of the REC.

Table 2: Peer-reviewed and technical papers.

Paper	Relevance	KPIs included
From a Comprehensive Pool to a Project-Specific List of Key Performance Indicators for Monitoring the Positive Energy Transition of Smart Cities—An Experience-Based Approach (Komninos Angelakoglou) [23]	Smart Cities, Positive Energy Districts	Self-Sufficiency Ratio, Peak Load reduction, Air Quality Index, Legal Framework Compatibility.
Key Performance Indicators for an Energy Community Based on Sustainable Technologies (Giovanni Bianco) [12]	Energy communities	Heat Recovery Ratio, Self-Sufficiency Ratio, adapted Peak Load Reduction, Payback Period.
Energy Poverty Advisory Hub (EPAH) Handbook 1: A Guide to Energy Poverty Diagnosis, 2023 [24]	Energy Poverty in buildings	Technology thermal intensity, electricity-self production, self-consumption ratio.
INDICATOR SELECTION FOR SMART ENERGY COMMUNITIES (Kari Sørnes, Researcher SINTEF Building and Infrastructure) [25]	Smart Energy communities	Social energy poverty indicators like the share of household experiencing thermal discomfort, those under the poverty threshold or the share of buildings in each EPC grade.

The analysis of the aforementioned project indicators framework, along with technical documents and peer-reviewed literature, led to the first preliminary list ok KPIs as the initial step of the planned Task 3.1 workflow (see Figure 4).

3.3 Inputs from other WPs

Collecting inputs on regulatory frameworks, market dynamics, and business models is crucial for providing recommendations to energy communities. This ensures compliance with regulations, informs about market trends, and aligns with existing business models to ensure financial feasibility.

D2.1 - Gap analysis and use case capitalisation towards a consumer-centric energy system [26]

The work developed in Task 2.1 and collected in D2.1 offers interesting insights regarding the targets of the ENPOWER pilot sites, including their needs, requirements and possible barriers for the actions to implement as part of the ENPOWER strategy. The information reported there is summarized here for each of the six real life pilots (4 Front Runners and 2 Early Adopters):

- **Pilot 1: Austria (Front Runner)**. The target of the Austrian pilot site, Energiegemeinschaft (Regional Energy Communities) Dreißgen-Spörbichl (REC DS) is to enhance participation in peer-to-peer (P2P) renewable energy marketplace, increasing the number of participants from 25 to 150 members and integrating additional PV generation. The main barrier from the Austrian legislative framework is related to the Spörbichl windfarm. The inclusion of wind turbines in Energy Communities is quite complicated as of today for two main reasons: first, the Energy Communitie needs to be owner of the windfarm and second, the Spörbichl windfarm capacity and the Energy Communities sizes are mismatched. However, in upcoming regulation EIWG (Elektrizitätswirtschaftsgesetz) it is likely that Energy Communities will be no longer required to own generation.
- **Pilot 2: Portugal (Front Runner)**. The target of the Portuguese pilot site is, on one side, to integrate cross-sector local collective self-consumption with virtual community flexibility, while on the other increase energy literacy and community engagement, supported by the implementation of a 30 kWp PV unit in the REC. The main barrier from the Portuguese regulatory framework is related to the integration of smart EV chargers in RECs, due to the DSO still not being able to associate the energy flows within the smart chargers.
- **Pilot 3: Greece (Front Runner)**. The target of the Greek pilot site is to increase the share of RES on the island of Chalki, implementing optimal management of the locally generated energy specially to avoid power outages in summer tourist season. The focus here is on households and small businesses, representing the vast majority of the community members, and the aim is to turn Chalki into a 100% green, sustainable, and autonomous destination. Existing regulation does not affect the implementation of the ENPOWER actions in the pilot. Strategies to encourage demand-response among the community members, like financial discounts in the cost for grid usage, are under investigation.
- **Pilot 4: Ireland (Front Runner)**. The target of the Irish pilot site is to integrate RES into the agricultural sector, focusing on the rural region of the Dingle peninsula. This sector suffers from grid connections inefficiency and therefore the need for increased self-sufficiency is crucial. The ENPOWER strategy in this case will focus on integrating DR strategies and PV and battery storage systems in the community. Targeted Agricultural Modernisation Schemes (TAMs) grants can reach 60% for solar installation in the agricultural sector but export of excess electricity generation to the grid is not allowed. This leads to investment in batteries and to probably not optimal deployment of the technology. Apart from this, the grant application process is not efficient and the vast majority of them is rejected. Another major barrier is that applying for grants require farm inspections, and farmers can face much higher expenses coming from these than the actual savings from energy grants.
- **Pilot 5: Hungary (Early Adopter)**. The Hungarian pilot site in the Békéscsaba municipality is facing a number of barriers, being the regulation not suitable for the development of REC projects. Clear evidence for this is that energy sharing is only allowed

between properties belonging to the same parcel. The consequence is that Energy Communities initiative hardly become established legal entities in Hungary by the moment.

- **Pilot 6: Spain (Early Adopter)**. The target of the Spanish pilot site in the Agron village is to establish a REC with 30-80 members and expanding an existing PV plant from 58 kW to 100 kW. The major regulatory barrier here is that minimum capacity units for DR are required, the roles of aggregators are not clearly defined and the regulation and procedures for shared self-consumption are not straightforward. Spain's regulatory landscape prioritizes demand flexibility and the development of aggregator roles. Changes in regulation are needed to support the integration of smaller flexible resources and streamline administrative processes for energy community activation. Nonetheless, bureaucracy further complicate the establishing of RECs in Spain.

D2.2 – Active societal participation, emergence and consolidation factors of energy activated citizens and data-driven energy-secure communities [27]

The work collected in D2.2 provides an overview of social aspects to be considered to increase engagement and citizen participation:

Table 3. Issues covered by ENPOWER deliverable D2.2

Issues covered	Details
Participant Insights	Workshops to gather opinions on energy data sharing, crucial for informing project partners and shaping policies, were conducted.
Promotion of active participation	Promotion of active participation was emphasized as essential for promoting transparency, accountability, inclusivity, fostering innovation, building social acceptance, empowering individuals and communities
Increase a sense of community identity	To foster community identity and emotional investment educational workshops, community events, celebrations, collaborative projects, were performed to increase engagement
Stakeholder and policymaker engagement	For the success of energy community projects and participatory processes was crucial to involve policy makers and different stakeholders to ensure diverse input and support
Identification of engagement barriers	Complexities in legislation, lack of knowledge, social reluctance identified as barriers, need to address these for greater participation

D2.3 – ENPOWER Business Sandbox [28]

Finally, D2.3 – Business models analysis the business models and economic benefits of the different pilots in ENPOWER project:

Table 4. Business models and economic benefits from ENPOWER deliverable D2.2

Pilots	Business model	Economic benefits
AT	Peer-to-peer (P2P) energy trading within local energy markets, engaging residents, small and medium-sized enterprises (SMEs), farmers	Reduced energy costs, carbon emissions, job creation, improved comfort, financial and non-financial benefits
PT	Community Energy Service Companies (ESCO), Local Energy Markets (LEM), E-mobility cooperatives to enhance energy efficiency and mobility services	Energy efficiency, mobility services, combination of various innovative business models

GR	Community aggregation and E-mobility cooperative business models to optimize energy consumption and enhance mobility services	Optimized energy consumption, enhanced mobility services, economic benefits of decentralized energy systems
IR	Local energy market community model emphasizing economic benefits of decentralized energy systems and flexibility assets	Enhanced local energy security, reduced dependency on external energy sources, job creation, improved comfort
ES	Combination of Community ESCO with mobility services and E-mobility cooperatives to incentivize citizen engagement	Market access and flexibility, fostering inclusive and participatory energy system
HU	Early adoption of innovative business models and technical enablers to raise awareness and educate citizens	Increased awareness and education about new technologies and energy management practices

3.4 Refinement of KPIs and testing in a workshop

The methodology to prioritise KPIs began with an extensive analysis of technical and peer-reviewed papers and the indicators frameworks developed in another EU project. This led to the ENPOWER preliminary KPIs list, which included 96 indicators (see Appendix) aimed at assessing the technical, economic, environmental, and social benefits generated by the newly established REC project or a new scenario (including individual and community-level changes) on citizens. The outcome of the analysis was collected in a dedicated template for partners involved in Task 3.1 to fill out. Each indicator was characterized by a code, a name, an acronym, and a brief description. They were also associated with the service they refer to (both from the community to others and from stakeholders to the community), including, for instance, Community/Building energy management optimization, E-mobility, Energy poverty, and Increasing the liveability of the energy community.

The indicators were also categorized as quantitative or qualitative, depending on whether they were derived from formula or a Likert scale questionnaire, respectively. The applicability of each indicator in the ENPOWER project's four Front Runners and two Early Adopters was also assessed according to the information on the communities' goals and the current or foreseen technology installed available in the Grant Agreement.

Partners were first asked to review the indicators in case they perceived that some areas and requirements were left uncovered (see Figure 1 from Appendix B), as well as to score the relevance of each indicator on a Low/Medium/High scale, assuming the perspective of either technical experts and stakeholders or non-technical community members. For clarity:

- **High Relevance** indicates that the information provided by the KPI is useful and of interest to tool users. For technical expert, it could potentially guide the deployment of services for the community.
- **Medium relevance** indicates that the information may be of interest but may not be as immediately useful.
- **Low relevance** indicates that the information is not particularly useful, or if the users are community members, it may be difficult for them to fully understand the indicator

The results of the KPI relevance assessment from all partners in Task 3.1 were collected and the low-to-high scores were converted into numerical values: 1, 2 and 3. Average scores for each KPI were computed for both the citizen and the technical expert perspectives. With a lower bound of the averaged score set at 2.8, 22 indicators were found to be useful and interesting for technical experts while only 7 were deemed relevant for citizens (results are reported in Appendix B).

Each section from table 3 reports the final KPIs list.

Table 5: Refined KPI list.

KPI category	Page
Social	37
Technical	39
Financial	46
Environmental	49
Information and Communication Technology	50
Legal	51

3.4.1 Workshop

During the first ENPOWER General Assembly, held on the 28th and 29th of May 2024 in Vienna (Austria), a workshop was organized by CARTIF under the framework of Task 3.1 *"KPIs identification and prioritisation for energy-secure communities".* Two activities were prepared for the workshop, the first focused on citizen-journey indicators and the other on understanding the motivation that could drive citizen to join RECs.

The first activity aimed to identify and define *"Citizen Journey indicators"* to track the progression of citizens on their journey to becoming energy-activated citizens. The second part of the workshop was focused on identifying the motivations for different "community member archetypes" to join an energy community.

For these activities, the attendees were divided into six groups based on both their relation to project's pilots and replicators and the number of attendees, as reported in Figure 5.

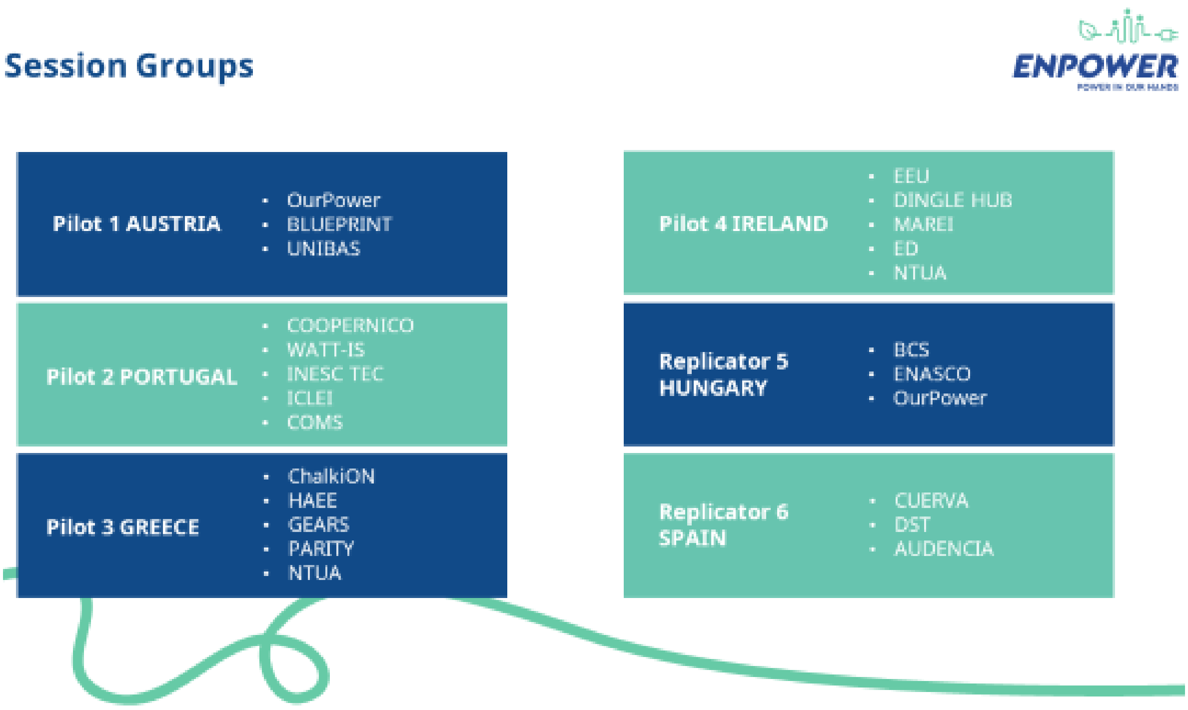


Figure 5. Workshop session groups

3.4.2 Citizen journey indicators workshop

For the first part of the workshop, the concept of *"Citizen Journey indicators"* was introduced as a mean to assess citizens' progress from being traditional consumers to energy-activated prosumers. While traditional technical, economic, environmental and social KPIs can rely on well-consolidated methodologies for their calculation, this does not apply to the measurement of Citizen Journey indicators. An innovative approach in their definition is thus needed.

The proposed approach to identify variables to measure citizen engagement and learning is divided into four different engagement areas, as shown in Figure 6. Since the journey needs to be applied to the Planning tool, these areas include:

- Tool usage
- Energy literacy
- Energy usage questionnaires
- Contribution to the community

Tool usage:
Regular and proficient utilization of the tool to optimize energy demand and increase renewable self-consumption as a community member

Energy literacy:
Explore energy topics in the tool, to increase member's awareness regarding renewable energy sources, their benefits, and their impact on the environment and society, enabling informed decision-making and active participation.

Energy usage questionnaires:
Completion of questionnaires regarding web topics to understand members' energy consumption habits and attitudes, enabling personalized guidance and fostering a more responsible energy usage.

Contribution to the community:
Encouraging active participation in community-led initiatives, triggering collective empowerment and sustainable development.

Figure 6. Citizen Journey Indicator's engagement areas

To guide the KPI identification process, the workshop used creative problem-solving techniques like the "Six Thinking Hats" methodology [29]. The aim is to identify innovative ways to measure and track the citizen's journey and engagement avoiding logic-based critical thinking.

For this workshop, the methodology was adapted focusing on three hats: Green, White and Black:

- **Green Hat - Creativity**: The objective is to generate new ideas and innovative solutions to track the citizen progression. Questions to be addressed include:

  What Citizen journey indicators could be relevant for the user?

  How can energy usage questionnaires be creatively designed to encourage participation?

  What are the next steps?

- **White Hat** - Information/**Data needs**: The objective is to identify the data needed to calculate the ideas from the Green Hat. Questions to be addressed include:

What data is available to assess progress?

What are the key facts to measure the impact of becoming an energy activated citizen?

What other information do we need? (e.g. assumptions, questionnaires, etc.)

- **Black Hat - Risks and challenges**: This exercise aims to identify risks and challenges, similar to a SWOT matrix analysis. Questions to be addressed include:

  What are the potential risks and challenges? (e.g. social acceptance difficult to measure when there is no social engagement in place)

  What critical factors might impede community members' acceptance?

  How do we solve them?

For the first workshop activity, each group was given a table to apply the previously defined methodology (Green, White and Black Hat) to each of the engagement areas (Tool usage, Energy Literacy, Energy usage questionnaires and Contribution to the community). For each area, the most relevant citizen journey indicators for the user and for stakeholders, the data needs to calculate them, and any possible risk and challenge related to the area were analysed by each group.

Main results from this exercise can be seen in Figure 2 from Appendix B. As shown, for **tool usage,** metrics such as "time spent", "individual and aggregated results", or "feedback" to the tool which could include "likes" or tool ratings were identified. Other engagement metrics could include number of users registered per community, the number of scenarios performed by each user or by the community, which could also be measured with the individual and aggregated results.

Challenges might include time-consuming usage, engagement, tool or energy literacy, GDPR issues on the results, gamification strategies to increase engagement, the measurement of user navigation (leading to GDPR issues), or the added value provided compared to other tools.

Main outcomes per area are listed below.

- **Tool usage**

  Metrics such as "time spent", "individual and aggregated results", or "feedback" to the tool which could include "likes" or tool rating. Other engagement metrics could include number of users registered per community, number of scenarios performed by each user or by the community, which could be measured too with the individual and aggregated results.

  Challenges might include: time-consuming usage, engagement, tool or energy literacy, as well as GDPR issues on the results, gamification strategies to increase engagement, the measurement of user navigation (which leads to GDPR issues), or the added value provided compared to other tools.

- **Energy literacy**

  Metrics for this case might include measuring the navigation through different articles and webpage information; this could allow ranking articles based on their technical complexity or their relevance to community goals.

  Challenges might include the use of technical language or topics that could limit the target group due to lack of knowledge.

- **Energy usage questionnaires**

Metrics for this activity might include the percentage of completion, the number of attempts to retake tests for better scores on the ranking of the community, and the time spent on questionnaires to indicate engagement.

Challenges might include the time-consuming usage, the use of technical language or topics, and finding the right frequency (too high can cause annoyance, while too low can lead to disengagement). There may also be issues with participants providing random answers or manipulating responses to achieve a better rank.

- **Contribution to the community**

  Metrics for this activity might include the active participation data like the number of attended assemblies or the number of created scenarios on the tool. Additionally, fostering a community feeling, with a regional focus (i.e. geographical dependent indicators), and tailoring content to meet specific needs are essential. Having a hero, champion, or role model can also enhance engagement and motivation within the community.

  Challenges might include the user's limited time for participating, limited benefits from the participation to REC activities or high participation fees. It is crucial to include both individual and aggregated results to understand the average perception from the whole community rather than just single citizens

In general, the workshop results emphasize that citizen engagement indicators should measure active participation, using feedback and badges or ranks to motivate ongoing involvement. Furthermore, there is lack of provision of the benefits of joining a community and obtaining both individual and collective results.

The identified risks and challenges include the excessive use of technical language or topics, foreseen tool complexity for non-technical users and the risk for the tool to become overly time-consuming through excessive gamification. In addition, it is crucial to distribute optimally in time the tests and tasks for the user to carry on as to avoid annoyance and disengagement.

From this part of the workshop, and assessing the existing KPI list, the KPIs that seem relevant to what was discussed are:

- User Acceptance (UA), an indicator aggregating perceived usefulness, ease of use and behaviour within the app/dashboard – which can be summarized as "tool rating"
- Education (ED), an indicator that will measure the awareness-raising, knowledge sharing and learning process. – which can be exploited through "consumption habits", "join and demonstrated activate engagement", and "ranks with other users"

The former one can be measured in the tool and serves for including a feedback loop that allows to improve usability and functionalities of the tool. The latter can be calculated as a composite indicator of the three measurements and be summarized as "a measurement of energy-activated citizens (EAC)" KPI.

3.4.3 Second part of the Workshop

For the second activity of the workshop another table was given to the session groups Figure 7 with the aim to define user motivation towards joining an energy community, and what narrative or indicator could be the most suitable to convince each one of the 5 different community member archetypes:

- Old lady

- Mayor
- Small and medium-sized enterprises (SME) Owner
- Community Hero
- Bank owner

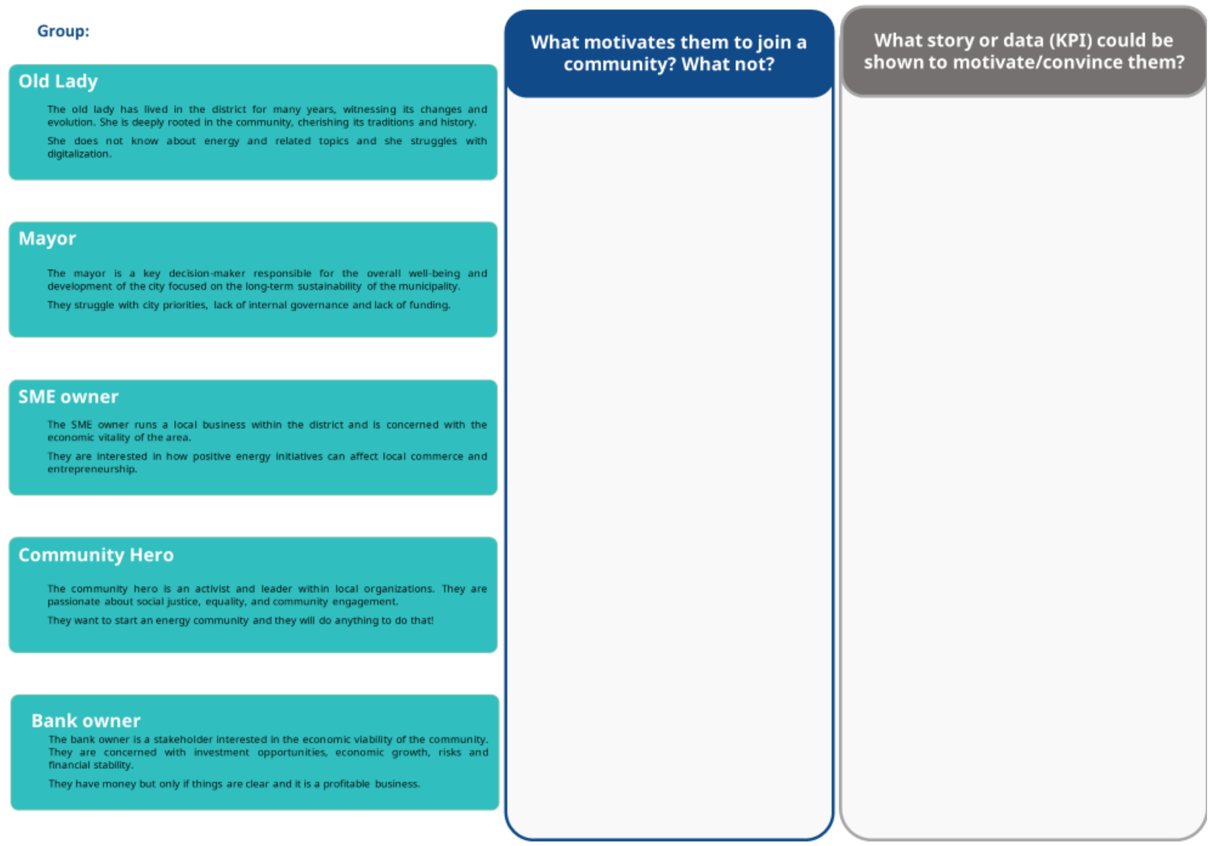


Figure 7. Citizen engagement table

Main results obtained from this exercise could be summarized in the Figure 8, where it can be seen that the most common motivation to join an energy community are economic savings and the potential financial benefits from energy sales and for obtaining green funds and incentives. Additionally, the social impact can trigger engagement, potentially leading to new networking or business possibilities, political promotion and even boosting tourism.

CHARACTER	MAIN MOTIVATIONS
Old lady	Economic saving & Social & Future Sustainability
Mayor	Economic funding & Political Promotion and energy targets --> Case studies & Savings and Social impact
SME owner	Economic savings and funding (incentives) & Collective benefits
Community hero	Future Sustainability & Collective engagement --> Savings & Independence (from grid, gas...)
Bank owner	Economic funding (green funds, incentives) & Promotion (networking)

Figure 8. Citizen engagement main results

Economic savings are measured by different indicators such as energy bills reduction, or user monetary savings in electricity bill.

Future sustainability can be measured with a composite indicator as a result of: jobs created (economic), acceptance of the community (social), and GHG emissions reduction (Environmental).

Political promotion and energy targets are indirectly supported by the indicators regarding the support of the legal framework of energy communities.

3.5 KPI framework

When possible, for each KPI the following information is reported: KPI code, title, description and definition, units, and required data to calculate it (calculation method).

Some nomenclature and definitions are based on IEA SHC Task 60 [30] in order to increase ENPOWER dissemination and its impact through as much different communication channels as possible.

Table 6: Nomenclature from IEA SHC Task 60.

Term	Description
Q	Energy in the form of heat
E	Energy in the form of electricity
C	A negative amount of heat (“cold”). C = -Q
G	Global solar irradiation. With a subscript “h”, denotes the irradiation on a horizontal surface and subscript “col” for irradiation on the collector plane
$\dot{Q}, \dot{E}, \dot{C}, \ldots$	Energy flow rates: quantities representing a thermal or an electric power
A	Area. With a subscript “col”, denotes the area of the solar collector. With a superscript “gross” denotes the gross solar collector area (it may be denoted to a different reference area: effective area, etc.)
Sys	Subscript sys can be used to bundle all system components. It denotes that the energy is used within the system boundary
h	Subscript “h” can be used to denote useful energy used for heating purposes. Also SH, space heating, and DHW, domestic hot water, can be used
c	Subscript “c” can be used to denote useful energy used for cooling purposes
f	Subscript “f” can be used to denote final energy coming from fossil fuels (e.g. natural gas, GLP, etc.)
EC	Economic flow
GHG	Environmental flow, subscript (CO_2, CH_4, CO2eq, etc.) indicates the gas. IPCC default accounting methodology will be considered when there is no available data at country level.
Bef	Subscript “bef” denotes baseline conditions (i.e. before any action has been undertaken)
Scen,x	Subscript “scen” denotes scenario conditions (i.e. when one or several actions are being studied or have been implemented), while x denotes the number of the scenario (in case there are several).
*****	An asterisk means the sum of all heat or electrical energy that flows away from a component QA,* or that is consumed by a component Q*,A. Asterisk can be omitted if the context permits it, e.g., all electrical energy consumed by a heat pump: E*,HP or EHP [30].
Subscripts	When a quantity of heat, cold or electricity that flows from a component A to a component B can be denoted by: QA,B , CA,B(=-QB,A) or EA,B.

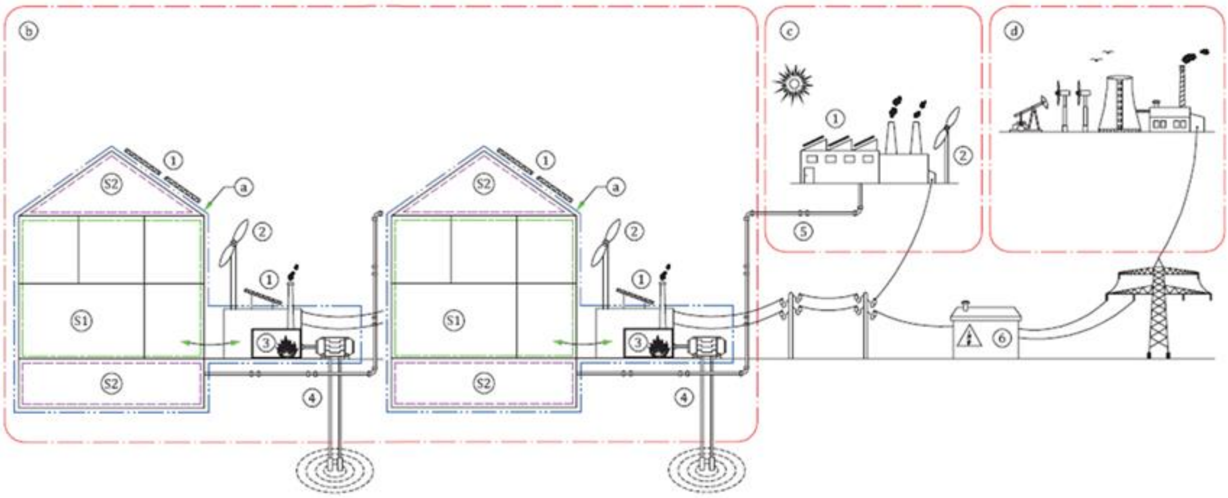
The formulas of each KPI are summarised in Appendix C.

Energy quantities can be represented as absolute values (kWh) or per square meters (area within the assessment boundary, i.e. without considering spaces that are not thermal conditioned).

Figure 9 shows what is generally intended with assessment boundaries in the context of energy communities:

- ***b*** is the **perimeter on-site**. It refers to the physical boundary of the community and it can include all its members and assets (owned and managed by the community).
- ***c*** is the **perimeter of the nearby assets**, including for instance possible district heating network not owned by the district.
- ***d*** is the **perimeter of the distant assets**, including for instance the power and gas grids.

When virtual boundaries are considered (i.e., those that are not physical boundaries), ***b*** includes off-site assets owned and managed by the community.



Key

a	assessment boundary (use energy balance)	1	PV, solar
b	perimeter: on-site	2	wind
c	perimeter: nearby	3	boiler room
d	perimeter: distant	4	heat pump
S1	thermally conditioned space	5	district heating/cooling
S2	space outside thermal envelope	6	substation (low/medium voltage and possible storage)

Figure 9. Assessment Boundaries (figure adapted from ISO52000-2 [31]**).**

3.5.1 Social KPIs

This family of indicators measures various aspects of social impact and engagement within renewable energy communities (RECs), such as data transparency, investments made from earnings of the community, energy activated citizens KPI and user acceptance.

SOC.01 - DATA TRANSPARENCY (DT)

Description

This KPI measures the user perceived tool transparency about data security. The indicator qualitatively evaluates to which extent the user is informed about the data that are collected, analysed and possibly shared to other tool users. This aims at evaluating whether the user feels safe with sharing personal data about the community members, the buildings' location or not. This indicator can drive the developers towards improving data practices and meeting user expectations and the legal standards on sensitive data.

Calculation method

The calculation method is through questionnaires:

- To which extent you find the Data Policies section complete and informative, i.e. rate the comprehensiveness and readability of the privacy policy, the accessibility of data usage information, and user feedback on policy clarity. (Scale: 1-5)
- To which extent you believe the tool provides transparent information on the exact data that is collected, stored and shared with other tool users and its amount. (Scale: 1-5)

SOC.02 - INVESTMENTS MADE FROM EARNINGS OF THE COMMUNITY (REINV)

Description

This KPI measures the share of profits and earnings generated by the REC that are reinvested back in the community, including any investment or financial expenditure directed towards better community's infrastructure and assets or social and environmental initiatives aimed to actively involve the members of the community. The indicator provides insights into how efficient and structured the reinvestment mechanism is in the REC and the extent to which members are committed to it towards continuous improvement.

Calculation method

The calculation method is through questionnaires:

- How much of the community's earnings were reinvested in infrastructure improvement?
- How much of the community's earnings were reinvested for social and environmental awareness-raising initiatives?
- How is the reinvestment from community earnings redistributed among the REC members?

SOC.03 – ENERGY-ACTIVATED CITIZENS (EAC)

Description

This KPI measures the degree to which the awareness-raising, knowledge sharing and the learning processes of the tool and the energy community is helping a citizen that joins an energy community to become an activated citizen.

It can be measured through various sub-indicators, such as consumption habits, activate engagement (through the participation in the tool or educational activities), or by making rankings with other users to compare the user performance in the tool.

Calculation method

The calculation method is through questionnaires available in the tool.

- Consumption habits (1 – not likely at all, 5 – very likely)
    - How likely are you to switch off your lights when you do not need them?
    - How likely are you to use your appliances (or program them) during daylight?

- How likely are you to switch off your appliances if the community predicts a potential blackout?
    - Have you implemented any energy-saving measures in the past six months? (e.g., switching to energy-efficient appliances, reducing usage during peak hours)
- Tracking participation and active involvement in educational activities.
    - numbers of questionnaires performed (compared to peers)
    - number of articles read in the tool
    - How frequently do you apply the knowledge gained from educational activities to your daily life?
- Comparing performance and engagement of users in the tool:
    - number of scenarios performed compared to peers
    - invitations sent to peers to join the energy community

The periodicity of these will depend in the community preferences, but by default, it can be repeated every 6 months. Considering ED_i as the sub-indicator representing each different educational measurement (each question within each level).

$$EAC = \sum w_i \cdot ED_i \qquad \textbf{Eq. 1}$$

Where w_i represents the individual weight of each educational KPI, which can be equally distributed (i.e. 1/3) or adjusted by the community in case they want to give more weight to one specific sub-indicator (such as consumption habits). These values can also be normalized by dividing by their maximum possible value, and within each category, they can also be weighted with more or less importance.

SOC.04 - USER ACCEPTANCE (UA)

Description

This KPI measures the extent to which the tool is useful and easy to use for the user as part of the workflow related to the energy community modelling. It provides insights on whether the user is satisfied and engaged with the tool and whether the interface and the results are aligned with their needs and expectations. The indicator can drive the developers towards a continuous improvement of the tool.

Calculation method

The calculation method is through questionnaires.

- To which extent are the results meeting your needs and expectations, i.e. their relevance? (Scale: 1-5)
- To which extent do you find the tool easy to use? (Scale: 1-5)

3.5.2 Technical KPIs

This family of indicators is designed for external stakeholders or advanced users with technical knowledge. They cover various aspects of energy performance, including self-consumption ratios, self-sufficiency, and the performance of flexibility services such as demand response.

TE.01 AND TE.02 – TOTAL AND NON-RENEWABLE PRIMARY ENERGY SAVINGS TRIGGERED BY THE PROJECT (PES and PES_{NREN})

Description

The KPIs measure respectively the variation in the total (summing up the renewable and non-renewable shares) and non-renewable consumption of primary energy by the members of the community after the establishment of the REC and/or after a new scenario is generated.

Calculation method

$$PES = \frac{\left(PE_{tot\_bef} - PE_{tot\_scen,x}\right)}{PE_{tot,bef}} \qquad \textbf{Eq. 2}$$

where:

$PE_{tot} = PE_{nren} + PE_{ren}$ (MWh) is the sum of the renewable and non-renewable primary energy consumption in the community.

PE_{tot_bef} (MWh) is the total primary energy consumption before an action is applied to the energy community.

$PE_{tot\_scen,x}$ (MWh) is the total primary energy consumption after an action is applied to the energy community.

For a typical energy consumer where the power grid supplies the electricity to cover its needs ($E_{GRID,sys}$) the $PE_{tot\_scen,x}$ is calculated as follows.

$$PE_{tot\_scen,x} = E_{GRID,sys} \cdot PEF_{tot,GRID} \qquad \textbf{Eq. 3}$$

Where $PEF_{tot,GRID}$ is the total primary enerfy factor. For a prosumer, exports and imports are compared (see Eq. 8), which results in:

$$PE_{tot\_scen,x} = E_{GRID,sys} \cdot PEF_{tot,GRID} - E_{*,exp} \cdot PEF_{tot,GRID} \qquad \textbf{Eq. 4}$$

When using non-renewable primary energy factors, TE.02 is calculated, which results in

$$PES = \frac{\left(PE_{nren_{bef}} - PE_{nren_{scen},x}\right)}{PE_{nren,bef}} \qquad \textbf{Eq. 5}$$

TE.03 - RENEWABLE ENERGY RATIO (RER)

Description

This KPI measures the ratio of renewable energy consumed within the chosen boundaries (from a single member to the entire REC) out of the total primary energy consumed. It can be expressed as a percentage variation after the establishment of the community and/or after a new scenario is generated. The indicator evaluates the level of integration of renewables sources in the REC project energy mix.

Calculation method

For the evaluation of the RER:

$$RER_{scen,x} = \left(\frac{PE_{ren}}{PE_{tot}}\right)_{scen,x} \qquad \textbf{Eq. 6}$$

For the variation:

$$RER = \frac{\left(\frac{PE_{ren}}{PE_{tot}}\right)_{scen,x} - \left(\frac{PE_{ren}}{PE_{tot}}\right)_{bef}}{\left(\frac{PE_{ren}}{PE_{tot}}\right)_{bef}} \quad \textbf{Eq. 7}$$

where:

$\left(\frac{PE_{ren}}{PE_{tot}}\right)_{bef}$ (-) is the ratio between the renewable and the total primary energy consumption before an action is applied to the energy community.

$\left(\frac{PE_{ren}}{PE_{tot}}\right)_{scen,x}$ (-) is the ratio between the renewable and the total primary energy consumption after an action is applied to the energy community.

TE.04 - LOCAL ENERGY EXPORTED ($E_{*,exp}$)

Description

This KPI measures the amount of the energy produced locally by the community that is exported to the grid due to low demand. The energy generated locally in the REC that cannot be consumed within 15 minutes is exported to the grid. The indicator therefore evaluates the efficiency in the energy management of the community, including the effectiveness of storage solutions, and help in understanding whether the energy management strategy adopted is beneficial to the members or not also from an economical perspective.

Calculation method

$$E_{*,exp} = E_{RES,*} - E_{RES,sys} \quad \textbf{Eq. 8}$$

where:

$E_{RES,*}$ (kWh) is the total energy generation from the community RES.

$E_{RES,sys}$ (kWh) is the energy generation from the community RES that is consumed locally.

TE.05 - SELF-CONSUMPTION RATIO (SCR)

Description

This KPI measures the share of local renewable energy generation over the total energy consumption, including imports from the external grid. The indicator measures how much of the total local renewable generation is used within the community boundaries and therefore could be helpful in optimizing the timing of energy-intensive activities, so that they match periods of high-RES generation. On the other side, the KPI helps in the sizing of storage solutions, as a low SCR could mean that a large amount of RES generation out of the total is not consumed locally end therefore exported.

Calculation method

$$SCR = \frac{E_{RES,sys}}{E_{RES,*}} \quad \textbf{Eq. 9}$$

where

$E_{RES,sys}$ (kWh) is the energy generation from the community RES that is consumed locally. This should be calculated for electricity (see TE.15) and heat separately.

$E_{RES,*}$ (kWh) is the total energy generation from the community RES.

TE.06 - COMMUNITY SELF-SUFFICIENCY RATIO (SSR)

Description

This KPI measures the amount of locally consumed renewable energy over the total community consumption. The KPI takes as input the locally consumed renewable energy as the sum over all 15-minutes time slots of the minimum between the renewable energy production and consumed energy in each time slot.

Calculation method

$$SSR = \frac{E_{RES,sys}}{E_{*,sys}} \qquad \textbf{Eq. 10}$$

where

$E_{RES,sys} = MIN(E_{RES,*}, D_{*,sys})$ (kWh) is the energy consumed from the community RES locally (electricity or thermal).

$E_{*,sys}$ (kWh) is the total energy consumption (electricity or thermal), which is the sum that comes from RES and from the power grid.

TE.07 - RES PENETRATION FOR COVERING THERMAL USE (RER_{th})

Description

This KPI measures the share of thermal energy consumption met by local renewable generation over the total thermal consumption in the community.

Calculation method

$$RER_{th} = \frac{Q_{RES,sys}}{Q_{*,sys}} \qquad \textbf{Eq. 11}$$

where

$Q_{RES,sys}$ (kWh) is the renewable thermal energy generation that is consumed locally (meters or simulations).

$Q_{*,sys}$ (kWh) is the total thermal energy consumption (meters).

TE.08 – THERMAL DEMAND RESPONSE DEVIATION ($\Delta Q_{DRevent}$)

Description

This KPI measures the change in thermal energy demand during peak hours thanks to demand response event through Power-to-Heat (P2H) and Heat-to-Power (H2P) devices. The indicator provides insights on the effectiveness of such technologies in managing for instance excess electricity production, converting it to thermal energy and storing it for later use at peak heating demand.

Calculation method

$$\Delta Q_{DRevent} = Q_{needs,bef} - Q_{needs,DRevent} \qquad \textbf{Eq. 12}$$

where

$Q_{needs,bef}$ (kWh) is the thermal energy demand during the peak hours before a DR action is applied to the energy community.

$Q_{needs,DRevent}$ (kWh) is the thermal energy demand during the peak hours after a DR action is applied to the energy community.

TE.09 - GRID CONGESTION (GC)

Description

This KPI measures how the integration of the proposed solutions impact energy curtailment due to grid congestion, or, in other words, it quantifies the reduction in energy curtailment due to an improved management of grid congestion events after setting the energy community or after a new scenario is generated.

Calculation method

$$GC = \frac{(E_{RES,curtailed\_bef} - E_{RES,curtailed\_scen,x})}{E_{RES,curtailed\_bef}} \qquad \textbf{Eq. 13}$$

where

$E_{RES,curtailed\_bef}$ (kWh) is the energy curtailment before an action is applied to the energy community.

$E_{RES,curtailed\_scen,x}$ (kWh) is the energy curtailment after an action is applied to the energy community.

TE.10 - PEAK LOAD REDUCTION (PLR)

Description

This KPI measures the reduction in the maximum electrical power demand in periods of high usage, known as peak periods, after the establishment of the REC and/or after a new scenario is generated. This can be pursued through Demand Response strategies, applying energy efficiency measures and installing thermal and electrical storage devices. The indicator can be computed at different levels, from final consumer to feeder to network.

Calculation method

$$PLR = \frac{(E_{peak,bef} - E_{peak\_scen,x})}{E_{peak,bef}} \qquad \textbf{Eq. 14}$$

where

$E_{peak,bef}$ (kWh) is the peak electricity demand before an action is applied to the energy community.

$E_{peak\_scen,x}$ (kWh) is the peak electricity demand after an action is applied to the energy community.

TE.11 – DIFFERENCE OF ENERGY USE FROM A CONVENTIONAL SYSTEM (WITHOUT OPTIMAL ENERGY FLOWS) (ΔE_{conv})

Description

This KPI measures the variation in energy consumption between the system in normal conditions and the system in optimal conditions using smart devices, evaluating the improvement thanks to smart energy components such as Multi-linear programming controllers.

Calculation method

$$\Delta E_{conv} = \frac{\left(E_{*,bef} - E_{*\_scen,x}\right)}{E_{*,bef}} \qquad \text{Eq. 15}$$

where

$E_{*,bef}$ (MWh) is the energy consumption before an action is applied to the energy community.

$E_{*\_scen,x}$ (MWh) is the energy consumption after an action is applied to the energy community.

TE.12 – AMOUNT OF ENERGY EXCHANGED BY MEANS OF P2P ENERGY TRADING (E_{P2P})

Description

This KPI measures the total amount of energy that is traded directly between peers in the REC. High values of the indicator suggest high energy sharing among the community members, which lead to collective economic benefit and costs reduction. The KPI also gives a measure on the members' engagement in decentralized energy transactions.

Calculation method

Meters.

TE.13 - ENERGY CONSUMPTION OF THE PUBLIC EV CHARGERS (E_{EV})

Description

This KPI measures the amount of electricity that is consumed by Electric Vehicle (EV) chargers installed in the community. The indicator provides insights on whether the available infrastructure for the community EV fleet is satisfying the demand or new installations are necessary.

Calculation method

Meters.

TE.14 – STORAGE CAPACITY OF THE PEV BATTERIES OFFERED THROUGH V2G SERVICE (E_{PEV})

Description

This KPI measures the total amount of energy storage capacity that is provided by Plug-in Electric Vehicle (PEV) batteries available in the community. In particular, this capacity can be exploited as an additional source of flexibility for the community grid when Vehicle-To-Grid (V2G) services are available for the REC buildings. The indicator measures the potential amount of energy that can be fed into the grid from PEV batteries, which could be particularly helpful in peak demand periods. Excess energy production from renewables can be indeed stored in PEV batteries and supplied when needed.

Calculation method

The calculation method is through questionnaire:

- Do you own a Plug-in Electric Vehicle (PEV)?
- If yes, are V2G services available in your building?
- If yes, what is the capacity of your PEV battery in kWh?

TE.15 – ELECTRICITY SELF-CONSUMPTION (ESC)

Description

This KPI measures the extent to which the local electricity generation from the REC is actually consumed within the system boundaries in the form of a ratio between the share of generation that is consumed locally and the total electricity generation. The indicator helps in assessing how well the local generation is exploited, and, therefore, also how well electricity demand and generation within the system boundaries match.

Calculation method

$$ESC = \frac{E_{RES,sys}}{E_{RES,*}} \quad \textbf{Eq. 16}$$

where

$E_{RES,sys}$ (MWh) is the electricity generated and consumed within the assessment boundaries.

$E_{RES,*}$ (MWh) is the total electricity generated within the assessment boundaries.

TE.16 – CUMULATIVE ELECTRICAL ESS CAPACITY ($E_{ESS,capacity}$)

Description

This KPI measures the total amount of electrical storage (in terms of nominal capacity) that is integrated in the REC energy system and available to reduce the electricity demand and generation mismatch due to renewables.

Calculation method

The calculation method is through questionnaires:

- Do you own Electrical Energy Storage (ESS) systems?
- If yes, what is the capacity of your ESS in kWh?

TE.17 – INSTALLED CAPACITY OF ELECTRICAL RES

Description

This KPI measures the total amount of electrical RES capacity within the boundaries of the community. It can be also expressed as the variation in installed capacity after setting the energy community or after a new scenario is generated.

Calculation method

The calculation method is through questionnaires:

- Do you own electrical Renewable Energy Systems (RES)?
- If yes, what is the capacity of your RES in kWh?

3.5.3 Financial KPIs

This family of indicators assesses the economic and financial health of the community. It measures the extent to which the community's financial situation can be improved through various metrics, including reductions in energy bills, operational cost avoidance, levelised cost of energy/electricity or heat, capital expenditure, internal rate of return, and payback period.

EC.01 – ENERGY BILLS' REDUCTION (f_{CBR})

Description

This KPI measures the reduction in the energy bills (accounting for both heating and electricity) that citizens experience after setting the energy community or after a new scenario is generated. The indicators measure the financial benefit derived from increased self-consumption as part of the community and the efficiency measures adopted.

Calculation method

$$f_{CBR} = EC_{bef} - EC_{scen,x} \quad \textbf{Eq. 17}$$

where

EC_{bef} (€) is the sum of the heating and electricity bills before an action is applied to the energy community.

$EC_{scen,x}$ (€) is the sum of the heating and electricity bills after an action is applied to the energy community.

Correction factors could be considered in case there is extreme changes in weather conditions or prices that could affect the calculation (following for instance, IPMVP methodology).

EC.02 – OPERATIONAL COSTS AVOIDANCE (OCA)

Description

This KPI measures the variation in the operational expenditure of the assets in the community after a specific intervention is carried out. The indicator helps in understanding whether the action, usually driven by energy efficiency and environmental concerns, is also economically favourable.

Calculation method

$$OCA = OPEX_{bef} - OPEX_{scen,x} \quad \textbf{Eq. 18}$$

where

$OPEX_{bef}$ (€) is the yearly estimated operational expenditure before an action is applied to the energy community.

$OPEX_{scen,x}$ (€) is the yearly estimated operational expenditure after an action is applied to the energy community.

EC.03 – LEVELISED COST OF ELECTRICITY (LCoE)

Description

This KPI measures the net present cost of electricity generation from a specific asset in the community. The indicator includes the initial capital expenditure and all the yearly costs associated with the asset operation and maintenance. Subsidies and decommissioning costs can be included to refine the indicator. It helps in comparing energy generation from a financial perspective on a common consistent basis, thus evaluating the cost-effectiveness of a specific technology in the REC context.

Calculation method

$$LCoE = \frac{C_0 - S_0 + S_D + \sum_{t=1}^{T} \frac{C_t}{(1+r)^t}}{\sum_{t=1}^{T} \frac{E_t}{(1+r)^t}} \quad \textbf{Eq. 19}$$

where

C_0 (€) is the initial cash outflow or cost at time zero.

S_0 (€) is the total initial amount of subsidies received by the community.

S_{d} (€) is the decommissioning cost at the end of the asset lifetime.

C_t (€) is the annual operation and maintenance cost in the year t.

E_t (kWh) is the amount of electricity generated in the year t.

r (-) is the discount rate reflecting the cost of capital.

T (years) is the lifetime of the asset.

EC.04 – CAPITAL EXPENDITURE (CAPEX)

Description

This KPI measures the total monetary expenditure related to the installation of new equipment in the community. In this context, the indicator sums up the investment cost related to the new equipment after a scenario (intended as a set of interventions in the community) is generated.

Calculation method

$$CAPEX = \sum_{n=1}^{N} CAPEX_{tech,n} \quad \textbf{Eq. 20}$$

where

$CAPEX_{tech,n}$ (€) is the capital expenditure due to new installation n.

EC.05 – CONTRIBUTION TO TOTAL SPEND (S)

Description

This KPI measures how the financial contributions are distributed among the community members, taking into consideration the energy cost, the investment for the REC infrastructure and all the operational and maintenance expenditure. This indicator helps in evaluating which is the actual monetary contribution to the community from each citizen, so that the generated benefits can be redistributed accordingly.

Calculation method

$$S_j = \frac{DI_{scen,x;j}}{CAPEX_{scen,x}} \qquad \textbf{Eq. 21}$$

where

S_j is the ratio of the contribution to total spent of a member of the community (j)

$DI_{i,j}$ (€) is the individual contribution of the member of the community (j) for the project scenario (scen,x).

$CAPEX_i$ (€) is the total capital expenditure of the project scenario (scen,x).

EC.06 – INTERNAL RATE OF RETURN (IRR)

Description

This KPI measures the profitability of the total investment related to the establishment of the energy community and the related infrastructure. This is the interest rate for which the Net Present Value (NPV) of the investment gets to zero in a specified period. The indicator provides a standardized tool to compare different scenarios so that decision-maker can select the option that yields better monetary returns.

Calculation method

$$IRR\ so\ that\ NPV = \sum_{t=1}^{T} \frac{C_t}{(1+IRR)^t} - C_0 = 0 \qquad \textbf{Eq. 22}$$

where

C_t (€) is the net annual cash inflow during the period t, including savings and possible generated revenues.

C_0 (€) is the initial cash outflow or cost at time zero.

T (years) is the number of considered time periods.

EC.07 – PAYBACK PERIOD (PB)

Description

This KPI measures the time required for the cumulative gains from an investment to equal the cumulative cost. Cumulative gains can include the reduction in the citizens' energy bills, the revenue from selling surplus energy to the grid or to other consumers outside of the REC but also possible financial incentives from the local government for REC projects. On the other hand, cumulative cost includes for sure the initial investment, with the installation of the community infrastructure and the renewable systems, but also maintenance costs over the years and possible additional administrative costs.

Calculation method

$$PB = \frac{(CAPEX + OPEX)}{C_t} \qquad \textbf{Eq. 23}$$

where

$CAPEX$ (€) is the total capital expenditure.

$OPEX$ (€) is the yearly operational expenditure.

C_t (€) is the net annual cash inflow during the period t, including savings and possible generated revenues.

3.5.4 Environmental KPIs

Although stakeholders from the project deemed these indicators less relevant for the energy communities involved, they are still included to create a comprehensive KPI framework. This family of indicators covers emission reduction, air quality index, land use for energy production, and other environmental impacts.

ENV.01 – GHG EMISSIONS REDUCTION (GHG_{sav})

Description

This KPI measures the variation in the total CO_2eq emissions of greenhouse gases emitted for all energy carriers for all the technologies installed in the community before and after a new scenario is generated.

Calculation method

$$GHG_{sav} = \sum_{f=1}^{F_{bef}} GHG_{f,bef} - \sum_{f=1}^{F_{scen,x}} GHG_{f\_scen,x} \qquad \textbf{Eq. 24}$$

where

$GHG_{f,bef}$ (tCO_2e) is the CO_2eq emission emitted for all energy carriers (usually fuels, denoted as f in the formula) before the generation of the new scenario. The total emissions for all fuels (F) or energy carriers with associated GHG emissions are calculated by multiplying the final energy consumption of each energy carrier by its respective emission factor.

$GHG_{f\_scen,x}$ (tCO_2e) is the CO_2eq emission emitted for all energy carriers (usually fuels, denoted as f in the formula) after the generation of the new scenario.

ENV.02 – AIR QUALITY INDEX (AQI_P)

Description

This KPI measures the level of air pollution for a specific pollutant in the REC area, including for instance particulate matter (PM2.5 and PM10), carbon monoxide (CO) sulphur dioxide (SO2) or nitrogen dioxide (NO2). The indicator helps in assessing the impact of air quality on the community members and individuating areas for improvement.

Calculation method

$$AQI_P = \frac{I_{Hi} - I_{Lo}}{BP_{Hi} - Bp_{Lo}} \cdot (C_P - BP_{Lo}) + I_{Lo} \qquad \textbf{Eq. 25}$$

where

C_p (ppm) is the measured concentration for pollutant P truncated to the nearest integer.

BP_{Hi} (ppm) is the concentration breakpoint that is greater than or equal to C_p. In other words, the upper limit of the concentration range in which C_p falls.

BP_{Lo} (ppm) is the concentration breakpoint that is less than or equal to C_p. In other words, the lower limit of the concentration range in which C_p falls.

I_{Hi} (-) is the AQI value corresponding to BP_{Hi}.

I_{Lo} (-) is the AQI value corresponding to BP_{Lo}.

Specific meters for measuring the pollutant concentration need to be installed. In the model this is calculated for all fuels (F) or energy carriers with associated PM, CO, etc. emissions by multiplying the final energy consumption of each energy carrier by its respective emission factor.

ENV.03 – LAND USE FOR ENERGY (LU)

Description

This KPI measures the proportional land area that is occupied by energy production units (total and/or categorized per energy carrier) and the related infrastructure in the community area. Rooftop solar installations are excluded as the land area would be anyway occupied by the building where the device is installed. The indicator provides insights on how efficiently distributed are the devices in terms of occupied land and thus possible improvements.

Calculation method

Equipment datasheet or estimation from average values per technology is considered in the models. The total capacity installed is multiplied by these average values to obtain the Land Use (LU) for energy.

3.5.5 Information and Communication Technology KPIs

Although these indicators are not utilized in the current models, they are included to define a comprehensive KPI framework. The indicators in this category include the ratio of data-to-errors, the number of suppliers with access to sensitive data, and the time-to-value. These metrics provide insights into data quality, security, and efficiency in data utilization.

ICT.01 – RATIO OF DATA-TO-ERRORS (DTOERR)

Description

This KPI measures the actual reliability of the data communication and processing for all data-handling devices, tools, meters in the community as part of ENPOWER ecosystem. The information is supplied by the technology and service providers.

Calculation method

$$DTOERR = \frac{Errors}{Items} \tag{Eq. 26}$$

where

$Errors$ (-) is the total number of erroneous data points in the meters.

$Items$ (-) is the total number of data points in the meters.

ICT.02 – NUMBER OF EXTERNAL SUPPLIERS WITH ACCESS TO PERSONAL/SENSITIVE DATA (DTOEXT)

Description

This KPI measures the total number of external suppliers and third parties that have access to personal or sensitive data supplied to and from the tools, the meters and all kinds of data-handling processes in the community as part of ENPOWER ecosystem.

Calculation method

Identify contracted third parties having access to data.

ICT.03 – TIME-TO-VALUE (TTOV)

Description

This KPI measures the time from when data is computed or collected from smart meters or any tool as part of ENPOWER ecosystem until it is utilized to generate value within the community. The indicator reflects the efficiency and effectiveness of the data processing and decision-making processes.

Calculation method

Track and report time.

3.5.6 Legal KPIs

This family of indicators measure the suitability and implementation of various legal frameworks relevant to energy communities and related technologies. The calculation method for each KPI is based on questionnaires, with responses measured using a Likert scale. Thus, it is not considered in the models either. Each KPI can be aggregated at the level of a single citizen, building, or energy community, providing views from both citizen and stakeholder perspectives.

LEG.01 – LEGAL FRAMEWORK ON ENERGY COMMUNITIES (LFEC)

Description

This KPI measures the citizen and stakeholders' perception of the extent to which EU legislation on energy communities has been transposed to national regulatory frameworks. It also aims to assess the perceived facilitation the regulation provides in the development and operation of RECs project.

Calculation method

The calculation method is through questionnaires:

- To which extent are you aware of the EU legislation regarding energy communities? (1 – not aware at all, 5 – very aware).
- To which extent are you aware of the transposition of the EU legislation to your country legislative framework for energy communities? (1 – not aware at all, 5 – very aware).
- To which extent do you believe that the current legal framework makes it feasible to establish energy community projects in your country? (1 – not feasible at all, 5 – very feasible).

LEG.02 – LEGAL FRAMEWORK ON COLLECTIVE SELF-CONSUMPTION (LFCSC)

Description

This KPI measures the suitability of the EU legislation and its country-level transposition for the development and operation of Collective Self-Consumption projects at RECs level, where multiple members share the benefits of locally generated energy.

Calculation method

The calculation method is through questionnaires:

- To which extent are you aware of the EU legislation regarding collective self-consumption? (1 – not aware at all, 5 – very aware).
- To which extent are you aware of the transposition of the EU legislation to your country legislative framework for collective self-consumption? (1 – not aware at all, 5 – very aware).
- To which extent do you believe that the current legal framework makes it feasible to participate in collective self-consumption initiatives in your country? (1 – not feasible at all, 5 – very feasible).

LEG.03 – LEGAL FRAMEWORK ON LOCAL GRID BALANCING (LFLGB)

Description

This KPI measures the suitability of the EU legislation of local grid balancing technologies and its country-level transposition in the context of RECs projects establishment and operation.

Calculation method

The calculation method is through questionnaires:

- To which extent are you aware of the EU legislation regarding local grid balancing technologies? (1 – not aware at all, 5 – very aware).
- To which extent are you aware of the transposition of the EU legislation to your country legislative framework for local grid balancing technologies? (1 – not aware at all, 5 – very aware).
- To which extent do you believe that the current legal framework makes it feasible to implement local grid balancing technologies in your country in the context of RECs projects? (1 – not feasible at all, 5 – very feasible).

LEG.04 – LEGAL FRAMEWORK ON MICRO-GRIDS (LFMG)

Description

This KPI measures the suitability of the EU legislation and its country-level transposition for micro-grids development in RECs projects. The indicator assesses how well the legal framework supports the development and operation of micro-grids, either independently or in conjunction with the main power grid.

Calculation method

The calculation method is through questionnaires:

- To which extent are you aware of the EU legislation regarding micro-grids? (1 – not aware at all, 5 – very aware).
- To which extent are you aware of the transposition of the EU legislation to your country legislative framework for micro-grids? (1 – not aware at all, 5 – very aware).
- To which extent do you believe that the current legal framework makes it feasible to implement micro grids in your country in the context of RECs projects? (1 – not feasible at all, 5 – very feasible).

LEG.05 – SUITABLE ENERGY STORAGE REGULATION (SESR)

Description

This KPI measures the suitability of the EU legislation and its country-level transposition for the inclusion of energy storage technologies in RECs projects. The indicator assesses how well the legal framework supports the development and operation of micro-grids, either independently or in conjunction with the main power grid.

Calculation method

The calculation method is through questionnaires:

- To which extent are you aware of the EU legislation regarding energy storage in RECs? (1 – not aware at all, 5 – very aware).
- To which extent are you aware of the transposition of the EU legislation to your country legislative framework for energy storage in RECs? (1 – not aware at all, 5 – very aware).
- To which extent do you believe that the current legal framework makes it feasible to implement energy storage systems in your country in the context of RECs projects? (1 – not feasible at all, 5 – very feasible).
- How supportive is the current legal framework in the implementation of energy storage systems in your country in the context of RECs projects? (1 – not supportive at all, 5 – very supportive).

4. Computation open-source modules for RES-based scenario generation and sizing

A set of services to evaluate the operation of an energy community with different configurations and attending to particular citizen and/or community restrictions (technical, social, economic and regulatory restrictions) are developed within WP3. The configurations of the energy communities will encompass five main components: generation, storage, loads, boundary conditions (weather, energy price, etc.) and user profiles.

The services will be created in a modular way, allowing them to be combined to set up different community configurations and scenarios for assessment. The aim of these computation modules is to provide flexible and adaptable tools that can simulate and optimize the performance of renewable energy systems within energy communities. By developing these modules as open source, the modules will enable transparency, collaboration, and continuous improvement by the wider research and developer community.

Three main modules are developed:

1. The electric assets module of INESC TEC: dedicated to electrical assets and will be responsible for the management and optimization of electricity generation, storage, and consumption.
2. The Thermal Assets and DHN Module focuses on sizing of thermal assets (decentralised heating and cooling systems) and District Heating Networks (DHNs). This module is crucial for optimizing the sizing and generation of thermal energy within the community.
3. The KPI module is essential for evaluating the effectiveness and impact of different energy community configurations. It will encompass the KPIs defined in section 3, as well as the integration of other modules from past tools, such as: creation of the baseline, and the RES-based scenario generator (which recommends high-level scenarios for energy communities) from LocalRES Project.

These computation modules are necessary to address the complexity and variability inherent in renewable energy systems. They allow for the detailed simulation of different scenarios, helping communities to understand the potential outcomes of various configurations and operational strategies. By incorporating technical, social, economic, and regulatory restrictions, these modules provide a holistic approach to energy community planning and operation. They enable informed decision-making, ensuring that the adopted solutions are sustainable, efficient, and aligned with the community's goals and constraints.

4.1 Electric assets definitions and sizing

The electric assets sizing module SITEC is for sizing electric resources such as PV panels or battery storage systems for renewable energy communities (REC) as considered in Task 3.2 of the ENPOWER project. This module can work standalone and will be integrated into Planning tool.

In the initial version of SITEC, the main inputs are the expected consumption and generation profiles of the REC members and their opportunity costs, in terms of the integral tariffs for buying or selling electricity from or to the main grid, and the outputs are the new capacity to be installed for electrical assets, the optimal operation of the flexible resources, and the individual and aggregated costs of the community members.

This section describes the initial version of SITEC, the inputs and outputs and the optimisation program that is solved, as well as the ongoing and next developments in the ENPOWER project.

4.1.1 Initial status

4.1.1.1 General description

RECs allow energy sharing among its members, which reduces the energy exchanged between each member and its energy retailer and/or aggregator, and, consequently, results in economic savings for the members and the community. How the energy and savings are shared among the members depends on the business model selected and on the existing regulatory framework. The business model can also include the possibility for other stakeholders to invest and participate in the economic and social benefits obtained by the deployment and operation of the community.

The module for the electric assets sizing solves a Mixed-Integer Linear Problem (MILP) considering the following main inputs:

1. The energy behaviour and existing assets of each potential REC member: consumption profile, existing photovoltaic panels installed and generation profile, existing batteries and their technical parameters, the opportunity costs for buying and selling energy from the main grid, and the grid access tariffs for self-consumption. The time horizon selected for these time series data have two implications. Reduced time periods may not represent properly the uncertainty and variability of the input data, resulting in suboptimal sizing that consider only specific situations. Large time horizons result in larger computational times but provide a better representation of the existing uncertainty and variability. As an alternative, clustering techniques can be applied to reduce the time horizon without compromising in excess the representation of the uncertainty and variability.

2. The constraints that limit the installation of new capacity assets, for example due to financial or physical limitations.

3. The technological characteristics and costs of the assets that will eventually be installed per member and potentially shared by them.

4. The business model selected that determines the objective function (e.g., maximise the self-consumed energy in the community, maximise the overall economic benefits, etc.).

Some of the main results of the optimisation are:

- The size of each individual and shared asset, as well as its optimal operation, in case of dispatchable assets, for the selected period.

- The energy shared among the members (or within the community), which includes compensation information such as the price of the internal energy transactions.

- The energy bill of the REC and its members.

Figure 10 provides an overview of SITEC, the main inputs and expected outputs.

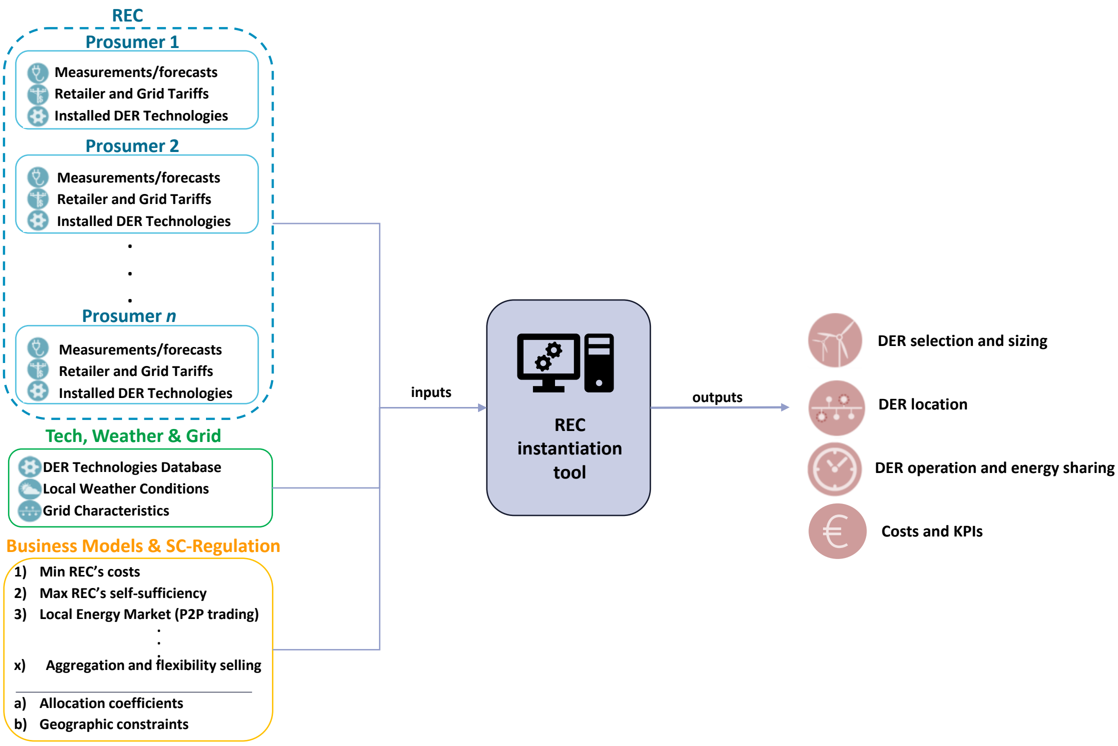


Figure 10. REC sizing tool overview

4.1.1.2 Assumptions

The description of the mathematical formulation of the initial version of SITEC is based on the following assumptions:

- REC has *N* members, called prosumers, who have a consumption profile and can also have PV generation and individual batteries. They can also have initial assets installed, such as PV systems and batteries.
- Consumption profiles of all consumers are available, as well as the production profiles of the PV panels, and the characteristics of the technology of the assets (e.g., pre-installed, the minimum and the maximum capacity to be installed).
- REC members can have different suppliers and aggregators, with different buying and selling tariffs. This is called as members' opportunity costs. These opportunity costs are known.
- In case of the REC generation is higher than REC consumption, the energy surplus can be sold by the members to their aggregators (or retailers). In case the REC generation is lower than its consumption, the energy deficit can be bought by the members from their retailers.
- No grid constraints are considered by this model.
- Electricity demand (consumption) is inelastic (being an input parameter). However, batteries and other flexible loads can provide flexibility and change the net consumption profile measured at the members' smart meters.

- There is a minimum amount of PV power and battery capacity that consumers must install, although these values can be set to 0 or adjusted to the minimum values available on the market.
- There is a maximum amount of PV power and battery capacity that prosumers can install, which may reflect a financial or physical (e.g. roof availability) limitation.
- The final capacity of the assets is equal to the initial capacity plus the new capacity installed as a result of the optimization model, and may depend on the business model selected.
- Economies of scale are not considered in the investment costs as they give rise to a non-linear problem.

4.1.1.3 SITEC flow

The flow of actions SITEC needs to carry out are the followings:

1. **Processing of technology data** – in this first step, the data regarding the technologies (PV and storage) technical and cost-related characteristics are read from a JSON file.
2. **Read inputs from the database** – retrieving the data stored in the database: technology related, as described in the first step, but also other inputs data (see 0 for more info regarding this topic).
3. **Inputs Adjustment** – consists of executing calculations to adjust (e.g., normalization) some inputs so that they present the desired order of magnitude, units, etc.
4. **Model definition** – defining decision variables, creating a MILP instance, and formulating and inserting the required constraints.
5. **Model execution** – saves and solves the proposed model.
6. **Export Results** – saves optimization outputs in optimal formats.

The Figure 11 shows the internal flow of the SITEC module.

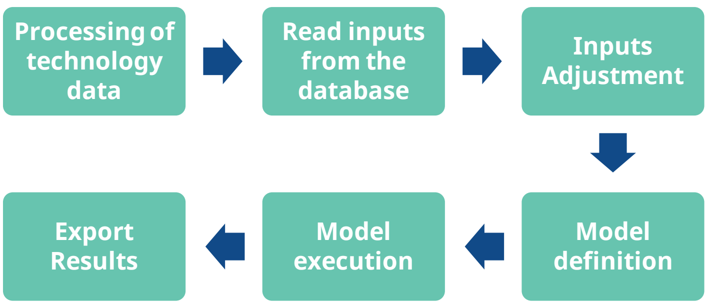


Figure 11. SITEC module flow.

The MILP problem, considering assumptions, variables, inputs, objective function and constraints, comprises the following:

1. An objective function to minimise some calculation (e.g., minimise the sum of the energy exchanged between each member and its retailer);
2. The main constraints:
    a. Energy balances, namely the members' net consumption, their individual exchanges with the grid/retailer as well as the physical and/or market energy exchanges between themselves.
    b. PV constraints, for both individual and shared systems, namely the energy output concerning its installed capacity and the maximum power capacity that can be installed.
    c. Storage constraints for both individual and shared systems, including the maximum energy capacity that can be installed, the maximum and minimum charge and discharge power, the maximum and minimum state-of-charge and one equation that computes the state-of-charge for each period.

4.1.1.4 Input data description

The tables in appendix D show sets and indices, parameters and decision variables of the model. Note that variables refer to magnitudes computed by the optimization model, while parameters are constant inputs that remain unchanged over the optimisation.

The parameters include:

- Costs: prices for supply of energy ($\hat{\lambda}_{n,t}^{buy}$), feed-in tariffs ($\hat{\lambda}_{n,t}^{sell}$), investment
- Energy: Generation profiles, installed capacities, contracted power, etc.

Whereas variables include the energy flows of the different systems.

4.1.1.5 Objective Function

The objective function of SITEC is the minimization of the total REC energy cost including operation and investments costs. The decision variables are the following:

- Energy bought by each prosumer from its retailer ($E_{n,t}^{SUP}$) or sold by each prosumer to its aggregator ($E_{n,t}^{SUR}$); Energy self-consumed by each member ($\boldsymbol{E_{n,t}^{SLC}}$). This can be done for each cluster ($\widehat{w}_{n,t}^{cluster}$)
- Using networks for self-consumed energy coming from the shared PV and storage systems (E_{n}^{BN}), and from trades in the internal markets.
- Contracted power, which has the associated cost of the contracted power tariff and limits the maximum amount of energy exchanged (consumed or injected) by each prosumer at its smart meter.

- Invested capacity for PV panels and batteries. Input investments costs must include financing, installation, operation, replacement and constant maintenance costs. While not yet, at a later stage, assets degradation may be considered in the optimization problem.

SITEC objective function is:

$$min \sum_{n \in N} \left(\sum_{t \in T} \left(\left(E_{n,t}^{SUP} \cdot \hat{\lambda}_{n,t}^{buy} - E_{n,t}^{SUR} \cdot \hat{\lambda}_{n,t}^{sell} + E_{n,t}^{SLC} \cdot \hat{\lambda}_{t}^{grid} \right) \cdot \widehat{w}_{n,t}^{cluster} \right) + P_{n}^{CONT} \cdot \hat{\lambda}_{n}^{cont} \cdot \widehat{D} + P_{n}^{GN} \cdot \hat{\lambda}_{n}^{G,ic} \cdot \widehat{D} + E_{n}^{BN} \cdot \hat{\lambda}_{n}^{B,ic} \cdot \widehat{D} \right) \quad \textbf{Eq. 27}$$

Where the optimization is performed for a time horizon $\widehat{D}$. This OF can be divided into three parts:

Costs of buying and selling energy between the prosumers and their retailers/aggregators, plus the self-consumption cost from the grid access tariffs applied to the energy self-consumed that uses the public:

$$min \sum_{n \in N} \left(\sum_{t \in T} \left(E_{n,t}^{SUP} \cdot \hat{\lambda}_{n,t}^{buy} - E_{n,t}^{SUR} \cdot \hat{\lambda}_{n,t}^{sell} + E_{n,t}^{SLC} \cdot \hat{\lambda}_{t}^{grid} \right) \right) \quad \textbf{Eq. 28}$$

Contracted power costs for the time horizon $\widehat{D}$ under analysis

$$P_{n}^{CONT} \cdot \hat{\lambda}_{n}^{cont} \cdot \widehat{D} \quad \textbf{Eq. 29}$$

Investment costs of the assets (PV and storage systems) that are installed for the time horizon $\widehat{D}$ considered:

$$P_{n}^{GN} \cdot \hat{\lambda}_{n}^{G,ic} \cdot \widehat{D} + E_{n}^{BN} \cdot \hat{\lambda}_{n}^{B,ic} \cdot \widehat{D} \quad \textbf{Eq. 30}$$

4.1.1.6 Model constraints

Model constraints include:

- Objective function
- Consumption constraints: net consumption, for determining self-consumption
- Trades and Equilibrium Constraints: Pool market equilibrium, impede simultaneous buy and sell from retailer, etc.
- Contracted Power Constraints
- Renewable Energy Sources (RES) Constraints in terms of capacity, storage constraints, etc.
- Allocation Coefficients Constraints for self-consumption.

Tables in Appendix D described more in detail these constraints.

4.1.1.7 SITEC outputs

The outputs of SITEC are:

- Total energy cost of the REC.
- Individual cost of the REC members.
- Energy trades among each member and its retailer/aggregator (purchases and sales).
- Energy trades among REC members.
- Net consumption behind-the-meter for each meter (member or facility).
- Self-consumed energy for each meter (member or facility).
- Size of each individual and shared PV system installed.
- Size of each individual storage system and optimal operation for the simulation horizon.
- Internal transactions pool price or bilateral transaction prices.

4.1.1.8 SITEC innovation

The tool demonstrates innovation by facilitating the comprehensive integration of several inputs and functions to enhance the optimisation of a renewable energy community operation and resource sizing. It offers the capability to integrate both shared and individual assets in members who may not yet own them considering their preferences, the possibility to select from a range of business models, and the limited development and practical implementation of such models. These models enable the implementation of a broad range of characteristics that will dictate the community operation (and consequently, its sizing) considering not only members' (i.e., participating self-consumers) but also other stakeholders' preferences, as it is the case, for example, of a small and medium enterprise intending to manage and invest in community assets.

4.1.2 Current status

During the working period corresponding to this first version of the deliverable, the following tasks have been carried out:

- Inputs/outputs collection and provision to CARTIF for the tool integration into CARTIF sizing tools
- Inputs/outputs detailed specification as inputs for the ontology development being developed in T4.2;
- SITEC KPIs identification (section 4.1.6)
- New assets integration into SITEC:
    - Revision of the mathematical model of electric water heaters (EWH) and integration into SITEC optimization (section 4.1.3.1)

- ○ Development of the mathematical model of electric vehicles (EVs) and integration into SITEC optimization (see 4.1.3.2)

- Implementation and testing of the new assets' integration.

4.1.3 New assets integration

4.1.3.1 Thermoelectric water heaters modelling

As current developments for D3.1, SITEC service now includes modelling of thermoelectric water heaters (EHW) totally integrated. All documentation, description, technical reviews, mathematical foundations, and others are directly sourced from this tool's original development project (i.e., Enershare).

Through a very reduced dataset, it is possible to carry out processes of optimization of EWH's functioning calendar. The objective is to estimate periods where it is possible to provide flexibility, by optimizing the operation of the EWH, using only the appliance consumption data as input. For this purpose, only with EWH electrical consumption data, it is possible to determine the periods in which the EWH should start operating, guaranteeing (with some restrictions), comfort levels defined by the consumer, while minimizing the cost of operation or just the total consumption. With the SITEC integration the EWH load is included in the total metered load with disaggregation (i.e., to the main's diagram, the EWH's original load is subtracted, and the optimized load is summed). The mathematical foundation of this EWH optimization model is structured as follows:

Objective Function

$$min \sum_{t}^{T} cost_t^{use} \cdot a_1 + penalty_t^{comf} \cdot a_2 \qquad \textbf{Eq. 31}$$

The objective of this problem is to minimize the operating costs of using hot water, but always wanting to ensure that the comfort threshold is respected. However, as described in constraint (45), a penalty is added that allows the operation, even if this limit is not respected. In this sense, this parameter with a positive sign is adding an additional "cost", due to the use of water below comfort. The values of parameters a_1 and a_2 must be adjusted, according to the importance that the user may give to comfort or price (default as $a_1 = 100, a_2 = 1000$).

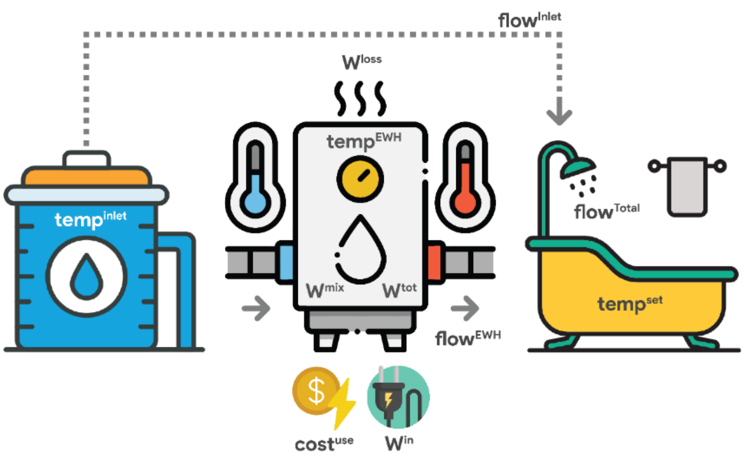


Figure 12. EWH Model Graphical Visualization

Mathematical Adjustments

- **Mixing Fluids**

The final temperature when mixing fluids is given by:

$$t_{out} = \frac{m_1 \cdot c_1 \cdot t_1 + m_2 \cdot c_2 \cdot t_2}{m_1 \cdot c_1 + m_2 \cdot c_2} \qquad \textbf{Eq. 32}$$

- **Temperature to Energy**

The final energy (kWh) is calculated below.

$$w_{out} = \frac{t_{out} \cdot m_{out} \cdot c}{3600} \qquad \textbf{Eq. 33}$$

A. Estimate the total hot water flow rate.

For a single hot water usage ($\widehat{flow}^{Total}$), the final usage temperature ($\widehat{temp}^{set}$) is given by the mixture of both EWH hot water flow ($flow_t^{EWH}$) at the current EWH temperature ($temp_t^{EWH}$) and Inlet flow ($flow_t^{Inlet}$) at the respective temperature ($\widehat{temp}^{inlet}$).

The objective is to estimate the necessary EWH flow rate that, at the current EWH temperature, should be mixed with inlet water. The inlet water flow should represent the difference between the usage total flow rate and the estimated EWH flow rate.

Assuming,

$$flow_t^{inlet} = \widehat{flow}^{Total} - flow_t^{EWH} \qquad \textbf{Eq. 34}$$

$$c^{EWH} = c^{inlet} = \hat{c} \qquad \textbf{Eq. 35}$$

Using the mixing fluid expression, gives:

$$\widehat{temp}^{set} = \frac{flow_t^{EWH} \cdot \hat{c} \cdot temp_t^{EWH} + \left(\widehat{flow}^{Total} - flow_t^{EWH}\right) \cdot \hat{c} \cdot \widehat{temp}^{inlet}}{flow_t^{EWH} \cdot \hat{c} + \left(\widehat{flow}^{Total} - flow_t^{inlet}\right) \cdot \hat{c}} \qquad \textbf{Eq. 36}$$

Solving to $flow_t^{EWH}$:

$$flow_t^{EWH} = \widehat{flow}^{Total} \frac{\widehat{temp}^{set} - \widehat{temp}^{inlet}}{temp_t^{EWH} - \widehat{temp}^{inlet}} \qquad \textbf{Eq. 37}$$

B. Estimate the EWH internal temperature after usage.

After a single hot water usage, the final EWH internal temperature ($temp_t^{mix}$) can be estimated using the fluid mixture expression. In this scenario, the final water mixture should address the remainder of the hot water inside the EWH after the usage ($\widehat{EWH}^{cap} - flow_t^{EWH}$) at the current temperature ($temp_{EWH}$) being mixed with the necessary inlet water to fill the amount that was used ($flow_t^{EWH}$) at inlet temperature ($\widehat{temp}^{inlet}$). Using the mixing fluid expression, gives:

$$temp_t^{mix} = \frac{\left(\widehat{EWH}^{cap} - flow_t^{EWH}\right) \cdot c \cdot temp_t^{EWH} + flow_t^{EWH} \cdot c \cdot \widehat{temp}^{inlet}}{\left(\widehat{EWH}^{cap} - flow_t^{EWH}\right) \cdot c + flow_t^{EWH} \cdot c} \quad \textbf{Eq. 38}$$

Simplifying:

$$temp_t^{mix} = \frac{\left(\widehat{EWH}^{cap} - flow_t^{EWH}\right) \cdot temp_t^{EWH} + flow_t^{EWH} \cdot \widehat{temp}^{inlet}}{\widehat{EWH}^{cap}} \quad \textbf{Eq. 39}$$

C. Estimating the total stored energy after a hot water usage

After estimating an expression to find the final temperature of the water inside the EWH after a single hot water usage, the $flow_{EWH}$ value can be replaced by the expression found in (A), thus resulting in an expression that relies only on the internal EWH temperature to estimate the total stored energy after a single hot water usage. By using the expression that allows converting temperature to stored energy, the amount of stored energy (kWh), after a hot water usage, is given by:

$$W_t^{mix} = \frac{temp_t^{mix} \cdot \widehat{EWH}^{cap} \cdot \hat{c}}{3600} \quad \textbf{Eq. 40}$$

Replacing the $temp_t^{mix}$ with the respective expression gives:

$$W_t^{mix} = \frac{\left(\frac{\left(\widehat{EWH}^{cap} - flow_t^{EWH}\right) \cdot temp_t^{EWH} + flow_t^{EWH} \cdot \widehat{temp}^{inlet}}{\widehat{EWH}^{cap}}\right) \cdot \widehat{EWH}^{cap} \cdot \hat{c}}{3600} \quad \textbf{Eq. 41}$$

That simplifies to:

$$W_t^{mix} = \frac{\left(\left(\widehat{EWH}^{cap} - flow_t^{EWH}\right) \cdot temp_t^{EWH} + flow_t^{EWH} \cdot \widehat{temp}^{inlet}\right) \cdot \hat{c}}{3600} \quad \textbf{Eq. 42}$$

Replacing $flow_t^{EWH}$ with the expression found in (A), when $temp_t^{EWH} \geq \widehat{temp}^{set}$:

$$W_t^{mix \mid temp_t^{EWH} \geq \widehat{temp}^{set}} = \frac{\left(\left(\widehat{EWH}^{cap} - \widehat{flow}^{Total} \frac{\widehat{temp}^{set} - \widehat{temp}^{inlet}}{temp_t^{EWH} - \widehat{temp}^{inlet}} \right) \cdot temp_t^{EWH} + \widehat{flow}^{Total} \frac{\widehat{temp}^{set} - \widehat{temp}^{inlet}}{temp_t^{EWH} - \widehat{temp}^{inlet}} \cdot \widehat{temp}^{inlet} \right) \cdot \hat{c}}{3600} \quad \textbf{Eq. 43}$$

However, when $temp_t^{EWH} < \widehat{temp}^{set}$, the EWH flow rate must be equal to the total flow rate, guaranteeing that the output temperature is actual temperature inside of the EWH, and hence:

$$W_t^{mix \mid temp_t^{EWH} < \widehat{temp}^{set}} = \frac{\left(\left(\widehat{EWH}^{cap} - \widehat{flow}^{Total} \right) \cdot temp_t^{EWH} + \widehat{flow}^{Total} \cdot \widehat{temp}^{inlet} \right) \cdot \hat{c}}{3600} \quad \textbf{Eq. 44}$$

D. Use-case Scenario & Linearization

Having described the two expressions, the next step involves the creation of two linear expressions, for each of the time intervals described above. To do so, all non-repeating $temp_{Inlet}$ input values are used, individually paired with $temp_t^{EWH}$ and δ_t^{use} values from each of the intervals and for each of the expressions. For example, for a single observation where $\widehat{temp}^{inlet} = 15°C$, assuming $\widehat{temp}^{set} = 40°C$, and $\widehat{temp}^{Max|EWH} = 80°C$, 41 final W_t^{mix}values are calculated (with $temp_t^{EWH}$values from 40 up to and including 80, and for every possible δ^{use}, dependent on selected resolution). This procedure is repeated for each non-repeated $temp_{Inlet}$value, for each of the expressions, with the respective ranges of $temp_t^{EWH}$ values). The range of possible δ_t^{use} values depend on the used sampling rate. For the original 1-minute resolution, there is only one possible value ($\delta^{use} = 1$), while for the 15-min resampled resolution, there are 15 different values that should cover all adjustment possibilities (i.e., $\frac{1}{15}, \frac{2}{15}, \ldots, \frac{15}{15}$).

EWH^{cap}	$temp^{inlet}$	$temp^{EWH}$	δ^{use}	$temp^{set}$	$flow^{Total}$	$flow^{EWH}$	W^{out}	$temp^{EWH}$	W^{mix}
100	20	20	1	40	8.5	8.500	0.198	20.0	**2.326**
100	20	21	1	40	8.5	8.500	0.208	20.9	**2.432**
100	20	22	1	40	8.5	8.500	0.217	21.8	**2.538**
100	20	23	1	40	8.5	8.500	0.227	22.7	**2.645**
...	...	...	...	...	...	...	...	...	**...**
100	20	37	1	40	8.5	8.500	0.366	35.6	**4.134**
100	20	38	1	40	8.5	8.500	0.376	36.5	**4.241**
100	20	39	1	40	8.5	8.500	0.385	37.4	**4.347**
100	20	40	1	40	8.5	8.500	0.395	38.3	**4.453**
100	20	40	1	40	8.5	8.500	0.395	38.3	**4.453**
100	20	41	1	40	8.5	8.095	0.386	39.3	**4.570**
100	20	42	1	40	8.5	7.727	0.377	40.3	**4.686**
100	20	43	1	40	8.5	7.391	0.370	41.3	**4.802**
...	...	...	...	...	...	...	...	...	**...**
100	20	77	1	40	8.5	2.982	0.267	75.3	**8.756**
100	20	78	1	40	8.5	2.931	0.266	76.3	**8.872**
100	20	79	1	40	8.5	2.881	0.265	77.3	**8.988**
100	20	80	1	40	8.5	2.833	0.264	78.3	**9.105**

Figure 13. Auxiliary dataset for calculating Wmix, for the two tempEWH levels.

Once this auxiliary dataset is created (see Figure 13), trend curves must be created for each of the levels (see Figure 14). The expressions of these trend curves will be those associated with the restriction that allows calculating the stored energy value after using hot water. In this way, the three linear parameters ($m_{\delta^{use}}, m_{temp^{EWH}}$, and b) are calculated for each of the levels. In this specific scenario, since it refers to the original 1-min resolution, δ^{use} has no weight on the regression. Furthermore, since $\widehat{temp}^{inlet}$ is constant, the m parameter is very close. Ultimately, the regressor strategy is fully prepared to deal with different values from both δ^{use} and $\widehat{temp}^{inlet}$.

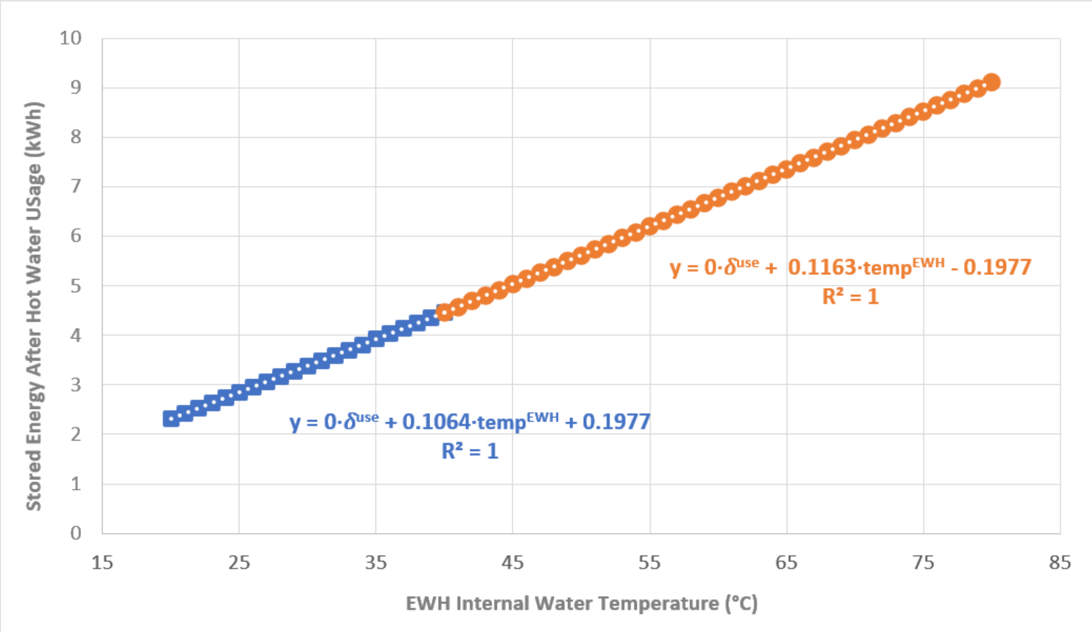


Figure 14. Example trendlines for the two EWH water temperature scenarios.

With the new values of the parameters ($m_{\delta^{use}}^{aboveSet}, m_{temp^{EWH}}^{aboveSet}, b^{aboveSet}, m_{\delta^{use}}^{belowSet}, m_{temp^{EWH}}^{belowSet}, b^{belowSet}$), it is possible to write the final restriction that allows to obtain the stored energy after a single use of hot water ($\hat{\delta}_t^{use} > 0$):

$$If\ \hat{\delta}_t^{use} > 0:$$

$$If\ temp_t^{EWH} < \widehat{temp}^{set}$$

$$W_t^{mix} = m_{\delta^{use}}^{belowSet} \cdot \hat{\delta}_t^{use} + m_{temp^{EWH}}^{belowSet} \cdot temp_t^{EWH} + b^{belowSet} \qquad \textbf{Eq. 45}$$

$$If\ temp_t^{EWH} \geq \widehat{temp}^{set}$$

$$W_t^{mix} = m_{\delta^{use}}^{aboveSet} \cdot \hat{\delta}_t^{use} + m_{temp^{EWH}}^{aboveSet} \cdot temp_t^{EWH} + b^{aboveSet}$$

When there is no hot water usage ($\hat{\delta}_t^{use} = 0$), the constraint is direct, and it uses an equivalent temperature to energy conversion using:

$$If\ \hat{\delta}_t^{use} = 0:$$

$$W_t^{mix} = temp_t^{EWH} \cdot \widehat{EWH}^{cap} \cdot \frac{\hat{c}}{3600} \cdot \Delta t \cdot 60 \qquad \textbf{Eq. 46}$$

<u>**Conditional Constraint**</u>

As shown in (*D*), the formulation results in a set of conditional constraints. In this type of problem, if the condition is based on an input variable, where it is possible, a priori, to verify its value, it is possible to program the conditional restriction. If the condition is imposed by a decision variable, it is not possible to program the restriction, since, internally, the restrictions, for all instants of time, are written in a file. In this sense, as the conditional variable has not yet been assigned a value, it is not possible to implement it in a conditional constraint. In this problem, two degrees of condition are considered: the first one, based on the input variable $\hat{\delta}_t^{use}$, can be introduced directly in the formulation. However, the second condition is based on the $temp_t^{EWH}$ variable, which, being a decision variable, prevents the implementation from being straightforward. In this sense, for this second part, it is necessary to transform the conditional constraint, through the introduction of sufficiently wide tolerance intervals. Through the formulations indicated in [32], the restrictions formulated in (*D*) are then transformed into:

$$If\ \hat{\delta}_t^{use} = 1:$$

$$\begin{gathered}
temp_t^{EWH} \geq \widehat{temp}^{set} - \widehat{M} \cdot (1 - \delta_t^{aux}) \\
temp_t^{EWH} \leq \widehat{temp}^{set} + \widehat{M} \cdot \delta_t^{aux} \\
W_t^{mix} \geq \left(m_{\delta^{use}}^{belowSet} \cdot \hat{\delta}_t^{use} + m_{temp^{EWH}}^{belowSet} \cdot temp_t^{EWH} + b^{belowSet} \right) - \widehat{M} \cdot \delta_t^{aux} \\
W_t^{mix} \leq \left(m_{\delta^{use}}^{belowSet} \cdot \hat{\delta}_t^{use} + m_{temp^{EWH}}^{belowSet} \cdot temp_t^{EWH} + b^{belowSet} \right) + \widehat{M} \cdot \delta_t^{aux} \\
W_t^{mix} \geq \left(m_{\delta^{use}}^{aboveSet} \cdot \hat{\delta}_t^{use} + m_{temp^{EWH}}^{aboveSet} \cdot temp_t^{EWH} + b^{aboveSet} \right) - \widehat{M} \cdot (1 - \delta_t^{aux}) \\
W_t^{mix} \leq \left(m_{\delta^{use}}^{aboveSet} \cdot \hat{\delta}_t^{use} + m_{temp^{EWH}}^{aboveSet} \cdot temp_t^{EWH} + b^{aboveSet} \right) + \widehat{M} \cdot (1 - \delta_t^{aux})
\end{gathered} \qquad \textbf{Eq. 47}$$

$$If\ \hat{\delta}_t^{use} = 0:$$

$$W_t^{mix} = temp_t^{EWH} \cdot \widehat{EWH}^{cap} \cdot \frac{\hat{c}}{3600} \cdot \Delta t \cdot 60 \qquad \textbf{Eq. 48}$$

E. Comfort

Since it is already possible to calculate the volume of energy stored after using hot water, the aim is now to ensure that the comfort temperature is respected. To this end, a restriction is added that indicates that, at the beginning of the period following the use of water, the stored energy of the water in the EWH is at least equal to the energy associated with the comfort temperature. In this sense, the energy value associated with the comfort temperature is calculated using the temperature to energy expression, as follows:

$$W_{confort} = \frac{\widehat{temp}^{set} \cdot \widehat{EWH}^{cap} \cdot \hat{c}}{3600} \cdot \Delta t \cdot 60 \quad \textbf{Eq. 49}$$

There is also the need to use an auxiliary variable that allows the model to operate below the comfort threshold, but adding a penalty operating cost, which in turn is added to the objective function with a positive term. Hence, the final constraint:

$$If\ \delta_{usage}[t] - \delta_{usage}[t-1] < 0$$
$$W_{t-1}^{tot} \geq W_{confort} - penalty_t^{comf} \quad \textbf{Eq. 50}$$

Electric vehicles modelling

The following tables describe the new indices and sets, parameters and variables needed for the new version of SITEC.

Table 7 shows new indices and sets required for this optimisation problem.

Table 7: New indices and sets.

Indices/sets	Descriptions	Units
ev ∈ EV	Set of EVs within each meter.	-

Table 8 shows new indices and sets required for this optimisation problem.

Table 8: New parameters.

Parameters	Descriptions	Units
$\hat{E}_{n,ev,t}^{Trip}$	Vehicle ev at CPE n energy consumption in period t.	kWh
$\hat{E}_{n,ev}^{EV,MinCharge}$	Minimum stored energy to be guaranteed for vehicle ev at CPE n.	kWh
$\hat{E}_{n,ev}^{EV,BatCapacity}$	The battery energy capacity of vehicle ev at CPE n.	kWh
$\hat{\eta}_{n,ev}^{EV,C}$	Charging efficiency of vehicle ev at CPE n.	%
$\hat{\eta}_{n,ev}^{EV,D}$	Discharging efficiency of vehicle ev at CPE n.	%
$\hat{P}_{n,ev}^{EV,ChargeLimit}$	Maximum power charge of vehicle ev at CPE n.	kW
$\hat{P}_{n,ev}^{EV,DischargeLimit}$	Maximum power discharge of vehicle ev at CPE n.	kW
$\hat{X}_{n,ev,t}^{EV}$	Whether a vehicle ev at CPE n is plugged-in or not (if plugged-in = 1 else = 0).	-
$P_{n,ev,t}^{EV,Discharge}$	Power discharge of vehicle ev at CPE n in period t.	kW
Δt	Length of time intervals	h
$\widehat{EWH}^{power}$	Heating power of the EWH	kW
$\widehat{EWH}^{height}$	Height of the EWH	cm
$\widehat{EWH}^{cap}$	Internal water capacity of the EWH	l
$\widehat{EWH}^{max}$	Maximum allowable water temperature of the EWH	°C
$\widehat{EWH}^{min}$	Minimum allowable water temperature of the EWH	°C
$\hat{c}$	Specific heat capacity of water (4.18 J/g°C)	J/g°C
$\widehat{HC}$	Overall heat transfer coefficient of the EWH	kW/(m^{2}K)
$\widehat{temp}^{set}$	User-defined comfort temperature for hot water usage	°C

$\widehat{temp}^{amb}$	EWH room ambient temperature	°C
$\widehat{M}$	Sufficiently big number (e.g., 1E3 if EWH's nominal capacity is in the tens of kWh)	-
$\widehat{flowrate}$	Water usage flow rate (fixed/constant value).	kg/min
$\widehat{tariff}$	Selection between energy price tariffs between simple (1) or bi-hourly (2), etc.	-
$\hat{\delta}_t^{use}$	Boolean parameter indicating periods of hot water usage (1 = using)	-

Table 9 shows new variables required for this optimisation problem.

Table 9. New variables.

Variables	Descriptions	Units
$E_{n,ev,t}^{EV,Stored}$	Energy stored in vehicle ev at CPE n at the end of period t	kWh
$P_{n,ev,t}^{EV,Charge}$	Power charge of vehicle ev at CPE n in period t	kW
$P_{n,ev,t}^{EV,Discharge}$	Power discharge of vehicle ev at CPE n in period t.	kW
$\widehat{EWH}^{StartTemp}$	EWH internal water temperature at the beginning	°C
$\widehat{EWH}^{area}$	EWH Surface Area	m²
W^{init}	Total energy balance of the EWH at the beginning	kWh
W^{max}	Maximum energy balance of the EWH	kWh
W^{min}	Minimum energy balance of the EWH	kWh
$m_{\delta^{use}}^{belowSet}$	Auxiliary m linearization parameter from *belowSet* regressor for usage	-
$m_{temp^{EWH}}^{belowSet}$	Auxiliary b linearization parameter from *belowSet* regressor for temperature	-
$b^{belowSet}$	Auxiliary b linearization parameter from *belowSet* regressor	
$m_{\delta^{use}}^{aboveSet}$	Auxiliary m linearization parameter from *aboveSet* regressor for usage	-
$m_{temp^{EWH}}^{aboveSet}$	Auxiliary m linearization parameter from *aboveSet* regressor for temperature	
$b^{aboveSet}$	Auxiliary b linearization parameter from *aboveSet* regressor	-
$temp_t^{EWH}$	Temperature of water at EWH outlet at the beginning of time interval t	°C
W_t^{tot}	Total energy balance of prosumer's EWH at time interval t	kWh
W_t^{in}	Energy into the prosumer's EWH at time interval t	kWh
W_t^{loss}	Thermal energy losses at time interval t	kWh
W_t^{mix}	Thermal energy stored in the EWH after usage and mixing with inlet water at time interval t	kWh
δ_t^{in}	Variable for EWH operation status, [0,1], (1 = ON, 0 = OFF, for the full period)	-
δ_t^{aux}	Boolean variable for if-else in constraint (7) at time interval t	-
$penalty_t^{comf}$	Penalty cost associated with water temperature reaching below comfort at time interval t	-
$cost_t^{use}$	Total period cost of that specific energy usage at time interval t	€
$price_t^{net}$	Network pricing of energy usage at time interval t	€
$tariff^{m}$	Energy daily tariff for each m price sets	€

Table 10 shows the constraints under this REC sizing optimization problem.

Table 10. New constraints.

Constraints	Sets	Identifications
$E_{n,t}^{CMET} = \hat{E}_{n,t}^{C} - E_{n,t}^{G} + E_{n,t}^{B,C} - E_{n,t}^{B,D} + \sum_{ev \in EV} \left(P_{n,ev,t}^{EV,Charge} - P_{n,ev,t}^{EV,Discharge}\right)$	$\forall\, t \in T, n \in N$	(2)

$E^{G}_{n,t}, E^{B,C}_{n,t}, E^{B,D}_{n,t}, E^{EV,Stored}_{n,ev,t}, P^{EV,Charge}_{n,ev,t}, P^{EV,Disharge}_{n,ev,t}, E^{SUP}_{n,t}, E^{SUR}_{n,t}, E^{PUR}_{n,t}, E^{SALE}_{n,t}, E$ $P^{GN}_{n}, P^{GN,total}_{n}, E^{BN}_{n}, E^{BN,total}_{n}, E^{B}_{n,t}, E^{B,init}_{n}, E^{CMET,+}_{n,t}, E^{ALC+}_{n,t} \geq 0$	$\forall\, t \in T, n \in N$	(34)
$E^{EV,Stored}_{n,ev,t} = E^{EV,Stored}_{n,ev,t-1} + \hat{\eta}^{EV,C}_{n,ev} \cdot P^{EV,Charge}_{n,ev,t} - \frac{1}{\hat{\eta}^{EV,D}_{n,ev}} P^{EV,Discharge}_{n,ev,t} - \hat{E}^{Trip}_{n,ev,t}$	$\forall t \in T \setminus t = 1;\ \forall ev \in EV;$	(35)
$\frac{1}{\hat{\eta}^{EV,D}_{n,ev}} P^{EV,Discharge}_{n,ev,t} \leq \hat{P}^{EV,DischargeLimit}_{n,ev} \cdot \hat{X}^{EV}_{n,ev,t} \cdot \triangle t$	$\forall t \in T;\ \forall ev \in EV; \hat{X}^{EV}_{n,t} \in \{0,1\}$	(36)
$\hat{\eta}^{EV,C}_{n,ev} \cdot P^{EV,Charge}_{n,ev,t} \leq \hat{P}^{EV,ChargeLimit}_{n,ev} \cdot \hat{X}^{EV}_{n,ev,t} \cdot \triangle t$	$\forall t \in T; \forall ev \in EV;$ $\hat{X}^{EV}_{n,t} \in \{0,1\}$	(37)
$E^{EV,Stored}_{n,ev,t} \leq \hat{E}^{EV,BatCapacity}_{n,ev}$	$\forall t \in T;\ \forall ev \in EV;$	(38)
$E^{EV,Stored}_{n,ev,t} \geq \hat{E}^{EV,MinCharge}_{n,ev}$	$\forall t \in T;\ \forall ev \in EV;$	(39)
$\begin{cases} W^{tot}_{t} = W^{init}, t = 0 \\ W^{tot}_{t} = W^{water}_{t-1} + W^{in}_{t-1} + W^{loss}_{t-1}, t > 0 \end{cases}$		(40)
$W^{in}_{t} = \widehat{EWH}^{power} \cdot \Delta t \cdot \delta^{in}_{t} \cdot (\Delta t \cdot 60)$	$\forall\, t \in T$	(41)
$cost^{use}_{t} = \delta^{in}_{t} \cdot \widehat{EWH}^{power} \cdot \Delta t \cdot price^{use}_{t} + tariff^{m} \cdot \frac{\Delta t}{24}$	$\forall\, t \in T$	(42)
$\begin{cases} temp^{EWH}_{t} = \widehat{EWH}^{StartTemp}, t = 0 \\ temp^{EWH}_{t} = \frac{W^{tot}_{t} \cdot 3600}{\widehat{EWH}^{cap} \cdot \hat{c}}, t > 0 \end{cases}$		(43)
$W^{loss}_{t} = \widehat{EWH}^{height} \cdot \widehat{EWH}^{area} \cdot \Delta t \cdot \left(temp^{EWH}_{t} - \widehat{temp}^{amb}\right) \cdot (\Delta t \cdot 60)$	$\forall\, t \in T$	(44)
$\begin{cases} W^{min}_{t} \leq W^{tot}_{t} \\ W^{tot}_{t} \leq W^{max}_{t} \\ \widehat{EWH}^{min} \leq temp^{EWH}_{t} \\ temp^{EWH}_{t} \leq \widehat{EWH}^{\max} \end{cases}$	$\forall\, t \in T$	(45)
$\begin{cases} W^{tot}_{t} \geq \widehat{temp}^{set} \cdot \widehat{EWH}^{cap} \cdot \frac{\hat{c}}{3600} \cdot (\Delta t \cdot 60) - penalty^{comf}_{t} \\ W^{tot}_{t-1} \geq \widehat{temp}^{set} \cdot \widehat{EWH}^{cap} \cdot \frac{\hat{c}}{3600} \cdot (\Delta t \cdot 60) - penalty^{comf}_{t-1} \end{cases}$	$\hat{\delta}^{use}_{t} = 1$, *or*: $\begin{cases} \hat{\delta}^{use}_{t} - \hat{\delta}^{use}_{t-1} \neq 0 \\ \hat{\delta}^{use}_{t} - \hat{\delta}^{use}_{t-1} = -\hat{\delta}^{us}_{t-} \end{cases}$	(46)
$\begin{cases} temp^{EWH}_{t} \geq \widehat{temp}^{set} - \hat{M} \cdot (1 - \delta^{aux}_{t}) \\ temp^{EWH}_{t} \leq \widehat{temp}^{set} + \hat{M} \cdot \delta^{aux}_{t} \\ W^{mix}_{t} \geq \left(m^{belowSet}_{\delta^{use}} \cdot \hat{\delta}^{use}_{t} + m^{belowSet}_{temp^{EWH}} \cdot temp^{EWH}_{t} + b^{belowSet}\right) - \hat{M} \cdot \delta_{i} \\ W^{mix}_{t} \leq \left(m^{belowSet}_{\delta^{use}} \cdot \hat{\delta}^{use}_{t} + m^{belowSet}_{temp^{EWH}} \cdot temp^{EWH}_{t} + b^{belowSet}\right) + \hat{M} \cdot \delta_{i} \\ W^{mix}_{t} \geq \left(m^{aboveSet}_{\delta^{use}} \cdot \hat{\delta}^{use}_{t} + m^{aboveSet}_{temp^{EWH}} \cdot temp^{EWH}_{t} + b^{aboveSet}\right) - \hat{M} \cdot (1 - \\ W^{mix}_{t} \leq \left(m^{aboveSet}_{\delta^{use}} \cdot \hat{\delta}^{use}_{t} + m^{aboveSet}_{temp^{EWH}} \cdot temp^{EWH}_{t} + b^{aboveSet}\right) + \hat{M} \cdot (1 - \\ W^{mix}_{t} = temp^{EWH}_{t} \cdot \widehat{EWH}^{cap} \cdot \frac{\hat{c}}{3600} \cdot \Delta t \cdot 60 \end{cases}$	$\hat{\delta}^{use}_{t} > 0$ $\hat{\delta}^{use}_{t} > 0$ $\hat{\delta}^{use}_{t} > 0$ $\hat{\delta}^{use}_{t} > 0$ $\hat{\delta}^{use}_{t} > 0$ $\hat{\delta}^{use}_{t} > 0$ $\hat{\delta}^{use}_{t} > 0$ $\hat{\delta}^{use}_{t} = 0$	(47)

Table 11 describes the above constraints.

Table 11. Descriptions of new constraints.

Constraints	Descriptions
(2)	Net consumption constraint
(34)	Constraint for signalling when the meter has deficit
(35)	Battery balance for each vehicle. The energy consumption for period travel has to be considered jointly with the energy remaining from the previous period and the charge/discharge in the period
(36)	Discharge limit for each vehicle considering the battery discharge rate
(37)	Charge limit for each vehicle considering the battery charge rate
(38)	Battery capacity limit for each vehicle
(39)	Minimum stored energy to be guaranteed at the end of each period
(40)	represents the total energy stored within the EWH in each period. For the first instant, it is equal to the value stipulated as initial (or equal to energy associated with the tank

	filled with water at inlet temperature). For the remaining periods, it depends on the total energy resulting from mixing water (46), the energy gain from heating (41), and the energy thermal losses (44).
(41)	represents additional energy introduced by the heating element of the EWH. It depends on the power of the element, the length of the time period and if the EWH is operational.
(42)	represents the total cost of operating the EWH, depending on the energy cost, the selected daily tariff, the power of the element, the length of the time period and if the EWH is operational or not.
(43)	represents the temperature value of the internal water of the EWH. For the initial instant, it is equivalent to the established input, while for the following instants, it establishes a conversion to equivalent temperature through the value of the accumulated energy (40)
(44)	represents the total thermal losses of the EWH through its surface, depending on the length of the time period.
(45)	mandates adherence to prescribed upper and lower limits for both temperature and energy, requiring precise management to sustain system stability within defined boundaries.
(46)	represents the need for the internal water temperature of the EWH after use to be equal to or greater than the threshold defined by the user. It uses an auxiliary variable that allows the model to operate below the comfort threshold, but adds a penalty operating cost, which in turn is added to the objective function with a positive term.
(47)	Definition of the variable that represents the accumulated energy after using hot water, and after internal mixing with inlet water. As it is a conditional (if-else) and non-linear constraint, its formulation is built in such a way that it is programmable. Please refer to the Mathematical Adjustments section for a detailed description.

Input data description

SITEC inputs are shown in the Table 12, organised into eight categories: simulation, REC, Information provided by the retailer for each prosumer, Prosumer, Storage technologies specifications, PV technologies specifications, EV and Thermal Resources (EWH).

Table 12. Input data description.

Description	System	Units	Variable Types	Format Types
Total time horizon of the simulation (service parameters)	Simulation	days	Integer	JSON
Duration of each timestep	Simulation	hours	integer	JSON
ID of each installation	REC	-	string	JSON
Power limit for transactions at the Point of Common Coupling	REC	kW	float	JSON
Buy and sell energy tariffs (input data)	Information provided by the retailer for each prosumer	€/kWh	time series(float)	JSON

Contracted power tariff	Information provided by the retailer for each prosumer	€/(kW.day)	float	JSON
Voltage level	Information provided by the retailer for each prosumer	-	string	JSON
Energy consumption diagram (for each time step)	Prosumer	kWh	time series(float)	JSON
Maximum and minimum state-of-charge	Storage technologies specifications	%	float	Sourced from CSV/Excel file. Stored in a DB
Maximum charge and discharge power (inverter)	Storage technologies specifications	kW	float	Sourced from CSV/Excel file. Stored in a DB
Charge and discharge efficiency	Storage technologies specifications	%	float	Sourced from CSV/Excel file. Stored in a DB
lifespan	Storage technologies specifications	years	float	Sourced from CSV/Excel file. Stored in a DB
investment costs	Storage technologies specifications	€/kWh	float	Sourced from CSV/Excel file. Stored in a DB
efficiency	PV technologies specifications	%	float	Sourced from CSV/Excel file. Stored in a DB
yearly degradation	PV technologies specifications	%	float	Sourced from CSV/Excel file. Stored in a DB
generation profile	PV technologies specifications	$kWh/kW_{installed}$	float	Sourced from CSV/Excel file. Stored in a DB
lifespan	PV technologies specifications	years	float	Sourced from CSV/Excel file. Stored in a DB
investment costs	PV technologies specifications	€/kW	float	Sourced from CSV/Excel file. Stored in a DB
members' ownership	PV technologies specifications	%/member	float	Sourced from CSV/Excel file. Stored in a DB

pre-installed, maximum and minimum storage to be installed	Storage technologies specifications	kWh	float	JSON
pre-installed, maximum and minimum PV to be installed	PV technologies specifications	kW	float	JSON
Grid access tariffs (provided by DSO)	REC	€/kWh	time series(float)	JSON
EV energy trip profile	EV	kWh	time series(float)	Sourced from CSV/Excel file. Stored in a DB
EV plugged or not	EV	-	bool	Sourced from CSV/Excel file. Stored in a DB
Minimum charge before unplugging	EV	kWh	float	Sourced from CSV/Excel file. Stored in a DB
EV battery capacity	EV	kWh	float	Sourced from CSV/Excel file. Stored in a DB
Charge and discharge EV efficiency	EV	%	float	Sourced from CSV/Excel file. Stored in a DB
Maximum charge and discharge EV power	EV	kW	float	Sourced from CSV/Excel file. Stored in a DB
Ownership Member - Resource	REC	%	Float matrix	Sourced from CSV/Excel file. Stored in a DB
EWH Consumption Diagram (1-min resolution)	Thermal Resources (EWH)	W	time series (float)	JSON
Hot-Water Usage Calendar (1-min resolution)	Thermal Resources (EWH)	-	time series (bool)	JSON
EWH Functioning Power	Thermal Resources (EWH)	W	integer	JSON
EWH Capacity	Thermal Resources (EWH)	l	integer	JSON

EWH Maximum Allowed Internal Water Temperature	Thermal Resources (EWH)	°C	integer	JSON
EWH Overall Heat Transfer Coefficient	Thermal Resources (EWH)	$W/(m^2 \cdot K)$	float	JSON
User-defined Hot-Water Usage Comfort Temperature	Thermal Resources (EWH)	°C	integer	JSON

4.1.4 Output data description

The outputs are described in the Table 13. It is important to note that all outputs are presented in JSON format. Their characteristics are divided according to the system, units and variable types.

Table 13. Output data description.

Descriptions	Systems	Units	Variable Types	Format Types
REC energy cost	REC	€	float	JSON
Batteries initial energy content	Storage	kWh	list(float)	JSON
Batteries energy content	Storage	kWh	list of time series(float)	JSON
Batteries charged and discharged energy	Storage	kWh	list of time series(float)	JSON
Net consumption behind-the-meter	REC/Members	kWh	list of time series(float)	JSON
PV generation	PV	kWh	list of time series(float)	JSON
Imported and exported energy from the retailer	REC/Members	kWh	list of time series(float)	JSON
To be installed PV power	PV	kW	list(float)	JSON
To be installed Battery capacity	Storage	kWh	list(float)	JSON
Contracted power (maximum metered power flow)	REC/Members	kW	list(float)	JSON
Total Installed PV power	PV	kW	list(float)	JSON
Total Installed Battery capacity	Storage	kWh	list(float)	JSON
Allocated generation from shared PV	PV	kWh	list of time series(float)	JSON
Self-consumption energy	REC/Members	kWh	list of time series(float)	JSON

Energy consumed from the community	REC/Members	kWh	list of time series(float)	JSON
Energy purchased from the community	REC/Members	kWh	list of time series(float)	JSON
Energy sold to the community	REC/Members	kWh	list of time series(float)	JSON
Pool price of the community or price of the bilateral transaction (dependent on the business model)	REC/Members	€/kWh	time series(float) or list of time series(float)	JSON
EVs charged and discharged energy	EVs	kWh	list of time series(float)	JSON
EVs energy content	EVs	kWh	list of time series(float)	JSON
EWH Optimized Functioning Calendar	Thermal Resources (EWH)	-	List of time series Bool	JSON
EWH Optimized Consumption Diagram	Thermal Resources (EWH)	W	List of time series Float	JSON

4.1.5 KPIs

KPIs are established by comparing outputs to benchmarks set from other scenarios, which may involve changing specific characteristics, such as those tested in a pilot study. Indeed, benchmarks may depend on each use case or pilot and must be defined accordingly. For example, in some cases, the benchmark could be an individual self-consumption compared with a collective self-consumption.

In the case of the sizing tool, optimal sizing must be part of the solution applied, so the KPI should assess the benefit of optimal resource sizing. KPIs such as Net Present Value, capture prices, are included besides the ones included in section 3.5.

4.1.6 Illustrative example

4.1.7.1 Case characterisation

This illustrative example features a simple REC with two members to facilitate the understanding of community dynamics and how minor adjustments in resources or set points can impact individual members and the overall community welfare. Each member can install a behind-the-meter battery and a bidirectional EV charger. The EV battery can assist members in trading with the community when prices are favourable. Each meter is allowed to increase its PV and battery capacities threefold, while thermoelectric water heaters can bring flexibility to the system.

Simulations were conducted over 24-hours and will be expanded in future deliverables. This duration means the initial state of the battery and EV battery significantly influences the results.

Various simulations were performed, including scenarios with and without EVs, EWH and batteries, to analyse different outcomes related to the objective function, individual costs, and the recommended sizing of assets.

The .json file with all the input data, based on input data from the section 4.1.1, can be found here [33].

4.1.7.2 Results

For the calculation, two meters, three types of electrical assets (batteries, EVs and EWHs) for one complete day were predefined. Based on this, three cases were defined to demonstrate the results, as shown in Table 14:

Table 14. Results.

Case	Meter#1			Meter#2			Section
	Battery	EVs	EWH	Battery	EVs	EWH	
1	x			x			0
2	x	x		x	x		0
3	x	x	x	x	x		0

These three named cases are analysed in the following sections:

- Case 1 – Meters 1 and 2 with electrical battery, without EVs and without EWH, in next section;
- Case 2 - Meters 1 and 2 with electrical battery, with EVs and without EWH, in next section;
- Case 3 - Meter 1 with battery, with EVs and with EWH and Meter 2 with battery, with EVs and without EWH, in section 4.1.7.4.

4.1.7.3 EV integration results

In this section, two distinct cases are initially analysed: the sizing and operation of the community with and without EVs.

Case 1 - Meters 1 and 2 with electrical battery, without EVs and without EWH

In the first case, batteries are the only assets in the system. There are no EVs or EWHs.

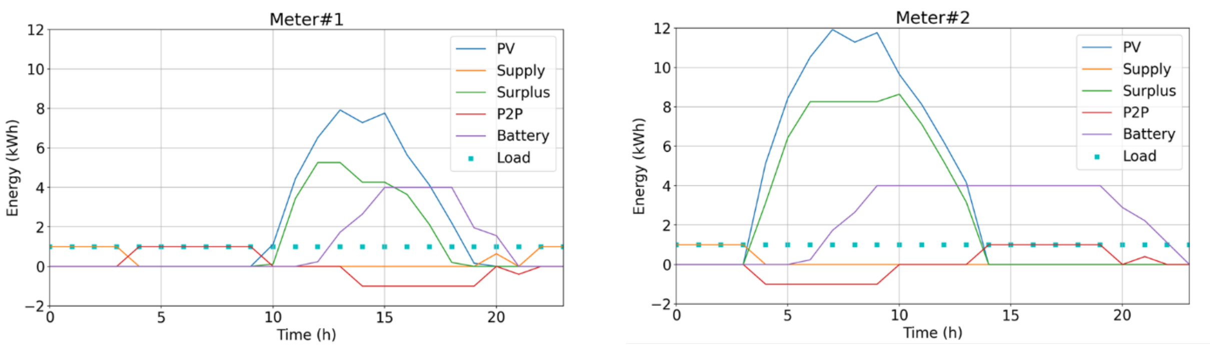


Figure 15. Meters 1 and 2 results with electrical battery, without EVs and without EWH.

In the results of this first case (see Figure 15), there remains a dependence on the external supplier (yellow line) to meet energy demands, particularly when PV generation is non-existent.

Case 2 - Meters 1 and 2 with electrical battery, with EVs and without EWH

In the second case, batteries and EVs are the only assets in the system. There are no EWH in the system.

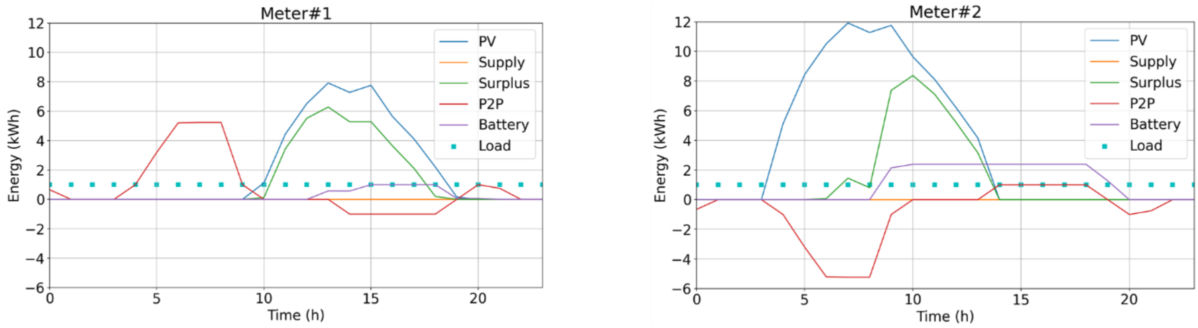


Figure 16. Meters 1 and 2 results with electrical battery, with EVs and without EWH.

In the results of this second case, conversely, the effect seen in case 1 diminishes in the presence of EVs, which can supply energy during these periods. When EVs are available, the meters achieve full energy independence, relying on the supplier solely to sell excess energy and to profit from it. As anticipated, battery usage decreases in the second scenario, as EVs fulfil the role of energy storage when available. For example, the EV associated with Meter #2 is travelling and not plugged in from hour 9 onwards, requiring the use of the electric battery during this period.

Looking at the results, it becomes evident that EV-equipped members exhibit a greater tendency towards P2P trading (see Figure 16), reaching peaks of 5 kWh during certain hours of the day. This increased trading activity is attributed to the enhanced flexibility provided by EVs.

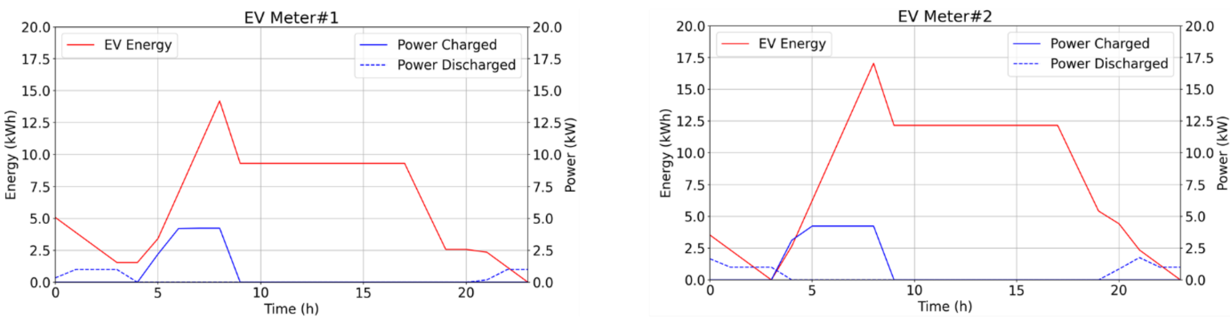


Figure 17. Meters 1 and 2 EVs' charging results – case 2.

Regarding charging, EVs in both meters demonstrate similar behaviour, predominantly discharging during non-PV hours to reduce the overall costs of the REC (see Figure 17). It is crucial to consider the initial battery status of each EV (5.48 kWh), which is sufficient to power the meters in the initial hours. This would not be true if the SoC were lower or if a dummy charging approach was employed.

Table 15. PV and Storage initial and final installed capacities and individual costs with and without EVs.

Outputs	Without EVs		With EVs	
	Meter#1	Meter#2	Meter#1	Meter#2
PV Initial Installed Capacity (kW)	1,00	1,00	1,00	1,00
PV Total Installed Capacity (kW)	4,00	4,00	4,00	4,00
Storage Initial Installed Capacity (kW)	1,00	1,00	1,00	1,00
Storage Total Installed Capacity (kW)	4,00	4,00	0,00	1,39
Individual Costs (€)	1,24	-0,28	-0,11	-0,02

Table 15 presents the results for the installed capacities and the new installed capacities suggested by this tool. It also shows the individual costs with and without EVs. For installed PV capacity, there are no differences between cases with and without EVs, as both meters choose to install the maximum allowed capacity of 3 kW. Conversely, the storage capacity shows a different behaviour: there is a decrease in the suggested installed capacity. Meter#1 does not require additional storage, while Meter#2 only needs an increase of 0.39 kW. This is due to the presence of EVs, which can replace the battery effect during certain periods of the day.

Regarding individual costs, the results vary slightly. With EVs, both meters achieve negative costs (profits), but the profits for Meter#2 are higher without EVs. This is mainly because both meters participate more in P2P trading and the community focuses on minimizing overall costs rather than individual ones.

4.1.7.4 EV and EWH integration joint results

In this section, the joint results of the integration of EV and heating and cooling assets are presented in the third case.

Case 3 - Meter 1 with battery, with EVs and with EWH and Meter 2 with battery, with EVs and without EWH.

In this third case, batteries, EVs and EWH are present in the system.

For comparison purposes, the graphical analysis follows the same structure as analysed in the previous section. Here, the same conditions and inputs are used, but now there is a EWH connected to Meter#1.

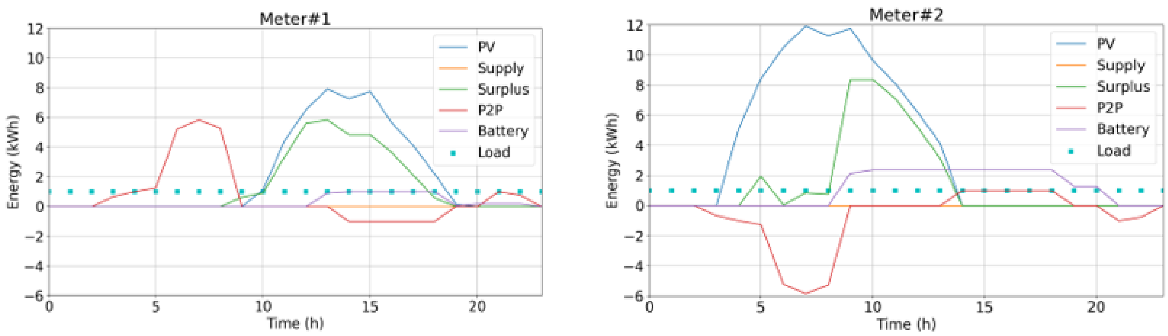


Figure 18. Meter 1 with battery, with EVs and with EWH and Meter 2 with battery, with EVs and without EWH results.

Figure 18 shows that the behaviour of the P2P curves continues to be opposite between Meter#1 and Meter#2, but with a small accentuation of the trades with a peak of 6 kWh at 7 a.m. in both meters, compared to the system without EWH.

Compared to the system without EWH, the surplus on Meter#1 is represented by a small decrease at 1 p.m. which reaches 5,8 kWh and two small increases, from 0 to reach approximately 1 kWh from 8 a.m. to 10 a.m., and 0,5 kWh at 6 p.m. The surplus on Meter#2, meanwhile, is represented by a small decrease at 7 p.m. which reaches 0,85 kWh and two small increases, being 2 kWh at 5 a.m., and reaching 8,4 kWh at 9 p.m. There are therefore slightly more P2P with EWH than without EWH. In addition, since there is more load, there is not much more surplus to be sold to the grid.

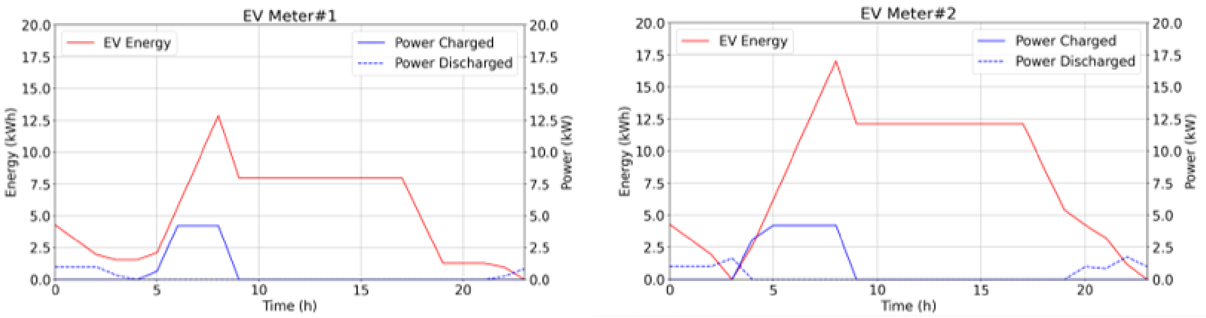


Figure 19. Meters 1 and 2 EVs' charging results – case 3.

Also compared to the system without EWH (see Figure 19), the main change is a reduction of approximately 2,5 kWh of EV energy throughout the day at Meter #1. The EV connected to Meter#1 (with EWH) needs to discharge earlier than the EV connected to Meter#2 (without EWH) to support this load cheaply.

Table 16. PV and Storage initial and final installed capacities and individual costs with and without EWH.

Outputs	With Battery, EVs And With EWH	With Battery, EVs And Without EWH
	Meter#1	Meter#2
PV Initial Installed Capacity (kW)	1,00	1,00
PV Total Installed Capacity (kW)	4,00	4,00
Storage Initial Installed Capacity (kW)	1,00	1,00
Storage Total Installed Capacity (kW)	0,00	1,39
Individual Costs (€)	-0,20	-0,02

Table 16 presents the results for the installed capacities and the newly installed capacities suggested by this tool for case 3. It also shows the individual costs with EVs and EWH on Meter#1 (second column) and with EVs and without EWH on Meter#2 (third column). For installed PV capacity, there are no differences between meters with and without EWH, as both meters keep choosing to install the maximum allowed capacity of 3 kW (the difference between the "PV Total Installed Capacity" and "PV Initial Installed Capacity"). Meter#1 does not require additional storage, while Meter#2 needs an increase of 0.39 kW. The justification is still the same. This is due to the presence of EVs, which can replace the battery effect during certain periods of the simulation.

Regarding individual costs, both meters achieve negative costs (profits) increasing this value with EWH on Meter#1.

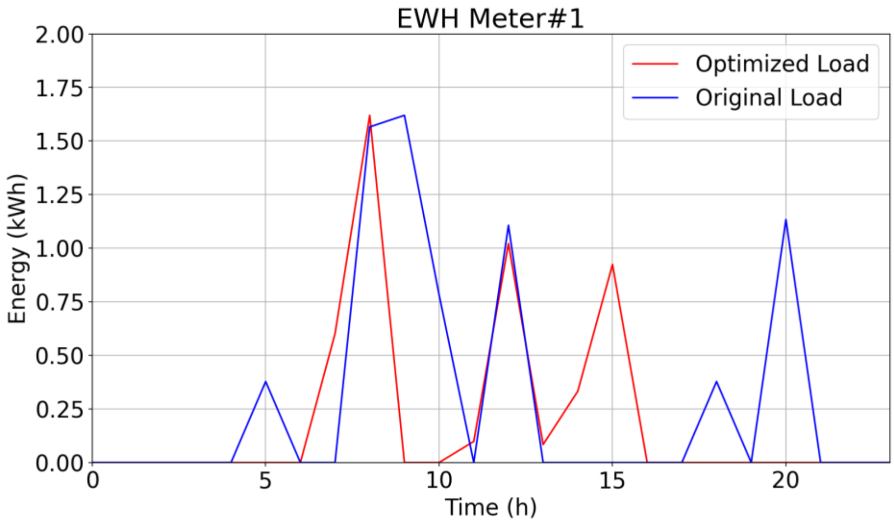


Figure 20. EWH loads

Figure 20 represents the original load overlaid with the optimised load of the EWH connected on Meter#1, for one day. It is possible to observe from the load diagram that the optimized curve was accommodated between 6 a.m. and 4 p.m., with 3 decreasing peaks that decay as time increases every 3 hours. The first one occurs between 6 a.m. and 9 a.m. reaching approximately 1.6 kWh, the second one occurs between 10 a.m. and 1 p.m. reaching approximately 1 kWh, the third one occurs between 1 p.m. and 4 p.m. reaching approximately 0.92 kWh. Table 17 shows the sum and the average of the Optimized Load and Original Load. In this case, the difference between them is 33%.

Table 17. Optimised load and original load comparison.

Loads	Sum (kWh)	Average per Hour (kWh)
Optimised Load (kWh)	4,68	0,20
Original Load (kWh)	6,97	0,29

4.1.7 Further developments

In addition to what has already been developed, the coming features are expected to analyse the feasibility and potential implementation of:

- REC business models (e.g., add external investors).
- New business models such as shared batteries.
- New thermal resources.
- Flexibility for commercial balancing and system services.
- KPI for business models and investments assessment.
- API interface to access the service.
- Assets degradation.

- Data reduction with clustering techniques.

4.2 Heating and cooling assets and networks

The heating and cooling assets and networks module will have two main submodules:

- The heating and cooling networks module: This submodule will be developed based on the REWARDHeat project [34], adapting its database and automating the generation of networks for energy communities.
- The heating and cooling assets module: this submodule enriches buildings with heating and cooling system archetypes. These archetypes can encompass different energy system models (steady-state or detailed energy models) of systems such as heat pumps, electric boilers, or solar thermal panels.

These two submodules are explained in detail, including the starting point and the way of moving forward in this section. As in the previous module, the submodules can work alone and will be integrated within the Planning tool.

4.2.1 Initial status of the heating and cooling networks module

For the design and sizing of the heating/cooling network, the predesign tool REWARDHeat [35] is used as starting point for ENPOWER project. The primary goal of REWARDHeat is to facilitate the integration of low-temperature renewable energy and waste heat sources into district heating and cooling networks at the urban level.

This tool is structured into three separate layers (data layer, business logic layer, and application layer), encompassing all the necessary components to craft a high-quality and user-friendly tool for identifying the most suitable solutions for designing district heating networks. These features make the corresponding modules of this tool suitable for consultation for this project.

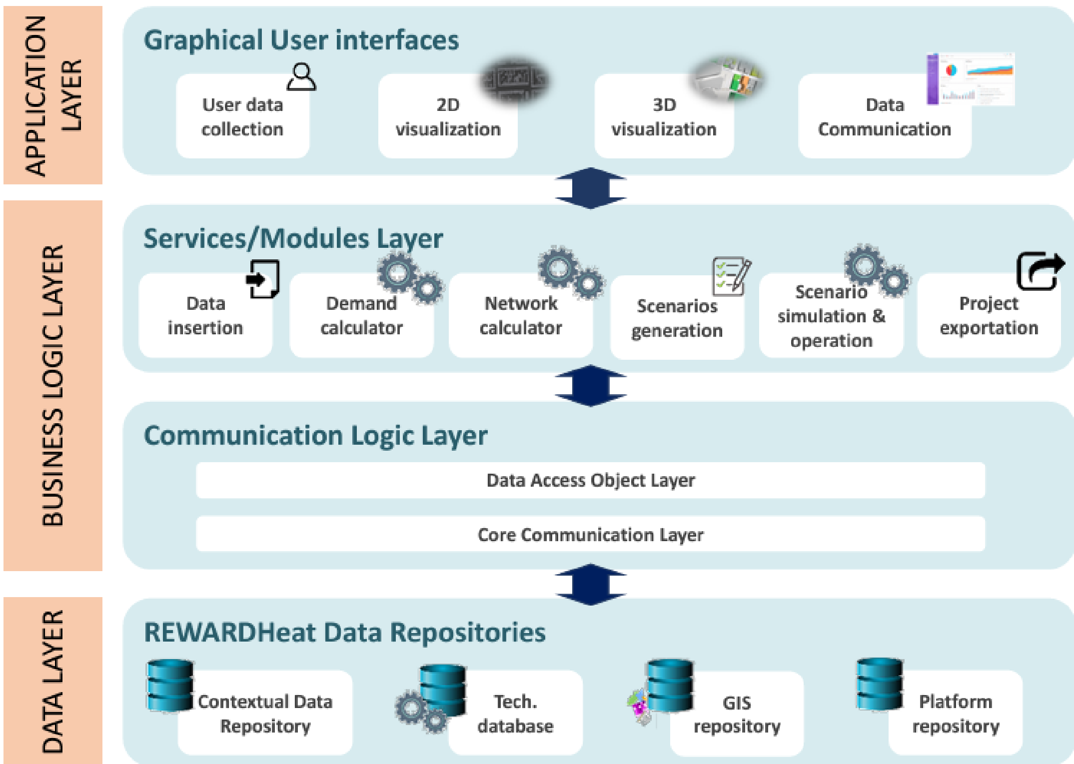


Figure 21. Architecture of the REWARDHeat Predesign Tool [35]

As mentioned, the sections that are of interest for this project, which incorporates the Rewardheat tool, are the ones to perform network route optimization and heating and cooling assets modeling. These modules will need to be adapted to the scope of the energy communities project in the upcoming months. For instance, the databases, the GIS repository and the platform repository will change, being adapted for the Planning tool as per explanations included in section 2.

4.2.1.1 REWARDHeat Database

The REWARDHeat predesign tool relies on a robust database architecture designed to manage and store comprehensive data required for DHCN predesign. This database includes GIS data of urban areas, building attributes, energy demand profiles, and information on available energy sources. The structure of the database is relational, allowing efficient data retrieval and manipulation necessary for the computational modules.

The database incorporates data from existing resources like the PLANHEAT project [36] and enriches it with new data generated by REWARDHeat own calculations. This includes tables for building attributes, energy demand, network routes, and environmental data. The flexibility of the database structure allows for the addition of new tables and relationships as needed by the evolving calculation algorithms and user requirements. To adapt the REWARDHeat database for use in energy communities, some modifications will be needed, for instance, the creation of the district heating network for several clusters or according to the regulation considerations or GIS-based data (e.g. availability of nearby networks). These adaptations aim to provide to the specific needs of district heating and cooling energy systems and enhance community-level energy management. Key considerations for adaptation include integrating community-specific data. The database must ensure scalability and flexibility, handling varying scales of energy communities.

4.2.1.2 Route Optimiser and Refinement for Energy Communities

The route optimizer in REWARDHeat is designed to create efficient network layouts by minimizing the distance between energy sources and consumers. It uses a **graph theory-based algorithm**, integrating data from **OpenStreetMap (OSM)** [37] and **user-defined inputs** to generate optimal network routes. The algorithm considers various factors, including the location of buildings, energy producers (like waste heat sources), and street layouts, to ensure the most efficient distribution network.

This method will need refinement for applicability to energy communities. For instance, the process from REWARDHeat is based on user-inputs. The incorporation of local constraints will need to rely on databases and GIS-data to define local constraints automatically, such as exclusion zones (areas where network installation is not permitted) and preferred routing paths to reflect community-specific planning requirements. Clustering of buildings according to energy demands or energy systems archetypes could be a way to automatise this process. Furthermore, multi-source integration will enhance the optimizer to handle multiple decentralized energy sources and sinks, ensuring balanced load distribution and efficient energy use.

Developing a more intuitive **user interface** will enable community administrators to easily input and modify network parameters.

As explained before, REWARDHeat tool includes detailed calculations for energy demand, primary energy, greenhouse gas (GHG) emissions, and operational costs. These calculations are fundamental for assessing the performance and feasibility of proposed DHCNs. In ENPOWER project it is important to distinguish between single-user assets (Address by the heating and cooling assets module) and shared community assets (Assessed by the DHN module) in the calculation models will involve assigning specific operational parameters and efficiency factors based on the asset type. By comparing both cases, the **benefits of energy communities** can be compared. Implementing algorithms to account for the dynamic distribution of energy loads among single and shared assets will ensure balanced and efficient energy use within the community. Developing methods to fairly allocate costs associated with shared assets among community members, considering factors like usage patterns and contribution to peak demand, will be essential and considered for future developments. Finally, incorporating user inputs will continuously refine and improve the accuracy of energy demand and supply calculations.

Figure 22. Example of the inputs and route optimizer of Rewardheat [34]

4.2.1.3 User Workflow in REWARDHeat Tool: From Building Definition to Network Route Calculation

After creating a new project in the user interface, an Area of interest (AOI) must be chosen. OpenStreetMaps [37] data could be used to define the area containing the buildings by drawing it on the map. Alternatively, a pre-defined shapefile with the buildings can be uploaded.

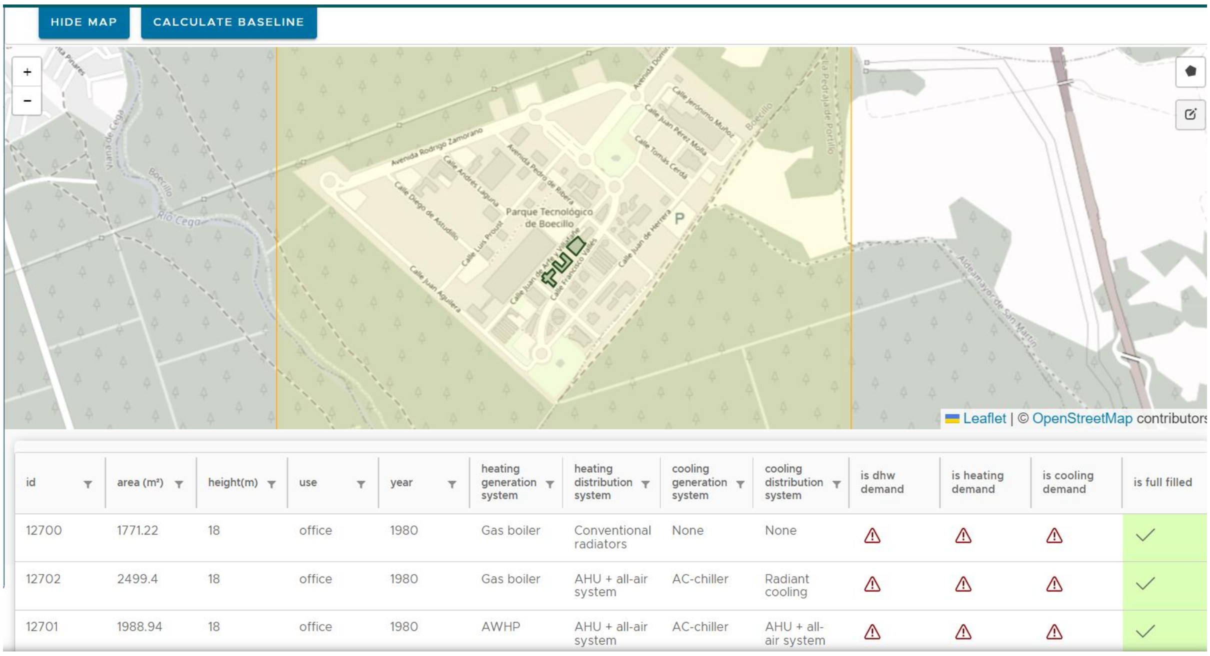


Figure 23. Selection of buildings and baseline definition, [Created by the author].

Next step is to establish a **baseline** by setting building attributes (see Figure 23) such as building use, year of construction, and height. Accurate data helps determine specific energy demand profiles. If actual energy consumption data is unavailable, the tool can estimate the energy demand using default values based on these attributes. These estimations consider factors such as heating degree days, cooling degree days, internal gains, and thermal transmittance (U-values) of the building envelope. This process is automatised in LocalRES project and will be adapted in ENPOWER for the district heating and cooling networks submodule.

After establishing the baseline, different **scenarios** must be created for analysis within the selected project. Each scenario can include specific design constraints and a set of energy sources and storage components. For instance, scenarios can explore varying levels of renewable energy integration, different types of energy storage solutions, or distinct economic constraints.

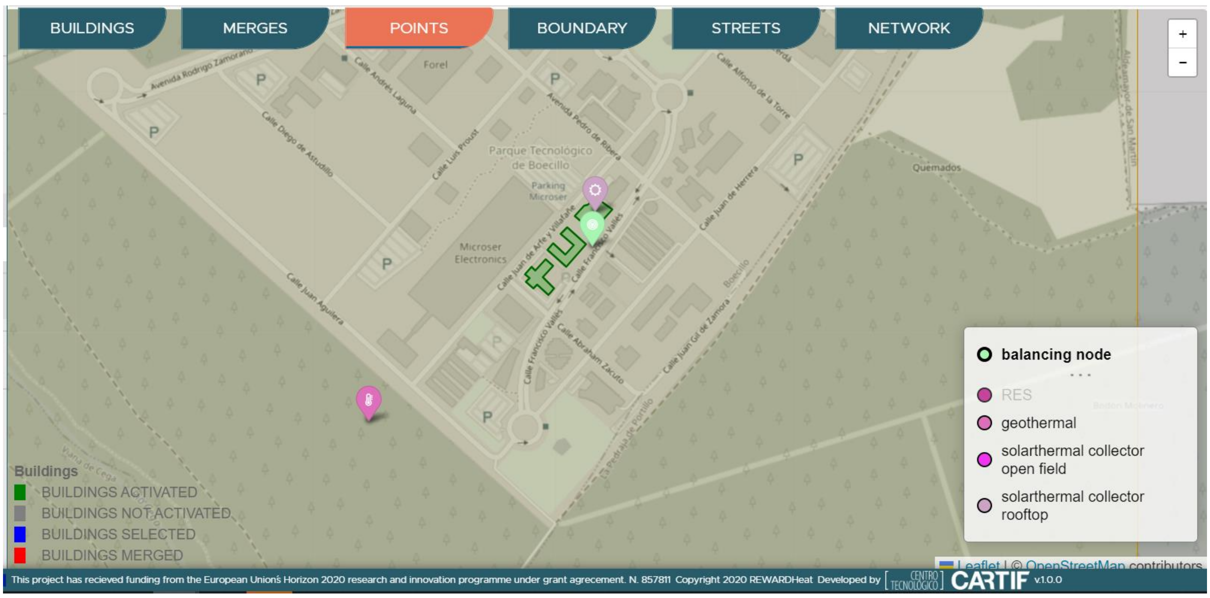


Figure 24. Creation of scenario

In each scenario, energy resources and network components need to be assigned by selecting them on the map. Energy resources include renewable energy sources such as solar thermal and geothermal, as well as waste heat sources like industrial waste heat and data centres. Network components involve defining and placing elements like central heating plants, substations, thermal storage systems, and connections to existing district heating systems. This process will be adapted in ENPOWER by automatizing the creation of scenarios.

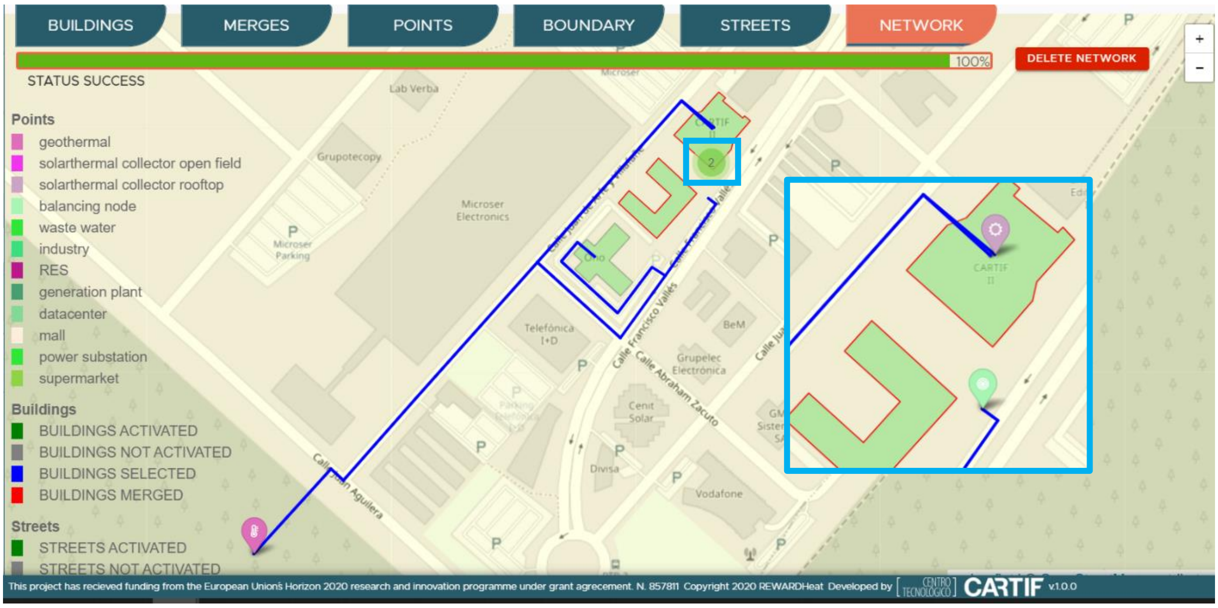


Figure 25. Network Route Calculation

Once the energy resources and network components are defined, the next step is to calculate the network route. The tool uses an optimization algorithm to determine the most efficient network layout, taking into account the spatial distribution of buildings, energy sources, and infrastructure. It considers various factors such as street layouts, geographic constraints, and user-defined exclusions. The output is an optimized network route displayed on the map, showing the proposed paths for district heating pipelines.

4.2.2 Current status of the heating and cooling assets submodule

In light of the opportunities and flexibility offered by the digitalisation of the local energy systems, the heating and cooling (H&C) assets optimization module is developed building on the **oemof.solph** [38] and **oemof.thermal** [39] python libraries. The aim of the H&C assets submodule module is to design the decentralised heating and cooling energy systems in the community and run the optimization routine for the energy flows according to the objectives and requirements specified by the tool user. H&C archetypes are automatically assigned to the buildings based on country data. From the RES-based scenario recommendation tool, new archetypes are assigned (such as heat pumps) to assess the impact of RES decentralized systems.

Oemof.solph is a versatile framework used to design and optimize energy systems as part of the Open Energy Modelling Framework (oemof) [9]. The two core functionalities offered by oemof.solph are:

1. **Energy System Modelling:** The user can create detailed models of energy systems including a set of basic and well-tested components including energy **sources**, energy

sinks, **buses**, **storage units** and **transformers**. More advanced components can be developed by oemof users (they are referred to as experimental components) but documentation could be not as complete and explanatory as the one for the basic components and sometimes these components could not work as intended.

Whatever type of components is included in the energy system model, they are defined within a network of buses that facilitate energy flows through the system.

2. **Optimisation**

Once the energy system is defined, an optimization problem can be defined depending on the objective of the user, including **costs minimization**, **emissions minimisation** and **maximisation of self-sufficiency**. Various solvers are available to run the optimisation routine, both open-source and commercial.

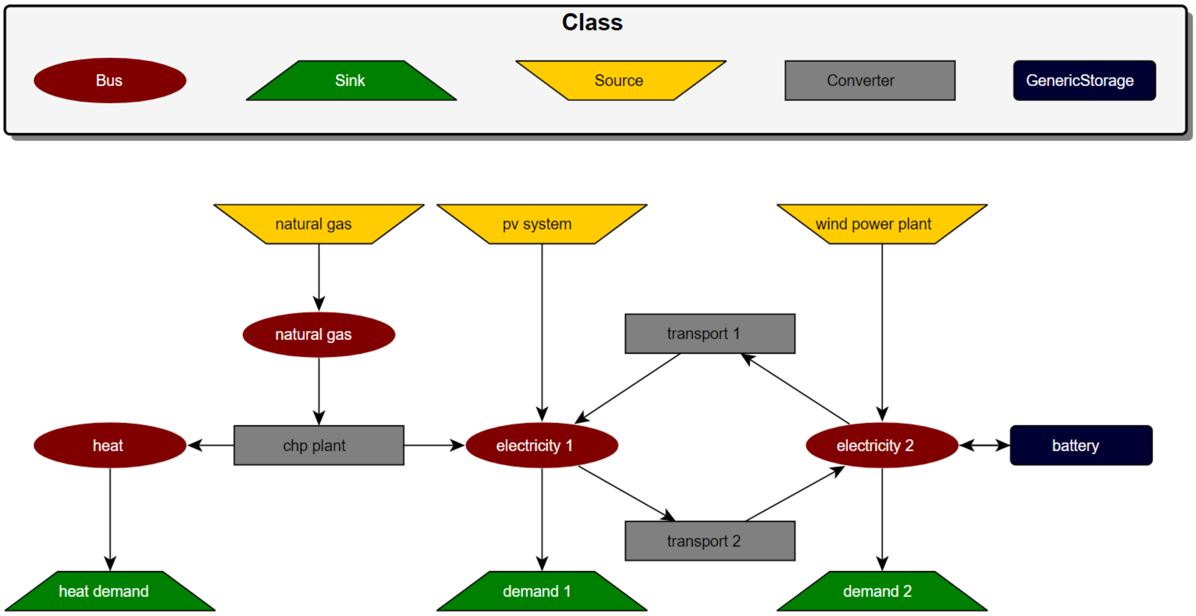


Figure 26. Schematic of an energy system model from oemof.solph User's guide [38].

On the other side, **oemof.thermal** is an extension of the Open Energy Modelling Framework (oemof) project that integrates H&C energy system models. These models will be adapted and integrated within the workflow in case a more detail analysis is needed for some scenarios.

4.2.3 Input data description

Both submodules developed for the ENPOWER project as the module for "heating and cooling assets and networks" will require various inputs to simulate and optimize the performance of thermal renewable energy systems within energy communities. These inputs can be categorised into several key areas:

- Geographic Information System (GIS) Data:
    - Existing district heating and cooling networks

- Existing waste heat sources or renewable energy potentials at local level
    - Building geometry data from OSM
    - Street layouts and geographic constraints
    - Exclusion zones where network installation is not permitted
- Building Attributes:
    - Building use (residential, commercial, industrial, etc.)
    - Year of construction
    - Building height and size
    - Thermal transmittance (U-values) of the building envelope
    - Heating and cooling system archetypes (e.g., heat pumps, electric boilers, solar thermal panels)
    - Energy demand profiles (heating and cooling degree days, internal gains, etc.)
- Energy system parameters:
    - Efficiency factors for different heating and cooling systems
    - energy carriers for each type of energy system or archetype
    - Capital expenditure (CapEx) for different energy systems
    - Operational costs (OpEx) for running and maintaining energy systems
    - Financial incentives and subsidies available
    - Land use data (e.g. square meters per capacity installed)
- Energy carrier's data:
    - Greenhouse gas (GHG) emission factors for various energy carriers
    - Environmental impact data (e.g., air quality indices)
- When available:
    - Local constraints (regarding renewable energy installation or energy communities)
    - Local incentives
- Weather data: from PVGIS

These inputs will be integrated into the models to enable detailed simulation.

4.2.4 Output data description

The outputs include size of each energy system, at building or community level, and the energy flows of the community. These outputs are used in later stages (either by the electric module or the KPI module) to calculate metrics.

4.2.5 Illustrative example

4.2.5.1 Case characterisation

A basic example is developed with the aid of the oemof.solph [38] Python package to illustrate what is the idea and the methodology behind the thermal assets optimization module of the Interactive Tool. While in this example demand profiles are generated with the **CityEnergyAnalyst (CEA)** software [40] for two buildings, a typical single-family house (**SFH**) and a typical multi-family house (**MFH**) both located in **Madrid, Spain**, in the tool module these will be retrieved through the **REWARDHEAT API** (See Section 4.2.1.). Appendix E shows the parameters selection to run the simulation in CEA and compute the heating demand for both buildings throughout an entire year. The building parameters are retrieved from the LocalRES Project database [41].

For the modelling of the thermal assets included in the energy system, oemof.thermal [39] parametrical models are employed. In particular, the past months the efforts have been focused on the modelling of **flat plate solar thermal collectors** (STC). Oemof.thermal provides a module for STCs that can be integrated in the energy system optimization.

A first **PVGIS API** call provides the **optimal tilt β and azimuth γ** angles for a collector in the chosen location.

The PVGIS API is also called to retrieve **weather data** for the location and thus simulate a realistic STC operation. In particular, the idea is to evaluate the dependence of the collector efficiency on the ambient temperature. For this reason, the weather variables will include here the hourly ambient temperature and the hourly global horizontal radiation, along with its direct diffuse and reflected components, in 2023 for the chosen location. The evolution of the normal radiation on the collector plate is computed knowing the three radiation components and the STC tilt and azimuth angles.

$$\delta = 23.45º \cdot sin\left(\frac{360º}{365} \cdot (284 + n)\right) \quad \textbf{Eq. 51}$$

$$h = 15º \cdot (local\ solar\ time - 12) \quad \textbf{Eq. 52}$$

$$sin\alpha_s = sin\phi \cdot sin\delta + cos\phi \cdot cos\delta \cdot cosh \quad \textbf{Eq. 53}$$

$$cos\theta = sin\alpha_s \cdot cos\beta + cos\alpha_s \cdot sin\beta \cdot cos\,(\gamma - \gamma_s) \quad \textbf{Eq. 54}$$

$$I_{b,t} = I_{b,h} \cdot cos\theta \quad \textbf{Eq. 55}$$

$$I_{d,t} = I_{d,h} \cdot \left(\frac{1 + cos\beta}{2}\right) \quad \textbf{Eq. 56}$$

$$I_{r,t} = I_{r,h} \cdot \rho \cdot \left(\frac{1 - cos\beta}{2}\right)$$ **Eq. 57**

$$I_{g,t} = I_{b,t} + I_{d,t} + I_{r,t}$$ **Eq. 58**

where

δ	(°)	is the Declination angle
n	(day)	is the Day of the year
h	(°)	is the Hour angle
α_s	(°)	is the Solar altitude angle
ϕ	(°)	is the latitude of the location
β	(°)	is the Collector tilt angle
γ	(°)	is the Collector azimuth angle
γ_s	(°)	is the Solar azimuth angle
$I_{b,h}$	(W/m^2)	is the Beam radiation on a horizontal surface
$I_{b,t}$	(W/m^2)	is the Beam radiation on the tilted collector surface
$I_{d,h}$	(W/m^2)	is the Diffuse radiation on a horizontal surface
$I_{d,t}$	(W/m^2)	is the Diffuse radiation on the tilted collector surface
$I_{r,h}$	(W/m^2)	is the Reflected radiation on a horizontal surface
$I_{r,t}$	(W/m^2)	is the Reflected radiation on the tilted collector surface
$I_{g,t}$	(W/m^2)	is the Global radiation on the tilted collector surface
ρ	(-)	is the albedo

The STC module from oemof.thermal provides functionality to compute the collector efficiency and heating power output per surface (see Figure 27).

```
precalc_data = flat_plate_precalc(
    latitude,
    longitude,
    collector_tilt,
    collector_azimuth,
    eta_0,
    a_1,
    a_2,
    temp_collector_inlet,
    delta_temp_n,
    irradiance_global=input_data['global_horizontal_W_m2'],
    irradiance_diffuse=input_data['diffuse_horizontal_W_m2'],
    temp_amb=input_data['temp_amb'],
)
```

Figure 27. STC pre-calculation functionality in oemof.thermal [39]

The equations included in the pre-calculation function are listed hereafter:

$$\eta_C = \eta_0 - a_1 \cdot \frac{\Delta T}{E_{coll}} - a_2 \cdot \frac{\Delta T^2}{E_{coll}} \qquad \textbf{Eq. 59}$$

$$\Delta T = T_{coll,in} + \Delta T_n - T_{amb} \qquad \textbf{Eq. 60}$$

$$\dot{Q}_{coll} = E_{coll} \cdot \eta_C \qquad \textbf{Eq. 61}$$

where

E_{coll}	(W/m^2)	is the radiation on the collector after losses
η_C	(-)	is the collector efficiency
ΔT	(°C)	is the difference between the collector temperature and the ambient one
$T_{coll,in}$	(°C)	is the collector fluid inlet temperature
ΔT_n	(°C)	is the difference between the mean and inlet fluid temperatures
T_{amb}	(°C)	is the ambient temperature
η_0	(-)	is the collector optical efficiency
$\dot{Q}_{coll}$	(W/m^2)	is the collector thermal power output

Table 18 reports the **fixed parameters** selected for this illustrative example as far as the STC modelling in *oemof.thermal* is concerned. A reasonable value for ΔT_n in the case of an optimized collector design in a typical Mediterranean climate could be 15 °C.

Table 18. Fixed parameters for the STC oemof.thermal simulation.

Symbol	Parameter	Unit of measurement	Value
β	Optimal tilt angle	°	37
γ	Optimal azimuth angle	°	-4
A_{coll}	Solar collector area	m^2	10
ρ	Albedo	-	0.2
a_1	Thermal loss parameter 1	W/m^2K	3.5
a_2	Thermal loss parameter 2	W/m^2K^2	0.015
ΔT_n	Difference between mean and inlet fluid temperature	°C	15
η_0	Optical efficiency of the collector	-	0.8

With the optimal values of tilt and azimuth angles for the collector in the selected location, the total normal radiation on the collector surface is computed for the entire year and plotted along with the weather variables retrieved from the PVGIS API.

The idea is to evaluate how the **collector efficiency varies with the ambient temperature and the global horizontal radiation** before integrating the module as a heat source in the wider energy system developed in oemof.solph.

An entire yearly time series of the two weather variables are considered, for the analysis and plot of them against the STC efficiency computed with the oemof.thermal STC module are considered.

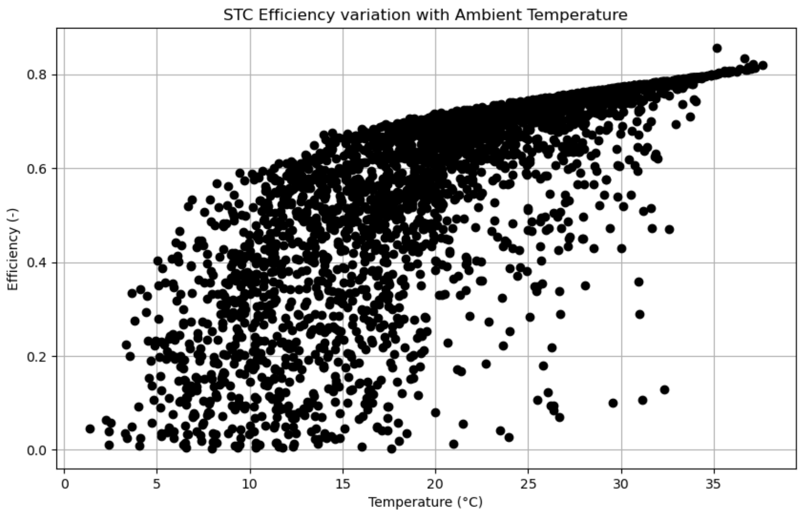


Figure 28. STC efficiency evolution with Ambient Temperature.

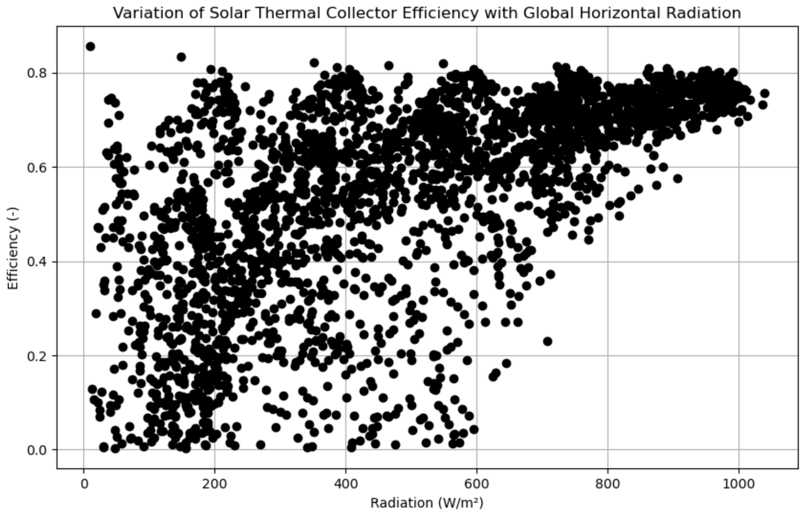


Figure 29. STC efficiency evolution with Global Horizontal Radiation.

The results in Figure 28 and Figure 29 clearly show a general **upward evolution of the collector efficiency with both weather variables** as expected. For both results, the other weather variable is not fixed but instead it follows the evolution provided by PVGIS. For this reason, Figure 30 shows the evolution of the collector efficiency as a combination of the two weather variables considered here, peaking at the condition for which both the ambient temperature and the global radiation reach their maxima.

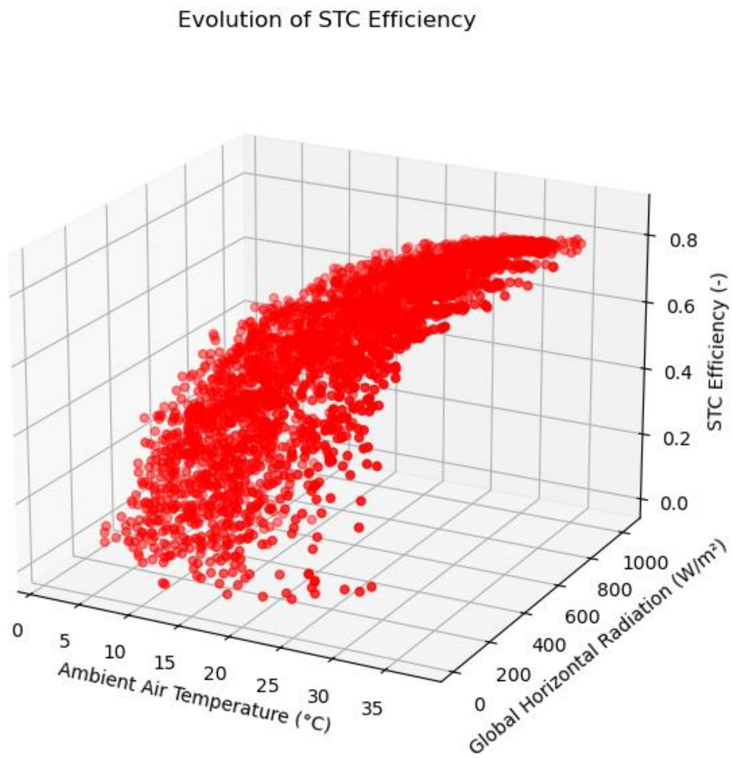


Figure 30. STC Efficiency evolution with Ambient Temperature and Global horizontal Radiation.

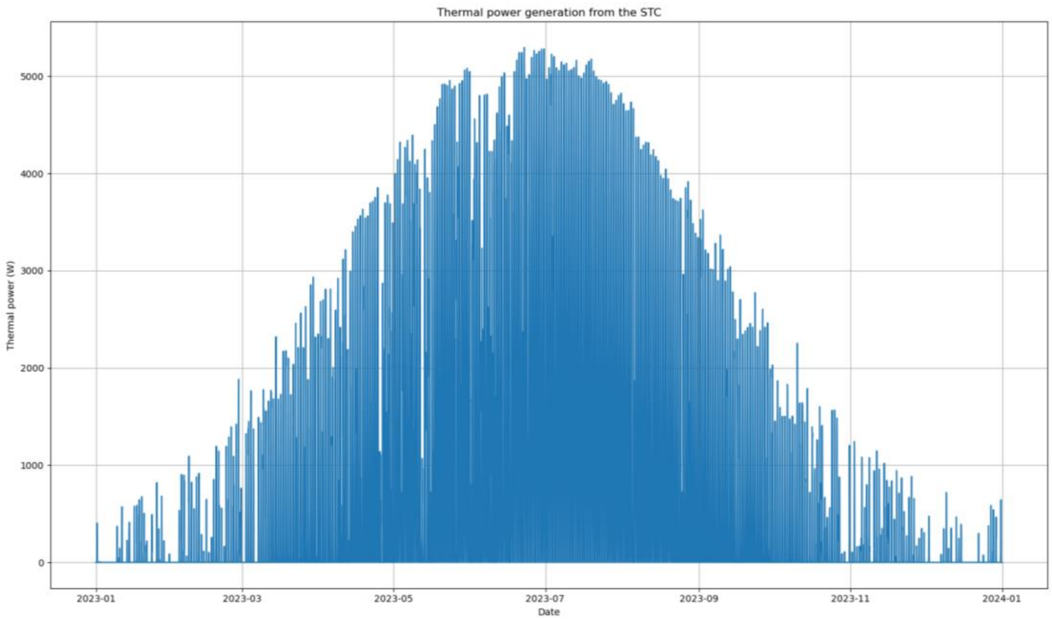


Figure 31. Thermal power generation from the STC.

Peak and annual generation from the STC module reach **0.547 kWh/m^2** and **708.7 kWh/m^2** respectively.

The optimization of the energy system in oemof.solph is as follows. In this basic example the **STC** is integrated as a **fixed thermal power source**. Apart from this, the heating demand from the two buildings is met with the aid of a **CHP plant** running on natural gas and a **thermal storage**. The generating units and the storage are coupled with the demands through the heat bus. An excess electricity sink needs to be integrated in the model as there is no electricity demand in the model and the CHP unit will produce power anyway when needed according to the result of the optimization. An excess heat sink is also integrated to face possible overproduction.

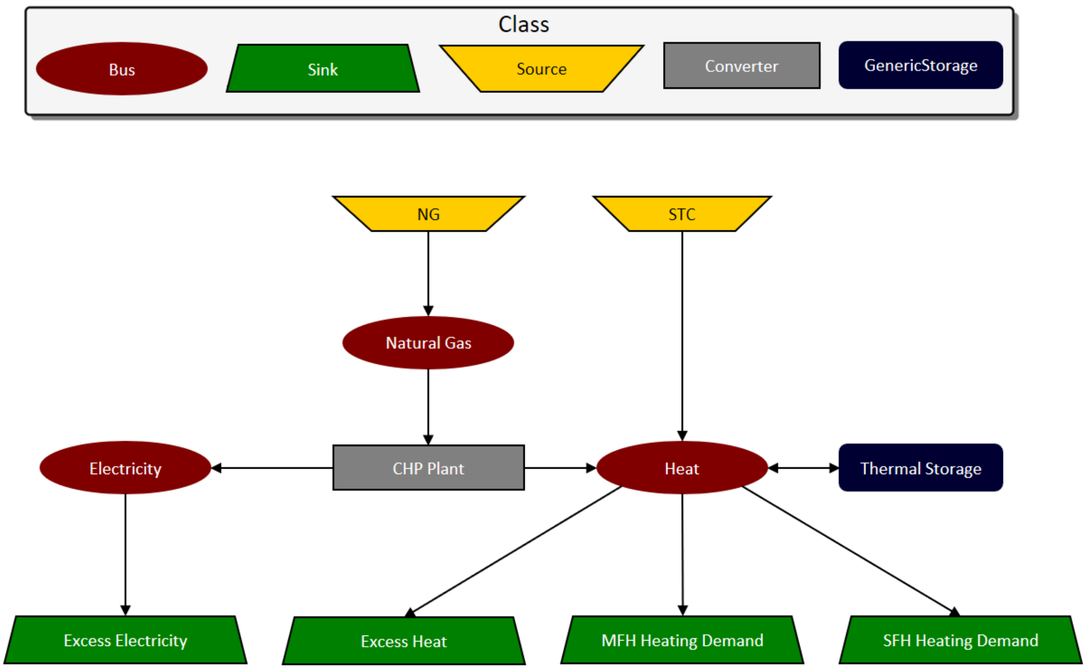


Figure 32. Schematic of the energy system as modelled in oemof.solph.

Table 19. Energy system components.

Component	Class	Inputs	Outputs
NG	Source	-	To *Natural Gas*
STC	Source	-	To *Heat*
Natural Gas	Bus	From *NG*	To *CHP Plant*
Heat	Bus	From *STC*	To *Excess Heat* *To SFH Heating Demand* *To MFH Heating Demand*
CHP Plant	Converter	From *Natural Gas*	To *Heat* To *Excess Electricity*
Thermal Storage	GenericStorage	From *Heat*	To *Heat*
Excess Electricity	Sink	From *CHP Plant*	-
Excess Heat	Sink	From *Heat*	-
MFH Heating Demand	Sink	From *Heat*	-
SFH Heating Demand	Sink	From *Heat*	-

Every component of the energy system is linked to the others through inputs and outputs. These interconnections stand for the energy flows to be optimized in the system. Table 20 to

Table **23** show the **fixed parameters adopted in the optimization of the energy system**. Additional entries, such as investment cost or fixed and variable O&M costs, can be included to run an investment optimization of the system but this is beyond of the scope of the example. Additional parameters to better model the operation of the storage, such as loss rates or charging/discharging efficiency, can also be included but they do not add relevant information for the scope of this example.

Table 20. Fixed parameters for the NG commodity source component.

Parameter	Unit of measurement	Value
Hourly gas import limit	kWh	100
Annual gas import limit	Hours	3000
Variable costs of the gas source	€/kWh	0.10

Table 21. Fixed parameters for the Thermal Storage component.

Parameter	Unit of measurement	Value
Nominal Storage Capacity	kWh	50
Maximum Charging Rate	kW	20
Maximum Discharging Rate	kW	20

Table 22. Fixed parameters for the domestic CHP Plant converter component.

Parameter	Unit of measurement	Value
Maximum Heating Capacity	kWh	100
Electricity Conversion Factor	-	0.2
Heating Conversion Factor	-	0.6
Variable Costs	€/kWh	0.02

Table 23. Fixed parameters for the STC source component.

Parameter	Unit of measurement	Value
Variable Costs	€/kWh	0

4.2.5.2 Results

The results of the optimisation routine provide the yearly evolution of the energy flows among all the sources, converters, storages, buses and sinks included in the energy system. It shown in detail in Appendix E. A summary of the results is shown in Figure 33. the **Sankey diagram** shows how the optimized energy flows redistribute among the system components. First, **the STC surface can be increased** to better exploit the solar resource. For a rooftop installation, the available surface from the two buildings is far beyond those 10 m^2 set in the simulation, even considering the collector tilt. On the other side, **the thermal storage is clearly underutilized**. Its operation can be improved modifying the oemof.solph storage component definition.

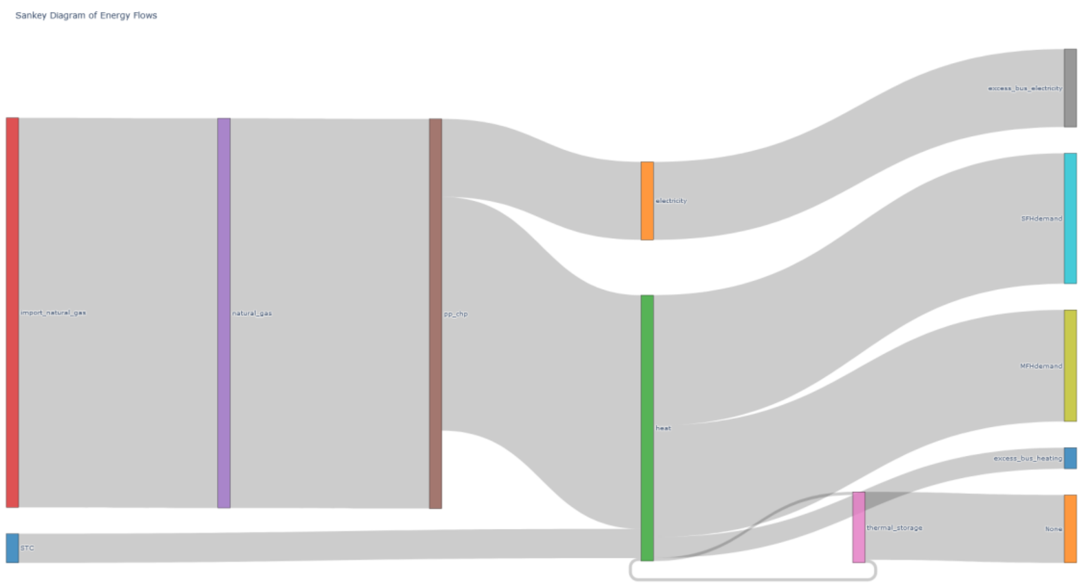


Figure 33. Sankey diagram for the yearly energy flows.

4.2.5.3 Further developments

As further developments, the module will develop:

- Modify the REWARDHeat database to accommodate community-specific data, integrating GIS-based data and consider regulatory aspects for the creation of district heating networks under several conditions (e.g. clusters).
- Refine the route optimizer to include local constraints automatically using databases and GIS data.
- Incorporate multi-source integration for handling multiple decentralized energy sources and sinks.
- Develop a more intuitive user interface for community administrators to input and modify network parameters easily, as well as automatising the process to the extent of possible.
- Assign specific operational parameters and efficiency factors based on the asset type (single-user or shared community assets).

- Implement algorithms to account for the dynamic distribution of energy loads among single and shared assets.
- Adapt the existing process from LocalRES project for establishing baselines and automating the assignment of H&C system archetypes to buildings. Automate the process of creating scenarios within the selected project, incorporating varying levels of renewable energy integration, decentralised and centralised systems, different types of energy storage solutions, or distinct economic constraints
- Use the oemof.solph and oemof.thermal Python libraries to design decentralized heating and cooling energy systems in the community and optimize energy flows. Automatise the creation of the oemof.solph models
- Develop and integrate advanced H&C energy system models for detailed analysis when needed.
- Ensure that the optimization problems can be defined depending on user objectives, such as cost minimization, emissions minimization, and maximization of self-sufficiency.

4.3 KPI module

The KPI module will allow to evaluate the different scenarios offered to prosumers and energy communities. The KPI module will consider different submodules from past projects:

- RES-based scenario generator from LocalRES Project
- Citizen-KPIs module from LocalRES Project
- Energy demand calculation from REWARDHeat

Thus, the KPI module will integrate the following functionalities in the ENPOWER’s Planning tool:

- Current status of the community: calculation of energy demand and creation of the baseline scenario
- Future status of the community: generation of future scenarios and modification of the data model of the energy community within the database to launch other modules (***Thermal and cooling assets and networks module*** and ***Electric module***).
- Metrics to compare both: integrating citizen-KPIs from LocalRES project and section 3 new KPIs

The definition of scenarios will consider, among other aspects, the targets of the energy communities, the boundaries of the community environment and the barriers defined by the users’ preferences, the specific market regulation, technical restrictions and financing possibilities. This scenario generator is performed by the former module. After the definition of scenario, the optimisation of the electric (see section 4.1) and thermal assets (see section 4.2) are launched.

4.3.1 Initial status

At the start of the project, the RES-based scenario generator and Citizen-KPIs module from LocalRES project were considered as starting point.

The former module recommends the user technology packages to run different scenarios in their energy community. These recommendations depend on the location, boundary restrictions, specific market regulation, technical restrictions and possibilities. At the same time, the RES-based scenario generator tries to fill the gaps in terms of data availability by estimating a baseline for the community and providing insights of what alternatives can be explored in the community according to their goals and country barrier. The baseline is estimated using predefined default profiles or using the algorithm from REWARDHeat code to calculate the energy demand from U-values, building footprint, schedules, solar radiation and building use of each building selected for the energy community.

The latter module, the citizen-KPIs assumes a user might not understand technical KPIs and the module translate them into user-centric indicators and narratives. To compute the scenarios and citizen-KPIs, the modules rely on a database that contains country specific data (primary energy factors, weather data, etc.) for Austria, Finland, Spain and Italy; asset parameters, default electricity profiles for different type of users (couple, retired couple, couple with kids, single person, etc.), and country statistic data for assuming a thermal profile. Furthermore, the LocalRES Planning Tool, defines “Alerts” which comprehend the following topics:

- guide the user in the user of the tool
- regulatory topics
- glossary and definitions relevant to energy communities

The mathematical formulations of the citizen-KPIs will be available in D2.6 from LocalRES project [not published yet].

The alerts, the database for the ENPOWER countries and the new KPIs will be the main activities to perform within the KPI module.

4.3.2 Current status

The task starts by mapping the needs from the communities of ENPOWER project and revision of use cases mapping (From WP2). These two will allow to define the targets, boundaries, barriers (market regulation, technical restrictions, financing possibilities) of each community to map the scenarios that could be performed and the data needed of each case. This is done in section 3.3. This data will be integrated into the database in later steps.

As said, the KPI module from CARTIF will include:

- Refinement of the database.
- Refinement of the RES-based scenario generator, to integrate new technologies (e.g. from the Irish pilot, as farmers were not part of LocalRES Project).
- New KPIs.

LocalRES database includes country specific data from Austria, Spain, Italy and Finland. The first task is to include new data from ENPOWER countries (Hungary, Portugal, Greece, Ireland).

Furthermore, the asset database (Data structure) to include new technologies and parameters needed from INESC TEC, as well as new technologies for farmers will be considered in next steps.

New KPIs stated in section 3. Inputs and outputs from each KPI have been stated in this section and will be included in the python-based module.

4.3.3 Input data description

The initial step in the KPI module is to extract baseline data from the existing database, which includes information about the buildings, their current energy systems, energy consumption, and any other parameters (such as country statistics and national energy factors). The data is extracted from the database via an internal API that connects the module with the database.

For creation of scenarios, the retrieved data is generally inherited, resulting in a duplicate structure in a new context. If the goal is to increase electrification, the recommended actions (such as heat pumps, PV, or both) will be implemented in all buildings.

Thus, the inputs described in 4.1.4 and 4.2.3 are also inputs for the KPI module as it handles the data coming from the user and translate it into a “baseline” or a scenario.

For the calculation of the KPIs, generally the following energy flows are considered:

Table 24. Energy comparisons for KPI calculations.

Name	Frequency	Type	Attributes
Energy needs	Hourly	Estimated by KPI module	Per service (heating, cooling, DHW, lighting, appliances, other)
Energy use	Hourly	Estimated by other modules	Per service or building
Energy production	Hourly	Estimated by other modules	Per service or building
Final energy consumption	Hourly	Estimated by other modules	Per service or building

These energy flows will come for the baseline from the data model. This means each building is enriched with energy consumption data taking into account the efficiency of the consumption devices (existing ones) and the energy needs calculated from the energy demand submodule from REWARDHeat. For the scenarios, the energy flows will come from the different modules. The inputs and outputs in section 3 for each KPI are also inputs and outputs of the KPI module. An illustrative example will be included in D3.2. to describe this process with an example.

Next steps will include:

- Programming the KPI module: Implementing algorithms for detailed calculations of energy demand, primary energy, greenhouse gas (GHG) emissions, and operational costs, among other KPIs detailed in section 3.
- Develop algorithms to fairly allocate costs associated with shared assets among community members.

5. Decision support tool for energy community planning

In the context of the ENPOWER project, the development of a comprehensive decision support tool (TE-1) for energy community planning is crucial. The software modules described in section 4 are developed using Python, necessitating a certain level of coding to utilise them effectively. Similarly, the database management system employs SQL, which also requires specialized knowledge to manipulate and query the data.

However, for typical users within an energy community do not have the knowledge to use the modules by themselves. The idea is that these modules are abstracted away, operating in the background of a user interface. This abstraction ensures that users can access analytical insights and scenario simulations without needing to engage with the underlying code or database queries directly.

This tool will integrate the services developed in Task 3.2 and provide two distinct user views: one for citizens/consumers and another for value chain energy stakeholders.

The tool aims to make energy community planning accessible, engaging, and functional for all users, ensuring that both technical and non-technical stakeholders can benefit from its features. To facilitate this, a user-friendly interface has been designed, featuring two distinct views. This interface enables users to interact with the system intuitively, ensuring accessibility and usability for individuals without technical expertise.

To co-design the user interface and apply it effectively to the different context of the pilots at least two workshops with citizens will be organized to test various mock-ups, ensuring the tool is intuitive and meets the needs of its users.

To start with the task, a benchmarking and review of tools is performed to map the gaps of existing tools with regards to the two views and build upon existing user interfaces but incorporating user-friendly features to assist in the decision-making of energy communities.

5.1 Tools review

Based on the definition of the "*Decision Support Tool for Energy Community Planning*" in Task 3.3, it is emphasized that the tool should not only calculate electrical and thermal scenarios on energy communities, but also adapt to the needs of both non-technical users and professionals within the energy sector, differentiating between a Citizen/Consumer View and a Value chain/Stakeholder View.

For citizens, the focus will be on making the tool engaging and intuitive, incorporating gamification strategies to simplify interaction and encourage usage. For stakeholders, the tool will aim to facilitate collaboration, exchange best practices, and provide technical assistance to enhance capacity building and engagement.

To evaluate the gaps and good practices of existing web-based tools, a review of tools that perform energy scenarios on districts or communities is conducted. Furthermore, a benchmarking of one-stop shops (see section 5.2) is performed to evaluate the different possibilities for the Value chain/Stakeholder View. The following selection of tools studied is included in this section:

- StEmp Tool Heat
- THERMOS
- Engage tool
- Grid Singularity Map

5.1.1 StEmp Tool Heat

The Stakeholder Empowerment Tool or StEmp Tool Heat [42] is a technical calculation program designed to support and engage different interest groups by providing a technological assessment of new heating system investments in an accessible and understandable manner.

Users may create a district by combining multiple household archetypes (single-family and multifamily), setting default or user-defined values for parameters like floor space, occupation and energy requirements. The assets per household can then be defined, with default or user-defined economic and technical parameters.

For the scenario simulation, the StEmp tool utilizes Open Energy System Modelling Framework (oemof) [9] to optimize the energy system model using linear optimization for the generation, demand and storage of electrical and thermal energy over a year.

The results page offers a comparison of selected technologies based on investment and fuel costs, CO_2 emissions, and primary energy demand.

The key takeaways from this tool is that:

- Allows **scenario creation** with default and customizable parameters.
- Offers **detailed comparisons** of scenarios.
- **Intuitive navigation** with clear labels and icons.
- Uses **interactive** elements with immediate feedback.
- The interface is optimized for **mobile** devices.

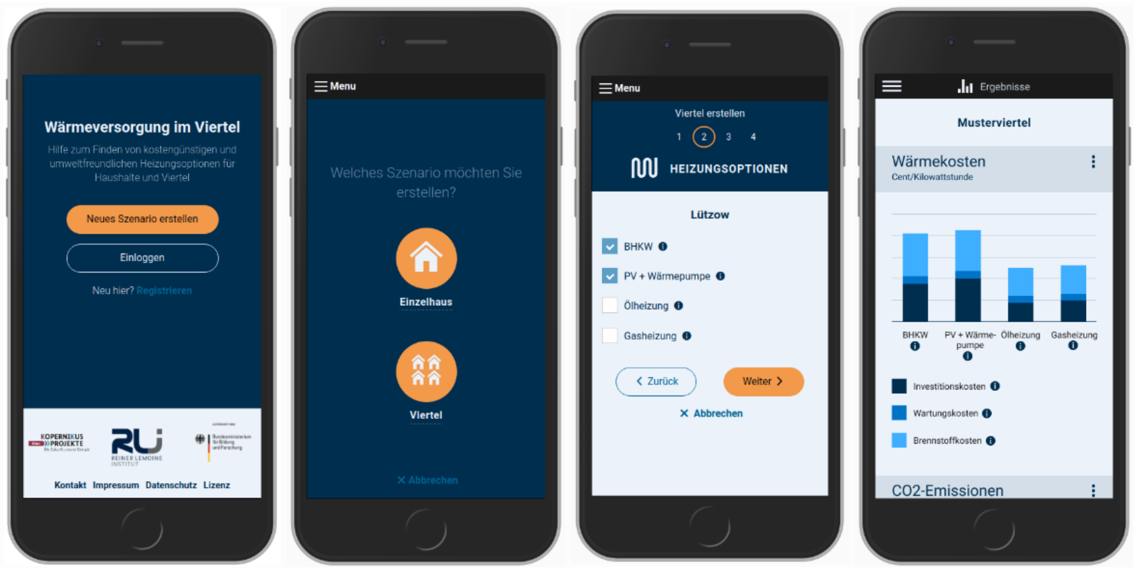


Figure 34. StEmp Tool Heat, User interface.

Figure 35. StEmp Tool Heat, Building archetypes.

5.1.2 THERMOS

THERMOS [43] is a free, web-based energy planning software that provides accurate heat and cold network options analysis instantly within a user-friendly interface. The tool enables the identification of optimal paths and connections for the expansion of existing District Heating and Cooling network (DHCN), considering local heat demand and local energy sources and potentials.

Figure 36. THERMOS, Heating network route optimization.

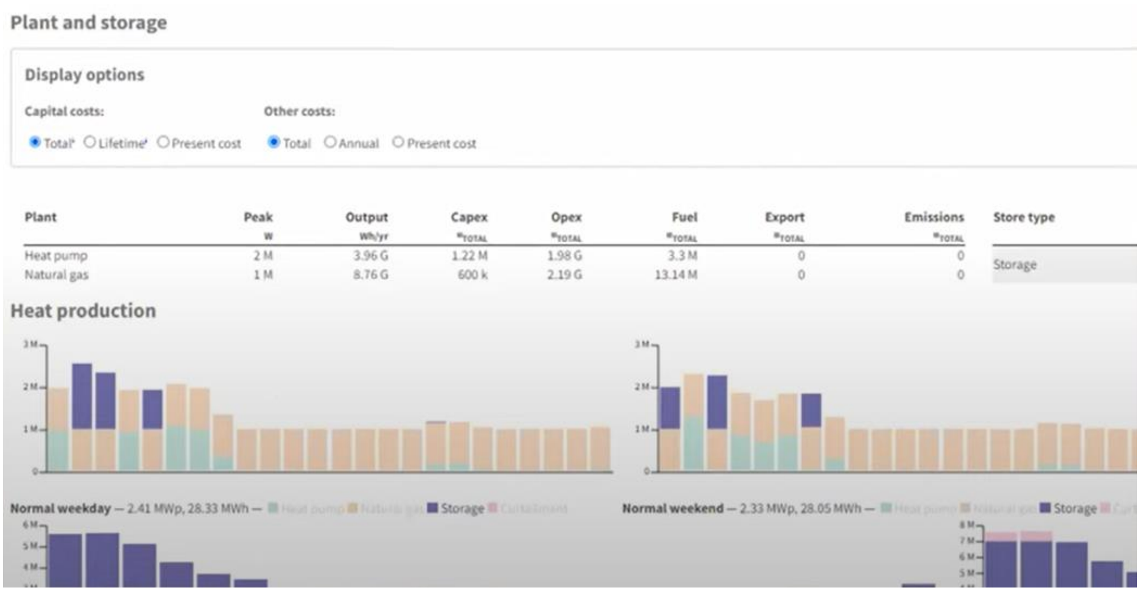


Figure 37. THERMOS, Results overview.

KEY TAKEAWAY

- The interface is **intuitive** and easy to navigate.
- Provides precise and **instant analysis** of network options.
- Enables **identification of optimal paths** for network expansion.
- Incorporates local **heat demand** and energy sources in planning.

- Presents comprehensive results with **clear visualizations**.

5.1.3 Engage tool

The Engage tool [44], developed by National Renewable Energy Laboratory (NREL), is a versatile and accessible energy modelling tool designed to facilitate comprehensive scenario exploration across a wide range of scales, from local microgrids to national energy systems. It operates under the Calliope framework [45], a well-documented open-source platform for cross-sectoral energy simulation and planning. This integration enables economic dispatch modelling, crucial for optimizing the operation of electricity generation and transmission assets while maintaining reliability under uncertainty and other constraints.

Engage features a web interface and cloud-based shared data model, enhancing collaboration among diverse stakeholder groups, teams, and experts. This facilitates their access to model future energy scenarios tailored to specific community needs and goals.

This energy model includes features such as planning electricity generation and transmission assets, analysing costs, and identifying the most economical pathways to achieve energy transition goals. The model can be applied to simulate different scenarios such as electric vehicle integration, reducing fossil fuel consumption, or enhancing building energy efficiency at various scales.

	Technologies	Version Tag	Locations
natural gas to heat	Natural Gas Boiler	Unit Expansion	X2
natural gas to heat	Natural Gas Boiler	Linear Expansion	X2
natural gas to heat	Natural Gas Boiler	Unit Expansion	X3
natural gas to heat	Natural Gas Boiler	Linear Expansion	X3
natural gas to electricity, heat	Combined Heat & Power (CHP)	Linear Expansion	X1
natural gas to electricity, heat	Combined Heat & Power (CHP)	Unit Expansion	X1
electricity	Electrical Demand		X1
electricity	Electrical Demand		X2
electricity	Electrical Demand		X3

Figure 38. Engage, Scenario definition (assets and connections).

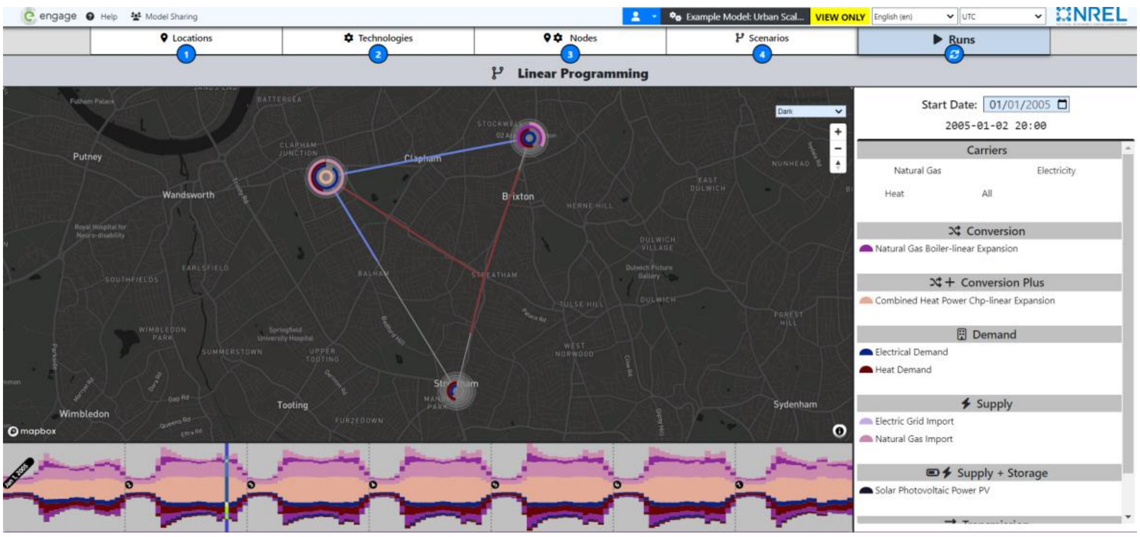


Figure 39. Engage, Energy flow results.

key takeaway

- The interface is **intuitive** and supports easy navigation.
- Provides comprehensive **scenario planning** for energy systems.
- **Facilitates collaboration** with a cloud-based shared data model.
- Includes **detailed visualization** of energy flow results.
- Offers **flexibility** in defining assets and connections.

5.1.4 Grid Singularity

Grid Singularity Map [46] is an open-source and modular platform designed to optimize the utilization of local resources. It facilitates the connection of users' smart meters and energy assets with various stakeholders, including local companies and suppliers, to enable peer-to-peer and community energy trading. This includes integrating prosumers and consumers who are part of or interested in joining, energy communities or microgrids.

The platform allows users to determine when and how they want to buy or sell energy to/from the main grid, promoting flexibility and control over energy transactions. Grid Singularity also assesses the financial and social benefits of local trading, evaluating the impact of different energy assets and system actions, such as applying various grid tariff models.

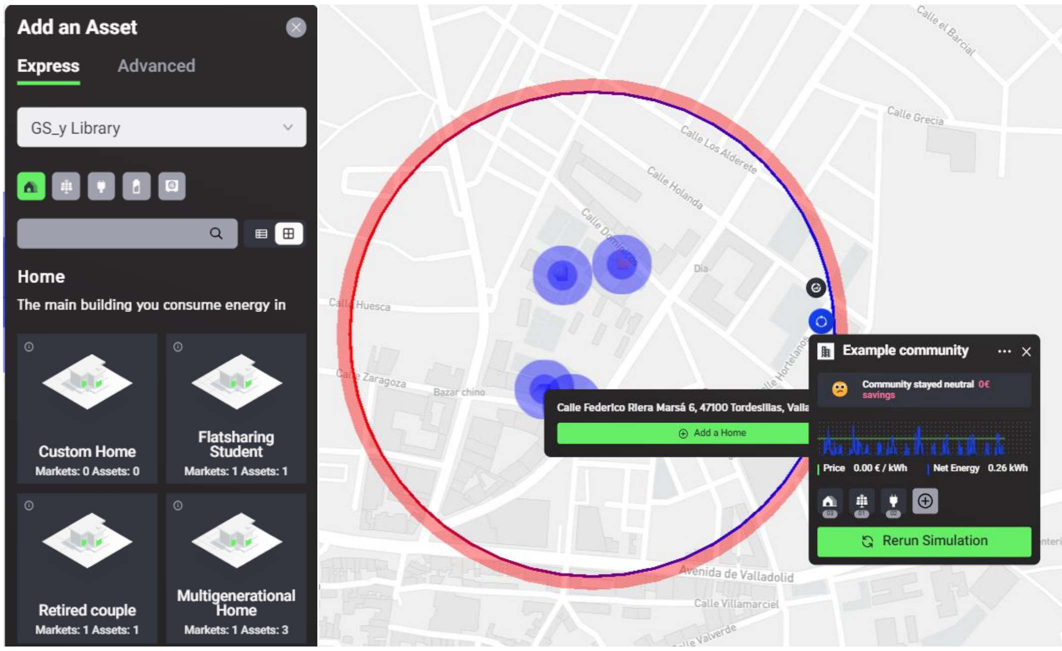


Figure 40. Grid Singularity, Community definition (building archetypes and loads)

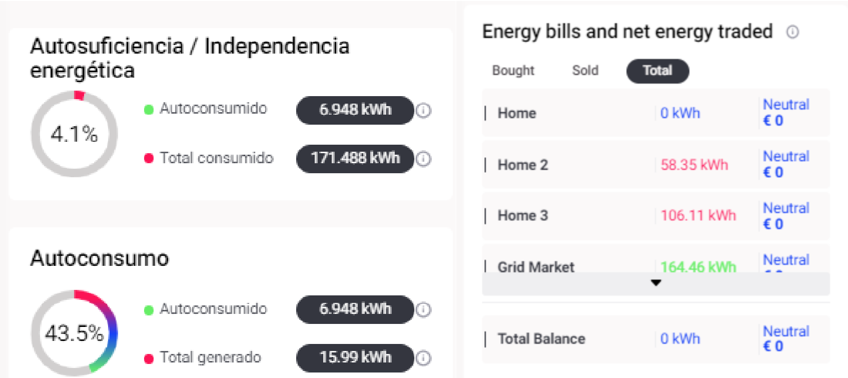


Figure 41. Grid Singularity, Results overview (aggregated and individual)

KEY TAKEAWAY

- **Intuitive and modular interface** for easy navigation and use.
- Seamless **connection** of smart meters and energy assets with local **stakeholders**.
- Enables flexible and controlled peer-to-peer and **community energy trading**.
- Allows assessment of the financial and social benefits of local trading with clear **visualizations**.
- **Supports integration** of prosumers and consumers into energy communities and micro grids.

As a summary, the tools reviewed provide the following functionalities:

Table 25. Review of tools summary

Tool	Functionalities	Oriented view	User's language
StEmp Tool Heat	Thermal and DHN	Stakeholder basic and citizen/consumer	Clear labels, interactive elements
THERMOS	Thermal and DHN	Stakeholder basic	User-friendly, instant analysis
Engage Tool from NREL	Electrical assets	Stakeholder technical	Intuitive, collaborative interface
Singularity Map	Electrical assets	Stakeholder basic and citizen/consumer	Modular, flexible trading controls

From this analysis, it can be concluded that although the tools commonly provide functionalities that support energy and community planning, they lack features like gamification and capacity building measures, which are essential for citizen engagement and active participation.

In terms of future development, the decision support tool should incorporate some of the key aspects identified in the workshop “KPIs identification and prioritisation for energy-secure communities” described in (section). Some of the identified aspects to be highlighted could be the use of non-technical language, user-understandable KPIs, and a clear differentiation between individual and collective results. Additionally, features like a simple and easy-to-navigate user-interface, feedback mechanisms, badges, and ranks should be included to make the tool more attractive to non-technical users.

The aim is to create a tool that not only facilitates technical calculations but also engages users effectively through intuitive design and accessible information.

5.2 One-Stop Shop review

For the stakeholder view, a one stop shop (OSS) review is performed as it tends to be more convenient for meeting multiple user needs and act as an umbrella of multiple products or resources. Theoretically, OSS can refer to *a business that offers a multitude of products or services to its customers, all under one roof. The business can be in a physical place or a web-based platform*. According to the literature, the goals of OSS can be [47]:

- Streamline stakeholders and user experiences.
- Reduce complexity, saving time, money and effort.
- Enhance accessibility to various digital services.
- Create greater trust. When a single partner centralizes processes and resources, coordinating all operations, relationships are simplified as there are only two parties involved, creating greater trust between them.
- Achieve better final results. There is more potential for innovation and achieving a unique end-result that is tailored to the user.

In the context of energy tools, the ENPOWER platform should enable individuals to simulate and optimize their energy consumption and production while offering comprehensive information and services for ambitious global energy renovation projects. Additionally, it should enable stakeholders to connect and discover new business opportunities. In this context, the authors of this document think energy OSSs might be the best way to cover these needs. Energy-related OSS typically cover the following services:

- **Information and resources**: Comprehensive information, guides, case studies, and best practices related to emissions reduction, renewable energy adoption, energy efficiency measures, sustainable transportation, waste management, and other key areas.
- **Tools and templates**: Access to tools, calculators, templates, and software to help citizens, stakeholders and energy communities assess their current emissions, set targets, develop action plans, track progress, and measure impact.
- **Expertise and support**: Opportunities for cities to connect with experts, consultants, and peer cities for advice, technical assistance, capacity building, and peer-to-peer learning.
- **Networking and collaboration**: Forums, webinars, workshops, and networking events to facilitate collaboration, knowledge sharing, and partnerships among cities, organizations, businesses, and stakeholders working towards common goals.

- **Policy and regulatory guidance**: Updates on relevant policies, regulations, incentives, and funding opportunities at the local, national, and international levels to support cities in their transition to net-zero emissions.

However, the scope of ENPOWER and the Decision Support Tool for Energy Community Planning is limited and among these services, some will be prioritized. A workshop or a survey could be performed to the stakeholders of the project to assess their needs.

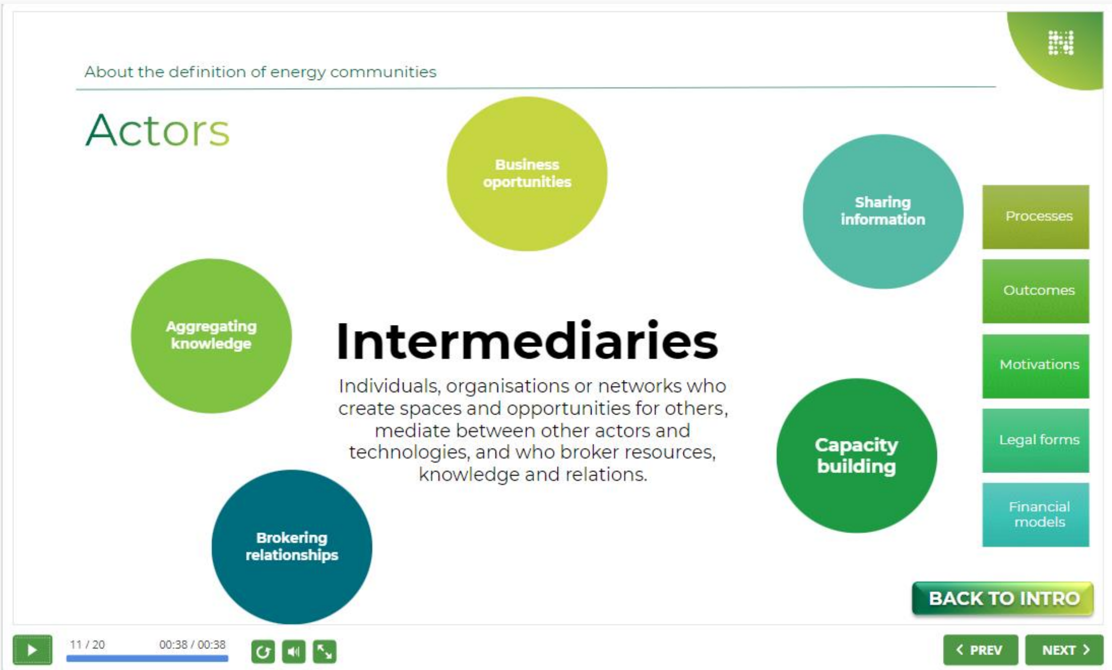


Figure 42. Our Energy OSS: Explanation of the intermediaries within Energy Communities to provide services.

Figure 43. Our Energy OSS: Diagram of Energy Communities as One-Stop Shops.

5.2.1 Benchmarking of One-Stop Shop tools (OSS)

Similarly, to the analysis of energy tools, a benchmarking study of OSS was conducted, specifically focusing on digital OSS centred on energy. As a result, it has been found that such initiatives are spreading in the energy sector; however, as of the time of writing this report, the examples are limited and in some cases are not specifically referred to as OSS. Below, some relevant examples are included.

5.2.2 Our Energy

Our Energy [48] is an online platform dedicated to educating and raising awareness about clean energy communities in Europe. It offers expert-reviewed multimedia content that covers social, economic, and regulatory aspects in just 10 to 15 minutes. The platform features educational and advisory presentations designed to enhance knowledge and provide practical guidance. Users can gain inspiration from real-world ideas and experiences shared by energy communities and researchers. By registering, users receive personalized content recommendations tailored to their interests.

One relevant feature is "Connect me," a page where you can discover and connect with energy stakeholders. All content is free and openly accessible, ensuring broad and inclusive access to valuable information.

Figure 44. Screenshot of "CONNECT ME" menu webpage from Our Energy website.

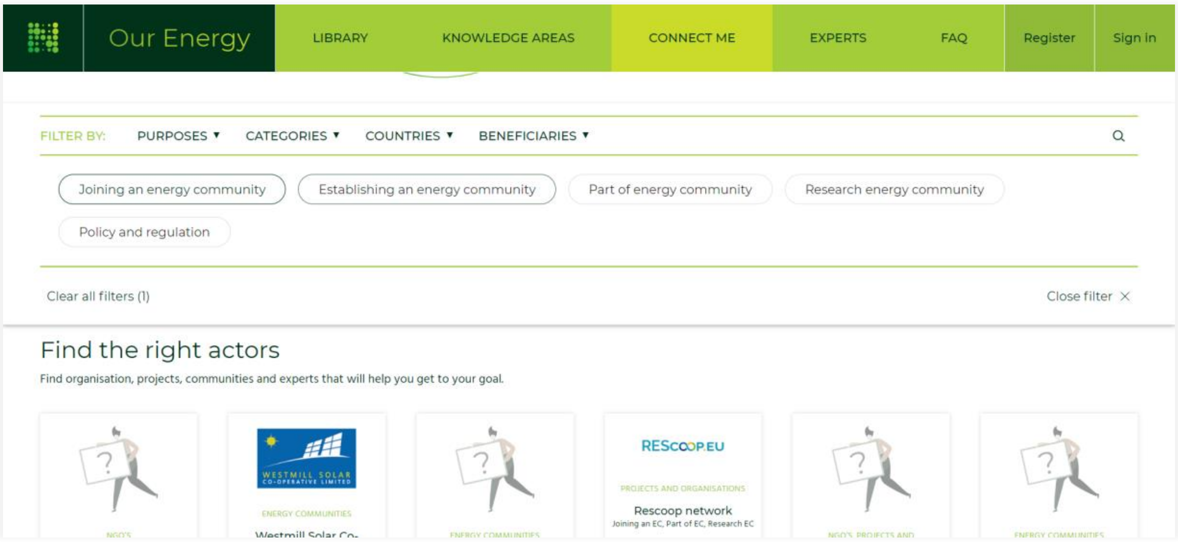


Figure 45. Screenshot of "CONNECT ME" directory webpage from Our Energy website.

5.2.3 Europa One Stop

Europa One Stop Shop [49]is a project committed to simplifying and enhancing deep renovations of residential buildings in different regions of Europe. Their vision revolves around creating safer, healthier, and more comfortable living spaces while minimizing the carbon footprint. The project aims to involve all stakeholders and experts in a transparent renovation process. The key points are:

- **Mission**: Europa brings together expertise from nine European partners to streamline deep renovations. They offer a better business model through regional One-Stop-Shops integrated with an Energy Efficiency Subscription model.
- **One-Stop-Shops**: These regional centres accelerate building renovation in pilot implementation regions across Italy, Germany, France, Portugal, and Latvia. Each One-Stop-Shop tailors the common objective to its specific context.
- **Resources Hub**: Europa provides project outcomes, deliverables, training materials, and related results to promote awareness and the benefits of energy-efficient deep renovations. The hub includes regional videos showcasing successful renovation projects

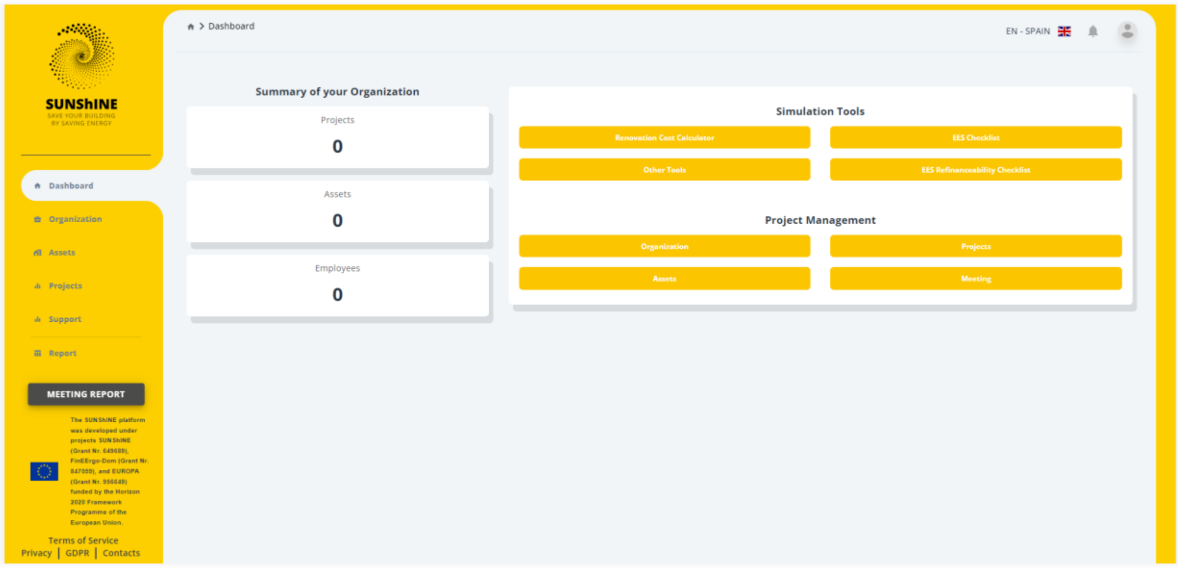


Figure 46. Screenshot of Europa One Stop webpage.

5.2.4 Net Zero Cities

Net Zero Cities [50] serves as a comprehensive resource for cities aiming to achieve climate neutrality by 2030. It aligns with the EU's Mission "100 Climate-Neutral and Smart Cities by 2030" and provides tailored expertise, services, and collaboration opportunities to empower cities in their pursuit of sustainable practices. Rather than navigating multiple sources, cities can find the necessary support and guidance within this initiative, making it a convenient "one-stop shop" for their climate ambitions.

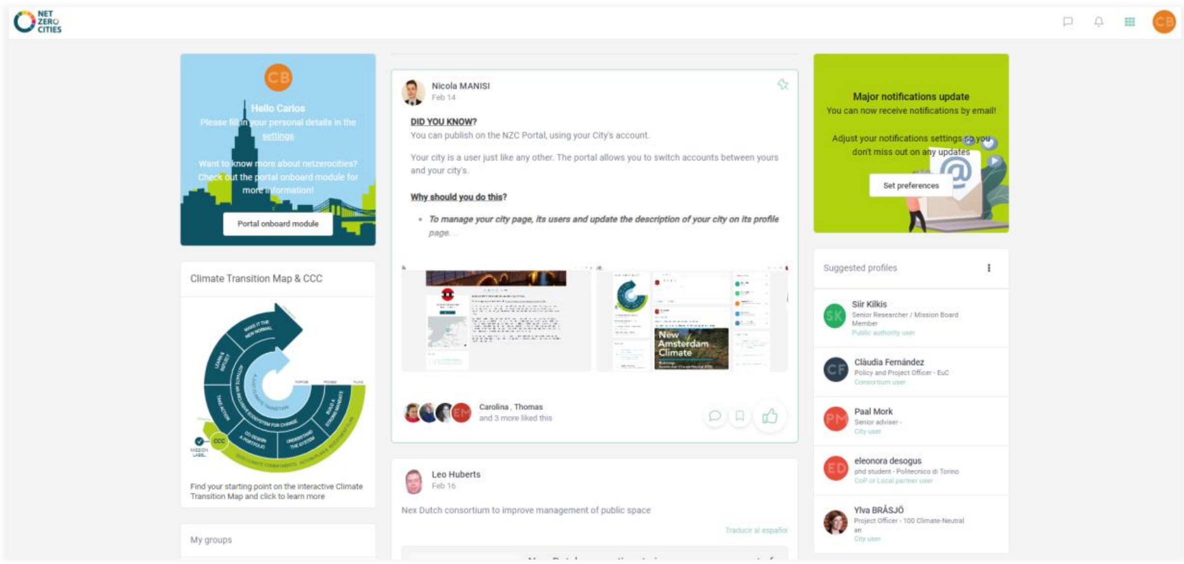


Figure 47. Screenshot of Net Zero Cities webpage.

5.2.5 SEAI ENERGY HUB

The SEAI (Sustainable Energy Authority of Ireland) Energy Hub [51] acts as a one-stop shop for sustainable energy information, making it easier for Irish individuals and businesses to access relevant content and stay informed about energy-related topics. The platform offers a variety of grants and funding supports for homes, businesses, and community projects, reducing the costs of energy efficiency improvements and renewable energy installations.

For homeowners, the Energy Hub provides insights into improving home energy efficiency, offering guidance on practical steps and upgrades. Community energy projects are also supported, empowering communities to implement sustainable energy solutions.

Businesses and the public sector can access resources to reduce energy costs and improve efficiency. The platform includes tools for analysing energy use and identifying savings opportunities.

Additionally, the Energy Hub features a comprehensive data and insights section, providing evidence-based research for informed decision-making. SEAI also promotes clean energy technologies, showcasing innovative projects that shape Ireland's energy future.

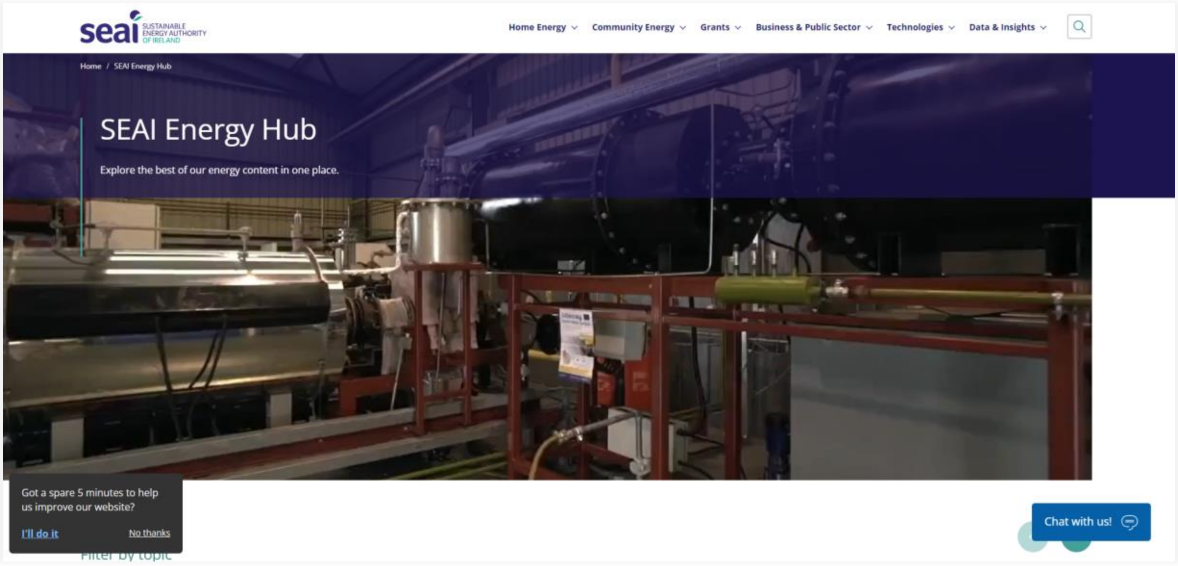


Figure 48. Screenshot of SEAI Energy Hub webpage.

ENERGY COMMUNITIES HUB

The Energy Communities Hub is a resource centre for RECs and CECs. This platform stands out due to its intuitive interface and user-friendly design, which make it easy to explore EC around the globe, analyse and compare regulations by country, and connect with other partners from the energy industry. It offers:

- Updated information about legal and policy changes affecting energy communities.
- Energy community initiatives comparisons across different countries to understand variations in regulations and best practices.

- Emerging Communities: allows the user to discover and collaborate with emerging energy communities based on EU definitions.

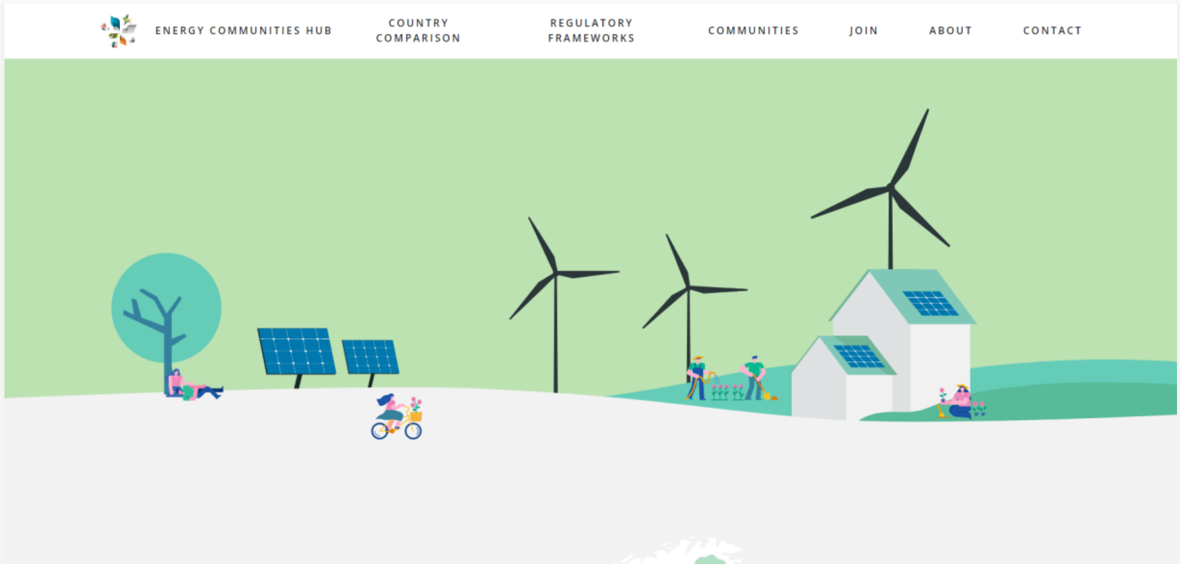


Figure 49. Screenshot of Energy Communities Hub webpage.

5.2.6 SOM COMUNITATS

Som Comunitat [52] is an energy one-stop shop offering expert guidance and resources for forming and managing energy communities. The platform provides tools for locating and joining local energy communities, educational content, advisory services, and personalized recommendations in the context of Spain. It supports users in navigating the social, economic, and regulatory aspects of clean energy projects, facilitating collaboration and knowledge sharing. Som Comunitat ensures broad access to valuable information, promoting sustainable energy practices and community empowerment.

Figure 50: Screenshot of the homepage from Som Comunitats webpage.

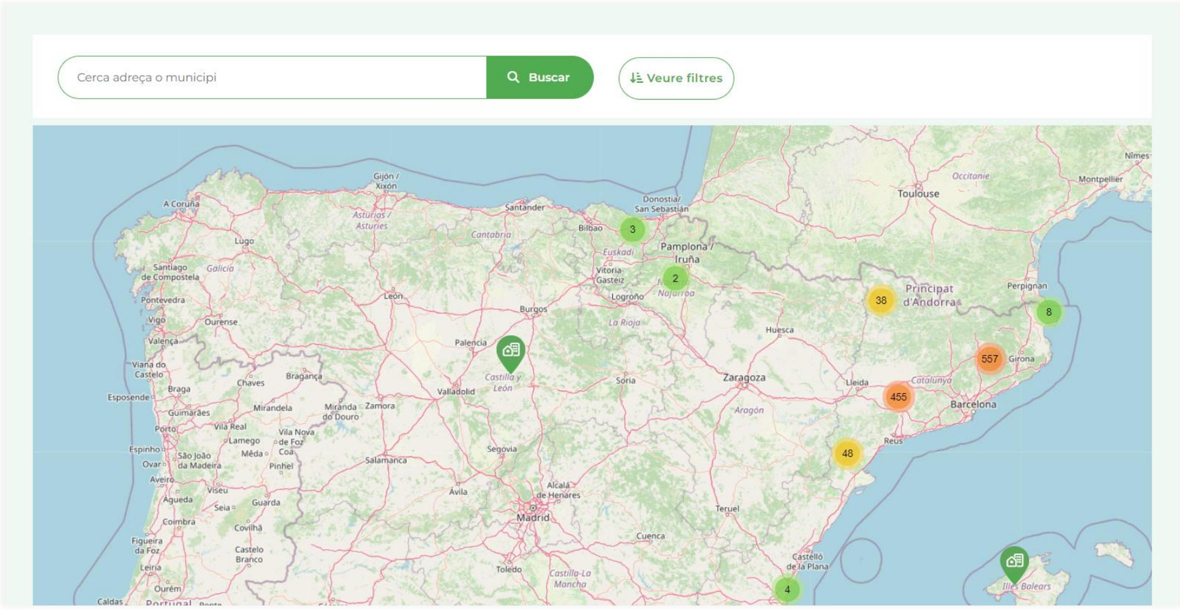


Figure 51. Screenshot of the map from Som Comunitats webpage.

5.2.7 Key takeaway from the benchmarking of OSS

The benchmarking study of digital energy OSS highlights the growing presence of these platforms within the energy sector, though the number of examples remains limited. Each reviewed platform offers unique functionalities designed to simplify access to energy-related information, support energy efficiency improvements, and foster community collaboration. These features make them valuable resources for individuals, businesses, and communities seeking to navigate the complexities of sustainable energy practices and find business partners and opportunities within the energy industry.

5.3 Preliminary definition of the Citizen view

As said, to use the standalone modules in section 4 users require coding experience. Thus, a user interface with two views to address the need of different users (citizens and stakeholders) are needed.

Regarding the Citizen View, it aims to facilitate the interaction and engagement of citizens within energy communities. This interface will be designed to empower citizens by providing them with the necessary tools and information to actively participate in and benefit from the community's energy activities. An intuitive, user-friendly experience will be emphasized, encouraging citizen involvement and enhancing their engagement in energy communities and understanding of energy consumption, production, and possible alternatives. The following draft specifications provide preliminary guidelines for the upcoming co-design processes, which will take place in the scope of Task 3.3. Therefore, while they will be used as a reference, these guidelines may be modified based on the co-creation outcomes.

5.3.1 Objectives

- **Ease of use**: Ensure the interface is simple and easy to navigate, allowing citizens of all ages and technical skills to use it effectively.

- **Transparency**: Provide clear and transparent information regarding estimates on energy consumption, production, and the financial benefits of participating in the energy community.
- **Engagement**: Encourage active participation by integrating features that allow citizens to explore and evaluate different energy alternatives for their community.
- **Education**: Offer educational resources to help citizens understand renewable energy, energy efficiency, and the benefits of energy communities.

5.3.2 Key Features

The expected key futures could include:

- **Community and personal results**: Data-based visualization of individual and community energy KPIs as consumption, production, financial savings, etc. Easy-to-understand clickable cards which graphs and charts to show historical and current data and citizen indicators.
- **Alternatives**: Highlight alternatives that have been simulated by the user or other community members, providing insights and comparisons.
- **Gamification features**: Include resources to enhance citizen engagement and encourage active participation on the platform, like progress bars and competition tables for energy goals.

Furthermore, the citizen view will enable users to either simulate the creation of a custom energy community tailored to their needs, allowing them to explore its operation before it is actually constituted, or register an already existing community on the platform for better collaborative management and decision-making of energy-related actions within the community. The possible to explore existing energy communities in their area that they might want to join will be explored in the project. This could allow them to contact communities through an integrated communication channel for a direct interaction.

As said in section 4, users will provide their energy goals they want to achieve and recommendations based on their community data and specified goals will be given, when data sharing rights are given by the users. From these recommendations, the tool will offer the analysis of different scenarios.

Relevant documents and resources both resulting from ENPOWER project and other projects and initiatives to promote the capacity building of users to understand energy data and the implications of taking part of an energy community well be included. Additionally, specific resources about the tool, such as step-by-step tutorials and guides on platform usage. This educational information will be also made available in the Value chain/Stakeholder View.

Another, key feature will be to include Frequently Answered Questions on ENPOWER Project and its decision support tool, as well as general aspects on energy or energy communities.

5.3.3 User Journey

Regarding the user journey, it is expected that the user will have three main uses: onboarding, daily use and long-term engagement. Below, a preliminary proposal of contents and features related to these uses are briefly described. Nevertheless, the actual user journey will be defined in following stages, considering the outcomes and inputs from the workshop sessions planned to be carried out within the project.

Onboarding:

- **Homepage**: Easy-to-understand page in which the ENPOWER Project is explained and a primary Call to Action (CTA) element can be found. This practice is part of the broader design strategy known as "Visual Hierarchy," where design elements are arranged to guide the user's attention to the most important actions or information on the page.
- **Welcome tour**: A guided tour to introduce new users to platform features and functionalities.

Daily Use:

- **Dashboard interaction**: Regular interaction with the dashboard to monitor individual and community KPIs, alternatives and gamification results.
- **Community participation**: Engage in community results, vote, and participate in alternative proposals.

Long-term Engagement:

- **Goal tracking**: The possibility of manually track energy goals and performance.
- **Learning and growth**: Ongoing education through platform resources, leading to increased energy literacy and informed participation.

5.4 Preliminary definition stakeholder view

Regarding the Stakeholder View within the ENPOWER project caters to the diverse needs of stakeholders involved in the energy community ecosystem, such as energy providers, community administrators, technology providers or financial institutions and regulators. This part of the tool aims to provide a platform for contact and collaboration of involved actors, sharing of best practices and fostering of capacity building, which aligns with the OSS concept outlined in Section 5.2.

The objectives of this Value chain/Stakeholder View are:

- **Connection and collaboration**: Facilitate a directory where different energy actors can explore and connect with other stakeholders, fostering business growth opportunities.
- **Expert assistance**: Connect energy stakeholders with expert contacts to facilitate the development of energy projects and enhance energy community performance.

From the above-mentioned features typically include in OSS, the following features will be considered:

- **Directory**: Comprehensive directory with detailed profiles for all stakeholders.
- **Collaboration**: Interactive portal for communication and collaboration among stakeholders. For instance, making available forums and webinars, to facilitate collaboration, knowledge sharing

- **Information and resources:** provide comprehensive information, guides, case studies, and best practices related to energy communities, covering topics such as emissions reduction, renewable energy adoption, energy efficiency measures, business models, and other key areas. A directory of the legal framework by country will be made available to support communities in their decision-making.
- **Tools**: Access to the ***Planning tool,*** to help citizens, and the surrounding stakeholders in energy communities assess their current emissions and future scenarios to assist in the decision-making.
- **Expertise and support**: Opportunities for communities to connect with experts, or dedicated support for advice, and technical assistance could be considered, especially during the scope of the project.

As a conclusion, this section has detailed the integration of services into the decision support tool, focusing on creating two distinct views for citizens and energy stakeholders. Through organized workshops and continuous testing, the tool aims to be intuitive and meet the diverse needs of its users. The ***Citizen/Consumer View*** will empower individuals to actively engage in energy communities by simulating alternatives and sharing knowledge, whereas the ***Value chain/Stakeholder View*** will support stakeholder collaboration through a One-Stop Shop model. A benchmarking study revealed that while existing tools offer valuable functionalities, they often lack features that promote citizen engagement and capacity building. Thus, the preliminary specifications outlined in this section are a starting point and may evolve through co-design and iterative processes to ensure the final tool is both user-friendly and effective in meeting its objectives.

6. Conclusions

The ENPOWER project aims to develop a comprehensive suite of tools and modules designed to optimize the performance of renewable energy systems within energy communities. By integrating various KPIs into the KPI module, the project ensures a thorough evaluation of technical, social, economic, and regulatory aspects, providing a holistic view of the energy community's performance. The heating and cooling assets and networks module, leveraging from the tool of REWARDHeat and LocalRES Project, focuses on optimizing the design and operation of decentralized heating and cooling systems and District Heating Networks (DHNs). Similarly, the electric assets module of INESC TEC is dedicated to the management and optimization of electricity generation, storage, and consumption, ensuring efficient use of renewable resources. All these three modules are part of the Planning tool, to help citizens, and the surrounding stakeholders in energy communities assess their current emissions and future scenarios to assist in the decision-making.

Section 3 shows the methodology followed to define the comprehensive KPI framework of ENPOWER project. These KPIs cover a wide range of dimensions, including technical, social, economic, environmental, data and regulatory aspects. Technical KPIs focus on metrics like energy performance, self-consumption ratios, and the efficiency of demand response services. Social KPIs measure aspects such as data transparency, community reinvestment from earnings, and the level of citizen engagement in energy activities. Economic KPIs assess financial indicators such as energy bill reductions, operational cost avoidance, and the overall return on investment for energy community projects. Environmental KPIs evaluate the performance in terms of GHG emissions, air quality index, and land use of energy. Data KPIs cover topics related to meters and use of data. Legal KPIs evaluate the extent to which local and national laws support the development and operation of energy communities. The integration of these KPIs into the KPI module enables a comprehensive analysis of various energy community configurations, providing valuable insights for joining an energy community.

Three main modules will be developed in WP3 in ENPOWER project. The document serves as a basis for the next months, covering the current status of the modules, the different inputs and outputs, and developments done so far.

Lastly, the UI development is covered in section 5. From the review of tools, it is seen the need for a dual focus, addressing both non-technical users and professionals in the energy sector. This review benchmarks existing tools to evaluate how well they support energy community planning, highlighting areas for improvement. One-stop shops are also reviewed to streamline the creation of the stakeholder-view. This view should be designed in a way that allows enhancing accessibility, creating greater trust, and delivering better results tailored to users.

The development of the decision support tool or Planning tool (TE-1) is a significant milestone in the project. It is designed to be user-friendly and accessible, with two distinct views catering to both citizens/consumers view and value chain energy stakeholders' view. The present report analyses the gaps from existing tools as well as the starting point of the different modules that will be integrated in the TE-1. The modification of the current CARTIF's databases, the development of the modules (with new features) and the organization of workshops are emphasized as next steps for WP3.

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Appendix A – Glossary

Action: an individual change in the community. Baseline (scenario): the current status of the energy system of the community. When a new installation is performed (in reality), the user can select a scenario, that has that installation, as their new baseline.

Benefit: an economic, social or environmental profit generated by services or actions performed by the community and addressed to energy community members, either directly or indirectly.

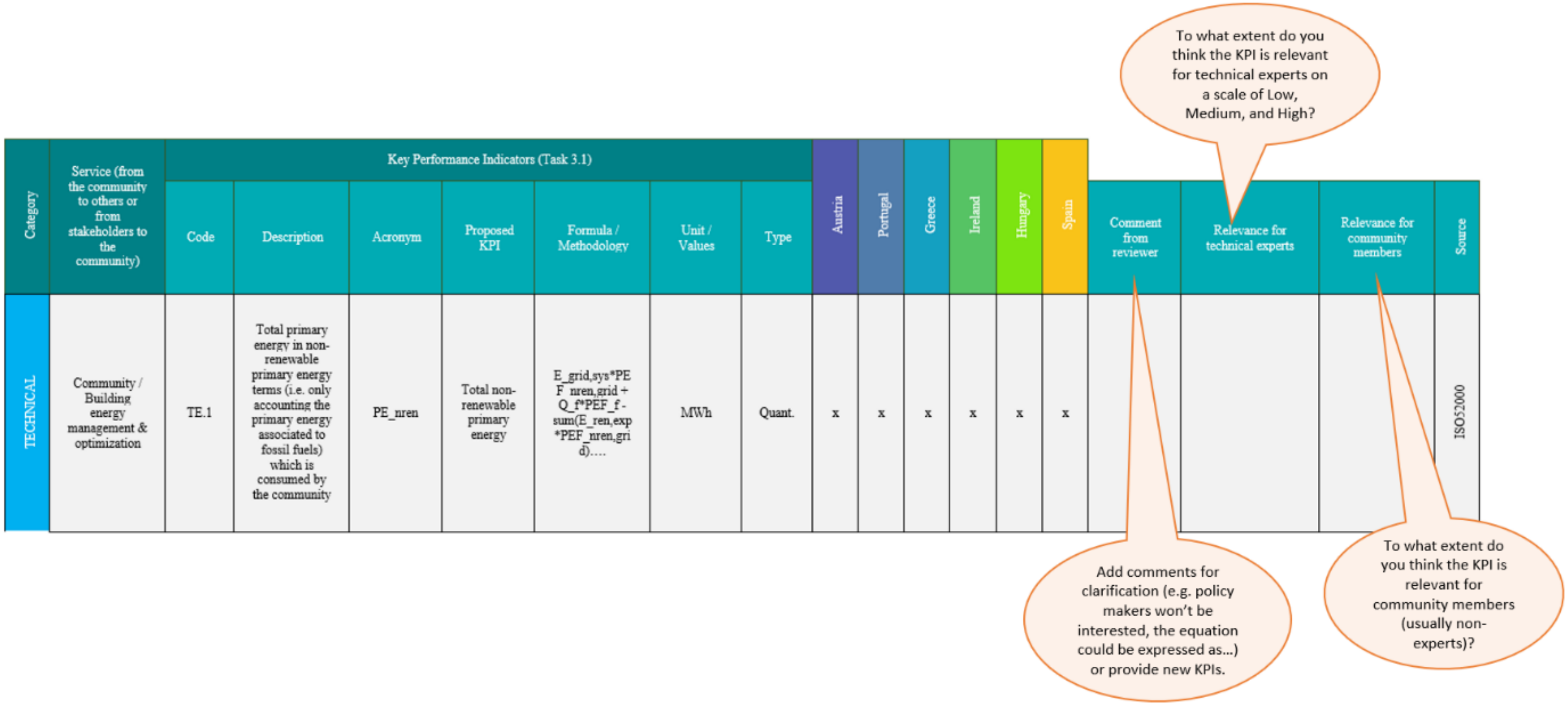
Bottom-up approach: modelling technique that represents mathematically a system component per component.

Modular approach: modelling technique of combining several components together in a module to allow interaction between components (e.g. PV system with a battery and a grid can form a module).

Scenario: state of a system under specific circumstances. Each change in a system -i.e. an action- or combination of actions that changes a system (e.g. a new renewable energy installation or a new member of a community) defines a different scenario.

Service: every activity offered by the community, either to their internal users (within the boundaries of the community), to external ones (e.g. third parties, market), or both (Source "D1.2 LocalRES") [1].

Appendix B – Preliminary KPIs list



Category	Service (from the community to others or from stakeholders to the community)	Key Performance Indicators (Task 3.1)							Austria	Portugal	Greece	Ireland	Hungary	Spain	Comment from reviewer	Relevance for technical experts	Relevance for community members	Source
		Code	Description	Acronym	Proposed KPI	Formula / Methodology	Unit / Values	Type										
TECHNICAL	Community / Building energy management & optimization	TE.1	Total primary energy in non-renewable primary energy terms (i.e. only accounting the primary energy associated to fossil fuels) which is consumed by the community	PE_nren	Total non-renewable primary energy	E_grid,sys*PEF_nren,grid + Q_f*PEF_f - sum(E_ren,exp*PEF_nren,grid)....	MWh	Quant.	x	x	x	x	x	x				ISO52000

Figure 52: Preliminary KPI template for partners' review.

Proposed KPI	STAKEHOLDER VIEW	CITIZEN VIEW
Total non-renewable primary energy	2.4	2.0
Total renewable primary energy	2.5	2.3
Total primary energy savings triggered by the project	3.0	2.6
Non-renewable primary energy savings triggered by the project	2.7	2.0
Renewable primary energy savings triggered by the project	2.4	2.1
Renewable Energy Ratio	2.8	2.5
Energy savings from the grid	2.6	2.5
External Energy consumption	2.5	1.9
Local energy exported	2.9	2.3
Energy Curtailment of RES/DES	2.7	2.0
Self-consumption ratio	2.9	2.8
Community self-sufficiency ratio	2.9	2.8
Thermal energy use	2.4	2.1
Installed capacity of RES (thermal)	2.4	1.8
Cumulative Thermal ESS capacity	2.6	1.8
Share of RES for thermal use	2.7	2.4
Time outside of Heating Comfort	2.1	1.6
Time outside of Cooling Comfort	2.1	1.6
Technology thermal intensity	2.6	2.1
RES thermal intensity	2.4	2.0
Reduction of wasted energy in form of WH	2.2	1.9
Heat Recovery Ratio	2.5	1.7
Deviation in thermal energy demand during the peak hours (demand response event) through P2H and H2P	2.9	1.6
Traded volumes in energy markets (sold or bought)	2.6	1.7
Loss of load time to withstand a potential blackout using available flexibility	2.5	1.8
Backup power supplied during blackouts	2.1	1.5
Grid congestion	2.9	1.7
Peak Load Reduction	2.9	1.7
Time during which the network frequency is out of the nominal operating values	2.4	1.0
Frequency deviation ratio (FDR)	2.6	1.1
Number of events in which the REC has been involved (within the REC, or in the main grid)	2.4	1.3
Difference of energy use from a conventional system (without optimal energy flows).	2.7	1.8

LEGEND	
3	High Relevance
2	Medium Relevance
1	Low Relevance

Proposed KPI	STAKEHOLDER VIEW	CITIZEN VIEW
Amount of energy exchanged by means of P2P energy trading	2.7	2.1
Number of users involved in P2P energy trading	2.5	2.2
Energy consumption of the public EV chargers	3.0	1.7
Storage capacity of the PEV batteries offered through V2G service	2.8	1.5
Electricity consumption of the e-buses or e-boats in the community	2.4	1.6
Electricity self-consumption	3.0	2.6
Voltage deviation ratio (VDR)	2.6	1.2
Cumulative Electrical ESS capacity	2.8	2.3
Installed capacity of RES (electrical)	2.8	2.3
Equivalent food (nº of pizzas in the oven) thanks to energy savings	1.4	2.4
Equivalent hours of streaming thanks to energy savings	1.5	2.3
GHG emissions reduction	2.5	2.5
Air Quality Index	1.8	2.1
Noise pollution variation	1.6	2.1
Land use for energy	1.9	2.0
Equivalent trees planted (thanks to CO2eq saved)	1.5	2.3
Equivalent number of flights (thanks to CO2eq saved)	1.3	1.9
Energy bills' reduction	2.5	3.0
Operational Costs Avoidance	2.7	2.2
Levelised Cost of Electricity	2.7	2.4
Levelised Cost of Heat	2.5	2.2
Capital expenditure	2.6	2.8
Operational expenditure	2.6	2.2
Maintenance costs	2.5	2.0
Financing costs	2.6	2.4
Contribution to total spend	2.2	2.8
Net Present Value	2.6	2.3
Economic earnings associated to participating in a specific service	2.5	2.5
Life-cycle cost of energy generation	2.5	1.8
Internal Rate of Return (IRR)	2.8	2.1
Payback Period	2.9	2.7
Social Economic/prosperity indicator	2.6	2.0
User monetary savings in electricity bill	2.5	3.0
Number of members constituting the REC	2.5	2.4
Number of participants in activities associated to the REC (members or not)	2.4	2.5
Numbers of members of the REC within energy poverty threshold	2.6	2.2

Proposed KPI	STAKEHOLDER VIEW	CITIZEN VIEW
Share of buildings with EPC at each grade	2.5	1.6
Persons or households under the poverty threshold	2.6	2.2
Number of households in discomfort	2.4	2.0
Energy expenditure to income ratio	2.6	1.6
Level of social acceptance of REC projects in the community	2.6	2.1
Gender	1.9	1.2
Age	2.2	1.5
Education level	2.1	1.4
Occupation	2.1	1.5
Nationality	2.0	1.4
Composition of the household	2.3	1.7
Average Income	2.1	1.5
User acceptance	2.6	2.3
Education	2.3	2.0
Data transparency	2.4	2.8
Overall Satisfaction	2.3	2.4
Jobs created (direct)	2.0	2.4
Jobs created (indirect)	2.0	2.4
Investments made from earnings of the community	2.1	2.7
ICT annual energy consumption	2.2	1.4
The ratio of data to errors	2.7	1.1
Number of external suppliers with access to personal/sensitive data	2.7	2.6
Time-to-value	2.6	1.2
Legal Framework on Energy Communities	2.8	2.5
Collective Self-Consumption	2.8	2.5
Local grid balancing legal framework development	2.6	2.0
Legal framework on Micro-Grids	2.6	2.0
Suitable Energy Storage Regulation	2.6	2.0

KPI list with a relevance score greater than 2.5 according to partners (ordered from greatest to lowest score):

- Total primary energy savings triggered by the project
- Energy consumption of the public EV chargers
- Electricity self-consumption
- Local energy exported
- Self-consumption ratio
- Community self-sufficiency ratio
- Payback Period
- Grid congestion
- Peak Load Reduction
- Deviation in thermal energy demand during the peak hours (demand response event) through P2H and H2P
- Renewable Energy Ratio.
- Internal Rate of Return (IRR)
- Storage capacity of the PEV batteries offered through V2G service
- Cumulative Electrical ESS capacity
- Installed capacity of RES (electrical)
- Legal Framework on Energy Communities
- Collective Self-Consumption legal framework
- Non-renewable primary energy savings triggered by the project
- Difference of energy use from a conventional system (without optimal energy flows).
- Amount of energy exchanged by means of P2P energy trading
- Operational Costs Avoidance
- Levelised Cost of Electricity
- Share of RES for thermal use
- The ratio of data to errors
- Number of external suppliers with access to personal/sensitive data
- Local grid balancing legal framework development
- Legal framework on Micro-Grids
- Suitable Energy Storage Regulation

- Time-to-value

For citizens:

- Energy bills' reduction
- User monetary savings in electricity bill
- Self-consumption ratio
- Community self-sufficiency ratio
- Contribution to total spend
- Data transparency
- Capital expenditure
- Investments made from earnings of the community
- Payback Period
- Total primary energy savings triggered by the project
- Electricity self-consumption
- Number of external suppliers with access to personal/sensitive data
- Legal framework on Energy Communities
- Legal framework on Collective Self-Consumption

From the citizen list, the KPIs that are not in the stakeholder list are the following:

- Energy bills' reduction
- User monetary savings in electricity bill
- Contribution to total spend
- Data transparency
- Capital expenditure
- Investments made from earnings of the community

Workshop details

Main outcomes per area are listed below.

- **Tool usage**

Metrics such as "time spent", "individual and aggregated results", or "feedback" to the tool which could include "likes" or tool rating. Other engagement metrics could include number of users registered per community, number of scenarios performed by each user or by the community, which could be measured too with the individual and aggregated results.

Challenges might include: time-consuming usage, engagement, tool or energy literacy, as well as GDPR issues on the results, gamification strategies to increase engagement, the measurement of user navigation (which leads to GDPR issues), or the added value provided compared to other tools.

- **Energy literacy**

Metrics for this case might include measuring the navigation through different articles and webpage information; this could allow ranking articles based on their technical complexity or their relevance to community goals.

Challenges might include the use of technical language or topics that could limit the target group.

- **Energy usage questionnaires**

Metrics for this activity might include the percentage of completion, the number of attempts to retake tests for better scores on the ranking of the community, and the time spent on questionnaires to indicate engagement.

Challenges might include the time-consuming usage, the use of technical language or topics, and finding the right frequency (too high can cause annoyance, while too low can lead to disengagement). There may also be issues with participants providing random answers or manipulating responses to achieve a better rank.

- **Contribution to the community**

Metrics for this activity might include the active participation data like the number of attended assemblies or the number of created scenarios on the tool. Additionally, fostering a community feeling, including a regional focus, and tailoring content to meet specific needs are essential. Having a hero, champion, or role model can also enhance engagement and motivation within the community.

Challenges might include the user’s limited time for participating limited benefits from the participation to REC activities or high participation fees. It is crucial to include both individual and aggregated results to understand the average perception from the whole community rather than just single citizens.

	Citizen Journey indicators	Data needs	Risks & challenges
Tool usage / engagement	Irish: join and demonstrate active engagement Austrian: Goals and feedback Austrian: Individual and aggregated results Spain: join and demonstrate active engagement Hungary: time spent Hungary: join and demonstrate active engagement->tool interaction and feedback (likes) Greek: tool rating (1-5)	Irish: % on registration Austrian: Goals and feedback Spain: % on registration Portugal: Most used features Portugal: % on registration Hungary: time spent Hungary: Duality of interaction (forced results)	Irish: aggregated measures/results Irish: Process/Journey too simple Austrian: Tool too complicated Spain: Tool too complicated Spain: gamification -> time consuming Portugal: Tool too complicated Portugal: Slow data refresh Greek: Random/Duality of interaction (forced results) Greek: Tool too complicated
Energy literacy	Irish: Navigate large volumes of info Austrian: non-technical language Austrian: customized content Spain: Navigate large volumes of info Spain: rank articles based on compleixity Hungary: Goals and feedback (rank to be compared with other users)	Hungary: Number of downloads of articles	Austrian: Too technical language or topics Spain: Too technical language or topics Portugal: Too technical language or topics Hungary: limited target group
Energy usage questionnaires	Austrian: Clear purpose Spain: Find the right frequency (high/low) Spain: periodic Spain: time spent Portugal: Periodic Portugal: consumption habits Hungary: Goals and feedback Greek: consumption habits	Austrian: alternatives approaches like workshops or events Portugal: % completion Hungary:% completion Hungary: retake test to improve ranking Greek: energy assets and RES production prediction	Austrian: Find the right frequency (high/low) Austrian: Too technical language or topics Spain: Random/Duality of interaction (forced results) Portugal: Random/Duality of interaction (forced results) Portugal: time consuming Hungary: Find the right frequency (high/low)-> annoyance Hungary: limited target group Greek: Random/Duality of interaction (forced results)
Contribution to the community	Austrian: Individual and aggregated results Austrian: democratic structure, you need hero/champion/role model Spain: join and demonstrate active engagement Hungary: Existence of rentention strategy Hungary: join and demonstrate active engagement->assemblies attended	Austrian: tailoring needs Portugal: participation data/members Hungary: participation data/members Greek: participation data/members	Austrian: wrong expectation Spain: time consuming Spain: aggregated measures/results Spain: limited benefits or high participation fees Hungary: low engagement/negative attitude

Figure 53: Main results per pilot for Citizen Journey Indicators.

Nº	Green hat	Nº	White hat	Nº	Black hat
3	Join and demonstrate active engagement	3	% on registration	4	Tool too complicated
2	Goals and feedback (rank to be compared with other users)	3	Participation data/members	4	Random/duality of interaction (forced results)
2	Individual and aggregated results	2	% completion	4	Too technical language or topics
2	Navigate large volumes of info	1	Most used features	3	Find the right frequency (high/low)
2	Periodic	1	Time spent	3	Gamification -> time consuming
2	Consumption habits	1	Number of downloads of articles	2	Aggregated measures/results
2	Tool rating (1-5) / articles based on complexity	1	Retake test to improve ranking	2	Limited target group
1	Non-technical language	1	Energy assets and res production prediction	1	Process/journey too simple
1	Customized content	1	Tailoring needs	1	Slow data refresh
1	Clear purpose			1	Wrong expectation
1	Democratic structure, you need hero/champion/role model			1	Limited benefits or high participation fees
1	Existence of retention strategy			1	Low engagement/negative attitude

Figure 54: Most common results for Citizen Journey Indicators

Appendix C– Possible Appendix for KPI framework as the sum of summary tables

Social KPIs

SOC.01 - DATA TRANSPARENCY (DT)

KPI CODE	SOC.01 - DT	
Definition	**Data transparency**	
Description	Transparency about what kind and amount of user data is collected, stored and analysed.	
Type	Qualitative	
Calculation	Questionnaire	
Unit of measurement	Likert Scale	
Level of aggregation	*Single citizen* or *Building* or *Energy Community*	
	Citizen View	Stakeholder View

SOC.02 - INVESTMENTS MADE FROM EARNINGS OF THE COMMUNITY (REINV)

KPI CODE	SOC.02 - REINV	
Definition	**Investments made from earnings of the community**	
Description	Total value of financial investments or capital expenditures derived from the earnings or profits of the community.	
Type	Qualitative	
Calculation	Count/Questionnaire	
Unit of measurement	Likert Scale € or %	
Level of aggregation	*Single citizen* or *Building* or *Energy Community*	
	Citizen View	Stakeholder View

SOC.03 – ENERGY-ACTIVATED CITIZENS (EAC)

KPI CODE	SOC.03 - EAC
Definition	**Energy-activated Citizens**

Description	Level of social acceptance of REC projects in the community.	
Type	Quantitative	
Calculation	$$EAC = \sum w_i \cdot ED_i$$	
Unit of measurement	Likert Scale	
Level of aggregation	Single citizen or Energy Community	
	Citizen View	Stakeholder View

SOC.04 - USER ACCEPTANCE (UA)

KPI CODE	SOC.04 - UA	
Definition	**User acceptance**	
Description	Indicator aggregating perceived usefulness, ease of use and behaviour within the app/dashboard.	
Type	Qualitative	
Calculation	Questionnaire	
Unit of measurement	Likert Scale	
Level of aggregation	*Single citizen* or *Building* or *Energy Community*	
	Citizen View	Stakeholder View

Technical KPIs

TE.01 AND TE.02 – TOTAL AND NON-RENEWABLE PRIMARY ENERGY SAVINGS TRIGGERED BY THE PROJECT

KPI CODE	TE.01 - PES
Definition	**Total primary energy savings triggered by the project**
Description	Difference in primary energy (expressed in total terms, i.e. the renewable and non-renewable part) consumed by the members of the community before and after the creation of the REC.
Type	Quantitative
Calculation	

	$$PES = \frac{(PE_{tot\_bef} - PE_{tot\_scen,x})}{PE_{tot,bef}}$$	
Unit of measurement	%	
Level of aggregation	Energy Community	
	Citizen View	Stakeholder View

KPI CODE	**TE.02 – PES_{nren}**	
Definition	**Non-renewable primary energy savings triggered by the project**	
Description	Difference in primary energy (expressed in non-renewable terms) consumed by the members of the community before and after the creation of the REC.	
Type	Quantitative	
Calculation	$$PES = \frac{(PE_{nren\_bef} - PE_{nren\_scen,x})}{PE_{nren,bef}}$$	
Unit of measurement	%	
Level of aggregation	Energy Community	
	Citizen View	Stakeholder View

TE.03 - RENEWABLE ENERGY RATIO (RER)

KPI CODE	**TE.03 - RER**
Definition	**Renewable Energy Ratio**
Description	Renewable energy ratio is the amount of renewable primary energy that is used within the system's boundaries out of the total primary energy used. Can be compared before and after setting the energy community.
Type	Quantitative
Calculation	

	$$RER = \frac{\left(\frac{PE_{ren}}{PE_{tot}}\right)_{scen,x} - \left(\frac{PE_{ren}}{PE_{tot}}\right)_{bef}}{\left(\frac{PE_{ren}}{PE_{tot}}\right)_{bef}}$$	
Unit of measurement	%	
Level of aggregation	*Single citizen* or *Building* or *Energy Community*	
	Citizen View	Stakeholder View

TE.04 - LOCAL ENERGY EXPORTED

KPI CODE	**TE.04 - $E_{*,exp}$**	
Definition	**Local energy exported**	
Description	Amount of energy exported by the community to the grid relative to all locally generated energy. All energy that is generated locally and cannot be consumed within 15 minutes is exported.	
Type	Quantitative	
Calculation	$$E_{*,exp} = E_{RES,*} - E_{RES,sys}$$	
Unit of measurement	kWh	
Level of aggregation	Energy Community	
	Citizen View	Stakeholder View

TE.05 - SELF-CONSUMPTION RATIO (SCR)

KPI CODE	**TE.05 - SCR**
Definition	**Self-consumption ratio**
Description	The indicator measures how much of the total local renewable generation is used within the community boundaries and therefore could be helpful in optimizing the timing of energy-intensive activities, so that they match periods of high RES generation. On the other side, the KPI helps in the sizing of storage solutions, as a low SCR could mean that a large amount of RES generation out of the total is not consumed locally end therefore exported. This

	indicator should be calculated separately for electricity and heat.
Type	Quantitative
Calculation	$$SCR = \frac{E_{RES,sys}}{E_{RES,*}}$$
Unit of measurement	%
Level of aggregation	Energy Community
	Citizen View Stakeholder View

TE.06 - COMMUNITY SELF-SUFFICIENCY RATIO (SSR)

KPI CODE	TE.06 - SSR
Definition	**Community self-sufficiency ratio**
Description	Amount of locally consumed renewable energy relative to all consumed energy. Locally consumed renewable energy is the actual energy from local RES production that feeds into the demand (i.e. amount that is self-consumed and therefore non-exported energy, non-imported from the grid), which can be calculated as the sum over all 15-minute time slots of the minimum between the renewable energy production and consumed energy in each time slot.
Type	Quantitative
Calculation	$$SSR = \frac{E_{RES,sys}}{E_{*,sys}}$$
Unit of measurement	%
Level of aggregation	Energy Community
	Citizen View Stakeholder View

TE.07 - RES PENETRATION FOR COVERING THERMAL USE (RER_{th})

KPI CODE	TE.07 – RER_{th}
Definition	**RES penetration for covering thermal use**

Description	Share of RES for thermal use.	
Type	Quantitative	
Calculation	$$RER_{th} = \frac{Q_{RES,sys}}{Q_{*,sys}}$$	
Unit of measurement	%	
Level of aggregation	*Single citizen* or *Building* or *Energy Community*	
	Citizen View	Stakeholder View

TE.08 – THERMAL DEMAND RESPONSE DEVIATION

KPI CODE	**TE.08 - $\Delta Q_{DRevent}$**	
Definition	**Thermal demand response deviation**	
Description	Deviation in thermal energy demand during the peak hours (demand response event) through P2H and H2P.	
Type	Quantitative	
Calculation	$$\Delta Q_{DRevent} = Q_{needs,bef} - Q_{needs,DRevent}$$	
Unit of measurement	MWh or %	
Level of aggregation	*Single citizen* or *Building* or *Energy Community*	
	Citizen View	Stakeholder View

TE.09 - GRID CONGESTION (GC)

KPI CODE	**TE.09 - GC**
Definition	**Grid congestion**
Description	The difference between the energy curtailments before and after the integration of a/all the proposed solutions.
Type	Quantitative
Calculation	

	$$GC = \frac{\left(E_{RES,curtailed\_bef} - E_{RES,curtailed\_scen,x}\right)}{E_{RES,curtailed\_bef}}$$
Unit of measurement	%
Level of aggregation	*Single citizen* or *Building* or *Energy Community*
	Citizen View / Stakeholder View

TE.10 - PEAK LOAD REDUCTION (PLR)

KPI CODE	TE.10 - PLR
Definition	**Peak Load Reduction**
Description	The indicator compares the peak use before the aggregator implementation (baseline) with the peak use after; per final consumer, per feeder, per network.
Type	Quantitative
Calculation	Formula
Unit of measurement	%
Level of aggregation	*Single citizen* or *Building* or *Energy Community*
	Citizen View / Stakeholder View

TE.11 – DIFFERENCE OF ENERGY USE FROM A CONVENTIONAL SYSTEM (WITHOUT OPTIMAL ENERGY FLOWS)

KPI CODE	TE.11 - ΔE_{conv}
Definition	
Description	Variation in energy consumption between the system in normal conditions and the system in optimal conditions (using smart devices).
Type	Quantitative
Calculation	$$\Delta E_{conv} = \frac{\left(E_{*,bef} - E_{*scen,smart\ devices}\right)}{E_{*,bef}}$$
Unit of measurement	%

Level of aggregation	*Single citizen* or *Building* or *Energy Community*	
	Citizen View	Stakeholder View

TE.12 – AMOUNT OF ENERGY EXCHANGED BY MEANS OF P2P ENERGY TRADING (E_{P2P})

KPI CODE	TE.12 – E_{P2P}	
Definition	**Amount of energy exchanged by means of P2P energy trading**	
Description	Measures the volume of energy traded directly between users within a Peer-to-Peer (P2P) energy trading system.	
Type	Quantitative	
Calculation	Meters	
Unit of measurement	MWh	
Level of aggregation	*Single citizen* or *Building* or *Energy Community*	
	Citizen View	Stakeholder View

TE.13 - ENERGY CONSUMPTION OF THE PUBLIC EV CHARGERS (E_{EV})

KPI CODE	TE.13 - E_{EV}	
Definition	**Energy consumption of the public EV chargers**	
Description	Amount of electricity consumed by Electric Vehicle (EV) chargers installed in the community.	
Type	Quantitative	
Calculation	Meters	
Unit of measurement	MWh	
Level of aggregation	*Single citizen* or *Building* or *Energy Community*	
	Citizen View	Stakeholder View

TE.14 – STORAGE CAPACITY OF THE PEV BATTERIES OFFERED THROUGH V2G SERVICE (E_{PEV})

KPI CODE	TE.14 - E_{PEV}
Definition	**Storage capacity of the PEV batteries offered through V2G service**

Description	The indicator represents the total energy storage capacity of Plug-in Electric Vehicle (PEV) batteries utilized in Vehicle-To-Grid (V2G) services.	
Type	Quantitative	
Calculation	Questionnaire	
Unit of measurement	kWh	
Level of aggregation	*Single citizen* or *Building* or *Energy Community*	
	Citizen View	Stakeholder View

TE.15 – ELECTRICITY SELF-CONSUMPTION

KPI CODE	TE.15 - ESC	
Definition	**Electricity self-consumption**	
Description	Ratio between the overall electrical energy that is self-consumed within the assessment boundaries and the total production within the assessment boundaries.	
Type	Quantitative	
Calculation	$$ESC = \frac{E_{RES,sys}}{E_{RES,*}}$$	
Unit of measurement	%	
Level of aggregation	Energy Community	
	Citizen View	Stakeholder View

TE.16 – CUMULATIVE ELECTRICAL ESS CAPACITY

KPI CODE	TE.16 – $E_{ESS,capacity}$
Definition	**Cumulative Electrical ESS capacity**
Description	The total amount of electrical energy storage capacity connected to the system.
Type	Quantitative
Calculation	Questionnaire
Unit of measurement	kWh

Level of aggregation	*Single citizen* or *Building* or *Energy Community*	
	Citizen View	Stakeholder View

TE.17 – INSTALLED CAPACITY OF ELECTRICAL RES

KPI CODE	**TE.17 - $E_{RES,capacity}$**	
Definition	**Installed capacity of electrical RES**	
Description	The total amount of electrical RES capacity installed in the community.	
Type	Quantitative	
Calculation	Questionnaire	
Unit of measurement	kW	
Level of aggregation	Energy Community	
	Citizen View	Stakeholder View

Financial KPIs

EC.01 – ENERGY BILLS' REDUCTION (f_{CBR})

KPI CODE	**EC.01 - f_{CBR}**	
Definition	**Energy bills' reduction**	
Description	Economic saving in the energy bills for the citizens after setting the energy community.	
Type	Quantitative	
Calculation	$$f_{CBR} = EC_{bef} - EC_{scen,x}$$	
Unit of measurement	€ or %	
Level of aggregation	*Single citizen* or *Building* or *Energy Community*	
	Citizen View	Stakeholder View

EC.02 – OPERATIONAL COSTS AVOIDANCE (OCA)

KPI CODE	**EC.02 - OCA**

Definition	**Operational costs avoidance**	
Description	Variation in the operational expenditure in the community after an action is applied.	
Type	Quantitative	
Calculation	$$OCA = OPEX_{bef} - OPEX_{scen,x}$$	
Unit of measurement	€	
Level of aggregation	*Single citizen* or *Building* or *Energy Community*	
	Citizen View	Stakeholder View

EC.03 – LEVELISED COST OF ELECTRICITY (LCoE)

KPI CODE	**EC.03 - LCoE**	
Definition	**Levelised cost of electricity**	
Description	Average total cost to build and operate a power-generating asset over its lifetime divided by the total energy output of the same asset over its lifetime.	
Type	Quantitative	
Calculation	$$LCoE = \frac{C_0 - S_0 + S_D + \sum_{t=1}^{T} \frac{C_t}{(1+r)^t}}{\sum_{t=1}^{T} \frac{E_t}{(1+r)^t}}$$	
Unit of measurement	€/kWh	
Level of aggregation	Single asset	
	Citizen View	Stakeholder View

EC.04 – CAPITAL EXPENDITURE (CAPEX)

KPI CODE	**EC.04 - CAPEX**
Definition	**Capital expenditure**
Description	Investment cost for a new scenario, intended as a set of interventions in the community.

Type	Quantitative	
Calculation	$$CAPEX = \sum_{n=1}^{N} CAPEX_{tech,n}$$	
Unit of measurement	€	
Level of aggregation	*Single citizen* or *Building* or *Energy Community*	
	Citizen View	Stakeholder View

EC.05 – CONTRIBUTION TO TOTAL SPEND (S)

KPI CODE	**EC.05 - S**	
Definition	**Contribution to total spend**	
Description	Measures how the monetary resources are shared among the citizens in the community.	
Type	Quantitative	
Calculation	Formula	
Unit of measurement	%	
Level of aggregation	Single citizen or Building	
	Citizen View	Stakeholder View

EC.06 – INTERNAL RATE OF RETURN (IRR)

KPI CODE	**EC.06 - IRR**
Definition	**Internal Rate of Return**
Description	The interest rate at which the NPV of the investment is zero.
Type	Quantitative
Calculation	$$IRR \text{ so that } NPV = \sum_{t=1}^{T} \frac{C_t}{(1+IRR)^t} - C_0 = 0$$
Unit of measurement	%
Level of aggregation	*Single citizen* or *Building* or *Energy Community*

	Citizen View	Stakeholder View

EC.07 – PAYBACK PERIOD (PB)

KPI CODE	EC.07 - PB	
Definition	**Payback Period**	
Description	The period of time needed for the cumulative gains from an investment to equal the cumulative cost.	
Type	Quantitative	
Calculation	$$PB = \frac{(CAPEX + OPEX)}{C_t}$$	
Unit of measurement	Years	
Level of aggregation	*Single citizen* or *Building* or *Energy Community*	
	Citizen View	Stakeholder View

Environmental KPIs

ENV.01 – GHG EMISSIONS REDUCTION (GHG_{sav})

KPI CODE	ENV.01 – GHG_{SAV}	
Definition	**GHG Emissions reduction**	
Description	Variation of the total CO_2eq emissions of greenhouse gases emitted for all energy carriers.	
Type	Quantitative	
Calculation	$$GHG_{sav} = \sum_{f=1}^{F_{bef}} GHG_{f,bef} - \sum_{f=1}^{F_{scen,x}} GHG_{f\_scen,x}$$	
Unit of measurement	tCO_2e	
Level of aggregation	*Single citizen* or *Building* or *Energy Community*	
	Citizen View	Stakeholder View

ENV.02 – AIR QUALITY INDEX (AQI_P)

KPI CODE	ENV.02 - AQI_p	
Definition	**Air Quality Index**	
Description	Level of air pollution for a specific pollutant in the range 0 to 500 (low to high level of concern).	
Type	Quantitative	
Calculation	$$AQI_P = \frac{I_{Hi} - I_{Lo}}{BP_{Hi} - Bp_{Lo}} \cdot (C_P - BP_{Lo}) + I_{Lo}$$	
Unit of measurement	-	
Level of aggregation	Energy Community	
	Citizen View	Stakeholder View

ENV.03 – LAND USE FOR ENERGY (LU)

KPI CODE	ENV.03 - LU	
Definition	**Land use for energy**	
Description	Proportional land area occupied by the energy production units in the REC area without considering rooftop solar (as the building would anyway occupy that land).	
Type	Quantitative	
Calculation	Equipment datasheet or estimation from average values per technology.	
Unit of measurement	m^2/MW	
Level of aggregation	*Single citizen* or *Building* or *Energy Community*	
	Citizen View	Stakeholder View

Information and Communication Technology KPIs

ICT.01 – RATIO OF DATA-TO-ERRORS (DTOERR)

KPI CODE	ICT.01 - DTOERR
Definition	**Ratio of data-to-errors**
Description	Relation between data points showing errors and empty values.

Type	Quantitative	
Calculation	$$DTOERR = \frac{Errors}{Items}$$	
Unit of measurement	%	
Level of aggregation	*Single citizen* or *Building* or *Energy Community*	
	Citizen View	Stakeholder View

ICT.02 – NUMBER OF EXTERNAL SUPPLIERS WITH ACCESS TO PERSONAL/SENSITIVE DATA (DTOEXT)

KPI CODE	ICT.02 – DTOEXT	
Definition	**Number of external suppliers with access to personal/sensitive data**	
Description	Total number of external suppliers and third parties having access to sensible or personal data.	
Type	Quantitative	
Calculation	Identify contracted third parties having access to data.	
Unit of measurement	-	
Level of aggregation	*Single citizen* or *Building* or *Energy Community*	
	Citizen View	Stakeholder View

ICT.03 – TIME-TO-VALUE (TTOV)

KPI CODE	ICT.03 - TTOV	
Definition	**Time-to-value**	
Description	Period of time since data is computed until it is used to generate value.	
Type	Quantitative	
Calculation	Track and report time	
Unit of measurement	Days	
Level of aggregation	*Single citizen* or *Building* or *Energy Community*	
	Citizen View	Stakeholder View

Legal KPIs

LEG.01 – LEGAL FRAMEWORK ON ENERGY COMMUNITIES (LFEC)

KPI CODE	LEG.01 - LFEC	
Definition	**Legal framework on energy communities**	
Description	To which degree the EU legislation has been transposed to the country and thus is legally feasible to develop energy communities.	
Type	Qualitative	
Calculation	Questionnaire	
Unit of measurement	Likert Scale	
Level of aggregation	*Single citizen* or *Building* or *Energy Community*	
	Citizen View	Stakeholder View

LEG.02 – LEGAL FRAMEWORK ON COLLECTIVE SELF-CONSUMPTION (LFCSC)

KPI CODE	LEG.02 - LFCSC	
Definition	**Legal framework on Collective Self-Consumption**	
Description	The extent to which energy collective self-consumption regulation is suitable at EU level and at RECs level.	
Type	Qualitative	
Calculation	Questionnaire	
Unit of measurement	Likert Scale	
Level of aggregation	*Single citizen* or *Building* or *Energy Community*	
	Citizen View	Stakeholder View

LEG.03 – LEGAL FRAMEWORK ON LOCAL GRID BALANCING (LFLGB)

KPI CODE	LEG.03 - LFLGB
Definition	**Legal framework on local grid balancing**
Description	The extent to which local grid balancing technologies' regulation is suitable at EU level and at RECs level.
Type	Qualitative

Calculation	Questionnaire	
Unit of measurement	Likert Scale	
Level of aggregation	*Single citizen* or *Building* or *Energy Community*	
	Citizen View	Stakeholder View

LEG.04 – LEGAL FRAMEWORK ON MICRO-GRIDS (LFMG)

KPI CODE	**LEG.04 - SESR**	
Definition	**Legal framework on Micro-Grids**	
Description	The extent to which micro-grids regulation is suitable at EU level and at RECs level.	
Type	Qualitative	
Calculation	Questionnaire	
Unit of measurement	Likert Scale	
Level of aggregation	*Single citizen* or *Building* or *Energy Community*	
	Citizen View	Stakeholder View

LEG.05 – SUITABLE ENERGY STORAGE REGULATION (SESR)

KPI CODE	**LEG.05 -**	
Definition		
Description	The extent to which energy storage regulation is suitable at EU level and at RECs level.	
Type	Qualitative	
Calculation	Questionnaire	
Unit of measurement	Likert Scale	
Level of aggregation	*Single citizen* or *Building* or *Energy Community*	
	Citizen View	Stakeholder View

Appendix D– Electric assets definitions and sizing

Input data description

Table 26. Indices and sets

Indices/sets	Descriptions	Units
$\boldsymbol{t \in T}$	Set of time intervals/slots over the operation period.	-
$\boldsymbol{t \in T^{24}}$	Subset of time intervals/slots comprised by end-of-day steps only. E.g., if the optimization step is 1h and the horizon is 48h, this subset includes steps 23 and 47; E.g., if the optimization step is 15' and the horizon is 48h. this subset includes steps 95 and 191.	-
$\boldsymbol{n \in N}$	Set of CPEs.	-

Table 27. Parameters

Service parameters	Descriptions	Units
$\hat{\lambda}_{n,t}^{buy}$	Supply energy tariff of *n* at *t*.	€/kWh
$\hat{\lambda}_{n,t}^{sell}$	Feed-in energy tariff of *n* at *t*.	€/kWh
$\hat{\lambda}_{t}^{grid}$	Global access tariff for self-consumption, at *t*.	€/kWh
$\hat{w}_{n,t}^{cluster}$	Number of days represented by the time series clustered data used ($\hat{\lambda}_{n,t}^{buy}, \hat{\lambda}_{n,t}^{sell}, \hat{f}_{n,t}^{G}, \hat{E}_{n,t}^{C}$). If the data used was not subjected to a clustering procedure, these values should always be equal to 1.	Days
$\hat{\lambda}_{n}^{cont}$	Contracted power tariff of *n*, adjusted to one day.	€/kW· day
$\hat{D}$	Number of days in the optimization horizon.	Days
$\hat{\lambda}_{n}^{G,ic}$	Investment cost for RES installation, adjusted to one day.	€/kW· day
$\hat{\lambda}_{n}^{B,ic}$	Investment cost for storage installation, adjusted to one day.	€/kWh· day
$\hat{E}_{n,t}^{C}$	CPE *n* load profile at *t*.	kWh
$\hat{P}_{n}^{CPE,max}$	Maximum allowed power flow through the CPE of *n*.	kW
$\hat{P}_{n}^{GN,init}$	Initial installed RES capacity at CPE *n*.	kW
$\hat{f}_{n,t}^{G}$	Generation profile factor of RES for CPE *n* location at *t*.	frac.

Δt	Optimization step.	h
$\hat{P}_{n}^{GN,min}$	Minimum RES capacity to be installed at CPE *n*.	kW
$\hat{P}_{n}^{GN,max}$	Maximum RES capacity to be installed at CPE *n*.	kW
$\hat{E}_{n}^{BN,init}$	Initial installed storage capacity at CPE *n*.	kW
$\hat{E}_{n}^{BN,min}$	Minimum storage capacity to be installed at CPE *n*.	kW
$\hat{E}_{n}^{BN,max}$	Maximum storage capacity to be installed at CPE *n*.	kW
$\frac{\hat{P}^{B,ref}}{\hat{E}^{B,ref}}$	Ratio between the reference maximum admissible input and output storage power and the reference storage nominal capacity.	kW/kWh
$\widehat{SOC}_{n}^{B,min}$	Minimum state of charge of the storage system(s) in *n*.	%
$\hat{\eta}_{n}^{B,C}$	Charging efficiency of the storage system(s) in *n*.	frac.
$\hat{\eta}_{n}^{B,D}$	Discharging efficiency of the storage system(s) in *n*.	frac.
$\widehat{SOC}_{n}^{B,max}$	Maximum state of charge of the storage system(s) in *n*.	%
$\hat{M}$	A very big number (e.g., 1E6).	kWh
$\hat{m}$	A very small number (e.g., 1E-4). Used to avoid infeasibility when big M method is used and constraint can be ≤ 0 (e.g., if constraint is ≤ 0, sometimes, 0 is approximated by a very small negative number, and since the left side of the constraint needs to be positive, this generates an infeasibility).	kWh

Table 28. Variables

Decision Variables	Descriptions	Units
$E_{n,t}^{CMET}$	Net consumption at meter *n*, at *t*.	kWh
$E_{n,t}^{G}$	CPE *n* behind-the-meter generation at *t*.	kWh
$E_{n,t}^{B,C}$	Energy charged by the storage system(s) in *n*, at *t*.	kWh
$E_{n,t}^{B,D}$	Energy discharged by the storage system(s)in *n*, at *t*.	kWh
$E_{n,t}^{SUP}$	Energy supplied to *n* from its retailer, at *t*.	kWh
$E_{n,t}^{SUR}$	Energy surplus sold by *n* to its retailer, at *t*.	kWh
$E_{n,t}^{PUR}$	Energy bought locally by *n*, at *t*.	kWh
$E_{n,t}^{SALE}$	Energy sold locally by *n*, at *t*.	kWh
$E_{n,t}^{SLC}$	Energy self-consumed by *n*, at *t* (in theory, g.t.e. that value).	kWh

P_n^{CONT}	Contracted power at CPE *n*.	kW
P_n^{GN}	New installed RES capacity at CPE *n*.	kW
$P_n^{GN,total}$	Total installed RES capacity at CPE *n*.	kW
E_n^{BN}	New installed storage capacity at CPE *n*.	kWh
$E_n^{BN,total}$	Total installed storage capacity at CPE *n*.	kWh
$E_{n,t}^{B}$	Energy stored by the storage system(s) in *n*, at *t*.	kWh
$E_n^{B,init}$	Initial energy stored on the storage system(s) in *n*, at *t*.	kWh
$\delta_{n,t}^{SUP}$	Auxiliary binary variable to impede *n* from simultaneously buying and selling to the retailer at *t*.	-
$E_{n,t}^{CMET,+}$	Consumption at meter *n*, at *t* (in theory, g.t.e. that value).	kWh
$E_{n,t}^{ALC+}$	Consumed energy bought locally by *n*, at *t* (in theory, g.t.e. that value).	kWh
$\delta_{n,t}^{SLC}$	Auxiliary binary variable for defining self-consumed energy by n.	-
$\delta_{n,t}^{cmet}$	Auxiliary binary variable for defining $E_{n,t}^{CMET,+}$ when $\hat{\lambda}_t^{grid} < 0$.	-
$\delta_{n,t}^{alc}$	Auxiliary binary variable for defining $E_{n,t}^{ALC,+}$ when $\hat{\lambda}_t^{grid} < 0$.	-
$\delta_{n,t}^{coeff}$	Auxiliary binary variable for imposing positive allocation coefficients.	-
$\delta_t^{rec\_balance}$	Auxiliary binary variable that is 1 if the REC has surplus energy and 0 if it has deficit	-
$\delta_{n,t}^{meter\_balance}$	Auxiliary binary variable that is 1 if meter *n* has surplus energy and 0 if it has deficit	-

Model constraints

Model constraints include:

- Objective function
- Consumption constraints: net consumption, for determining self-consumption
- Trades and Equilibrium Constraints: Pool market equilibrium, impede simultaneous buy and sell from retailer, etc.
- Contracted Power Constraints
- Renewable Energy Sources (RES) Constraints in terms of capacity, storage constraints, etc.
- Allocation Coefficients Constraints for self-consumption.

The tables below describe more in detail these constraints.

Table 29. Constraints

Constraints	Sets	Identifications
$E_{n,t}^{CMET} = \widehat{E}_{n,t}^{C} - E_{n,t}^{G} + E_{n,t}^{B,C} - E_{n,t}^{B,D}$	$\forall\, t \in T, n \in N$	(2)
(general case) $E_{n,t}^{CMET} = E_{n,t}^{SUP} - E_{n,t}^{SUR} + E_{n,t}^{PUR} - E_{n,t}^{SALE}$	$\forall\, t \in T, n \in N$	(3)
(Portuguese regulation case) $E_{n,t}^{CMET} = E_{n,t}^{SUP} - E_{n,t}^{SUR} + E_{n,t}^{SLC} - E_{n,t}^{SALE}$	$\forall\, t \in T, n \in N$	(3.b)
$-P_{n}^{CONT} \leq \dfrac{E_{n,t}^{CMET}}{\Delta t} \leq P_{n}^{CONT}$	$\forall\, t \in T, n \in N$	(4)
$P_{n}^{CONT} \leq \widehat{P}_{n}^{CPE,max}$	$\forall\, n \in N$	(5)
$P_{n}^{GN} = P_{n}^{GN,total} - \widehat{P}_{n}^{GN,init}$	$\forall\, n \in N$	(6)
$E_{n,t}^{G} = \widehat{f}_{n,t}^{G} \cdot P_{n}^{GN,total} \cdot \Delta t$	$\forall\, t \in T, n \in N$	(7)
$\widehat{P}_{n}^{GN,min} \leq P_{n}^{GN} \leq \widehat{P}_{n}^{GN,max}$	$\forall\, n \in N$	(8)
$E_{n}^{BN} = E_{n}^{BN,total} - \widehat{E}_{n}^{BN,init}$	$\forall\, n \in N$	(9)
$\widehat{E}_{n}^{BN,min} \leq E_{n}^{BN} \leq \widehat{E}_{n}^{BN,max}$	$\forall\, n \in N$	(10)
$\dfrac{E_{n,t}^{B,C}}{\Delta t} \leq E_{n}^{BN,total} \cdot \dfrac{\widehat{P}^{B,ref}}{\widehat{E}^{B,ref}}$	$\forall\, t \in T, n \in N$	(11)
$\dfrac{E_{n,t}^{B,D}}{\Delta t} \leq E_{n}^{BN,total} \cdot \dfrac{\widehat{P}^{B,ref}}{\widehat{E}^{B,ref}}$	$\forall\, t \in T, n \in N$	(12)
$E_{n}^{B,init} = \dfrac{\widehat{SOC}_{n}^{B,min}}{100} \cdot E_{n}^{BN,total}$	$\forall\, n \in N$	(13)
$E_{n,t}^{B} = E_{n}^{B,init} + \left(E_{n,t}^{B,C} \cdot \widehat{\eta}_{n}^{B,C} - \dfrac{E_{n,t}^{B,D}}{\widehat{\eta}_{n}^{B,D}} \right)$	$t = 0, \forall\, n \in N$	(14)
$E_{n,t}^{B} = E_{n,t-1}^{B} + \left(E_{n,t}^{B,C} \cdot \widehat{\eta}_{n}^{B,C} - \dfrac{E_{n,t}^{B,D}}{\widehat{\eta}_{n}^{B,D}} \right)$	$\forall\, t > 0 \in T, n \in N$	(15)
$\dfrac{\widehat{SOC}_{n}^{B,min}}{100} \cdot E_{n}^{BN,total} \leq E_{n,t}^{B} \leq \dfrac{\widehat{SOC}_{n}^{B,max}}{100} \cdot E_{n}^{BN,total}$	$\forall\, t \in T, n \in N$	(16)
$\sum_{n} \left(E_{n,t}^{PUR} \right) - \sum_{n} \left(E_{n,t}^{SALE} \right) = 0$	$\forall\, t \in T$	(17)

$\boldsymbol{E_{n,t}^{SUP} \leq \widehat{M} \cdot \left(\delta_{n,t}^{SUP}\right) + \widehat{m}}$ $\boldsymbol{E_{n,t}^{SUR} \leq \widehat{M} \cdot \left(1 - \delta_{n,t}^{SUP}\right) + \widehat{m}}$	$\forall\, t \in T, n \in N$	(18)
$\boldsymbol{E_{n,t}^{CMET+} \geq E_{n,t}^{CMET}}$	$\forall\, t \in T, n \in N$	(19)
$\boldsymbol{E_{n,t}^{ALC+} \geq E_{n,t}^{PUR} - E_{n,t}^{SALE}}$	$\forall\, t \in T, n \in N$	(20)
$\boldsymbol{E_{n,t}^{SLC} \geq E_{n,t}^{CMET+} - \widehat{M} \cdot (1 - \delta_{n,t}^{SLC})}$	$\forall\, t \in T, n \in N$	(21)
$\boldsymbol{E_{n,t}^{SLC} \geq E_{n,t}^{ALC+} - \widehat{M} \cdot \delta_{n,t}^{SLC}}$	$\forall\, t \in T, n \in N$	(22)
$\boldsymbol{E_{n,t}^{SALE} - E_{n,t}^{PUR} \leq -E_{n,t}^{CMET} + \widehat{M} \cdot \delta_{n,t}^{coeff}}$	$\forall\, t \in T, n \in N$	(23)
$\boldsymbol{E_{n,t}^{SALE} - E_{n,t}^{PUR} \leq \widehat{M} \cdot \left(1 - \delta_{n,t}^{coeff}\right)}$	$\forall\, t \in T, n \in N$	(24)
$\boldsymbol{\sum_{n} E_{n,t}^{CMET} \geq -\widehat{M} \cdot \delta_{t}^{rec\_balance}}$	$\forall\, t \in T$	(25)
$\boldsymbol{\sum_{n} E_{n,t}^{CMET} \leq \widehat{M} \cdot \left(1 - \delta_{t}^{rec\_balance}\right) + \widehat{m}}$	$\forall\, t \in T$	(26)
$\boldsymbol{E_{n,t}^{CMET} \geq -\widehat{M} \cdot \delta_{n,t}^{meter\_balance}}$	$\forall\, t \in T, n \in N$	(27)
$\boldsymbol{E_{n,t}^{CMET} \leq \widehat{M} \cdot \left(1 - \delta_{n,t}^{meter\_balance}\right) + \widehat{m}}$	$\forall\, t \in T, n \in N$	(28)
$\boldsymbol{E_{n,t}^{SALE} \geq -E_{n,t}^{CMET} - \widehat{M} \cdot (1 - \delta_{n,t}^{meter\_balance} + \delta_{t}^{rec\_balance})}$	$\forall\, t \in T, n \in N$	(29)
$\boldsymbol{E_{n,t}^{SALE} \leq -E_{n,t}^{CMET} + \widehat{M} \cdot (1 - \delta_{n,t}^{meter\_balance} + \delta_{t}^{rec\_balance})}$	$\forall\, t \in T, n \in N$	(30)
$\boldsymbol{E_{n,t}^{PUR} \geq E_{n,t}^{CMET} - \widehat{M} \cdot (1 - \delta_{t}^{rec\_balance} + \delta_{n,t}^{meter\_balance})}$	$\forall\, t \in T, n \in N$	(31)
$\boldsymbol{E_{n,t}^{PUR} \leq E_{n,t}^{CMET} + \widehat{M} \cdot (1 - \delta_{t}^{rec\_balance} + \delta_{n,t}^{meter\_balance})}$	$\forall\, t \in T, n \in N$	(32)
$\boldsymbol{E_{n,t}^{B} = E_{n}^{B,init}}$	$\forall\, t \in T^{24}, n \in N$	(33)
$\boldsymbol{E_{n,t}^{G}, E_{n,t}^{B,C}, E_{n,t}^{B,D}, E_{n,t}^{SUP}, E_{n,t}^{SUR}, E_{n,t}^{PUR}, E_{n,t}^{SALE}, E_{n,t}^{SLC}, P_{n}^{CONT},}$ $\boldsymbol{P_{n}^{GN}, P_{n}^{GN,total}, E_{n}^{BN}, E_{n}^{BN,total}, E_{n,t}^{B}, E_{n}^{B,init}, E_{n,t}^{CMET,+}, E_{n,t}^{ALC+} \geq 0}$	$\forall\, t \in T, n \in N$	(34)

Notes:

$E_{n,t}^{CMET,+} = max\left(E_{n,t}^{CMET}, 0\right)$

$E_{n,m,t}^{ALC+} = max\left(E_{n,t}^{PUR} - E_{n,t}^{SALE}, 0\right)$

$E_{n,t}^{SLC} = min(max(E_{n,t}^{CMET}, 0), max(E_{n,t}^{PUR} - E_{n,t}^{SALE}, 0))$

The descriptions of the above constraints are included below:

Table 30. Constraints descriptions

Constraints	Descriptions
(1)	Arbitrage objective function
(2)	Net consumption constraint
(3)	Trades equilibrium constraint
(4)	Required contracted power per meter
(5)	Contracted power limited to the maximum CPE power limit
(6)	Definition of the installed RES capacity
(7)	Definition of the total RES generation (pre-installed + new)
(8)	Limits the RES capacity to be installed
(9)	Definition of the installed storage capacity
(10)	Limits the storage capacity to be installed
(11)	Storage charge power limit constraints
(12)	Storage discharge power limit constraints
(13)	Definition of the storage initial energy content
(14)	Storage energy content update constraint (*t=0*)
(15)	Storage energy content update constraint (*t>0*)
(16)	Storage SoC limits constraints
(17)	Pool market equilibrium
(18)	Impede simultaneous buy and sell from retailer
(19)	Positive net consumption constraint (for determining self-consumption)
(20)	Positive allocated energy constraint (for determining self-consumption)
(21)	Self-consumption definition constraint (when bottom-limited by positive net consumption)
(22)	Self-consumption definition constraint (when bottom-limited by positive allocated energy)
(23)	Constraint for imposing positive allocation coefficients *(maximum* = $-E_{n,t}^{CMET}$)
(24)	Constraint for imposing positive allocation coefficients (*minimum* = 0)

(25)	Constraint for signalling when the REC has surplus
(26)	Constraint for signalling when the REC has deficit
(27)	Constraint for signalling when the meter has surplus
(28)	Constraint for signalling when the meter has deficit
(29)	Constraint for imposing that all injected energy must be allocated to other meters when the REC has a deficit and the meter has a surplus (lower limit)
(30)	Constraint for imposing that all injected energy must be allocated to other meters when the REC has a deficit and the meter has a surplus (upper limit)
(31)	Constraint for imposing that all consumed energy must be allocated from other meters when the REC has surplus and the meter has a deficit (lower limit)
(32)	Constraint for imposing that all consumed energy must be allocated from other meters when the REC has a surplus and the meter has deficit (upper limit)
(33)	Positive variables' constraints

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Table 31. New indices and sets

Indices/sets	Descriptions	Units
ev ∈ ***EV***	Set of EVs within each CPE's meter.	-

Table 32. New parameters

Parameters	Descriptions	Units
$\hat{E}^{Trip}_{n,ev,t}$	Vehicle ev at meter n energy consumption in period t.	kWh
$\hat{E}^{EV,MinCharge}_{n,ev}$	Minimum stored energy to be guaranteed for vehicle ev at meter n.	kWh
$\hat{E}^{EV,BatCapacity}_{n,ev}$	The battery energy capacity of vehicle ev at meter n.	kWh
$\hat{\eta}^{EV,C}_{n,ev}$	Charging efficiency of vehicle ev at meter n.	%
$\hat{\eta}^{EV,D}_{n,ev}$	Discharging efficiency of vehicle ev at meter n.	%
$\hat{P}^{EV,ChargeLimit}_{n,ev}$	Maximum power charge of vehicle ev at meter n.	kW
$\hat{P}^{EV,DischargeLimit}_{n,ev}$	Maximum power discharge of vehicle ev at meter n.	kW

$\hat{X}^{EV}_{n,ev,t}$	Whether a vehicle ev at meter n is plugged-in or not (if plugged-in = 1 else = 0).	-
$P^{EV,Discharge}_{n,ev,t}$	Power discharge of vehicle ev at meter n in period t.	kW
Δt	Length of time intervals	h
$\widehat{EWH}^{power}$	Heating power of the EWH	kW
$\widehat{EWH}^{height}$	Height of the EWH	cm
$\widehat{EWH}^{cap}$	Internal water capacity of the EWH	l
$\widehat{EWH}^{\max}$	Maximum allowable water temperature of the EWH	°C
$\widehat{EWH}^{min}$	Minimum allowable water temperature of the EWH	°C
$\hat{c}$	Specific heat capacity of water (4.18 J/g°C)	J/g°C
$\widehat{HC}$	Overall heat transfer coefficient of the EWH	kW/(m^{2}K)
$\widehat{temp}^{set}$	User-defined comfort temperature for hot water usage	°C
$\widehat{temp}^{amb}$	EWH room ambient temperature	°C
$\hat{M}$	Sufficiently big number (e.g., 1E3 if EWH's nominal capacity is in the tens of kWh)	-
$\widehat{flowrate}$	Water usage flow rate (fixed/constant value).	kg/min
$\widehat{tariff}$	Selection between energy price tariffs between simple (1) or bi-hourly (2), etc.	-
$\hat{\delta}^{use}_{t}$	Boolean parameter indicating periods of hot water usage (1 = using)	-

Table 33. New variables

Variables	Descriptions	Units
$E^{EV,Stored}_{n,ev,t}$	Energy stored in vehicle ev at CPE n at the end of period *t*	kWh
$P^{EV,Charge}_{n,ev,t}$	Power charge of vehicle ev at CPE n in period *t*	kW
$P^{EV,Discharge}_{n,ev,t}$	Power discharge of vehicle ev at CPE n in period *t*.	kW
$\widehat{EWH}^{StartTemp}$	EWH internal water temperature at the beginning	°C
$\widehat{EWH}^{area}$	EWH Surface Area	m^2
W^{init}	Total energy balance of the EWH at the beginning	kWh
W^{max}	Maximum energy balance of the EWH	kWh
W^{min}	Minimum energy balance of the EWH	kWh

$m_{\delta use}^{belowSet}$	Auxiliary m linearization parameter from *belowSet* regressor for usage	-
$m_{temp^{EWH}}^{belowSet}$	Auxiliary b linearization parameter from *belowSet* regressor for temperature	-
$b^{belowSet}$	Auxiliary b linearization parameter from *belowSet* regressor	
$m_{\delta use}^{aboveSet}$	Auxiliary m linearization parameter from *aboveSet* regressor for usage	-
$m_{temp^{EWH}}^{aboveSet}$	Auxiliary m linearization parameter from *aboveSet* regressor for temperature	
$b^{aboveSet}$	Auxiliary b linearization parameter from *aboveSet* regressor	-
$temp_t^{EWH}$	Temperature of water at EWH outlet at the beginning of time interval t	°C
W_t^{tot}	Total energy balance of prosumer's EWH at time interval t	kWh
W_t^{in}	Energy into the prosumer's EWH at time interval t	kWh
W_t^{loss}	Thermal energy losses at time interval t	kWh
W_t^{mix}	Thermal energy stored in the EWH after usage and mixing with inlet water at time interval t	kWh
δ_t^{in}	Variable for EWH operation status, [0,1], (1 = ON, 0 = OFF, for the full period)	-
δ_t^{aux}	Boolean variable for if-else in constraint (7) at time interval t	-
$penalty_t^{comf}$	Penalty cost associated with water temperature reaching below comfort at time interval t	-
$cost_t^{use}$	Total period cost of that specific energy usage at time interval t	€
$price_t^{net}$	Network pricing of energy usage at time interval t	€
$tariff^m$	Energy daily tariff for each m price sets	€

Table 34. New constraints

Constraints	Sets	Identifications
$E_{n,t}^{CMET} = \widehat{E}_{n,t}^{C} - E_{n,t}^{G} + E_{n,t}^{B,C} - E_{n,t}^{B,D} + \sum_{ev \in EV} \left(P_{n,ev,t}^{EV,Charge} - P_{n,ev,t}^{EV,Discharge}\right)$	$\forall\, t \in T, n \in N$	(2)

$E_{n,t}^{G}, E_{n,t}^{B,C}, E_{n,t}^{B,D}, E_{n,ev,t}^{EV,Stored}, P_{n,ev,t}^{EV,Charge}, P_{n,ev,t}^{EV,Disharge}, E_{n,t}^{SUP}, E_{n,t}^{SUR}, E_{n,t}^{PUR}, E$ $P_{n}^{GN}, P_{n}^{GN,total}, E_{n}^{BN}, E_{n}^{BN,total}, E_{n,t}^{B}, E_{n}^{B,init}, E_{n,t}^{CMET,+}, E_{n,t}^{ALC+} \geq 0$	$\forall\, t \in T, n \in N$	(34)
$E_{n,ev,t}^{EV,Stored} = E_{n,ev,t-1}^{EV,Stored} + \hat{\eta}_{n,ev}^{EV,C} \cdot P_{n,ev,t}^{EV,Charge} - \frac{1}{\hat{\eta}_{n,ev}^{EV,D}} P_{n,ev,t}^{EV,Discharge} - \hat{E}_{n,ev,t}^{Trip}$	$\forall t \in T \setminus t = 1;\ \forall ev \in\ EV;$	(35)
$\frac{1}{\hat{\eta}_{n,ev}^{EV,D}} P_{n,ev,t}^{EV,Discharge} \leq \hat{P}_{n,ev}^{EV,DischargeLimit} \cdot \hat{X}_{n,ev,t}^{EV} \cdot \triangle t$	$\forall t \in T;\ \forall ev \in\ EV; \hat{X}_{n,t}^{EV} \in \{0,1\}$	(36)
$\hat{\eta}_{n,ev}^{EV,C} \cdot P_{n,ev,t}^{EV,Charge} \leq \hat{P}_{n,ev}^{EV,ChargeLimit} \cdot \hat{X}_{n,ev,t}^{EV} \cdot \triangle t$	$\forall t \in T; \forall ev \in EV;\ \hat{X}_{n,t}^{EV} \in \{0,1\}$	(37)
$E_{n,ev,t}^{EV,Stored} \leq \hat{E}_{n,ev}^{EV,BatCapacity}$	$\forall t \in T;\ \forall ev \in EV;$	(38)
$E_{n,ev,t}^{EV,Stored} \geq \hat{E}_{n,ev}^{EV,MinCharge}$	$\forall t \in T;\ \forall ev \in EV;$	(39)
$\begin{cases} W_t^{tot} = W^{init}, t = 0 \\ W_t^{tot} = W_{t-1}^{water} + W_{t-1}^{in} + W_{t-1}^{loss}, t > 0 \end{cases}$		(40)
$W_t^{in} = \widehat{EWH}^{power} \cdot \Delta t \cdot \delta_t^{in} \cdot (\Delta t \cdot 60)$	$\forall\, t \in T$	(41)
$cost_t^{use} = \delta_t^{in} \cdot \widehat{EWH}^{power} \cdot \Delta t \cdot price_t^{use} + tariff^{m} \cdot \frac{\Delta t}{24}$	$\forall\, t \in T$	(42)
$\begin{cases} temp_t^{EWH} = \widehat{EWH}^{StartTemp}, t = 0 \\ temp_t^{EWH} = \frac{W_t^{tot} \cdot 3600}{\widehat{EWH}^{cap} \cdot \hat{c}}, t > 0 \end{cases}$		(43)
$W_t^{loss} = \widehat{EWH}^{height} \cdot \widehat{EWH}^{area} \cdot \Delta t \cdot \left(temp_t^{EWH} - \widehat{temp}^{amb}\right) \cdot (\Delta t \cdot 60)$	$\forall\, t \in T$	(44)
$\begin{cases} W_t^{min} \leq W_t^{tot} \\ W_t^{tot} \leq W_t^{max} \\ \widehat{EWH}^{min} \leq temp_t^{EWH} \\ temp_t^{EWH} \leq \widehat{EWH}^{max} \end{cases}$	$\forall\, t \in T$	(45)
$\begin{cases} W_t^{tot} \geq \widehat{temp}^{set} \cdot \widehat{EWH}^{cap} \cdot \frac{\hat{c}}{3600} \cdot (\Delta t \cdot 60) - penalty_t^{comf} \\ W_{t-1}^{tot} \geq \widehat{temp}^{set} \cdot \widehat{EWH}^{cap} \cdot \frac{\hat{c}}{3600} \cdot (\Delta t \cdot 60) - penalty_{t-1}^{comf} \end{cases}$	$\hat{\delta}_t^{use} = 1,\quad or:$ $\begin{cases} \hat{\delta}_t^{use} - \hat{\delta}_{t-1}^{use} \neq (\\ \hat{\delta}_t^{use} - \hat{\delta}_{t-1}^{use} = -\hat{\delta} \end{cases}$	(46)

$$
\begin{array}{ll}
 & \hat{\delta}_t^{use} > 0 \\
\left\{\begin{array}{c}
temp_t^{EWH} \geq \widehat{temp}^{set} - \widehat{M} \cdot (1 - \delta_t^{aux}) \\
temp_t^{EWH} \leq \widehat{temp}^{set} + \widehat{M} \cdot \delta_t^{aux} \\
W_t^{mix} \geq \left(m_{\delta^{use}}^{belowSet} \cdot \widehat{\delta}_t^{use} + m_{temp^{EWH}}^{belowSet} \cdot temp_t^{EWH} + b^{belowSet} \right) - \\
W_t^{mix} \leq \left(m_{\delta^{use}}^{belowSet} \cdot \widehat{\delta}_t^{use} + m_{temp^{EWH}}^{belowSet} \cdot temp_t^{EWH} + b^{belowSet} \right) + \\
W_t^{mix} \geq \left(m_{\delta^{use}}^{aboveSet} \cdot \widehat{\delta}_t^{use} + m_{temp^{EWH}}^{aboveSet} \cdot temp_t^{EWH} + b^{aboveSet} \right) - \widehat{M} \\
W_t^{mix} \leq \left(m_{\delta^{use}}^{aboveSet} \cdot \widehat{\delta}_t^{use} + m_{temp^{EWH}}^{aboveSet} \cdot temp_t^{EWH} + b^{aboveSet} \right) + \widehat{M} \\
W_t^{mix} = temp_t^{EWH} \cdot \widehat{EWH}^{cap} \cdot \frac{\hat{c}}{3600} \cdot \Delta t \cdot 60
\end{array}\right. &
\begin{array}{l}
\hat{\delta}_t^{use} > 0 \\
\hat{\delta}_t^{use} > 0 \\
\hat{\delta}_t^{use} > 0 \\
\hat{\delta}_t^{use} > 0 \\
\hat{\delta}_t^{use} > 0 \\
\hat{\delta}_t^{use} > 0
\end{array} \\
 & \hat{\delta}_t^{use} = 0
\end{array}
\qquad (47)
$$

Table 35. Descriptions of new constraints

Constraints	Descriptions
(2)	Net consumption constraint
(34)	Constraint for signalling when the meter has deficit
(35)	Battery balance for each vehicle. The energy consumption for period travel has to be considered jointly with the energy remaining from the previous period and the charge/discharge in the period
(36)	Discharge limit for each vehicle considering the battery discharge rate
(37)	Charge limit for each vehicle considering the battery charge rate
(38)	Battery capacity limit for each vehicle
(39)	Minimum stored energy to be guaranteed at the end of each period
(40)	represents the total energy stored within the EWH in each period. For the first instant, it is equal to the value stipulated as initial (or equal to energy associated with the tank filled with water at inlet temperature). For the remaining periods, it depends on the total energy resulting from mixing water (46), the energy gain from heating (41), and the energy thermal losses (44).
(41)	represents additional energy introduced by the heating element of the EWH. It depends on the power of the element, the length of the time period and if the EWH is operational.
(42)	represents the total cost of operating the EWH, depending on the energy cost, the selected daily tariff, the power of the element, the length of the time period and if the EWH is operational or not.
(43)	represents the temperature value of the internal water of the EWH. For the initial instant, it is equivalent to the established input, while for the following

	instants, it establishes a conversion to equivalent temperature through the value of the accumulated energy (40)
(44)	represents the total thermal losses of the EWH through its surface, depending on the length of the time period.
(45)	mandates adherence to prescribed upper and lower limits for both temperature and energy, requiring precise management to sustain system stability within defined boundaries.
(46)	represents the need for the internal water temperature of the EWH after use to be equal to or greater than the threshold defined by the user. It uses an auxiliary variable that allows the model to operate below the comfort threshold, but adds a penalty operating cost, which in turn is added to the objective function with a positive term.
(47)	Definition of the variable that represents the accumulated energy after using hot water, and after internal mixing with inlet water. As it is a conditional (if-else) and non-linear constraint, its formulation is built in such a way that it is programmable. Please refer to the Mathematical Adjustments section for a detailed description.

Input data description

Table 36. Input data description

Description	System	Units	Variable Types	Format Types
Total time horizon of the simulation (service parameters)	Simulation	days	Integer	JSON
Duration of each timestep	Simulation	hours	integer	JSON
ID of each installation	REC	-	string	JSON
Power limit for transactions at the Point of Common Coupling	REC	kW	float	JSON
Buy and sell energy tariffs (input data)	Information provided by the	€/kWh	time series(float)	JSON

	retailer for each prosumer			
Contracted power tariff	Information provided by the retailer for each prosumer	€/(kW.day)	float	JSON
Voltage level	Information provided by the retailer for each prosumer	-	string	JSON
Energy consumption diagram (for each time step)	Prosumer	kWh	time series(float)	JSON
Maximum and minimum state-of-charge	Storage technologies specifications	%	float	Sourced from CSV/Excel file. Stored in a DB
Maximum charge and discharge power (inverter)	Storage technologies specifications	kW	float	Sourced from CSV/Excel file. Stored in a DB
Charge and discharge efficiency	Storage technologies specifications	%	float	Sourced from CSV/Excel file. Stored in a DB
lifespan	Storage technologies specifications	years	float	Sourced from CSV/Excel file. Stored in a DB
investment costs	Storage technologies specifications	€/kWh	float	Sourced from CSV/Excel file. Stored in a DB

efficiency	PV technologies specifications	%	float	Sourced from CSV/Excel file. Stored in a DB
yearly degradation	PV technologies specifications	%	float	Sourced from CSV/Excel file. Stored in a DB
generation profile	PV technologies specifications	$kWh/kW_{installed}$	float	Sourced from CSV/Excel file. Stored in a DB
lifespan	PV technologies specifications	years	float	Sourced from CSV/Excel file. Stored in a DB
investment costs	PV technologies specifications	€/kW	float	Sourced from CSV/Excel file. Stored in a DB
members' ownership	PV technologies specifications	%/member	float	Sourced from CSV/Excel file. Stored in a DB
pre-installed, maximum and minimum storage to be installed	Storage technologies specifications	kWh	float	JSON
pre-installed, maximum and minimum PV to be installed	PV technologies specifications	kW	float	JSON
Grid access tariffs (provided by DSO)	REC	€/kWh	time series(float)	JSON

EV energy trip profile	EV	kWh	time series(float)	Sourced from CSV/Excel file. Stored in a DB
EV plugged or not	EV	-	bool	Sourced from CSV/Excel file. Stored in a DB
Minimum charge before unplugging	EV	kWh	float	Sourced from CSV/Excel file. Stored in a DB
EV battery capacity	EV	kWh	float	Sourced from CSV/Excel file. Stored in a DB
Charge and discharge EV efficiency	EV	%	float	Sourced from CSV/Excel file. Stored in a DB
Maximum charge and discharge EV power	EV	kW	float	Sourced from CSV/Excel file. Stored in a DB
Ownership Member - Resource	REC	%	Float matrix	Sourced from CSV/Excel file. Stored in a DB
EWH Consumption Diagram (1-min resolution)	Thermal Resources (EWH)	W	time series (float)	JSON

Hot-Water Usage Calendar (1-min resolution)	Thermal Resources (EWH)	-	time series (bool)	JSON
EWH Functioning Power	Thermal Resources (EWH)	W	integer	JSON
EWH Capacity	Thermal Resources (EWH)	l	integer	JSON
EWH Maximum Allowed Internal Water Temperature	Thermal Resources (EWH)	°C	integer	JSON
EWH Overall Heat Transfer Coefficient	Thermal Resources (EWH)	$W/(m^2 \cdot K)$	float	JSON
User-defined Hot-Water Usage Comfort Temperature	Thermal Resources (EWH)	°C	integer	JSON

Output data description

Table 37. Output data description

Descriptions	Systems	Units	Variable Types	Format Types
REC energy cost	REC	€	float	JSON
Batteries initial energy content	Storage	kWh	list(float)	JSON
Batteries energy content	Storage	kWh	list of time series(float)	JSON
Batteries charged and discharged energy	Storage	kWh	list of time series(float)	JSON
Net consumption behind-the-meter	REC/Members	kWh	list of time series(float)	JSON
PV generation	PV	kWh	list of time series(float)	JSON

Imported and exported energy from the retailer	REC/Members	kWh	list of time series(float)	JSON
To be installed PV power	PV	kW	list(float)	JSON
To be installed Battery capacity	Storage	kWh	list(float)	JSON
Contracted power (maximum metered power flow)	REC/Members	kW	list(float)	JSON
Total Installed PV power	PV	kW	list(float)	JSON
Total Installed Battery capacity	Storage	kWh	list(float)	JSON
Allocated generation from shared PV	PV	kWh	list of time series(float)	JSON
Self-consumption energy	REC/Members	kWh	list of time series(float)	JSON
Energy consumed from the community	REC/Members	kWh	list of time series(float)	JSON
Energy purchased from the community	REC/Members	kWh	list of time series(float)	JSON
Energy sold to the community	REC/Members	kWh	list of time series(float)	JSON
Pool price of the community or price of the bilateral transaction (dependent on the business model)	REC/Members	€/kWh	time series(float) or list of time series(float)	JSON
EVs charged and discharged energy	EVs	kWh	list of time series(float)	JSON

EVs energy content	EVs	kWh	list of time series(float)	JSON
EWH Optimized Functioning Calendar	Thermal Resources (EWH)	-	List of time series Bool	JSON
EWH Optimized Consumption Diagram	Thermal Resources (EWH)	W	List of time series Float	JSON

KPIs

Table 38. KPI description

KPIs	Description	Type	KPI in Appendix C
Net Present Value	Represents the present value of the project's expected cash inflows and outflows, discounted at a specified rate. A positive NPV indicates that the project is expected to generate value and is potentially a financially sound investment.	Financial (Investment)	
Return on Investment	It is a ratio of the project's net profit to its initial cost. The ROI expresses the efficiency of the investment in generating returns. A higher ROI indicates a more efficient use of capital.	Financial (Investment)	
Payback Period	It is the time it takes for the initial investment to be recovered from the project's net cash inflows. A shorter payback period is often considered favourable as it implies a quicker return of the initial investment (years).	Financial (Investment)	EC.
Capture Prices	The capture prices (CP) can be calculated in two steps using hourly production (hP) values of a renewable energy project and electricity market spot prices (hSP) over a specific period.	Financial (Investment)	
Internal Rate of Return	The interest rate at which the NPV of the investment is zero.	Financial (Investment)	
Levelized Cost of Energy	It is the per-unit cost of generating electricity over the project's lifetime, considering all costs and expected energy production. The LCOE helps in comparing the cost competitiveness of	Financial (Investment)	

	renewable energy projects with different technologies and conventional energy sources.	
User monetary cost	Monetary costs for the end-user for belonging to the REC and consuming renewable energy.	Financial (Cost)
Individual Self-Consumption Rate	Expressed as a percentage and is calculated by dividing the energy that a member/installation consumes from its assets by the total energy produced/injected by its assets (%).	Energy
Collective Self-Consumption Rate	Expressed as a percentage and is calculated by dividing the energy that the community consumes from its assets by the total energy produced/injected by all the assets (%).	Energy
Energy Consumption	Energy consumption for each member, installation and the community overall.	Energy
Total renewable primary energy	Total primary energy in renewable primary energy terms (i.e. only accounting for the primary energy associated with renewable energy sources) which is consumed by the community.	Energy
Renewable Energy Ratio	Renewable energy ratio is the amount of renewable primary energy that is used within the system's boundaries out of the total primary energy used.	Energy
Energy consumption from the grid	The energy consumed from the grid.	Energy
Local energy exported	Amount of energy exported by the community to the grid relative to all locally generated energy.	Energy
Energy consumption of the public EV chargers	Quantifies the amount of electricity consumed by publicly accessible EV chargers, offering insights into the demand for EV infrastructure.	Energy
GHG emissions	Total CO2-eq emissions of greenhouse gases emitted.	Environment

Appendix E – Heating and Cooling assets and Networks

Input data description

Table 39: Buildings' parameters for the CEA simulation.

	Building use	RESIDENTIAL_MFH	RESIDENTIAL_SFH
General INFOs	Year of construction	2010	1945
	Surface [m2]	545.11	111.17
	Height [m]	3	3
	Floors Below Ground	0	0
	Floors Above Ground	1	1
	Standard used in CEA	MULTI_RES	SINGLE_RES
Construction			
	Fraction of above ground gross floor area air-conditioned [m2/m2]	0.82	0.82
	Fraction of gross floor area with electrical demands [m2/m2]	0.82	0.82
	Fraction of net gross floor area [m2/m2]	0.82	0.82
	Window to wall ratio (all facades) [m2/m2]	0.188333333	0.188333333
	Internal heat capacity per unit of air-conditioned area Cm_Af [J/Km2]	191666.7	191666.7

	Tightness - Air exchanges per hour at 50 Pa n50 [1/h]	3.5	3.5
	Thermal transmittance (U value) of windows U_win [-]	2.249	2.249
	Solar Heat gain coefficient G_win [-]	0.631	0.631
	Emissivity of window external surface e_win [-]	0.716	0.716
	Window frame fraction coefficient F_F [m2_frame/m2_window]	0.2	0.2
	GHG_win_kgCO2m2	78.8	78.8
	Service_Life_win	30	30
	Thermal transmittance (U value) of roof U_roof [-]	0.48	3,4
	Solar absorption coefficient of roof a_roof [-]	0.528571	0,528571
	Emissivity of external roof surface e_roof [-]	0.801429	0,801429
	Reflectance in the Red spectrum r_roof [-]	0.471429	0,471429
	GHG_roof_kgCO2	1122857	1122857
	Service_Life_roof	60	60
	Thermal transmittance (U value) of walls U_wall [-]	0.54	3,98

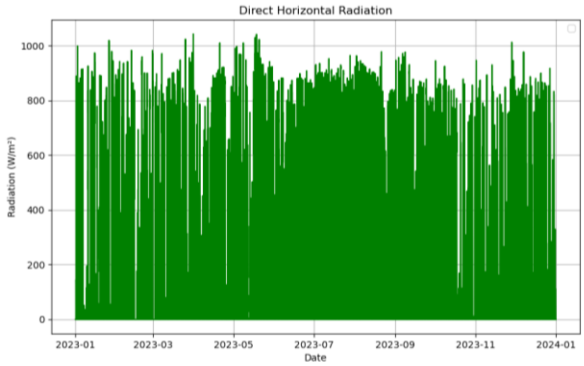
	Solar absorption coefficient a_wall [-]	0.61	0,61
	Emissivity of wall external surface e_wall [-]	0.925	0,925
	Reflectance of wall in the Red spectrum r_wall [-]	0.39	0,39
	GHG_wall_kgCO2m2	90.5	90,5
	Service_Life_wall	30	30
	Thermal transmittance (U value) of floors U_base [-]	0.77	1,43
	GHG_floor_kgCO2m2	217.5	217,5
	Service_Life_floor	45	45
	Shading coefficient when shading device is active rf_sh [-]	0.4575	0,4575
Internal loads			
	Occupancy density [m^2/person]	30	50
	Peak sensible heat load of people [W/person]	70	70
	Peak specific electrical load due to computers and devices [W/m^2]	8	8
	Peak specific electrical load due to artificial lighting [W/m^2]	2.7	2.7
	Peak specific electrical load due to industrial processes [W/m^2]	0	0

	Peak specific cooling load due to refrigeration (cooling rooms) [W/m²]	0	0
	Peak specific electrical load due to servers/data centres [W/m²]	0	0
	Peak capacity of electric battery per vehicle [W/m²]	0	0
	Peak specific process cooling load [W/m²]	0	0
	Peak specific process heating load [W/m²]	0	0
	Peak specific daily hot water consumption [l/day/person]	140	160
Indoor Comfort			
	Setpoint temperature for cooling system [°C]	26	26
	Setback temperature for cooling system [°C]	28	28
	Setpoint temperature for heating system [°C]	21	21
	Setback temperature for heating system [°C]	18	18
	Lower_bound of relative humidity [%]	30	30

	Upper bound of relative humidity [%]	60	60
	Minimum outdoor air ventilation rate per person for Air Quality [l/s/person]	8.33	8.33
Air-conditioning system			
	Type of cooling HVAC assembly (relates to "code" in HVAC assemblies)	HVAC_COOLING_AS1	HVAC_COOLING_AS1
	Type of heating HVAC assembly (relates to "code" in HVAC assemblies)	HVAC_HEATING_AS1	HVAC_HEATING_AS1
	Type of hot water HVAC assembly (relates to "code" in HVAC assemblies)	HVAC_HOTWATER_AS1	HVAC_HOTWATER_AS1
	Type of ventilation HVAC assembly (relates to "code" in HVAC assemblies)	HVAC_VENTILATION_AS1	HVAC_VENTILATION_AS1
	Start of the heating season	16|09	16|09
	End of the heating season	14|05	14|05
	Start of the cooling season	15|05	15|05
	End of the cooling season	15|09	15|09
Supply systems			
	Type of cooling supply assembly (refers to “code” in SUPPLY assemblies)	SUPPLY_COOLING_AS1	SUPPLY_COOLING_AS1
	Cooling supply efficiency	1	1
	Type of hot water supply assembly (refers to “code” in SUPPLY assemblies)	SUPPLY_HOTWATER_AS1	SUPPLY_HOTWATER_AS1
	Water supply efficiency	1	1
	Type of heating supply assembly (refers to “code” in SUPPLY assemblies)	SUPPLY_HEATING_AS1	SUPPLY_HEATING_AS1
	Heating supply efficiency	1	1

	Type of electricity assembly (refers to “code” in SUPPLY assemblies)	SUPPLY_ELECTRICITY_AS1	SUPPLY_ELECTRICITY_AS1
	Electricity supply efficiency	1	1

Results



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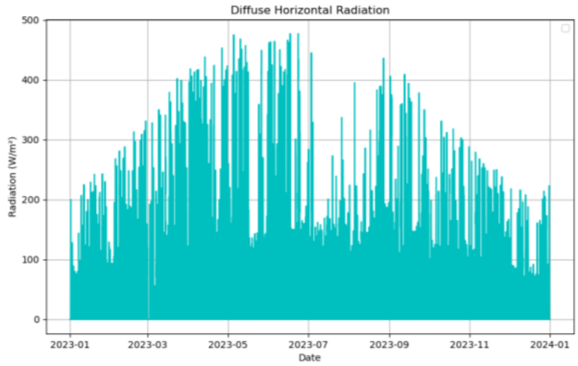

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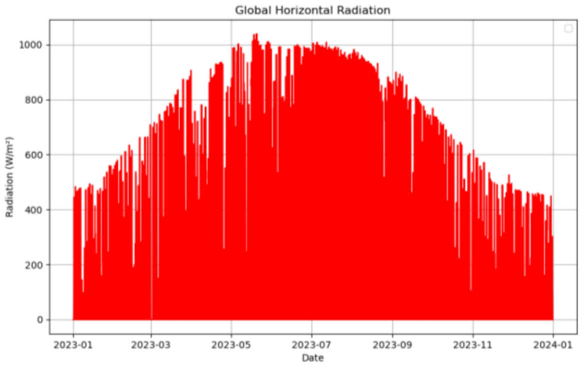

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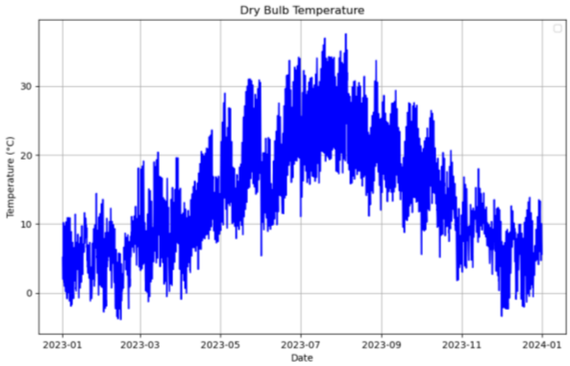

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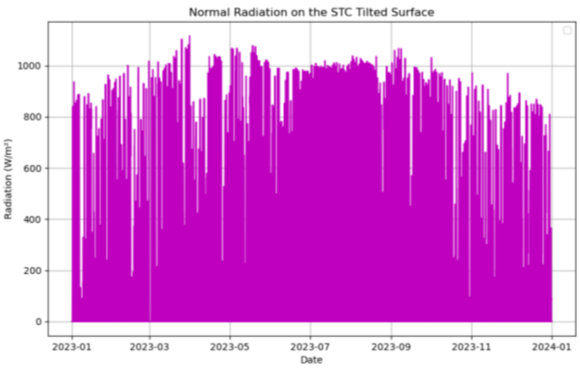
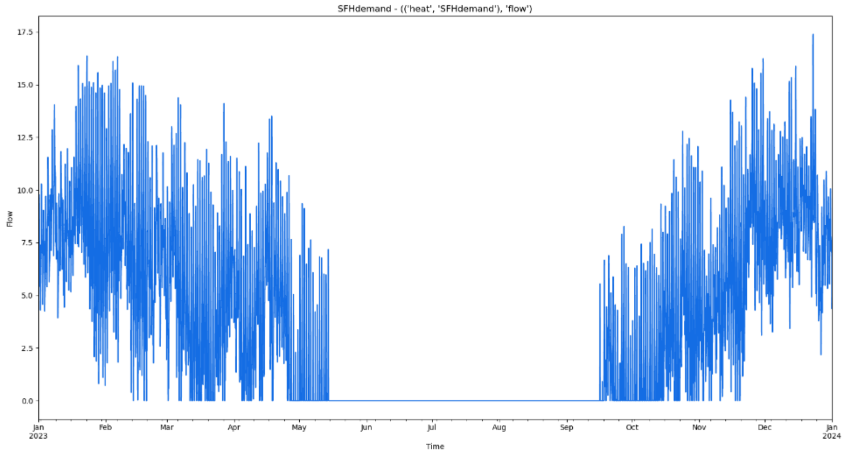
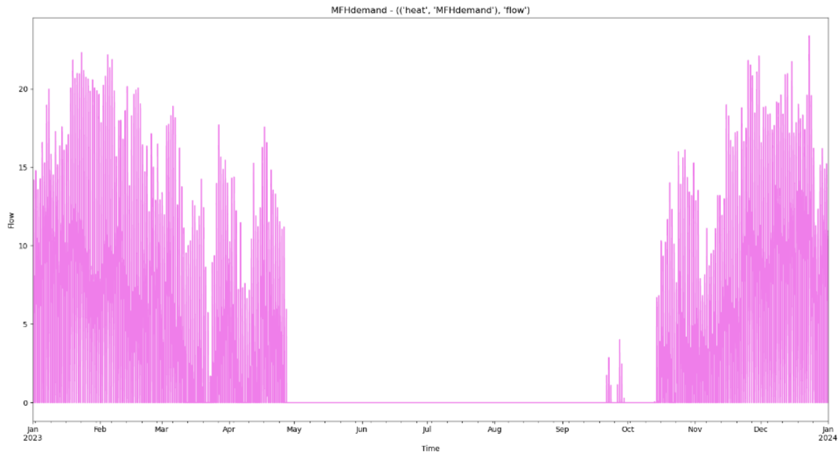


(e)

Figure 55. (a) Direct Horizontal Radiation, (b) Diffuse Horizontal Radiation, (c) Global Horizontal Radiation, (d) Ambient Temperature as retrieved from PVGIS API (Madrid, 2023) and (e) Normal Radiation on the STC Tilted Surface.



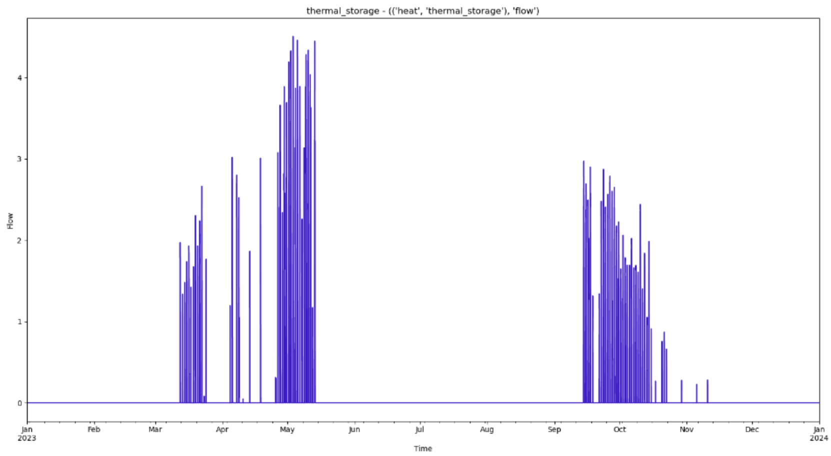
(a)



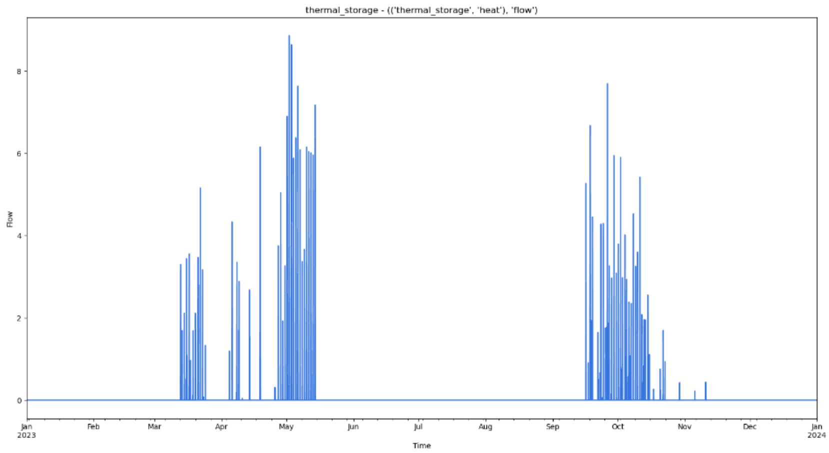
(b)

Figure 56. (a) Thermal energy flow from the heat bus to the SFH demand sink (i.e., heating demand of the SFH), (b) Thermal energy flow from the heat bus to the MFH demand sink (i.e., heating demand of the MFH), both in kWh.

First, we have a look at the evolution of the heating supply to the two buildings in the energy system. To ensure that the demand is satisfied at any time step, the hourly gas import limit is bounded at a high 100 kWh level but generation from the STC source is prioritized in the heat bus energy balance by setting a higher variable cost in the gas import and CHP plant operation.



(a)



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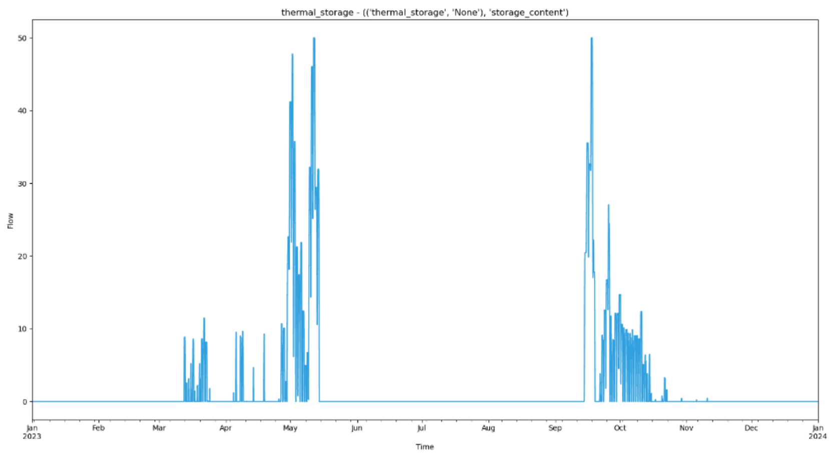


(c)

Figure 57. (a) Thermal energy flow from the heat bus to the thermal storage (i.e., thermal storage charge), (b) Thermal energy flow from the thermal storage to the heat bus (i.e., thermal storage discharge), (c) Thermal storage content level, in kWh.

The operation of the thermal storage is limited by both the nominal capacity and the charging and discharging rates. Figure 57 show the evolution of the inflow and outflow to and from the storage and its content level. The component is not operating when the STC generation is significative low as no surplus can be stored and a significant share of the demand is covered by the CHP plant generation at the exact same timestep.

The thermal storage content is limited by the storage nominal capacity as expected. No operation is observed when the heating demand is null and when the STC generation is low, as mentioned before.

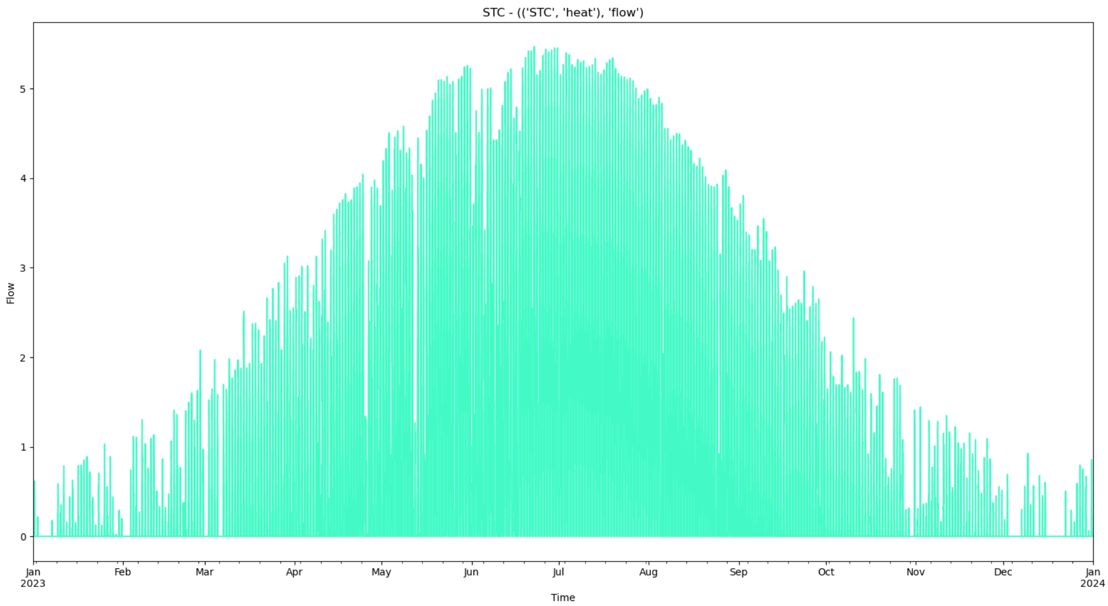
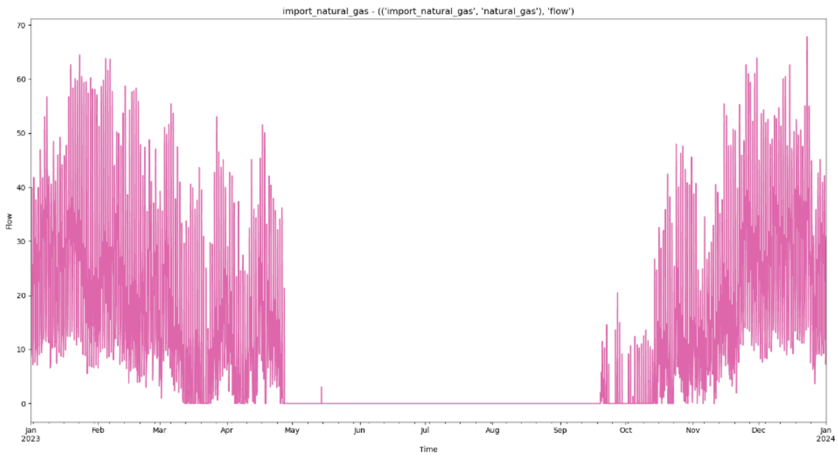
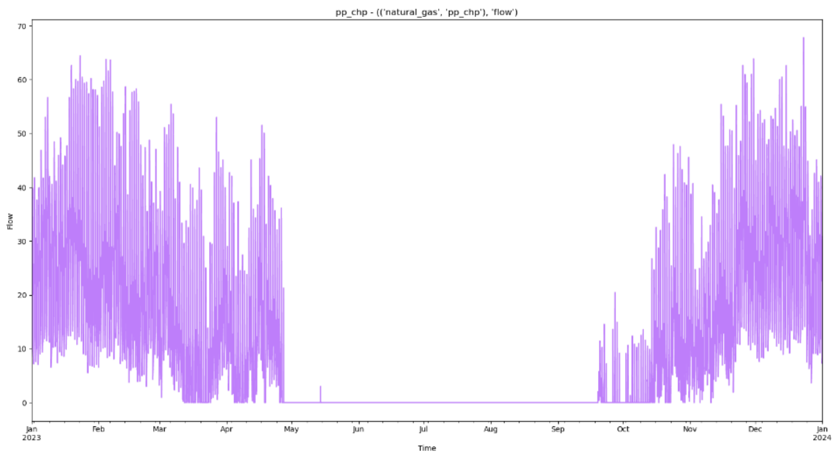


Figure 58. Thermal energy flow from the STC source to the heat bus (i.e., STC heat production) in kWh.

Figure 59 show the evolution of the natural gas import. The exact same information is displayed as the natural gas source has a unique output to the natural gas bus, and similarly the natural gas bus has a unique input from the natural gas source.



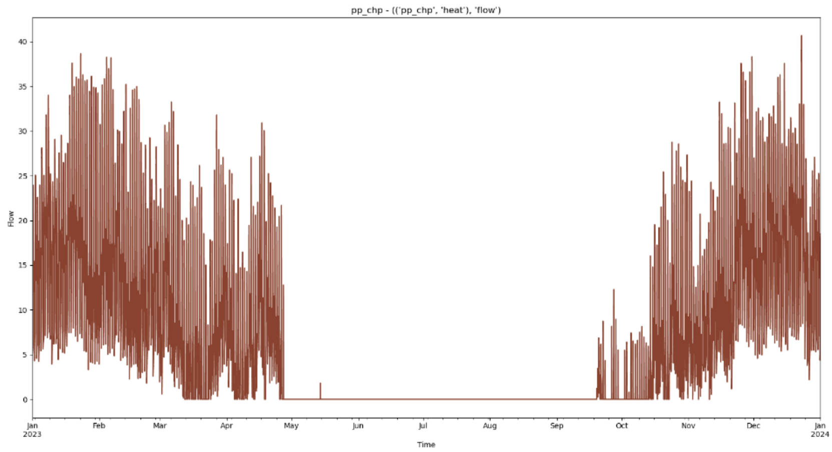
(a)



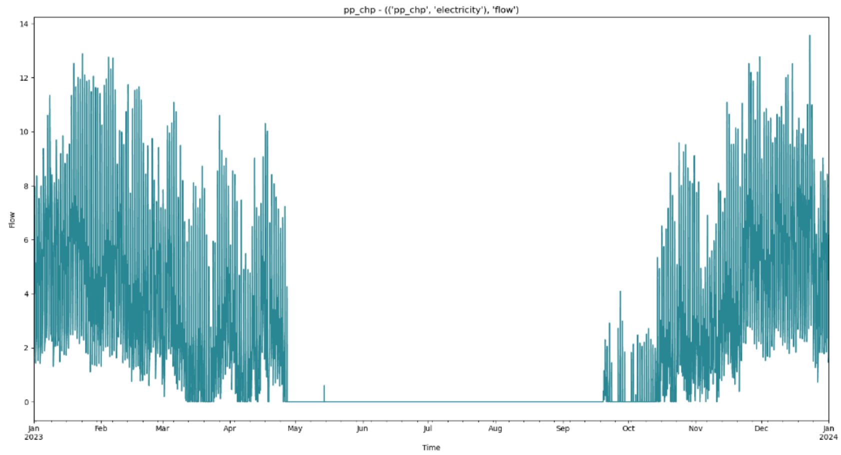
(b)

Figure 59. (a) Energy flow from the natural gas source to the natural gas bus (i.e., import of natural gas to the system), (b) Energy flow from the natural gas bus to the CHP plant converter (i.e., natural gas inlet to the CHP plant), both in kWh.

The generation from the CHP plant is intended to cover the needs of the two buildings when the STC generation and the thermal storage operation (limited by storage capacity and hourly discharge rate) are insufficient. However, **STC generation is prioritized** in the heat bus balance by setting a higher variable cost for both the natural gas source and the CHP plant converter compared to the STC source (which is set to zero here).



(a)



(b)

Figure 60. (a) Thermal energy flow from the CHP plant converter to the heat bus (i.e., heating production from the CHP plant), (b) Electricity flow from the CHP plant converter to the electricity (i.e., electricity production from the CHP plant), both in kWh.

In periods when the demand is lower than the generation, **energy exports** are observed. This is evident in the heat bus balance during the summer season, when no heating demand from the two buildings is expected and all generation from the STC is exported. As no electricity demand is included in the energy system, **electricity** generation coming exclusively from the CHP plant **is always exported** throughout the year.

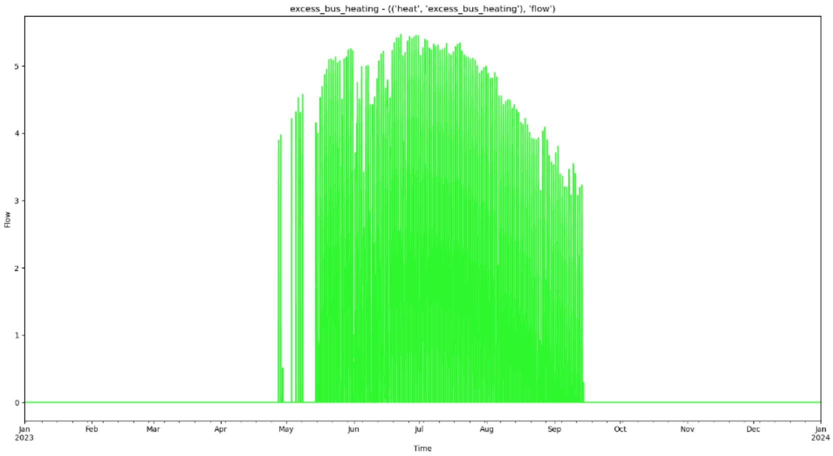


Figure 61. Thermal energy flow from the heat bus to the excess heat sink (i.e., heating export due to overproduction) in kWh.

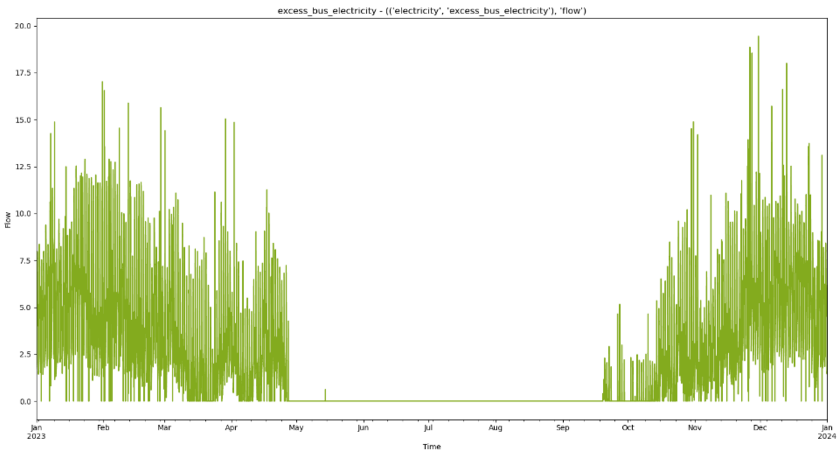


Figure 62. Electricity flow from the electricity bus to the excess electricity sink (i.e., electricity export due to overproduction) in kWh.