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## D2.4 ECOEMPOWER ENERGY-ICT PLATFORM VALIDATION AND ANALYSES OF THE ECOEMPOWER ENERGY COMMUNITIES – FIRST VERSION

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## ABBREVIATION LIST

| ABBREVIATION | DEFINITION                               |
|--------------|------------------------------------------|
| ACV          | Association des Centrales Villageoises   |
| API          | Application Programming Interface        |
| BEV          | Battery Electric Vehicle                 |
| DoA          | Description of Action                    |
| DSO          | Distribution System Operator             |
| EC           | Energy Community                         |
| EV           | Electric Vehicle                         |
| EWB          | Elektrizitätswerke Reutte                |
| GDPR         | General Data Protection Regulation       |
| GSE          | Gestore dei Servizi Energetici           |
| HEDNO        | Hellenic Distribution Network Operator   |
| HMI          | Human Machine Interface                  |
| ICT          | Information and Communication Technology |
| IoT          | Internet of Things                       |
| IT           | Information Technology                   |
| KPI          | Key Performance Indicator                |
| LEC          | Local Energy Community                   |
| LR           | Linear Regression                        |
| LS           | Least-Squares                            |
| ML           | Machine Learning                         |
| NZEB         | Nearly zero-emission building            |
| OSS          | One Stop Shop                            |

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|       |                                          |
|-------|------------------------------------------|
| PAT   | Provincia Autonoma di Trento             |
| PV    | Photovoltaic                             |
| RAE   | Regulatory Authority of Energy           |
| REC   | Renewable Energy Community               |
| RF    | Random Forest                            |
| ROCG  | Region of Central Greece                 |
| ROI   | Return Of Investment                     |
| SCADA | Supervisory Control and Data Acquisition |
| SSO   | Single Sign-on                           |
| UI    | User Interface                           |
| UC    | Use Case                                 |
| WP    | Work Package                             |
| LP    | Linear Programming                       |
| MILP  | Mixed-Integer Linear Programming         |

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## Contents

|       |                                                           |    |
|-------|-----------------------------------------------------------|----|
| 1     | Executive Summary .....                                   | 8  |
| 2     | Introduction .....                                        | 9  |
| 2.1   | Scope of the deliverable .....                            | 9  |
| 2.2   | Deliverable Structure .....                               | 9  |
| 2.3   | Interdependencies with other Tasks and Deliverables ..... | 9  |
| 3     | ICT Platform Redesign .....                               | 11 |
| 3.1   | Energy Forecasting Tool Key Changes .....                 | 11 |
| 3.2   | Energy Modelling Tool Key Changes .....                   | 12 |
| 3.3   | Cost-Benefit Analysis (CBA) Tool Key Changes .....        | 16 |
| 4     | First Round of Tool Validation .....                      | 18 |
| 4.1   | Validation of the Energy Forecast Tool .....              | 18 |
| 4.1.1 | Forecasting Interface Walkthrough and Validation .....    | 18 |
| 4.1.2 | Forecasting Result Validation .....                       | 22 |
| 4.2   | Validation of the Energy Modelling Tool .....             | 24 |
| 4.2.1 | Modelling Interface Walkthrough and Validation .....      | 24 |
| 4.2.2 | Modelling Result Validation .....                         | 31 |
| 4.3   | Validation of the Cost-Benefit Analysis (CBA) Tool .....  | 33 |
| 4.3.1 | CBA Interface Walkthrough and Validation .....            | 33 |
| 4.3.2 | CBA Results Validation .....                              | 36 |
| 5     | Conclusions and Next Steps .....                          | 38 |
| 6     | References .....                                          | 39 |
| 7     | List of Tables .....                                      | 40 |
| 8     | List of Figures .....                                     | 41 |
| A.    | Annex .....                                               | 43 |

## 1 EXECUTIVE SUMMARY

This document presents the validation-focused deliverable of Work Package 2 (WP2), reporting on the re-engineered ECOEMPOWER ICT Platform and its three tools, the Energy Forecasting Tool, the Energy Modelling & Scheduling Tool, and the Cost-Benefit Analysis (CBA) Tool. The platform was redesigned around a data-agnostic, user-driven workflow: minimal, standardized inputs, canonical time axes (monthly or hourly), transparent objectives, constraints and KPIs that can be reproduced from the same data without hidden assumptions. The validation campaign applies consistent protocols across pilots. In each case we document datasets, methods, and results, highlighting both strengths and limitations with clear, evidence-based interpretation.

The Forecasting Tool achieves planning-grade accuracy at community scale using a univariate seasonal approach that does not rely on local weather feeds, making it suitable for communities with limited ICT infrastructure. The Modelling & Scheduling Tool demonstrates correct energy balances and meaningful operational gains once shared resources and storage are activated; per-building vs. community scopes and alternative objectives (min cost, max self-consumption, max self-sufficiency) yield traceable differences in schedules and KPIs. The CBA Tool retains the established finance math (NPV, BCR, discounted payback) while surfacing all material assumptions (prices, escalations, CAPEX/OPEX, lifetimes, incentives) so financial outcomes reconcile directly with user-defined parameters. Together, the results confirm that the platform's methods are coherent, reproducible, and portable across diverse pilot conditions.

Looking ahead, the next validation round will extend testing to additional pilot sites with different data maturities and operating regimes to further stress-test agnosticism and cross-site comparability. Planned refinements include: (i) cold-start treatment and robust-oriented KPIs in forecasting; (ii) explicit prioritization rules for battery charging sources and stronger incentives for flexible loads in scheduling; and (iii) optioned time-of-use arbitrage and clarified lifetime/replacement conventions in CBA, supplemented by joint sensitivity analyses. These steps will consolidate external validity, enhance interpretability, and prepare the platform for finalization within WP2.

## 2 Introduction

### 2.1 Scope of the deliverable

The ECOEMPOWER project aims to empower regional authorities and local stakeholders to establish and manage energy communities through an integrated framework that combines technical, financial, and organizational support. Within this framework, the goal of the ICT Platform, which is validated in this deliverable, is to provide a user-friendly platform for energy communities (ECs), supporting them in the coordination of their energy resources and future activities planning. To achieve this, we have adopted a three-step approach, comprising (i) defining the platform requirements and identifying ECs' Use Cases (UCs), (ii) developing the platform to meet the needs of ECs, and (iii) validating the platform and energy analyses for the ECOEMPOWER ECs.

This deliverable results from the work carried out in T2.3 – Platform validation and dedicated studies for the ECOEMPOWER energy communities. Its scope is to document, in a coherent and reproducible manner, the validation of the re-engineered ICT Platform and its three agnostic tools - the Energy Forecasting Tool, the Energy Modelling & Scheduling Tool, and the Cost-Benefit Analysis (CBA) Tool - using pilot data and clearly stated assumptions. The document describes the validation datasets and protocols applied across pilot sites (e.g., monthly forecasting on the French RE, day-ahead scheduling on the German RE, and CBA parameterization on the Greek RE), the methodological rationale behind each tool (inputs, canonical time axes, objectives/constraints, KPIs), and the observed results including strengths, limitations, and targeted improvements.

Beyond presenting current evidence, the deliverable establishes the baseline for the next validation cycle in WP2. Overall, D2.3 provides a transparent record of the platform's validation status and a clear path to refine and finalize the tools and services by the end of the project.

### 2.2 Deliverable Structure

D.2.4 is structured in seven sections as follows:

- [Section 1: Executive summary](#) – This section provides a concise overview of the document's contents.
- [Section 2: Introduction](#) – Section 2 provides an overview of this document including the description of its purpose, structure, and its interdependencies to the other ECOEMPOWER tasks and deliverables.
- [Section 3: ICT Platform Redesign](#) – Section 3 provides an overview of the necessary design changes that had to be implemented to facilitate validation across pilot sites and replicators.
- [Section 4: First Round of Tool Validation](#) – This section presents the validation of the tools and their results using real pilot data.
- [Section 5: Conclusions and Next Steps](#) – In this Section, key deliverable outcomes are summarized and the subsequent steps or actions to be taken within the project are outlined.

### 2.3 Interdependencies with other Tasks and Deliverables

The interdependencies among the ECOEMPOWER tasks and deliverables are fundamental to ensuring the seamless development and implementation of the ECOEMPOWER project. Deliverable [D2.1](#) laid the groundwork by identifying and characterizing the requirements of ECs, providing crucial input for the development of the Energy ICT Tools . The ICT Platform that was developed and described in Deliverables [D2.2](#) and [D2.3](#) was then utilized to conduct energy studies in collaboration with the ECOEMPOWER pilot sites. Meanwhile, the data acquired during the initial phase of the project, including assessments detailed in Deliverable [D6.2](#) , will serve as a baseline for benchmarking purposes, providing essential insights into the existing infrastructure and planned initiatives within the targeted regions. The data collection continued throughout the first 18 months of the project , where more specialized data from the individual pilot sites were gathered and analyzed as part of the co-creation methodology. Also, a synergy has been identified with ECOEMPOWER Community Platform described in Deliverable [D4.4](#) as it can also serve as a secondary channel for the dissemination of the Energy Tools validated in this deliverable.

### 3 ICT Platform Redesign

This chapter outlines the core changes implemented to facilitate the validation and distribution of the ICT Energy Tools to the ECOEMPOWER Communities and potential replicators. The first iteration of the platform targeted a more advanced ICT stack for energy communities that included cloud native data storage and analytics with batch and stream processing through frameworks like [Spark](#) and [Kafka](#)), data pipelines and dashboard analytics aiming to provide real-time updates. That design approach maximized automation for communities with mature infrastructure and specialist support.

The present redesign addresses a different, equally important constraint. EC Managers must act without heavy technical capabilities, stable telemetry, or dedicated IT staff. We therefore replaced pilot-bound dashboards and infrastructure-dependent flows with a data-agnostic, user-driven workflow that operates on open inputs at well-defined resolutions. In this approach, users upload minimal, standardized datasets, the platform then validates them against canonical time axes and schemas, to finally perform necessary computations (forecasting, scheduling, and cost-benefit evaluation) deterministically on those inputs. This change reduces integration burden, removes dependencies on pilot specific APIs, and improves replicability as any result can be regenerated from the same uploaded series. It also preserves core principles from the original agreement (transparent methods, auditable processing, and privacy by design) while making the tools deployable in settings with limited ICT. In practice, this enables broader uptake within the ECOEMPOWER Communities and simplifies dissemination to replicators beyond it, who can adopt the same processes without rebuilding a complex data backbone.

The next sub-sections highlight the key reformulations to the three Energy ICT Tools: the Energy Forecasting Tool, the Energy Modelling Tool and the Cost-Benefit (CBA) Tool presented in this version of the Platform.

#### 3.1 Energy Forecasting Tool Key Changes

The current version of the Energy Forecasting Tool computes monthly PV generation forecasts without utilizing external weather APIs. This constraint is deliberate. The forecasting pipeline was redesigned to eliminate dependencies on local weather feeds and site-specific IT infrastructure, so that communities with limited data and resources can still obtain reliable forecasts. The system ingests historical monthly production per installation, aligns all series to a canonical monthly timeline, and produces a six-month horizon forecast at the same resolution. Where multiple installations are present, forecasts are generated per site and aggregated to the community level for presentation and export.

Methodologically, the model family is univariate and seasonal, trained solely on the historical production signal and trends estimated per installation, optionally pooled at the community level through shrinkage of hyper-parameters. In practice, the signal is decomposed into a smooth level-trend component and a fixed month-of-year seasonal pattern, with short autoregressive memory on recent months. This category of models captures the dominant drivers of monthly PV yield-installed capacity, degradation, and the astronomical cycle (sun path/photoperiod), which manifest as highly stable seasonal structure after aggregation from hours to months. Because month-level totals average out day-to-day cloud variability, exogenous weather covariates add limited incremental skill relative to their integration and maintenance cost, and they introduce location-specific dependencies that conflict with the platform's agnostic objective. Chronological rolling-origin validation (blocked folds) confirms that the seasonal baseline with damped trend attains planning-grade accuracy on monthly totals; adding weather features does not produce consistent, out-of-sample gains commensurate with the additional data and operational complexity.

This choice reduces data acquisition risks, removes location-specific coupling to external APIs, and ensures identical operation across communities regardless of ICT maturity. It also improves reproducibility as every forecast can be regenerated from the same historical series without auxiliary inputs. The interface enforces this discipline by accepting monthly generation as CSV/JSON in either “long” or “wide” batch formats, automatically sorting timestamps, normalizing types, and rejecting under-determined series.

Validation is embedded in the workflow. Users can upload actual monthly totals as they become available; the system aligns the uploaded months to the forecast horizon and computes error metrics (MAE, RMSE, MAPE) both at community level and per installation, using chronological alignment to avoid look-ahead. The same alignment underpins the charts that overlay actuals and forecasts for each site as well as the community aggregate, ensuring like-for-like comparisons across months.

The reformulation achieves agnosticism in two dimensions: data and deployment. On the data axis, the tool needs only historical monthly production. On the deployment axis, the same input schema and validation logic apply across locations, so communities with heterogeneous capabilities can share a single forecasting process. This is a necessary adjustment for scale: it avoids excluding communities lacking weather integrations while preserving scientific transparency in how predictions are constructed and evaluated.

Operationally, outputs are represented as month-stamped series for each site and for the community total. They can be exported and consumed by other platform components without transforms, since all tools share a common time-series shape and naming convention. Internally, the interface exposes summary statistics (horizon length, total forecasted energy, mean monthly level, peak/low months) derived directly from the forecast arrays, and it provides CSV templates to standardize subsequent validation uploads. Together, these elements create a forecasting service that is portable, reproducible, and usable by communities with limited data infrastructures, while preserving a clear path to future extensions (e.g., optional exogenous weather) without changing the public data contract.

### 3.2 Energy Modelling Tool Key Changes

The current version of the Modelling & Scheduling Tool transforms from a pilot-bound dashboard viewer into a scenario-based optimizer in which users define buildings, loads, PV, storage, flexible assets, and community resources for a chosen 24-hour horizon. The backend then applies an hourly power balance with explicit constraints on battery charge/discharge and flexible loads, solving either deterministically (simulation) or with mixed-integer linear programming (MILP) for day-ahead set-points. Policy toggles (e.g., charge/discharge exclusivity, end-of-day state-of-charge) and tariff-aware controls make the solver behavior transparent and tunable. Community sharing can be configured as pooled or contractual, and community-level PV/wind/battery can be superimposed on building assets under the same accounting.

Two methodological choices underpin the reformulation. First, canonical time indexing ensures that all series (load, PV, tariff, set-points) map to a single 24-hour UTC-aware calendar. This removes a common source of misalignment and enables consistent aggregation from buildings to community metrics. Second, all inputs are explicitly per-building, with validation that enforces 24 hourly entries for each declared building and clear warnings for orphaned or inconsistent records. These checks reduce silent failure modes and give users immediate feedback about data sufficiency before optimization proceeds.

Within this structure, the tool computes community KPIs that reflect operational objectives: energy imports (cost), instantaneous self-consumption, self-sufficiency, curtailment, and storage utilization. Flexible loads are represented with minimal but expressive parameters (e.g, EV energy and availability window; heat-pump power and usable hours), enabling the optimizer to allocate duty within constraints, while a replacement variable prevents double counting against the business-as-usual (BAU) load. For communities with shared resources, a dedicated parsing layer normalizes PV/wind/battery specifications and sharing contracts into hourly vectors that the solver can consume directly. The resulting schedules, together with traceable KPIs, constitute a decision-ready baseline that other tools can reference without reinterpretation.

The practical consequence of this redesign is portability: the same optimization pipeline can be executed for any community that supplies the minimum required inputs, and the same outputs (time-stamped series and KPIs) can be visualized and exported. It also makes what-if analysis first-class: changing community PV capacity, adding a community battery, or modifying shares produces a delta analysis (cost, imports, self-consumption) computed on the same horizon and constraints as the baseline, which strengthens causal attribution for stakeholders.

Some additional changes that were implemented in this version regard the introduction of different optimization objectives and scopes, as well as the inclusion of additional scheduling capabilities for the flexible loads. Starting with the different objectives, the tool now can facilitate three mutually exclusive objective functions, that are selectable in the UI and are mapped to different mathematical criteria:

1. **Minimize Cost** → The model minimizes total import expenditure over the selected horizon

$$\min \sum_t p_t \sum_b grid_{b,t}$$

2. **Maximize Self-Consumption** → Implemented as minimization of curtailment, which is equivalent to maximizing the share of PV used locally subject to constraints

$$\min \sum_{b,t} curt_{b,t}$$

3. **Maximize Self-Sufficiency** → Implemented as minimization of imports

$$\min \sum_{b,t} grid_{b,t}$$

*Table 1 Variable and Symbol Definition for the Optimization Objectives equations*

| Symbol | Definition                                 | Units | Additional Explanations                                                                 |
|--------|--------------------------------------------|-------|-----------------------------------------------------------------------------------------|
| $t$    | Time index within the optimization horizon | Hours | The current model runs over a fixed 24-hour horizon (one day-ahead optimization window) |

|              |                                                            |       |                                                                                                                                    |
|--------------|------------------------------------------------------------|-------|------------------------------------------------------------------------------------------------------------------------------------|
| $b$          | Building Index                                             | -     | Represents an individual building within the EC                                                                                    |
| $p_t$        | Electricity price at hour $t$                              | €/kWh | Imported from the tariff profile defined by the user                                                                               |
| $grid_{b,t}$ | Imported energy from the grid for building $b$ at time $t$ | kWh   | Represents the residual energy demand that cannot be covered by local PV or batteries                                              |
| $curt_{b,t}$ | Curtailed PV energy for building $b$ at time $t$           | kWh   | The portion of PV generation that is not self-consumed, stored, or shared within the community (potential renewable energy wasted) |

Because each objective optimizes a different operational metric, they can yield distinct schedules from the same inputs, which is useful for sensitivity analysis and stakeholder preference alignment.

Two optimization scopes were also made available to this version. The per-building scope optimizes each site using its own load, PV, tariff, flexibility, and (optional) battery. It is appropriate for decentralized decisions or when community assets and sharing rules are not in play. The community scope augments the model with shared generation and storage and a sharing policy. Community PV/wind can be pooled or contractually allocated by shares while an optional community battery adds charge/discharge variables at the community node with efficiencies and SoC constraints. This community approach was the scope of the first version of the tool that was also expanded to include contractual shares (if existing). These are then normalized and applied to allocate community generation. Pooled mode is allocated implicitly by the optimizer through the balance equations. This scope preserves building-level batteries and flexible loads while adding community-level variables and constraints, enabling truly aggregated strategies.

Apart from the battery optimization, we are also operationalizing the three types of flexible loads that we have also included in the previous version: EV Charges, Heat Pumps and HVACs.

1. **EV Chargers:** They use an availability gated power cap along with a daily energy requirement charge for the vehicles they facilitate. For building  $b$  and hour  $t$  we have:

$$EV_{b,t} \leq P_b^{max}, \sum_t EV_{b,t} = E_b^{req}$$

Where  $P_b^{max}$  encodes the user provided availability window

2. **Heat Pumps:** They are represented with an hourly power bound and a “usable-hours” (energy) budget

$$HP_{b,t} \leq P_b^{max}, \sum_t HP_{b,t} = P_b^{max} \cdot H_b^{usable}$$

3. **Central HVAC:** These are captured as bounded modulation around a baseline within a user-defined operating window. Let  $B_{b,t}$  be the baseline HVAC profile (kW) and  $a_b$  a symmetric flexibility band ( $\pm\%$ ). We introduce a modulation variable  $\Delta_{b,t}^{HVAC}$  and we set:

$$HVAC_{b,t} = B_{b,t} + \Delta_{b,t}^{HVAC}, -a_b B_{b,t} \leq \Delta_{b,t}^{HVAC} \leq a_b B_{b,t}$$

For  $t \in [t^{start}, t^{end}]$  and  $\Delta_{b,t}^{HVAC} = 0$  outside the window. Optionally, energy neutrality can be enforced over the window to avoid net comfort drift. This linear scheme matches the UI parameters and keeps the problem in LP form.

Table 2 Flexible Load Variable explanations and Operational Constrains for the Optimization equations

| Symbol         | Definition                                                                         | Units          | Additional Explanations                                                                                                                |
|----------------|------------------------------------------------------------------------------------|----------------|----------------------------------------------------------------------------------------------------------------------------------------|
| $EV_{b,t}$     | Charging power allocated to electric vehicle chargers at building $b$ and time $t$ | kWh (per hour) | Decision variable controlling when and how much the EVs are charged                                                                    |
| $P_b^{max}$    | Maximum available charging power for EVs at building $b$                           | kW             | Represents both the technical charging capacity and the user-defined availability window (charging allowed only during specific hours) |
| $E_b^{req}$    | Total daily energy required by the EVs at building $b$                             | kWh            | Specifies the total amount of energy that must be delivered within the available window                                                |
| $HP_{b,t}$     | Thermal or electrical power consumed by the heat pump at building $b$ and time $t$ | kWh (per hour) | Decision variable defining hourly operation of heat pumps for heating or cooling                                                       |
| $H_b^{usable}$ | Usable operating hours for the heat pump at building $b$ and time $t$              | Hours          | Indicates the total number of hours per day the heat pump is allowed to operate (energy budget)                                        |
| $B_{b,t}$      | Baseline HVAC load profile at building $b$ and time $t$                            | kW             | Represents the expected non-flexible HVAC power demand prior to optimization                                                           |
| $a_b$          | Flexibility band for                                                               | %              | Defines the symmetric range within                                                                                                     |

|                       |                                                                      |                                                                                                              |
|-----------------------|----------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------|
| $\Delta_{b,t}^{HVAC}$ | HVAC modulation at building $b$                                      | which the HVAC load can vary                                                                                 |
|                       | Modulation variable kW of the HVAC load at building $b$ and time $t$ | Represents the deviation from the baseline $B_{b,t}$ within the flexibility band                             |
| $t^{start}, t^{end}$  | Start and end hours of the HVAC operating window                     | Define the period during which HVAC flexibility is active; outside this window, modulation is fixed at zero. |

EV charging and heat-pump/HVAC duty represent large, schedulable end-uses with clear operational requirements (energy requirement and availability for EVs and rated power and usable hours for heating/cooling). Modeling them with linear constraints provides meaningful flexibility without heavy data demands or non-linear device physics, keeps problems tractable for day-ahead horizons, and aligns with the platform's agnostic principle: communities specify only a few parameters per building and obtain feasible schedules with transparent trade-offs. The UI could accommodate other classes if needed, but the current solver activates EVs and heat pumps/HVACs to keep optimization robust and explainable.

### 3.3 Cost-Benefit Analysis (CBA) Tool Key Changes

The current CBA Tool retains the same computational equations and decision metrics as before (NPV, Benefit–Cost Ratio, discounted payback, and sensitivity analyses) while restructuring how those calculations are parameterized and exposed to users. In the earlier setup, several parameters were implicit or pilot-specific (e.g, fixed incentive rules, CO<sub>2</sub> valuation, tariff indexation, degradation and inflation presets). Those assumptions were embedded in backend logic and fed by project data. In the new, agnostic version of the tool, every assumption that materially affects the time-value calculus is surfaced in the interface and can be edited, versioned, and exported. That includes CAPEX breakdowns, OPEX trajectories, asset lifetimes and residual values, price/inflation/indexation models, incentive structures, taxes and social charges (where applicable), financing terms (e.g, WACC or debt/equity split), degradation, and optional monetization of environmental externalities (e.g, CO<sub>2</sub> price paths). The mathematical core is unchanged and only the parameterization has moved from hidden defaults to user control.

A second structural change is the decoupling from long-term energy forecast feeds. Previously, the tool was designed to consume energy projections from pilot data and converted them into cash-flow items via fixed rules. This relied on a great volume of data that could not be provided by our current pilot sites. In the current design, those data have been replaced by fully parameterized financial inputs that capture the same effects without binding the tool to project or site-specific data infrastructures. Now, users specify annual savings and revenue mechanisms as explicit functions of their chosen parameters (e.g, avoided imports priced by a user-defined tariff trajectory; remunerated exports under user-defined rates; O&M escalators; incentive clawbacks; carbon credits with user-defined price paths). The result is a model where all drivers of cash flows are transparent and portable, while the cash-flow equations remains identical to the previous version.

Methodologically, analysis still begins from a baseline (no intervention) and proceeds to the chosen interventions (community PV, PV+storage as we had before). The baseline has zero initial investment but includes any ongoing costs revenues the user wishes to represent. Intervention scenarios then apply user-specified CAPEX/OPEX and revenue rules to produce annual net cash flows over the analysis horizon. Benefits are recognized through avoided purchases and priced exports (or service revenues), while costs include investment, financing, maintenance, replacements, and end-of-life adjustments (residual/salvage). Because these elements are now fully parameterized, the same computational backbone can be deployed across communities that differ in regulation, incentives, or tariff regimes without hidden presets.

The tool keeps the key outputs and interpretive principles stable:

- **NPV** at user-selected discount rate(s) and **BCR** on a common basis
- **discounted payback**, both financial and, optionally, societal when externalities (e.g., CO<sub>2</sub>) are monetized
- **scenario analyses** that sweep the parameters most influential to outcome variance (e.g., discount rate, CAPEX, tariff slope, degradation, CO<sub>2</sub> price).

Community managers can reformulate scenarios to match local rules and priorities, replicate analyses across geographies, and defend results with clear proof of every assumption while relying on the same, unchanged principles that underpinned the prior iteration.

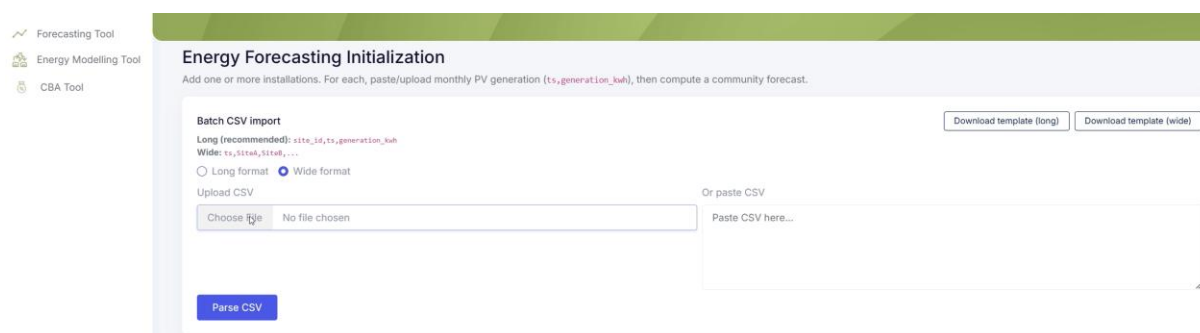
## 4 First Round of Tool Validation

This chapter documents how the platform's methods and outputs are validated across the three tools using data from the ECOEMPOWER REs. We will first show input validation, where uploaded series are checked against canonical time axes (24-hour or monthly), per-building completeness, unit consistency, and schema conformity. For the Forecasting Tool, monthly predictions are assessed with chronological holdout and reported using MAE, RMSE, and MAPE at installation and community levels. For the Modelling Tool, Optimal Day Ahead Schedules and Community KPIs will be presented under different objectives. For the CBA Tool, cash-flow validation is performed by reconciling parameterized assumptions (CAPEX/OPEX, tariffs, incentives, degradation) with the calculations of NPV, BCR, and discounted payback, including sensitivity sweeps. Throughout, results are presented alongside the minimal assumptions required to reproduce them, so readers can trace every figure back to inputs, constraints, and objective selections and verify that identical inputs yield identical outcomes.

### 4.1 Validation of the Energy Forecast Tool

#### 4.1.1 Forecasting Interface Walkthrough and Validation

This validation phase uses the French REs monthly PV production for 29 installations covering 2017-2023. Each installation has different data points and missing values, as their operation started in different time periods. For each site we retain the last 6 months as a strict out-of-time validation set and all earlier months are used for model fitting. Forecasts are generated per installation for the 6-month horizon (for our validation case, it's the period between November 2023 and April 2024) and then aggregated to the community for comparative analysis. The tool's batch interface ingests per-site histories (CSV/JSON, long or wide forms) and returns per-site forecasts plus aligned community totals. The format of the CSV is pre-determined through the parser and the template can be downloaded as can be seen in Figure 1. The template can also be found in the Annex of this deliverable.



The screenshot shows the 'Energy Forecasting Initialization' interface. On the left, there is a sidebar with three tools: 'Forecasting Tool' (selected), 'Energy Modelling Tool', and 'CBA Tool'. The main area is titled 'Energy Forecasting Initialization' and includes a sub-header 'Batch CSV import'. Below this, there is a description: 'Long (recommended): site\_id, ts, generation\_kwh' and 'Wide: ts, site\_id, site\_ts, ...'. There are two radio buttons: 'Long format' (selected) and 'Wide format'. Below the radio buttons, there is a section for 'Upload CSV' with a 'Choose file' button and a 'No file chosen' message. To the right of the 'Upload CSV' section, there is a section for 'Or paste CSV' with a 'Paste CSV here...' text area. At the bottom left, there is a 'Parse CSV' button. At the top right, there are two buttons: 'Download template (long)' and 'Download template (wide)'.

*Figure 1 Batch CSV import option to upload data from multiple installations. The format for the upload is indicated in the sample templates that can be downloaded by clicking on the buttons in the upper right corner*

Uploaded histories are parsed and normalized to a canonical monthly ISO timeline where types are enforced and site series are checked for alignment before any training or scoring. Community totals are computed as the aligned sum of per-site forecasts, ensuring that the same months index both the per-site arrays and the community series used in validation.

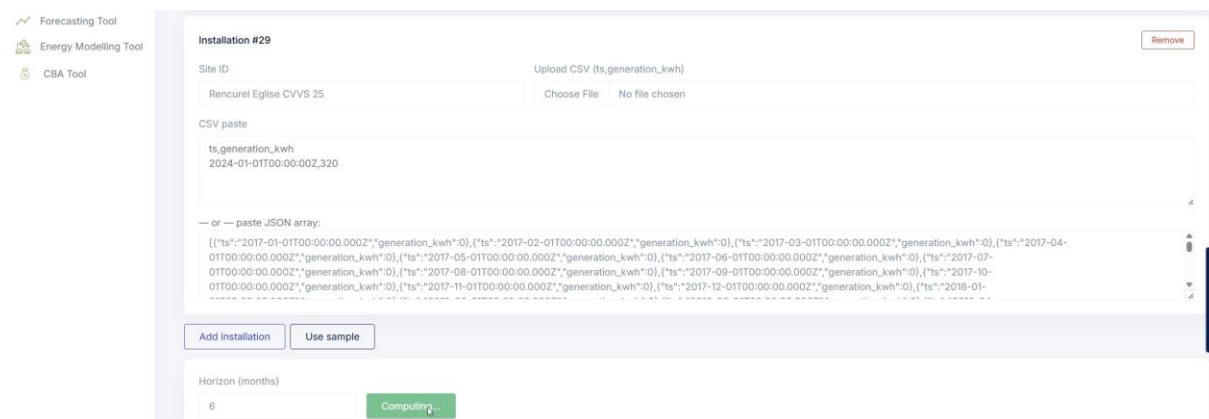
Parse CSV

29 site(s) detected.

| Site                                  | Rows | Last Month | Sample                                                                                |
|---------------------------------------|------|------------|---------------------------------------------------------------------------------------|
| Comcom CCVS 14                        | 82   | Oct 2023   | 2017-01-01 • 0 / 2017-02-01 • 0 / ... / 2023-09-01 • 1178 / 2023-10-01 • 854          |
| La Chapelle Cure CCVS 13              | 82   | Oct 2023   | 2017-01-01 • 197.2 / 2017-02-01 • 683.2 / ... / 2023-09-01 • 1074 / 2023-10-01 • 758  |
| La Chapelle Famiglia CCVS 4           | 82   | Oct 2023   | 2017-01-01 • 140.9 / 2017-02-01 • 732.7 / ... / 2023-09-01 • 2231 / 2023-10-01 • 1485 |
| La Chapelle Grands Champs CVVS 24     | 82   | Oct 2023   | 2017-01-01 • 0 / 2017-02-01 • 0 / ... / 2023-09-01 • 1028 / 2023-10-01 • 739          |
| La Chapelle Hangar Clet CVVS 8        | 82   | Oct 2023   | 2017-01-01 • 0 / 2017-02-01 • 0 / ... / 2023-09-01 • 4519 / 2023-10-01 • 3283         |
| La Chapelle Maison Aventure CVVS      | 82   | Oct 2023   | 2017-01-01 • 0 / 2017-02-01 • 0 / ... / 2023-09-01 • 0 / 2023-10-01 • 78              |
| Rencurel Ecole CVVS 10                | 82   | Oct 2023   | 2017-01-01 • 302.6 / 2017-02-01 • 714.6 / ... / 2023-09-01 • 1132 / 2023-10-01 • 852  |
| Rencurel Eglise CVVS 25               | 82   | Oct 2023   | 2017-01-01 • 0 / 2017-02-01 • 0 / ... / 2023-09-01 • 3216 / 2023-10-01 • 2357         |
| Rencurel Foyer ski CVVS 12            | 82   | Oct 2023   | 2017-01-01 • 0 / 2017-02-01 • 0 / ... / 2023-09-01 • 2170 / 2023-10-01 • 1455         |
| Saint Agnan Alles CVVS 11             | 82   | Oct 2023   | 2017-01-01 • 95.2 / 2017-02-01 • 678.1 / ... / 2023-09-01 • 1146 / 2023-10-01 • 808   |
| Saint Agnan Ecole CVVS 5              | 82   | Oct 2023   | 2017-01-01 • 152.1 / 2017-02-01 • 635 / ... / 2023-09-01 • 2187 / 2023-10-01 • 1534   |
| Saint Agnan La Pernanche CVVS 6       | 82   | Oct 2023   | 2017-01-01 • 186.5 / 2017-02-01 • 645.8 / ... / 2023-09-01 • 1118 / 2023-10-01 • 790  |
| Saint Julien Matrassière CVVS 22      | 82   | Oct 2023   | 2017-01-01 • 0 / 2017-02-01 • 0 / ... / 2023-09-01 • 1138 / 2023-10-01 • 811          |
| Saint Julien Presbytere CVVS 15       | 82   | Oct 2023   | 2017-01-01 • 0 / 2017-02-01 • 0 / ... / 2023-09-01 • 1118 / 2023-10-01 • 806          |
| Saint Julien Salle des fetes CVVS 7   | 82   | Oct 2023   | 2017-01-01 • 161.7 / 2017-02-01 • 678.4 / ... / 2023-09-01 • 1084 / 2023-10-01 • 777  |
| Saint Martin Bellier CVVS 8           | 82   | Oct 2023   | 2017-01-01 • 118.8 / 2017-02-01 • 615.4 / ... / 2023-09-01 • 1042 / 2023-10-01 • 748  |
| Saint Martin Cadeddu CVVS 2           | 82   | Oct 2023   | 2017-01-01 • 123.7 / 2017-02-01 • 594.3 / ... / 2023-09-01 • 1039 / 2023-10-01 • 744  |
| Saint Martin Gange Jallifier CVVS 28  | 82   | Oct 2023   | 2017-01-01 • 0 / 2017-02-01 • 0 / ... / 2023-09-01 • 4685 / 2023-10-01 • 3228         |
| Saint Martin hangar Jallifier CVVS 27 | 82   | Oct 2023   | 2017-01-01 • 0 / 2017-02-01 • 0 / ... / 2023-09-01 • 10723 / 2023-10-01 • 7479        |
| Saint Martin La Blachette CVVS 16     | 82   | Oct 2023   | 2017-01-01 • 0 / 2017-02-01 • 0 / ... / 2023-09-01 • 1091 / 2023-10-01 • 759          |
| Saint Martin Masson CVVS 17           | 82   | Oct 2023   | 2017-01-01 • 0 / 2017-02-01 • 0 / ... / 2023-09-01 • 1087 / 2023-10-01 • 779          |
| Saint Martin Prefolet CVVS 18         | 82   | Oct 2023   | 2017-01-01 • 0 / 2017-02-01 • 0 / ... / 2023-09-01 • 1044 / 2023-10-01 • 781          |
| Vassieux Chalets de la Frache CVVS 21 | 82   | Oct 2023   | 2017-01-01 • 0 / 2017-02-01 • 0 / ... / 2023-09-01 • 1230 / 2023-10-01 • 824          |
| Vassieux Champagne CVVS 26            | 82   | Oct 2023   | 2017-01-01 • 0 / 2017-02-01 • 0 / ... / 2023-09-01 • 4550 / 2023-10-01 • 3074         |
| Vassieux Ecole CVVS 13                | 82   | Oct 2023   | 2017-01-01 • 0 / 2017-02-01 • 0 / ... / 2023-09-01 • 1116 / 2023-10-01 • 779          |

Figure 2 The parsed data of the 29 installations of the VercorSoleil Pilot Site

The monthly model is **univariate and seasonal** (SARIMA/damped trend family), trained **without weather inputs** to keep the pipeline agnostic to site-specific ICT and external APIs. Each site is fit on its own history up to  $T - 6$ . The model then produces a 6-month forecast. Community totals are the month sum of site forecasts. The batch submit option of the ICT platform calls the backend through an API with the selected horizon as seen on the following picture:



Forecasting Tool

Energy Modelling Tool

CBA Tool

Installation #29

Site ID: Rencurel Eglise CVVS 25

Upload CSV (ts,generation\_kwh)

Choose File: No file chosen

CSV paste

ts,generation\_kwh

2024-01-01T00:00:00Z,320

— or — paste JSON array:

[{"ts":"2017-01-01T00:00:00Z","generation\_kwh":0}, {"ts":"2017-02-01T00:00:00Z","generation\_kwh":0}, {"ts":"2017-03-01T00:00:00Z","generation\_kwh":0}, {"ts":"2017-04-01T00:00:00Z","generation\_kwh":0}, {"ts":"2017-05-01T00:00:00Z","generation\_kwh":0}, {"ts":"2017-06-01T00:00:00Z","generation\_kwh":0}, {"ts":"2017-07-01T00:00:00Z","generation\_kwh":0}, {"ts":"2017-08-01T00:00:00Z","generation\_kwh":0}, {"ts":"2017-09-01T00:00:00Z","generation\_kwh":0}, {"ts":"2017-10-01T00:00:00Z","generation\_kwh":0}, {"ts":"2017-11-01T00:00:00Z","generation\_kwh":0}, {"ts":"2017-12-01T00:00:00Z","generation\_kwh":0}, {"ts":"2018-01-01T00:00:00Z","generation\_kwh":0}, {"ts":"2018-02-01T00:00:00Z","generation\_kwh":0}, {"ts":"2018-03-01T00:00:00Z","generation\_kwh":0}, {"ts":"2018-04-01T00:00:00Z","generation\_kwh":0}, {"ts":"2018-05-01T00:00:00Z","generation\_kwh":0}, {"ts":"2018-06-01T00:00:00Z","generation\_kwh":0}, {"ts":"2018-07-01T00:00:00Z","generation\_kwh":0}, {"ts":"2018-08-01T00:00:00Z","generation\_kwh":0}, {"ts":"2018-09-01T00:00:00Z","generation\_kwh":0}, {"ts":"2018-10-01T00:00:00Z","generation\_kwh":0}, {"ts":"2018-11-01T00:00:00Z","generation\_kwh":0}, {"ts":"2018-12-01T00:00:00Z","generation\_kwh":0}, {"ts":"2019-01-01T00:00:00Z","generation\_kwh":0}, {"ts":"2019-02-01T00:00:00Z","generation\_kwh":0}, {"ts":"2019-03-01T00:00:00Z","generation\_kwh":0}, {"ts":"2019-04-01T00:00:00Z","generation\_kwh":0}, {"ts":"2019-05-01T00:00:00Z","generation\_kwh":0}, {"ts":"2019-06-01T00:00:00Z","generation\_kwh":0}, {"ts":"2019-07-01T00:00:00Z","generation\_kwh":0}, {"ts":"2019-08-01T00:00:00Z","generation\_kwh":0}, {"ts":"2019-09-01T00:00:00Z","generation\_kwh":0}, {"ts":"2019-10-01T00:00:00Z","generation\_kwh":0}, {"ts":"2019-11-01T00:00:00Z","generation\_kwh":0}, {"ts":"2019-12-01T00:00:00Z","generation\_kwh":0}, {"ts":"2020-01-01T00:00:00Z","generation\_kwh":0}, {"ts":"2020-02-01T00:00:00Z","generation\_kwh":0}, {"ts":"2020-03-01T00:00:00Z","generation\_kwh":0}, {"ts":"2020-04-01T00:00:00Z","generation\_kwh":0}, {"ts":"2020-05-01T00:00:00Z","generation\_kwh":0}, {"ts":"2020-06-01T00:00:00Z","generation\_kwh":0}, {"ts":"2020-07-01T00:00:00Z","generation\_kwh":0}, {"ts":"2020-08-01T00:00:00Z","generation\_kwh":0}, {"ts":"2020-09-01T00:00:00Z","generation\_kwh":0}, {"ts":"2020-10-01T00:00:00Z","generation\_kwh":0}, {"ts":"2020-11-01T00:00:00Z","generation\_kwh":0}, {"ts":"2020-12-01T00:00:00Z","generation\_kwh":0}, {"ts":"2021-01-01T00:00:00Z","generation\_kwh":0}, {"ts":"2021-02-01T00:00:00Z","generation\_kwh":0}, {"ts":"2021-03-01T00:00:00Z","generation\_kwh":0}, {"ts":"2021-04-01T00:00:00Z","generation\_kwh":0}, {"ts":"2021-05-01T00:00:00Z","generation\_kwh":0}, {"ts":"2021-06-01T00:00:00Z","generation\_kwh":0}, {"ts":"2021-07-01T00:00:00Z","generation\_kwh":0}, {"ts":"2021-08-01T00:00:00Z","generation\_kwh":0}, {"ts":"2021-09-01T00:00:00Z","generation\_kwh":0}, {"ts":"2021-10-01T00:00:00Z","generation\_kwh":0}, {"ts":"2021-11-01T00:00:00Z","generation\_kwh":0}, {"ts":"2021-12-01T00:00:00Z","generation\_kwh":0}, {"ts":"2022-01-01T00:00:00Z","generation\_kwh":0}, {"ts":"2022-02-01T00:00:00Z","generation\_kwh":0}, {"ts":"2022-03-01T00:00:00Z","generation\_kwh":0}, {"ts":"2022-04-01T00:00:00Z","generation\_kwh":0}, {"ts":"2022-05-01T00:00:00Z","generation\_kwh":0}, {"ts":"2022-06-01T00:00:00Z","generation\_kwh":0}, {"ts":"2022-07-01T00:00:00Z","generation\_kwh":0}, {"ts":"2022-08-01T00:00:00Z","generation\_kwh":0}, {"ts":"2022-09-01T00:00:00Z","generation\_kwh":0}, {"ts":"2022-10-01T00:00:00Z","generation\_kwh":0}, {"ts":"2022-11-01T00:00:00Z","generation\_kwh":0}, {"ts":"2022-12-01T00:00:00Z","generation\_kwh":0}, {"ts":"2023-01-01T00:00:00Z","generation\_kwh":0}, {"ts":"2023-02-01T00:00:00Z","generation\_kwh":0}, {"ts":"2023-03-01T00:00:00Z","generation\_kwh":0}, {"ts":"2023-04-01T00:00:00Z","generation\_kwh":0}, {"ts":"2023-05-01T00:00:00Z","generation\_kwh":0}, {"ts":"2023-06-01T00:00:00Z","generation\_kwh":0}, {"ts":"2023-07-01T00:00:00Z","generation\_kwh":0}, {"ts":"2023-08-01T00:00:00Z","generation\_kwh":0}, {"ts":"2023-09-01T00:00:00Z","generation\_kwh":0}, {"ts":"2023-10-01T00:00:00Z","generation\_kwh":0}, {"ts":"2023-11-01T00:00:00Z","generation\_kwh":0}, {"ts":"2023-12-01T00:00:00Z","generation\_kwh":0}, {"ts":"2024-01-01T00:00:00Z","generation\_kwh":320}]

Add installation Use sample

Horizon (months)

6

Computing

Figure 3 Detail of the Forecast Horizon option which we have set to 6 months and some details of the last installation we have added to the Tool via CSV file

Once actuals are parsed, the tool computes the Forecasting Accuracy Metrics defined in D2.2: the Mean Absolut Error (MAE), the Root Mean Square Error (RMSE), and the Mean Absolut Percentage Error (MAPE) for:

1. the community aggregate (totals across all sites), and
2. each installation (per-site series).

Metrics are calculated only on aligned validation months, and missing values are filtered to avoid spurious penalties. Community and per-site scores are displayed together with the month-indexed arrays so that the same alignment drives both the numeric assessment and the visual overlays.

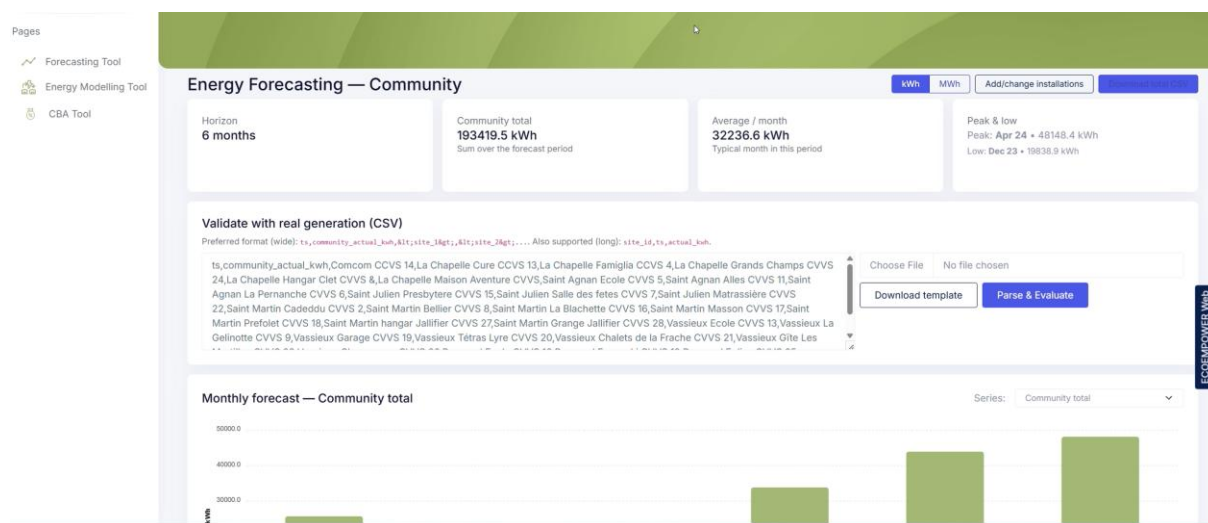


Figure 4 First view of the Forecasting Result Page and option to provide validation data

Before validating, the platform presents month-indexed totals aggregated across all installations, enabling quick assessment of expected production levels and seasonality at the community scale.

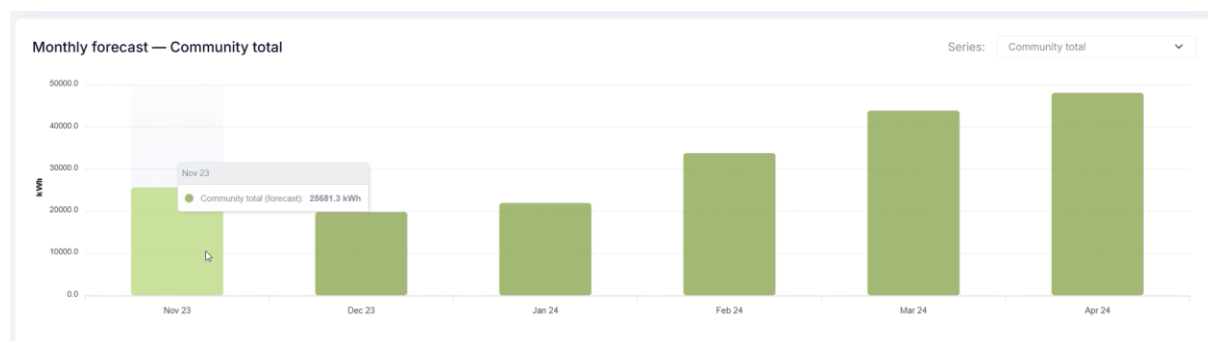


Figure 5 Monthly forecasts for the community for the selected 6-month period, with labelling

Users can switch to site-level series to inspect each installation's monthly forecast, compare contributions to the aggregate, and identify outliers or heterogeneity across assets.

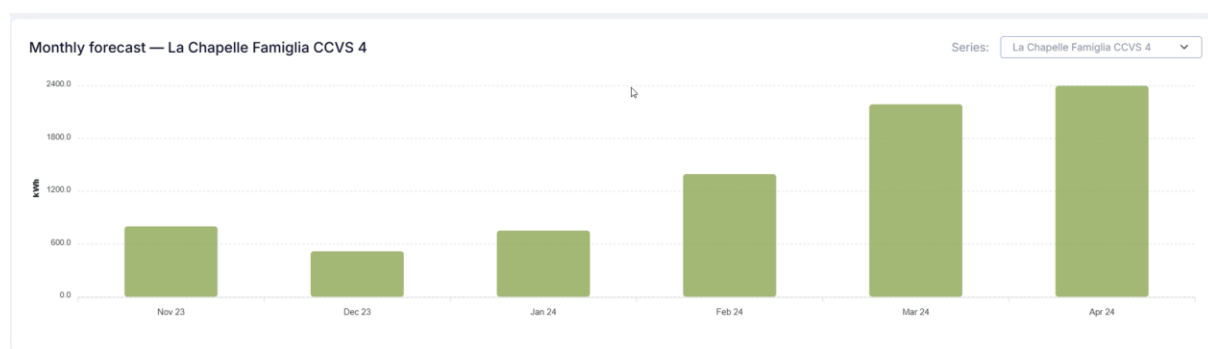


Figure 6 Monthly forecasts for individual Installations (La Chapelle Famiglia CCVS 4)

Pages

- Forecasting Tool
- Energy Modelling Tool
- CBA Tool

| Individual Installation Forecasts     |             |                    |
|---------------------------------------|-------------|--------------------|
| Site                                  | Total (KWh) | Share Of Community |
| Comcom CCVS 14                        | 3989.0 kWh  | 2.1%               |
| La Chapelle Cure CCVS 13              | 3745.1 kWh  | 1.9%               |
| La Chapelle Famiglia CCVS 4           | 8046.2 kWh  | 4.2%               |
| La Chapelle Grands Champs CCVS 24     | 4089.5 kWh  | 2.1%               |
| La Chapelle Hangar Clet CCVS 8        | 16849.5 kWh | 8.7%               |
| La Chapelle Maison Aventure CCVS      | 468.0 kWh   | 0.2%               |
| Saint Agnan Ecole CCVS 5              | 7794.8 kWh  | 4.0%               |
| Saint Agnan Allées CCVS 11            | 4011.3 kWh  | 2.1%               |
| Saint Agnan La Penanche CCVS 6        | 3848.6 kWh  | 2.0%               |
| Saint Julien Presbytère CCVS 15       | 3402.6 kWh  | 1.8%               |
| Saint Julien Salle des fêtes CCVS 7   | 3756.8 kWh  | 1.9%               |
| Saint Julien Matrasnière CCVS 22      | 3823.7 kWh  | 2.0%               |
| Saint Martin Cadeddu CCVS 2           | 3590.1 kWh  | 1.9%               |
| Saint Martin Bellier CCVS 8           | 3791.7 kWh  | 2.0%               |
| Saint Martin La Blachette CCVS 16     | 3729.4 kWh  | 1.9%               |
| Saint Martin Masson CCVS 17           | 3496.6 kWh  | 1.8%               |
| Saint Martin Prefolet CCVS 18         | 3606.0 kWh  | 1.9%               |
| Saint Martin hangar Jallifier CCVS 27 | 35742.4 kWh | 18.5%              |
| Saint Martin Grange Jallifier CCVS 28 | 950.5 kWh   | 0.5%               |
| Vassieux Ecole CCVS 13                | 3358.3 kWh  | 1.7%               |
| Vassieux La Gellinotte CCVS 9         | 10481.7 kWh | 5.4%               |

Figure 7 Totals for the 6-month period for the individual installations along with shares in % from the Total Generation

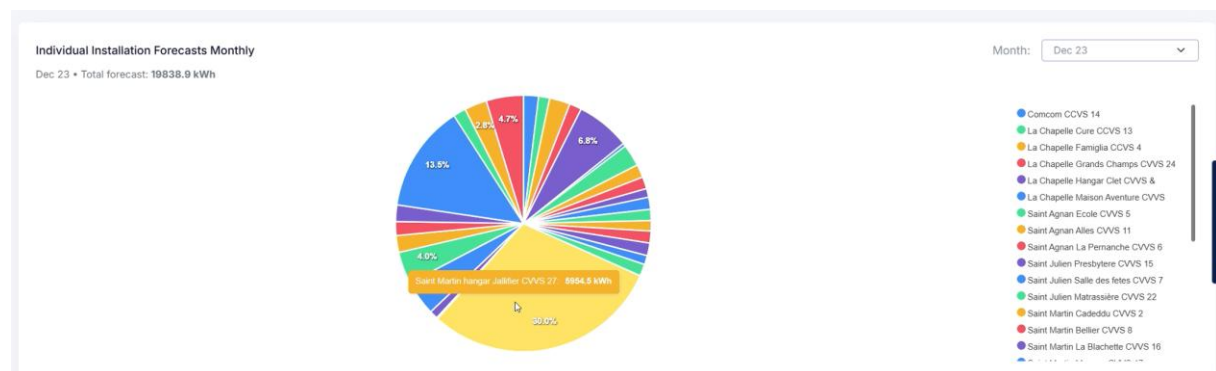


Figure 8 Pie chart showing per-month forecasts for each installation, with labels

If the user has available validation data for the 6-month period the tool provided forecasts for, they can upload it through the validation window to see the KPIs. Users can upload the holdout actuals (wide or long CSV) and the tool aligns months, computes MAE/RMSE/MAPE at community and site levels and surfaces any alignment or completeness warnings.

**Validate with real generation (CSV)**

Preferred format (wide): ts,community\_actual\_kwh,<site\_id>,<site\_id>,... Also supported (long): site\_id,ts,actual\_kwh.

Comcom CCVS 14,2023-12-01T00:00:00Z,431  
 Comcom CCVS 14,2024-01-01T00:00:00Z,444  
 Comcom CCVS 14,2024-02-01T00:00:00Z,612  
 Comcom CCVS 14,2024-03-01T00:00:00Z,851  
 Comcom CCVS 14,2024-04-01T00:00:00Z,990  
 La Chapelle Cure CCVS 13,2023-11-01T00:00:00Z,360

Choose File validation\_template.csv

Download template Parse & Evaluate

Community accuracy  
 MAE: 2447.6 kWh • RMSE: 2971.8 kWh • MAPE: 8.8%  
 Lower is better. MAE = typical absolute miss per month.

Download community comparison CSV

Figure 9 KPIs when we uploaded the actual generation data of the Pilot Site for months Nov 23-Apr 24. The MAPE is 8.8% which is low enough to be considered accurate forecast.

Individual Installation Accuracy

| Site                                  | N | MAE    | RMSE   | MAPE  |
|---------------------------------------|---|--------|--------|-------|
| Comcom CCVS 14                        | 6 | 55.3   | 60.5   | 8.8%  |
| La Chapelle Cure CCVS 13              | 6 | 69.7   | 83.2   | 11.3% |
| La Chapelle Famiglia CCVS 4           | 6 | 261.1  | 320.9  | 21.1% |
| La Chapelle Grands Champs CCVS 24     | 6 | 125.1  | 144.4  | 21.7% |
| La Chapelle Hangar Clet CCVS 8        | 6 | 478.1  | 558.8  | 18.7% |
| La Chapelle Maison Aventure CCVS      | 6 | 319.7  | 407.5  | 71.0% |
| Saint Agnan Ecole CCVS 5              | 6 | 209.6  | 258.6  | 16.3% |
| Saint Agnan Alles CCVS 11             | 6 | 79.1   | 92.0   | 12.2% |
| Saint Agnan La Pernanche CCVS 6       | 6 | 86.1   | 105.3  | 13.6% |
| Saint Julien Presbytere CCVS 15       | 6 | 56.9   | 69.9   | 12.5% |
| Saint Julien Salle des fetes CCVS 7   | 6 | 71.3   | 79.3   | 12.2% |
| Saint Julien Matrassière CCVS 22      | 6 | 90.0   | 101.4  | 15.1% |
| Saint Martin Cadeddu CCVS 2           | 6 | 73.8   | 90.5   | 13.6% |
| Saint Martin Bellier CCVS 8           | 6 | 63.6   | 70.4   | 11.0% |
| Saint Martin La Blachette CCVS 16     | 6 | 53.0   | 64.4   | 11.9% |
| Saint Martin Masson CCVS 17           | 6 | 59.8   | 72.2   | 11.7% |
| Saint Martin Prefolet CCVS 18         | 6 | 40.1   | 49.3   | 7.9%  |
| Saint Martin hangar Jallifier CCVS 27 | 6 | 2327.0 | 2515.8 | 52.0% |

Figure 10 Individual KPIs for the first 18 installations

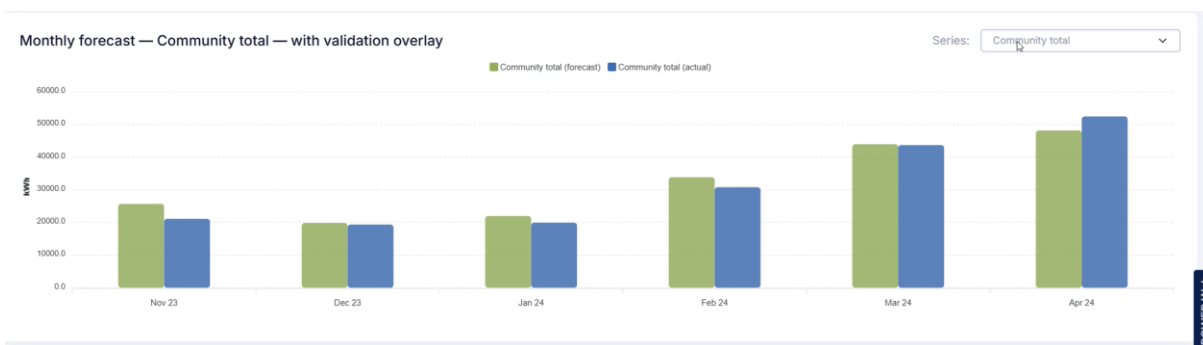


Figure 11 Monthly comparison between the forecasts and the actual generation data from the community

#### 4.1.2 Forecasting Result Validation

Using the French VercorSoleiL pilot dataset (29 installations), we trained per-site monthly models on all available history up to October 2023 and validated on the six validation months November 2023-April 2024. At the community level, the forecast closely tracks the seasonal ramp-up from winter to spring. Over the validation window, the community achieves MAE  $\approx 2,448$  kWh, RMSE  $\approx 2,972$  kWh, and MAPE  $\approx 8.84\%$ . Monthly absolute percentage errors are:

Table 3 MAPE Results for the selected validation window

| Validation Month | MAPE  |
|------------------|-------|
| Nov 23           | 21.6% |
| Dec 23           | 2.5%  |

|        |       |
|--------|-------|
| Jan 24 | 10.2% |
| Feb 24 | 9.9%  |
| Mar 24 | 0.6%  |
| Apr 24 | 8.2%  |

The worst month (November) precedes the winter minimum and concentrates most of the residual bias. March is essentially exact, and the remaining months are within single-digit to low-teens percentage error.

Across the validation months, the top four installations contribute  $\approx 40\%$  of total community energy, and the top ten contribute  $\approx 64\%$ . Two Saint-Martin sites dominate the tail: “hangar Jallifier CVVS 27” ( $\approx 32.8$  MWh over the six months) and “Grange Jallifier CVVS 28” ( $\approx 14.3$  MWh). Both are recently commissioned relative to the rest of the fleet with the first non-zero records appear in Jan 2023 (CVVS 27;  $\approx 16$  months of history by Apr 2024) and Jul 2023 (CVVS 28;  $\approx 10$  months). Several other sites also have short or sparse histories (e.g., La Chapelle Maison Aventure shows only  $\approx 7$  non-zero months overall). This asymmetry in data depth explains two effects seen in practice: 1) community-level accuracy remains strong because many long-running sites anchor the seasonal signal and 2) site-level errors can be inflated for new, high-output assets where commissioning ramps and limited history make the seasonal baseline less certain. As a general validation interpretation:

- The **8.8% community MAPE** over six out-of-time months indicates planning-grade performance using a weather-agnostic, univariate seasonal approach.
- The largest residuals occur at season transitions (November) and are attenuated thereafter as the seasonal component dominates (March-April).
- Data sufficiency rather than model form is the dominant risk for the few outlier sites with short histories ( $\leq 10$ – $16$  months) and commissioning effects can skew per-site KPIs, particularly when those sites contribute a large share of community energy.

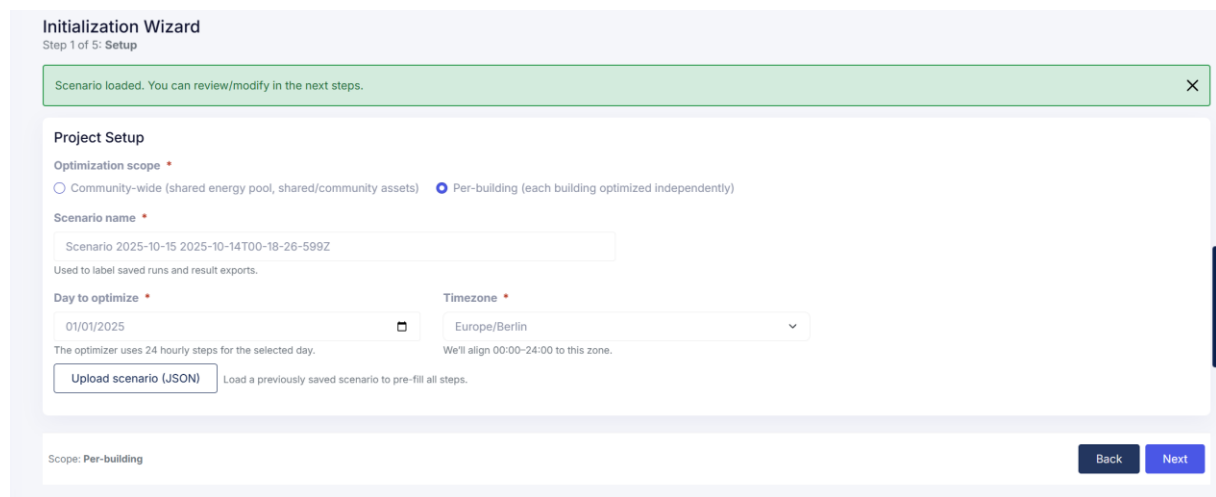
For the next validation rounds, some targeted improvements can be implemented:

1. A cold start treatment to newly commissioned installations could help produce more accurate results and reduce sensitivity
2. Pilot sites should try to include  $\geq 12$  consecutive months of non-zero production before formal scoring for new sites, apply explicit commissioning flags, and backfill missing months with consistent ISO timestamps so community and per-site validation remain comparable and reproducible.

## 4.2 Validation of the Energy Modelling Tool

### 4.2.1 Modelling Interface Walkthrough and Validation

This validation phase uses the German pilot's day-ahead scenario with five buildings (LW Eggensberger Landwirtschaft, LW Eggensberger Ferienwohnung, Hotel Eggensberger, Hoteldorf Hartung, Hotel Hirsch), each providing 24 hourly consumption values. The last three buildings also include 24 hourly generation series. No batteries are present in this scenario. Flexible loads are defined at building level (EV: daily energy with availability window and power cap; heat pump: rated power with usable hours; HVAC: baseline with  $\pm\%$  modulation in an operating window). The objective in the first stage of the tool is maximization of self-consumption at the building level. In the subsequent stages, we will introduce community assets and switch to a min-cost objective at the community scope, followed by a what-if extension.



**Initialization Wizard**  
Step 1 of 5: Setup

Scenario loaded. You can review/modify in the next steps. X

**Project Setup**

**Optimization scope \***

☐ Community-wide (shared energy pool, shared/community assets) ☒ Per-building (each building optimized independently)

**Scenario name \***

Scenario 2025-10-15 2025-10-14T00-18-26-599Z

Used to label saved runs and result exports.

**Day to optimize \***

01/01/2025

The optimizer uses 24 hourly steps for the selected day.

**Timezone \***

Europe/Berlin

We'll align 00:00-24:00 to this zone.

**Upload scenario (JSON)** Load a previously saved scenario to pre-fill all steps.

Scope: Per-building

**Back** **Next**

*Figure 12 Initialization Wizard of the Energy Modelling Tool where the user is prompted to provide their batch data and define the scope of the Optimization (in our case per-building)*

Uploaded series are parsed and normalized to the canonical 24-hour index, types are enforced with each declared building providing exactly 24-hour load rows and, if present, 24-hour PV rows. The platform raises alignment warnings for orphans or missing hours and computes summary statistics (totals, means) to confirm scale and plausibility prior to optimization. A scenario can also be uploaded as a JSON file with a specific, pre-determined schema that the Platform can process. An example can be found in the Annex.

**Initialization Wizard**  
Step 2 of 5: Data & Assets

Scenario loaded. You can review/modify in the next steps. ✕

**Building Setup** + Add Building

| ID                             | Type       | Consumption | PV      | Battery |                                       |
|--------------------------------|------------|-------------|---------|---------|---------------------------------------|
| LW_Eggensberger_Landwirtschaft | Commercial | 24 rows     | none    | none    | <span>Edit</span> <span>Remove</span> |
| LW_Eggensberger_Ferienwohnung  | Commercial | 24 rows     | none    | none    | <span>Edit</span> <span>Remove</span> |
| Hotel_Eggensberger             | Commercial | 24 rows     | 24 rows | none    | <span>Edit</span> <span>Remove</span> |
| Hoteldorf_Hartung              | Commercial | 24 rows     | 24 rows | none    | <span>Edit</span> <span>Remove</span> |
| Hotel_Hirsch                   | Commercial | 24 rows     | 24 rows | none    | <span>Edit</span> <span>Remove</span> |

Scope: Per-building Back Next

Figure 13 The parser transforms the data into editable building entities that the user can then edit further if needed

In case the user cannot provide batch data, they will be prompted to do so in the building editor as seen in the following figure:

**Edit building — Hotel\_Eggensberger** ✕

Building ID \*  Type \* Commercial ▼

Hourly Consumption Forecast (24 rows, kWh) \* Download template Upload CSV Clear

Preview



☒ Rooftop PV?

Hourly PV Forecast (24 rows, kWh) Download template Upload CSV Clear

Preview

☐ Battery?

☐ Flexible loads?

Cancel Save

Figure 14 Building editor where the user can upload and preview their csv files

From the same window, flexible loads from building heating and EV charging can be added manually as seen in figures 15 and 16:

## Edit building — Hotel\_Eggensberger



☒ Flexible loads?

Flexible loads (optional)

Type  
Heat Pump ▼

Heating capacity (kW)  Cooling capacity (kW)  COP (heating)  EER (cooling)

Building thermal capacity C (kWh/°C)  Heat loss coefficient U (kW/°C)

Comfort & Occupancy

Comfort band when occupied (°C)  –  Comfort band when unoccupied (°C)  –

Initial indoor temperature  $T_{in}$  (°C)

Occupancy (24h)

|       |       |       |       |       |       |       |       |
|-------|-------|-------|-------|-------|-------|-------|-------|
| 00:00 | 01:00 | 02:00 | 03:00 | 04:00 | 05:00 | 06:00 | 07:00 |
| 08:00 | 09:00 | 10:00 | 11:00 | 12:00 | 13:00 | 14:00 | 15:00 |
| 16:00 | 17:00 | 18:00 | 19:00 | 20:00 | 21:00 | 22:00 | 23:00 |

Occupied Unoccupied

Outdoor / ambient temperature ☒ Avg. Temp. ☐ 24hr Temp.

Avg. outdoor temperature (°C)

Cancel Save

Figure 15 Needed characteristics the user needs to include to the tool to optimize the Heat Pump Flexible load

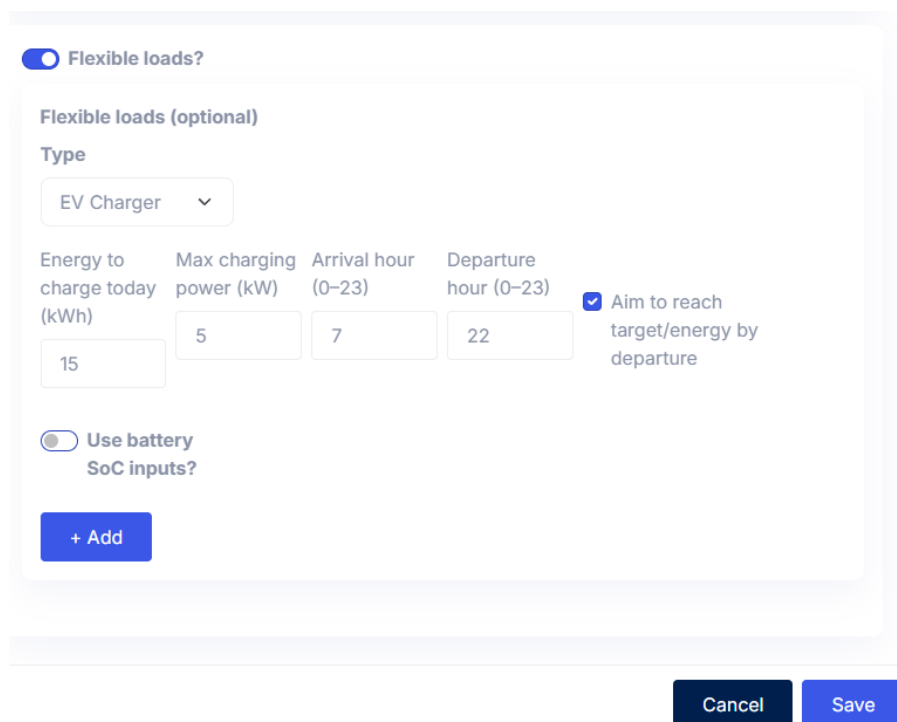


Figure 16 Needed characteristics the user needs to include to the tool to optimize the EV Charger Flexible load

After the user finalizes their scenario and chooses their desired parameters for optimization (including a typical price per kWh), the results are presented in the Optimization Result Window, starting with the KPIs.

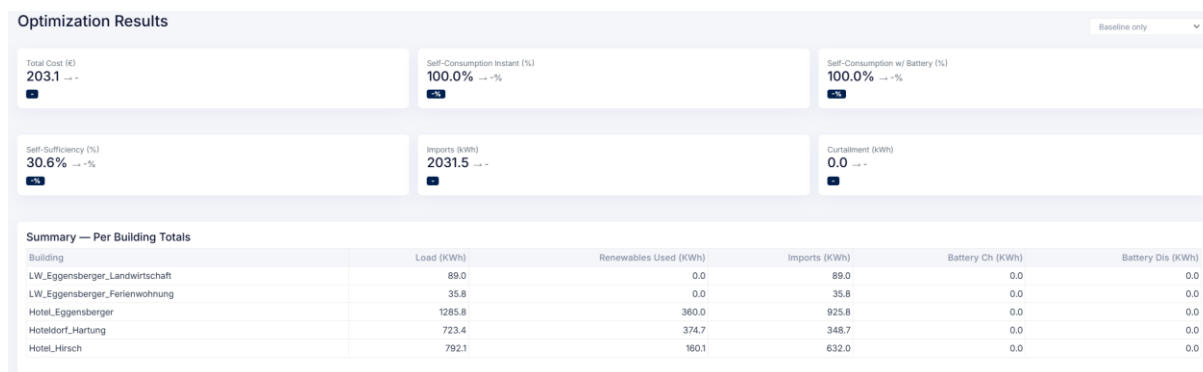


Figure 17 Calculated KPIs for selected scenario

The calculated timeseries are also presented in the same view, including charts for the load, generation, imports and battery (if existing). The flexible load scheduling is also being presented in a community view, followed by the activity.

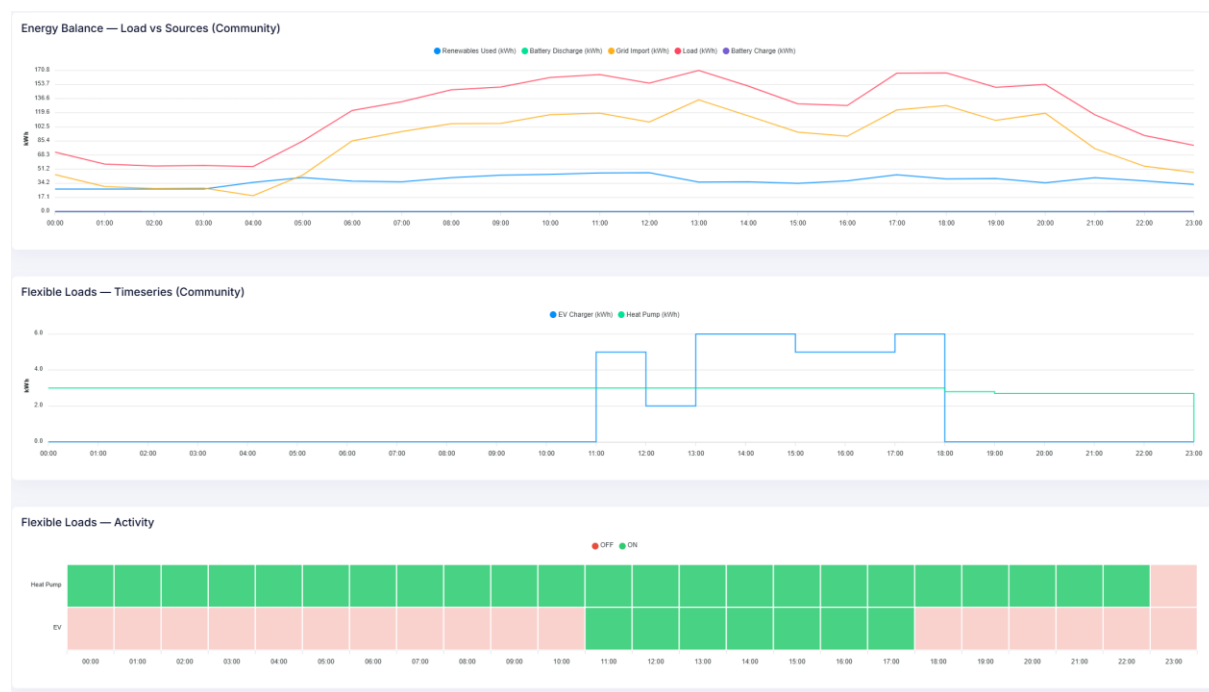


Figure 18 Optimization Timeseries and Flexible Loads for the whole community

In the end, we present hourly KPIs for the community.

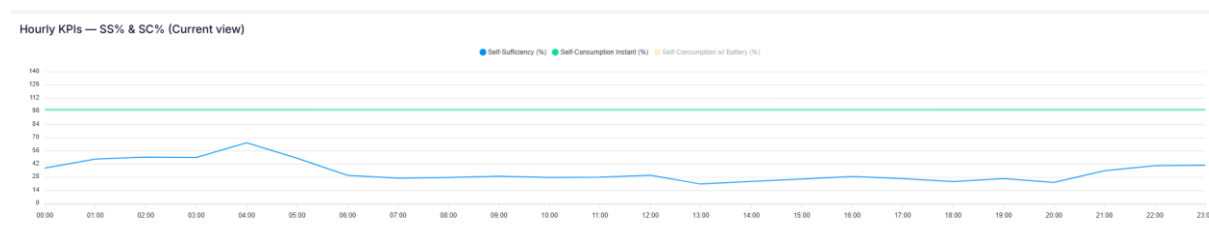


Figure 19 Hourly KPIs for the whole community (Self Sufficiency and Self Consumption)

Per building views are also included, in the same format.

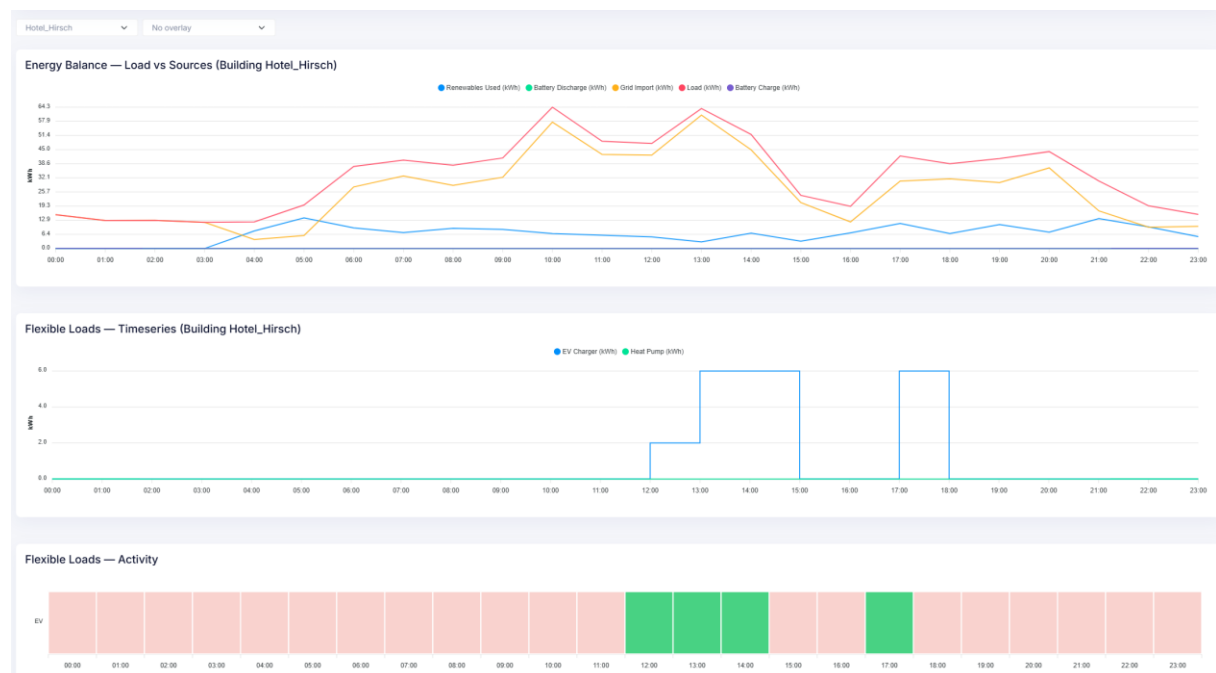


Figure 20 Optimization view for Hotel Hirsch building

The second stage activates community scope with shared generation and a community battery and sets the objective to Min Cost. Building-level flexible loads remain active. The community node introduces charge/discharge and state-of-charge dynamics with efficiency and bounds, and shared generation is allocated implicitly by the optimizer. Since our current scenario does not involve community assets, as a next step we will proceed to re-run with the same characteristics while changing the scope to community-wide optimization and adding the necessary assets.

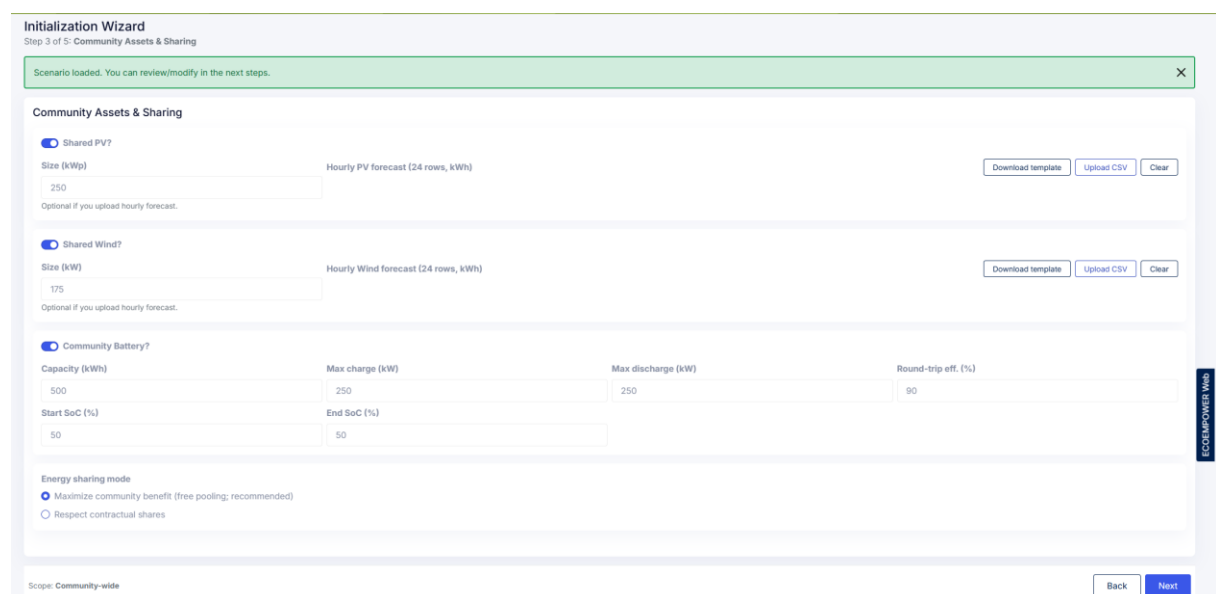


Figure 21 Community Assets and Sharing view of the Initialization wizard

To run an optimization with minimize cost objectives, we need to include the tariffs in the following view:

**Initialization Wizard**  
Step 4 of 5: Prices & Objective

Scenario loaded. You can review/modify in the next steps. X

**Prices & Objective**

**Tariff Input**

☒ Upload CSV (24 hourly values, columns: ts, eur\_per\_kwh)  
☐ Flat rate  
☐ Day/Night  
☐ Import market price (coming soon)

**Optimization objective**

☒ Minimize cost (uses tariff)  
☐ Maximize self-consumption  
☐ Maximize self-sufficiency

Scope: Community-wide

Figure 22 Prices and Objective view of the initialization wizard

**Initialization Wizard**  
Step 5 of 5: Overview

Scenario loaded. You can review/modify in the next steps. X

**Validation results**

Errors & warnings

- WARNING** — tariff\_ts\_mismatch: Tariff timestamps do not exactly match the 24h horizon. Values will be used by index.

| Building                       | Avg Consumption (KWh) | Avg Generation (KWh) | Battery Capacity (KWh) | Avg Tariff (€/KWh) |                                               |
|--------------------------------|-----------------------|----------------------|------------------------|--------------------|-----------------------------------------------|
| LW_Eggensberger_Landwirtschaft | 3.71                  | 0.00                 | 0.00                   | 0.100              | <input type="button" value="Energy Profile"/> |
| LW_Eggensberger_Ferienwohnung  | 1.49                  | 0.00                 | 0.00                   | 0.100              | <input type="button" value="Energy Profile"/> |
| Hotel_Eggensberger             | 50.76                 | 15.00                | 0.00                   | 0.100              | <input type="button" value="Energy Profile"/> |
| Hoteldorf_Hartung              | 29.52                 | 15.61                | 0.00                   | 0.100              | <input type="button" value="Energy Profile"/> |
| Hotel_Hirsch                   | 32.17                 | 6.67                 | 0.00                   | 0.100              | <input type="button" value="Energy Profile"/> |

Scope: Community-wide

Figure 23 Overview of our optimization scenario

With the community assets taken into consideration, the new optimization results are by far superior to the previous scenario, while costs have been minimized.

**Optimization Results** Baseline only

|                                           |                                                   |                                                      |
|-------------------------------------------|---------------------------------------------------|------------------------------------------------------|
| Total Cost (€)<br><b>41.3</b> → -         | Self-Consumption Instant (%)<br><b>94.5%</b> → -% | Self-Consumption w/ Battery (%)<br><b>99.4%</b> → -% |
| Self-Sufficiency (%)<br><b>85.4%</b> → -% | Imports (kWh)<br><b>413.4</b> → -                 | Curtailed (kWh)<br><b>0.0</b> → -                    |

**Summary — Per Building Totals**

| Building                       | Load (KWh) | Renewables Used (KWh) | Imports (KWh) | Battery Ch (KWh) | Battery Dis (KWh) |
|--------------------------------|------------|-----------------------|---------------|------------------|-------------------|
| LW_Eggensberger_Landwirtschaft | 89.0       | 42.0                  | 39.2          | 0.0              | 0.0               |
| LW_Eggensberger_Ferienwohnung  | 35.8       | 26.6                  | 9.2           | 0.0              | 0.0               |
| Hotel_Eggensberger             | 1218.2     | 991.0                 | 157.9         | 0.0              | 0.0               |
| Hoteldorf_Hartung              | 708.4      | 599.3                 | 93.9          | 0.0              | 0.0               |
| Hotel_Hirsch                   | 788.1      | 645.5                 | 113.1         | 0.0              | 0.0               |

Figure 24 New optimization scenario KPIs per building

Validation at this stage confirms:

1. community node balance including shared assets;
2. SoC recursion and limits respected;
3. cost reduction relative to the per-building baseline consistent with tariff shape;

4. expected shifts of flexible duty and battery charging into Renewable-rich hours, yielding higher self-consumption and lower imports.

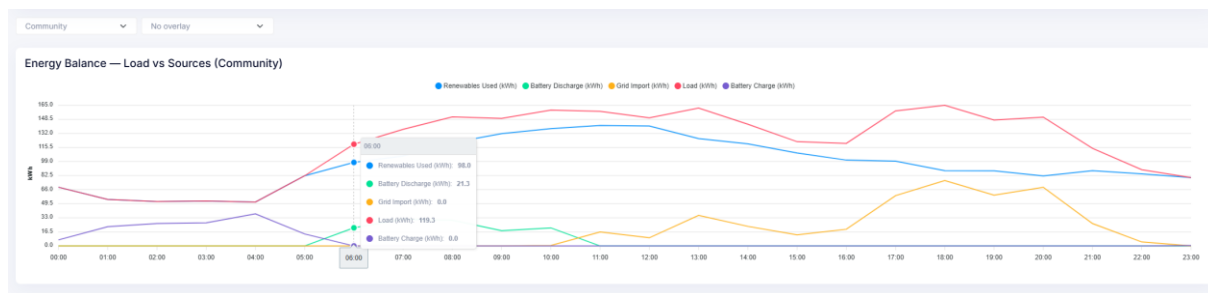


Figure 25 Optimization Timeseries including battery charge/discharge with equal sharing

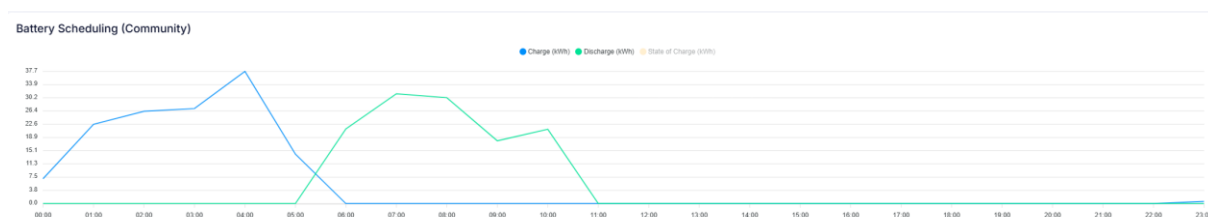


Figure 26 Battery Charge/Discharge behaviour, prioritizing wind generation

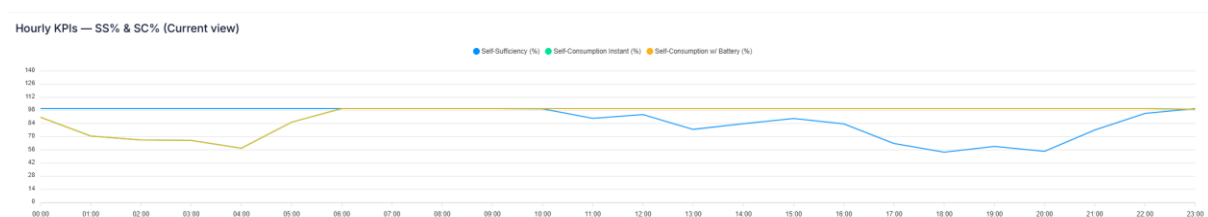


Figure 27 New KPIs for the community

#### 4.2.2 Modelling Result Validation

We validate the Energy Modelling Tool on the German pilot with five buildings (three with on-site generation potential). Two scenarios are assessed on the same 24-hour horizon and tariff: (i) building-only scheduling, no community assets; (ii) community assets enabled (pooled PV and wind plus a shared battery). Flexible loads include EV charging and HVAC/heat pumps with operational windows and power constraints as configured in the tool. The optimizer runs in community mode in both cases, but the first scenario has no community generation or storage configured; the second activates pooled RES and a community battery. Tool output JSON and UI traces underpin the results below.

Table 4 Building Only Optimization Scenario

| Configuration                                                             | Performance                                                                                | Flexible loads                                                                                   | Validation                                                                           |
|---------------------------------------------------------------------------|--------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------|
| Building optimizer with no community generation and no community battery; | Total grid imports are <b>≈2,031 kWh</b> with a cost of <b>€203.15</b> and community self- | EV energy is scheduled into daylight/shoulder slots (e.g., late morning to afternoon), and heat- | With only per-building PV and no battery or energy sharing, the optimizer has little |

|                                                                            |                                                                                                                                                                                                                                                                                                                     |                                                                                                                                                                                 |                                                                                                                                                                                                     |
|----------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| flexible loads enabled (EV, heat pump); per-building PV used only locally. | <b>sufficiency</b> $\approx 30.6\%$ . Because PV is only used behind-the-meter (no sharing) and no storage is available, instantaneous PV self-consumption appears as 100% (by definition $PV_{used} = \min(\text{load}, PV)$ at each building), but the system still relies heavily on imports at community level. | pump electrical use is spread in small quanta, but without shared storage these shifts have limited impact on imports. (EV and HP streams are present in the community series.) | latitude to reshape net imports; the low self-sufficiency and high imports quantify this limitation. This baseline is intentionally “asset-light” to expose the marginal value of community assets. |
|----------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|

Table 5 Community Asset Optimization Scenario

| Configuration                                                                                                      | Performance                                                                                                                                                                                                                  | Flexible loads                                                                                                                                                                                                                                                                                                                                                                 | Validation                                                                                                                                                                      |
|--------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Community optimizer with pooled PV and wind and a community battery; same tariff and flexible loads as Scenario A. | Grid imports drop to $\approx 413$ kWh, community <b>self-sufficiency rises to <math>\approx 85.4\%</math></b> , and cost falls to <b>€41.34</b> on the same day, demonstrating the compounding effect of sharing + storage. | <b>EV charging</b> is pulled into renewable-rich hours (e.g., 07:00–09:00 blocks), aligning with stored wind and ramping PV, reducing marginal imports. <b>Heat pump/HVAC</b> operation appears in small, distributed hourly quanta; under the community setup it is effectively absorbed by pooled RES and storage, keeping imports suppressed during comfort-critical hours. | The qualitative improvements match the mechanistic ones observed in the hourly traces: wind-led nighttime charging, strategic morning discharge, and PV-aligned flexible loads. |

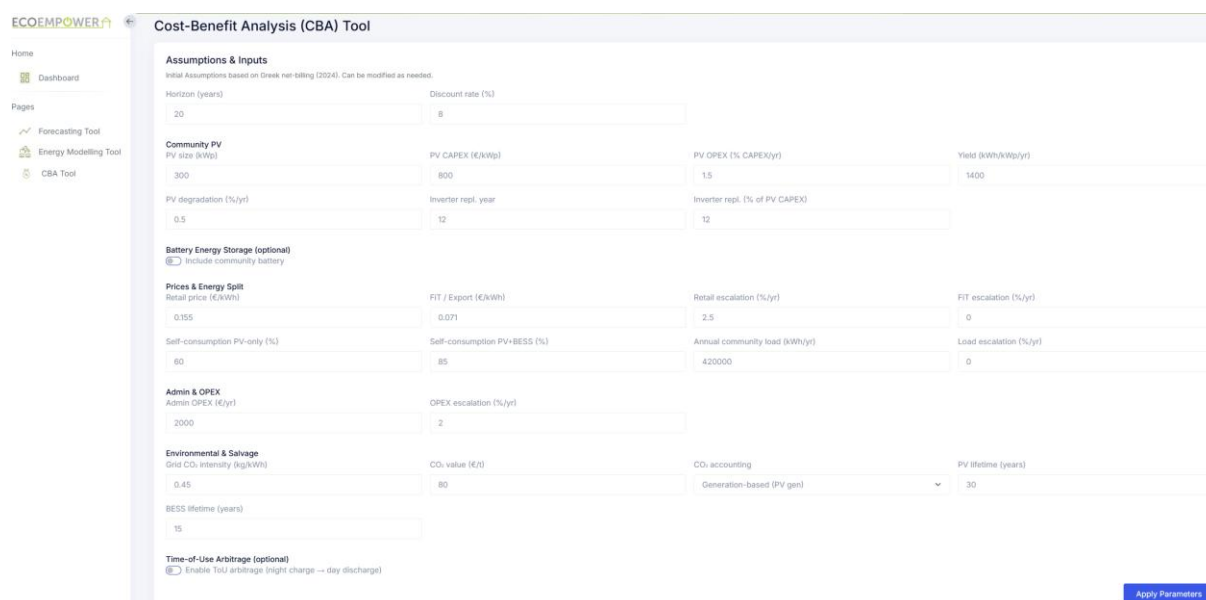
A useful next step is to refine the dispatch rules, so the optimizer encodes explicit priorities between renewables and exposes stronger incentives for flexibility. On storage, we can introduce hierarchical charging preferences (e.g., wind-first at night, PV-first in daytime) by adding tie-break terms to the objective or by using source-specific binaries with penalties. This removes ambiguity when both sources are available and yields more interpretable SoC trajectories. On flexible loads, we recommend augmenting the model with completion and timing penalties (e.g., slack variables with costs for unmet EV energy or off-window operation) and comfort-linked costs for HVAC/heat-pump modulation, so that shifting into renewable-rich/low-price hours is consistently optimal rather

than optional. Together, these adjustments keep the core LP/MILP structure but strengthen behavioral signals, reducing cases where batteries appear agnostic to source or flexible loads are partially ignored.

## 4.3 Validation of the Cost-Benefit Analysis (CBA) Tool

### 4.3.1 CBA Interface Walkthrough and Validation

This validation phase uses Greek pilot assumptions and datasets to assess the financial impacts of alternative interventions. Inputs include: tariff trajectories (base and indexed), CAPEX/OPEX breakdowns for community PV and BESS, asset lifetimes and residual values, incentive rules (where applicable), discount rate(s), degradation, and optional monetization of CO<sub>2</sub> externalities. The workflow begins from a baseline (No Intervention) and proceeds to counterfactual scenarios configured in the interface; all parameters are user-editable to reflect local rules.



**Cost-Benefit Analysis (CBA) Tool**

Initial Assumptions based on Greek net-billing (2024). Can be modified as needed.

**Assumptions & Inputs**

Horizon (years): 20 Discount rate (%): 8

**Community PV**

PV size (kWp): 300 PV CAPEX (€/kWp): 800 PV OPEX (% CAPEX/yr): 1.5 Yield (kWh/kWp/yr): 1400

PV degradation (%/yr): 0.5 Inverter repl. year: 12 Inverter repl. (% of PV CAPEX): 12

**Battery Energy Storage (optional)**

☐ Include community battery

**Prices & Energy Split**

Retail price (€/kWh): 0.155 FIT / Export (€/kWh): 0.071 Retail escalation (%/yr): 2.5 FIT escalation (%/yr): 0

Self-consumption PV-only (%): 60 Self-consumption PV+BESS (%): 85 Annual community load (kWh/yr): 420000 Load escalation (%/yr): 0

**Admin & OPEX**

Admin OPEX (€/yr): 2000 OPEX escalation (%/yr): 2

**Environmental & Salvage**

Grid CO<sub>2</sub> intensity (kg/kWh): 0.45 CO<sub>2</sub> value (€/t): 80 CO<sub>2</sub> accounting: Generation-based (PV gen) PV lifetime (years): 30

BESS lifetime (years): 15

**Time-of-Use Arbitrage (optional)**

☐ Enable ToU arbitrage (night charge → day discharge)

**Apply Parameters**

Figure 28 Assumption & input view of the CBA Tool

The CBA interface exposes all drivers of the cash-flow model in a single, structured form. Users define the analysis horizon and discount rate, then parameterize Community PV (size, CAPEX, OPEX as % CAPEX, expected yield, degradation, inverter replacement) and, optionally, Battery Energy Storage (capacity and lifetime), activating storage only when relevant. The Prices & Energy Split block captures the retail price and FIT/export rate with independent escalation paths, the assumed self-consumption shares for PV-only and PV+BESS cases, and the annual community load (with optional load escalation). Administrative and operating costs are specified via Admin OPEX and OPEX escalation. Environmental accounting is explicit: grid CO<sub>2</sub> intensity, CO<sub>2</sub> valuation, and the CO<sub>2</sub> accounting mode (e.g. generation-based) are selectable, along with asset lifetimes for salvage and replacement logic. An optional time-of-use arbitrage toggle encodes the policy “night charge → day discharge” for BESS. Pressing Apply Parameters recomputes the scenario cash flows and KPIs (NPV, BCR, discounted payback) directly from these user-visible assumptions.

**Battery Energy Storage (optional)**  
☒ Include community battery

|                         |                    |                                  |                     |
|-------------------------|--------------------|----------------------------------|---------------------|
| Battery capacity (kWh)  | BESS CAPEX (€/kWh) | BESS OPEX (% CAPEX/yr)           | Round-trip eff. (%) |
| 500                     | 300                | 1                                | 90                  |
| BESS degradation (%/yr) | BESS repl. year    | BESS repl. factor $\alpha$ (0-1) |                     |
| 2                       | 12                 | 0.5                              |                     |

Figure 29 Battery Scenario characteristics

The baseline represents current operation with zero initial investment. Recurrent costs/revenues relevant to the status quo can be entered (e.g., fixed service fees). The tool computes a reference annual cash-flow vector and Levelized Energy Cost where applicable; these provide the financial anchor for scenario deltas. Uploaded/entered data are validated for units, time basis (annualized), and internal consistency (e.g., non-negative rates, horizon  $\geq$  lifetime of assets contributing residual value).

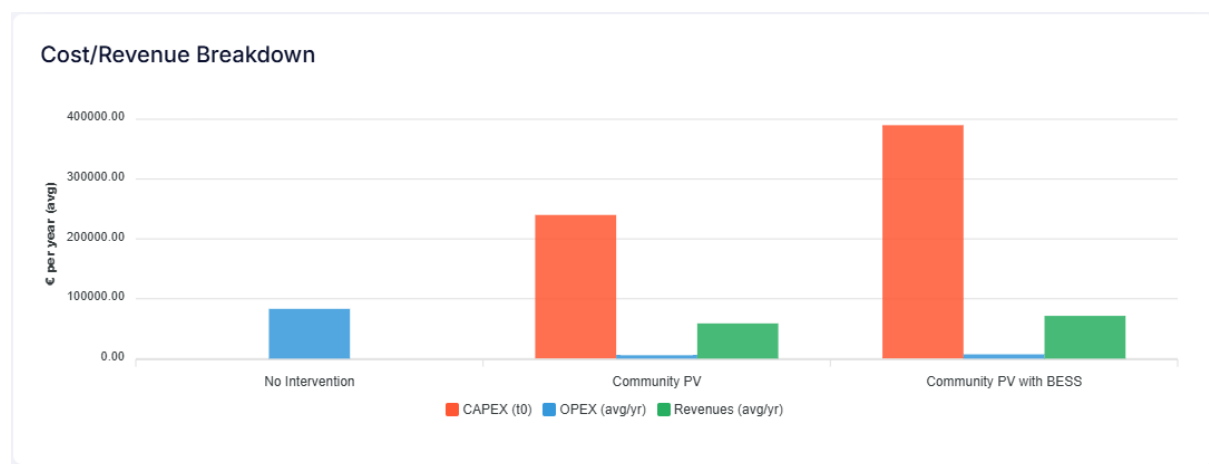


Figure 30 Cost/Revenue breakdown per scenario

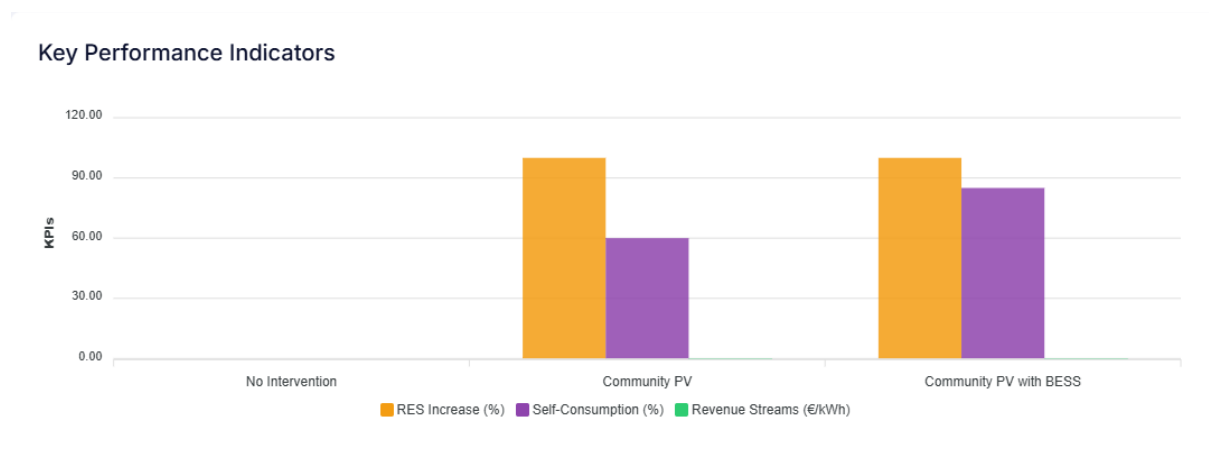


Figure 31 KPIs per scenario

For each scenario the tool reports NPV, Benefit–Cost Ratio (BCR), and discounted payback (financial and, if CO<sub>2</sub> is monetized, societal). A reconciliation table shows how annual cash flows arise from the parameterized assumptions (imports avoided  $\times$  tariff model, export revenues, O&M, replacements, incentives, residual value). This ensures that every KPI can be traced to explicit inputs rather than hidden presets.

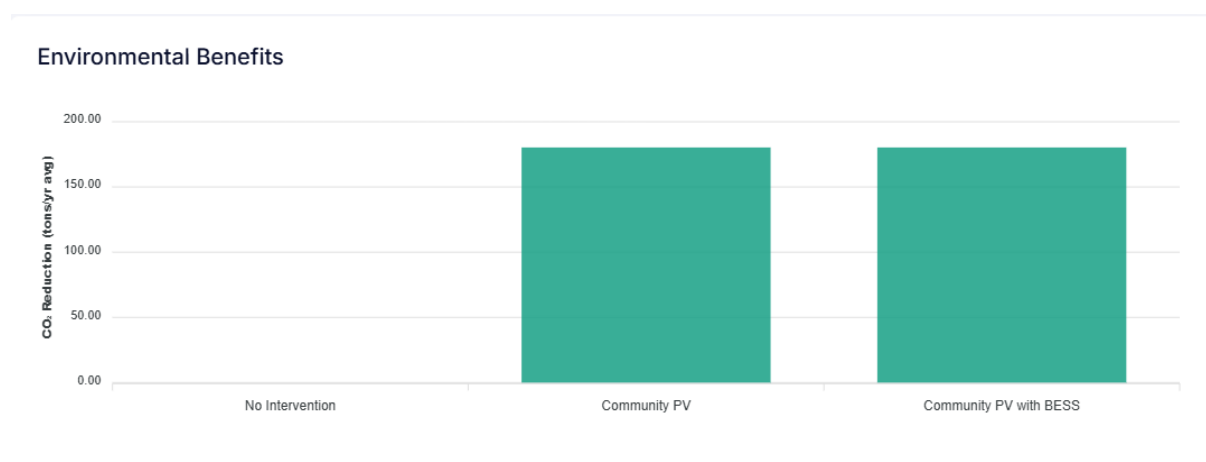


Figure 32 Environmental analysis per scenario

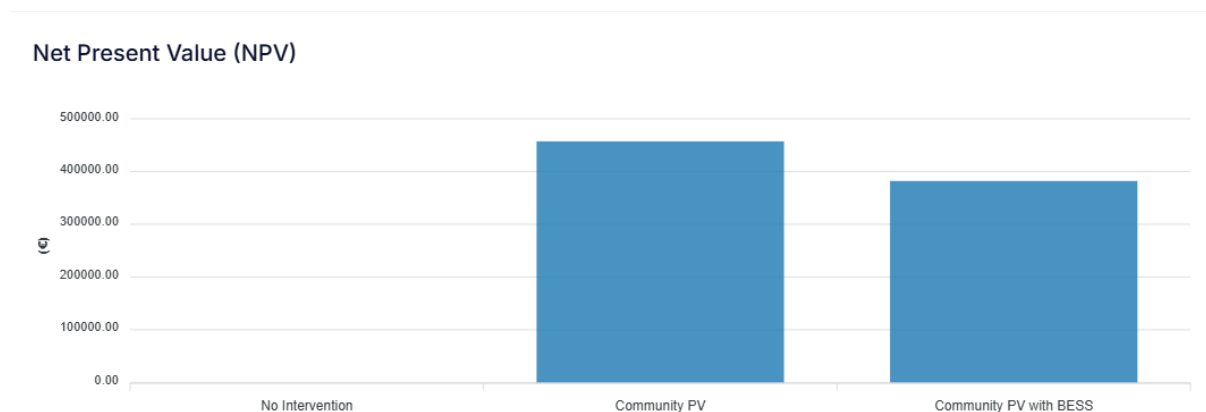


Figure 33 Net Present Value per scenario

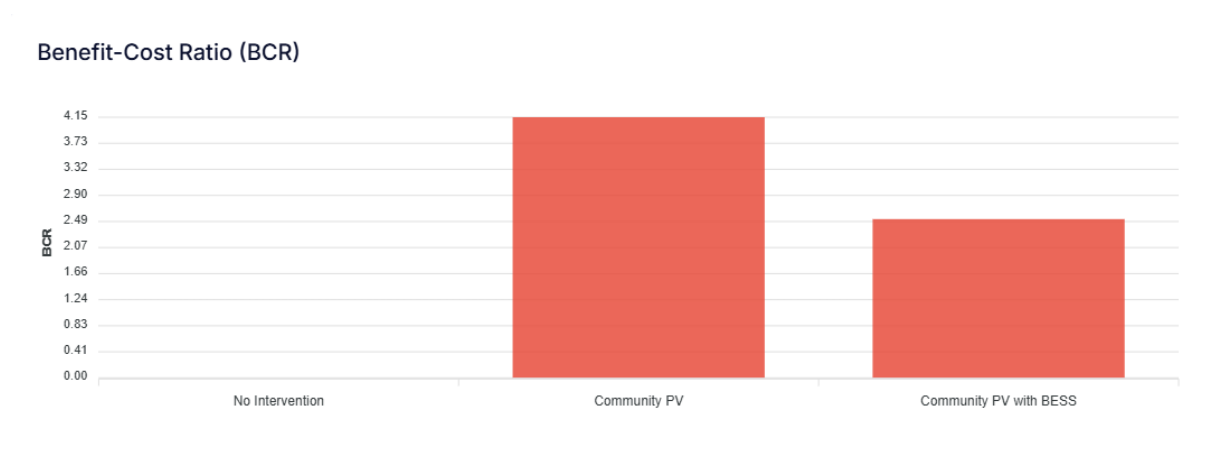


Figure 34 Benefit-Cost Ration per Scenario

Validation includes targeted sensitivity sweeps on the dominant drivers (discount rate, CAPEX, tariff slope, degradation, CO<sub>2</sub> price if used). Tornado bars and side-by-side scenario tables demonstrate KPI stability and identify break-even regions (e.g., BCR  $\geq 1$ ) under plausible parameter variation. Comparisons are made relative to the BAU baseline so that stakeholders can read benefits as deltas that are consistent across interventions.

### Sensitivity Analysis (Discount Rate vs NPV)

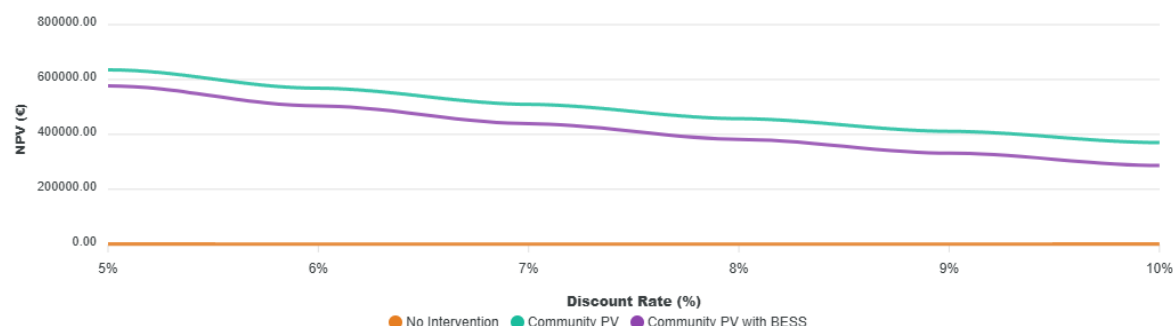


Figure 35 Sensitivity Analysis for different discount rates

| Summary                            | No Interv. | PV     | PV+BESS |
|------------------------------------|------------|--------|---------|
| NPV (€)                            | 0          | 457205 | 382060  |
| BCR (-)                            | 0.00       | 4.15   | 2.52    |
| CO <sub>2</sub> (t/yr)             | 0.00       | 180.29 | 180.29  |
| Payback (yrs, undisc.) — Societal  | —          | 3.9    | 5.6     |
| Payback (yrs, undisc.) — Financial | —          | 5.1    | 7.0     |

Export CSV

Figure 36 Summary table for the key results, including payback years

### 4.3.2 CBA Results Validation

This validation assesses the cost-benefit performance of alternative interventions using the Greek pilot parameter set and a 20-year analysis horizon at an 8% discount rate. Three configurations are examined on a common basis: the business-as-usual baseline with zero initial investment, a Community PV system sized at 300 kWp, and a hybrid PV + BESS option combining the same PV capacity with a 500 kWh battery. Prices and escalation are drawn from the Greek context. The retail tariff starts at €0.155/kWh and escalates at 2.5% annually, while the export/FIT rate is €0.071/kWh with no escalation. The PV subsystem assumes an expected yield of 1,400 kWh/kWp·yr with 0.5%/yr degradation, operating costs at 1.5% of CAPEX, and an inverter replacement at year 12 equal to 12% of PV CAPEX. Storage CAPEX is set at €300/kWh with 1%/yr OPEX, a 90% round-trip efficiency, and a mid-life replacement in year 12. To isolate the self-consumption effect, time-of-use arbitrage is disabled in this run. Environmental accounting is generation-based, with grid intensity of 0.45 t/MWh (in CO<sub>2</sub>) and a CO<sub>2</sub> valuation of €80/t.

Under these assumptions the baseline establishes the financial counterfactual (NPV = 0) and yields a representative average annual grid bill of roughly €83 k and annual emissions of approximately 189 t CO<sub>2</sub>. Introducing Community PV alone produces a decisive shift: the model returns NPV of about €457 k, a Benefit–Cost Ratio near 4.15, and an undiscounted payback of roughly 5.1 years, with societal payback (when the monetized CO<sub>2</sub> benefit is included) around 3.9 years. These values are commensurate with the energy balance implied by the inputs. A 300 kWp array at 1,400 kWh/kWp·yr generates about 420 MWh/yr. If 60% is self-consumed and the remainder exported, the annual cash benefit is dominated by avoided retail purchases priced at the escalated retail path, while export revenues contribute a smaller margin at the fixed FIT. After deducting degradation and modest operating costs, the reported average annual value of approximately €59 k is internally consistent with the tariff split and aligns with the observed capital efficiency.

Adding a 500 kWh battery on top of the same PV capacity modifies the cash-flow composition rather than the gross energy balance, because generation is unchanged. With arbitrage off, storage increases the self-consumption share from 60% to 85% by shifting energy that would otherwise be exported into on-site use. The incremental benefit of this export-to-self-consumption uplift is well approximated by the product of the additional on-site energy (about 105 MWh/yr) and the retail-minus-export price spread on the escalated trajectory, which yields a figure on the order of €13 k per year. The model's average annual value rises from €58.8 k for PV-only to €71.4 k for PV + BESS, a difference that sits exactly in this range after accounting for round-trip losses and degradation. Even so, once the added storage CAPEX, OPEX, and the assumed mid-life replacement are included, the hybrid option's NPV ( $\approx$  €382 k), BCR ( $\approx$  2.52), and payback ( $\approx$  7.0 years) are all weaker than PV-only, albeit still clearly positive. This pattern is expected: without price-based charging and discharging, a battery accrues value primarily by converting exports into avoided imports. Unless the retail-export spread is very large or capital costs are very low, the incremental return tends to prefer pure PV.

The environmental accounting further clarifies the mechanisms at work. Because the selected mode credits emissions reductions on a generation basis, PV-only and PV + BESS avoid the same CO<sub>2</sub> tonnage; storage changes the timing of consumption, not the quantity of PV generated. Consequently, differences in “societal” outcomes between the two interventions arise only through financial channels (discounting and cash costs), not through additional emissions abatement. This is a logical outcome of the chosen accounting rule and should be made explicit when interpreting results.

Finally, operating cost lines reconcile with inputs. PV-only OPEX sits near the expected 1.5% of CAPEX plus administrative costs, and the hybrid case adds approximately 1% of battery CAPEX to reflect storage operations, which is consistent with the reported annualized totals.

Summing up, the validation demonstrates that Community PV delivers very strong, capital-efficient benefits under Greek pilot conditions, with robust positive NPV, high BCR, and short payback. The PV + BESS configuration remains attractive but less efficient on a pure financial basis when valued only for self-consumption uplift, performing as theory predicts in the absence of arbitrage. These results are coherent with the tariff structure, escalation paths, degradation, and accounting choices, and they establish a clear baseline against which to test policy-sensitive extensions, most notably enabling time-of-use arbitrage and refining lifetime/replacement conventions, in the next validation cycle.

## 5 Conclusions and Next Steps

This deliverable documented the methods and validation outcomes of the three ECOEMPOWER tools (Forecasting, Modelling & Scheduling, and Cost–Benefit Analysis) under real pilot conditions. The current releases implement a fully agnostic, user-driven workflow with minimal, standardized inputs, canonical time axes, transparent objectives and constraints and KPIs that can be reproduced from the same data without hidden assumptions. Across pilots, the tools produced coherent results: monthly PV forecasts attained planning-grade accuracy at community scale without weather inputs, day-ahead schedules respected energy balances and showed large benefits once community assets and storage were activated and the CBA consistently reconciled financial outcomes with explicit parameter sets, yielding capital-efficient PV economics and traceable incremental value from storage.

The next validation round should expand beyond the sites used here to other pilots with different data maturities and operating conditions. Replicating the flows on heterogeneous datasets is essential to stress-test agnosticism, verify reproducibility under alternative regimes (tariffs, asset mixes, commissioning states), and firm up cross-site benchmarks for KPIs and robustness.

Planned refinements focus on clarity, incentives, and comparability:

- **Forecasting Tool:** add cold-start treatment for newly commissioned assets (capacity-normalized priors, optional hierarchical pooling), extend validation to rolling-origin backtests with seasonal blocks, and report robustness-oriented KPIs (capacity-normalized error) alongside MAE/RMSE/MAPE.
- **Modelling & Scheduling Tool:** formalize battery source prioritization (e.g., wind-first at night, PV-first by day), strengthen flexible-load incentives (completion/timing costs, comfort-linked penalties), enforce PV daylight masks and explicit PV vs. wind separation in reporting, and provide paired per-building  $\leftrightarrow$  community comparisons with standardized  $\Delta$ KPIs; include optional end-of-day SoC  $\approx$  start-of-day SoC for comparability.
- **CBA Tool:** enable and parameterize **time-of-use arbitrage** to separate self-consumption uplift from price-driven value, align lifetime/replacement conventions (or use residual values near the horizon), and add joint sensitivity sweeps (e.g., discount rate  $\times$  CAPEX, tariff slope  $\times$  degradation) for decision robustness.

## 6 References

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## 7 List of Tables

|                                                                                                                                                                                  |    |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----|
| Table 1 Variable and Symbol Definition for the Optimization Objectives equations .....                                                                                           | 13 |
| Table 2 Flexible Load Variable explanations and Operational Constrains for the Optimization equations .....                                                                      | 15 |
| Table 3 MAPE Results for the selected validation window .....                                                                                                                    | 22 |
| Table 4 Building Only Optimization Scenario .....                                                                                                                                | 31 |
| Table 5 Community Asset Optimization Scenario.....                                                                                                                               | 32 |
| Table 6 Generation Data CSV Template for the Energy Forecasting Tool, where ts is the ISO timestamp for each month and installation_name, the name of each PV installation ..... | 43 |
| Table 7 Sample JSON Scenario containing building, Energy and Flexible Load information in the format the Energy Modelling Tool can parse .....                                   | 44 |

## 8 List of Figures

|                                                                                                                                                                                                                    |                                              |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------|
| Figure 1 Batch CSV import option to upload data from multiple installations. The format for the upload is indicated in the sample templates that can be downloaded from the buttons in the upper right corner..... | 18                                           |
| Figure 2 The parsed data of the 29 installations of the VercorSoleiL Pilot Site.....                                                                                                                               | 19                                           |
| Figure 3 Detail of the Forecast Horizon option which we have set to 6 months and some details of the last installation we have added to the Tool via CSV file .....                                                | 19                                           |
| Figure 4 First view of the Forecasting Result Page and option to provide validation data .....                                                                                                                     | 20                                           |
| Figure 5 Monthly forecasts for the community for the selected 6-month period, with labelling .....                                                                                                                 | 20                                           |
| Figure 6 Monthly forecasts for individual Installations (La Chapelle Famiglia C CVS 4) .....                                                                                                                       | 20                                           |
| Figure 7 Totals for the 6-month period for the individual installations along with shares in % from the Total Generation.....                                                                                      | 21                                           |
| Figure 8 Pie chart showing per-month forecasts for each installation, with labels .....                                                                                                                            | 21                                           |
| Figure 9 KPIs when we uploaded the actual generation data of the Pilot Site for months Nov 23-Apr 24. The MAPE is 8.8% which is low enough to be considered accurate forecast.....                                 | 21                                           |
| Figure 10 Individual KPIs for the first 18 installations .....                                                                                                                                                     | 22                                           |
| Figure 11 Monthly comparison between the forecasts and the actual generation data from the community .....                                                                                                         | 22                                           |
| Figure 12 Initialization Wizard of the Energy Modelling Tool where the user is prompted to provide their batch data and define the scope of the Optimization (in our case per-building).....                       | 24                                           |
| Figure 13 The parser transforms the data into editable building entities that the user can then edit further if needed .....                                                                                       | 25                                           |
| Figure 14 Building editor where the user can upload and preview their csv files .....                                                                                                                              | 25                                           |
| Figure 15 Needed characteristics the user needs to include to the tool to optimize the Heat Pump Flexible load.....                                                                                                | 26                                           |
| Figure 16 Needed characteristics the user needs to include to the tool to optimize the EV Charger Flexible load.....                                                                                               | 27                                           |
| Figure 17 Calculated KPIs for selected scenario .....                                                                                                                                                              | 27                                           |
| Figure 18 Optimization Timeseries and Flexible Loads for the whole community .....                                                                                                                                 | 28                                           |
| Figure 19 Hourly KPIs for the whole community (Self Sufficiency and Self Consumption).....                                                                                                                         | 28                                           |
| Figure 20 Optimization view for Hotel Hirsh building .....                                                                                                                                                         | 29                                           |
| Figure 21 Community Assets and Sharing view of the Initialization wizard.....                                                                                                                                      | 29                                           |
| Figure 22 Prices and Objective view of the initialization wizard .....                                                                                                                                             | 30                                           |
| Figure 23 Overview of our optimization scenario .....                                                                                                                                                              | 30                                           |
| Figure 24 New optimization scenario KPIs per building .....                                                                                                                                                        | 30                                           |
| Figure 25 Optimization Timeseries including battery charge/discharge with equal sharing .....                                                                                                                      | 31                                           |
| Figure 26 Battery Charge/Discharge behaviour, prioritizing wind generation .....                                                                                                                                   | 31                                           |
| Figure 27 New KPIs for the community .....                                                                                                                                                                         | 31                                           |
| Figure 28 Building Only Optimization Scenario .....                                                                                                                                                                | <b>Errore. Il segnalibro non è definito.</b> |
| Figure 29 Community Asset Optimization Scenario .....                                                                                                                                                              | <b>Errore. Il segnalibro non è definito.</b> |
| Figure 30 Assumption & input view of the CBA Tool.....                                                                                                                                                             | 33                                           |
| Figure 31 Battery Scenario characteristics .....                                                                                                                                                                   | 34                                           |
| Figure 32 Cost/Revenue breakdown per scenario .....                                                                                                                                                                | 34                                           |
| Figure 33 KPIs per scenario .....                                                                                                                                                                                  | 34                                           |
| Figure 34 Environmental analysis per scenario .....                                                                                                                                                                | 35                                           |

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|                                                                            |    |
|----------------------------------------------------------------------------|----|
| Figure 35 Net Present Value per scenario .....                             | 35 |
| Figure 36 Benefit-Cost Ratio per Scenario.....                             | 35 |
| Figure 37 Sensitivity Analysis for different discount rates.....           | 36 |
| Figure 38 Summary table for the key results, including payback years ..... | 36 |

## A. Annex

Table 6 Generation Data CSV Template for the Energy Forecasting Tool, where *ts* is the ISO timestamp for each month and *installation\_name*, the name of each PV installation

| ts                   | installation_name_1        | installation_name_2        | installation_name_2        |
|----------------------|----------------------------|----------------------------|----------------------------|
| 2017-01-01T00:00:00Z | total_generation_per_month | total_generation_per_month | total_generation_per_month |
| 2017-02-01T00:00:00Z | total_generation_per_month | total_generation_per_month | total_generation_per_month |
| 2017-03-01T00:00:00Z | total_generation_per_month | total_generation_per_month | total_generation_per_month |
| 2017-04-01T00:00:00Z | total_generation_per_month | total_generation_per_month | total_generation_per_month |
| 2017-05-01T00:00:00Z | total_generation_per_month | total_generation_per_month | total_generation_per_month |
| 2017-06-01T00:00:00Z | total_generation_per_month | total_generation_per_month | total_generation_per_month |
| 2017-07-01T00:00:00Z | total_generation_per_month | total_generation_per_month | total_generation_per_month |
| 2017-08-01T00:00:00Z | total_generation_per_month | total_generation_per_month | total_generation_per_month |
| 2017-09-01T00:00:00Z | total_generation_per_month | total_generation_per_month | total_generation_per_month |

*Table 7 Sample JSON Scenario containing building, Energy and Flexible Load information in the format the Energy Modelling Tool can parse*

```
{
  "horizon_start_utc": "2025-09-08T00:00:00Z",
  "hours": 24,

  "buildings": [
    { "building_id": "B1", "profile": "Residential" },
    { "building_id": "B2", "profile": "Residential" },
    { "building_id": "B3", "profile": "Commercial" },
    { "building_id": "B4", "profile": "Municipal" }
  ],

  "load": [
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    { "building_id": "B1", "ts": "2025-09-08T01:00:00Z", "kwh": 0.8 },
    { "building_id": "B1", "ts": "2025-09-08T02:00:00Z", "kwh": 0.7 },
    { "building_id": "B1", "ts": "2025-09-08T03:00:00Z", "kwh": 0.7 },
    { "building_id": "B1", "ts": "2025-09-08T04:00:00Z", "kwh": 0.7 },
    { "building_id": "B1", "ts": "2025-09-08T05:00:00Z", "kwh": 0.8 },
    { "building_id": "B1", "ts": "2025-09-08T06:00:00Z", "kwh": 1.0 },
    { "building_id": "B1", "ts": "2025-09-08T07:00:00Z", "kwh": 1.5 },
    { "building_id": "B1", "ts": "2025-09-08T08:00:00Z", "kwh": 1.8 },
    { "building_id": "B1", "ts": "2025-09-08T09:00:00Z", "kwh": 1.6 },
    { "building_id": "B1", "ts": "2025-09-08T10:00:00Z", "kwh": 1.5 },
    { "building_id": "B1", "ts": "2025-09-08T11:00:00Z", "kwh": 1.5 },
    { "building_id": "B1", "ts": "2025-09-08T12:00:00Z", "kwh": 1.6 },
    { "building_id": "B1", "ts": "2025-09-08T13:00:00Z", "kwh": 1.6 },
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```

```
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{ "building_id": "B1", "ts": "2025-09-08T19:00:00Z", "kwh": 1.5 },  
{ "building_id": "B1", "ts": "2025-09-08T20:00:00Z", "kwh": 1.4 },  
{ "building_id": "B1", "ts": "2025-09-08T21:00:00Z", "kwh": 1.3 },  
{ "building_id": "B1", "ts": "2025-09-08T22:00:00Z", "kwh": 1.1 },  
{ "building_id": "B1", "ts": "2025-09-08T23:00:00Z", "kwh": 1.0 },
```

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{ "building_id": "B2", "ts": "2025-09-08T04:00:00Z", "kwh": 0.9 },  
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{ "building_id": "B2", "ts": "2025-09-08T06:00:00Z", "kwh": 1.3 },  
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{ "building_id": "B2", "ts": "2025-09-08T18:00:00Z", "kwh": 2.0 },  
{ "building_id": "B2", "ts": "2025-09-08T19:00:00Z", "kwh": 1.9 },  
{ "building_id": "B2", "ts": "2025-09-08T20:00:00Z", "kwh": 1.7 },  
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```
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{ "building_id": "B3", "ts": "2025-09-08T04:00:00Z", "kwh": 11.0 },
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{ "building_id": "B3", "ts": "2025-09-08T13:00:00Z", "kwh": 23.0 },
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{ "building_id": "B4", "ts": "2025-09-08T10:00:00Z", "kwh": 5.8 },  
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{ "building_id": "B4", "ts": "2025-09-08T18:00:00Z", "kwh": 4.0 },  
{ "building_id": "B4", "ts": "2025-09-08T19:00:00Z", "kwh": 3.8 },  
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```

```
"pv": [
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{ "building_id": "B3", "ts": "2025-09-08T09:00:00Z", "kwh": 15.0 },  
{ "building_id": "B3", "ts": "2025-09-08T10:00:00Z", "kwh": 18.0 },  
{ "building_id": "B3", "ts": "2025-09-08T11:00:00Z", "kwh": 20.0 },  
{ "building_id": "B3", "ts": "2025-09-08T12:00:00Z", "kwh": 19.0 },
```

```
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{ "building_id": "B3", "ts": "2025-09-08T16:00:00Z", "kwh": 5.0 },  
{ "building_id": "B3", "ts": "2025-09-08T17:00:00Z", "kwh": 2.0 },  
  
{ "building_id": "B4", "ts": "2025-09-08T06:00:00Z", "kwh": 0.8 },  
{ "building_id": "B4", "ts": "2025-09-08T07:00:00Z", "kwh": 2.0 },  
{ "building_id": "B4", "ts": "2025-09-08T08:00:00Z", "kwh": 4.0 },  
{ "building_id": "B4", "ts": "2025-09-08T09:00:00Z", "kwh": 6.0 },  
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{ "building_id": "B4", "ts": "2025-09-08T11:00:00Z", "kwh": 7.5 },  
{ "building_id": "B4", "ts": "2025-09-08T12:00:00Z", "kwh": 7.0 },  
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{ "building_id": "B4", "ts": "2025-09-08T14:00:00Z", "kwh": 4.5 },  
{ "building_id": "B4", "ts": "2025-09-08T15:00:00Z", "kwh": 3.0 },  
{ "building_id": "B4", "ts": "2025-09-08T16:00:00Z", "kwh": 1.8 },  
{ "building_id": "B4", "ts": "2025-09-08T17:00:00Z", "kwh": 0.7 },  
],
```

```
"battery": [  
  {  
    "building_id": "B4",  
    "capacity_kwh": 10.0,  
    "p_charge_kw": 5.0,  
    "p_discharge_kw": 5.0,  
    "eff_charge": 0.95,  
    "eff_discharge": 0.95,  
    "soc_init_kwh": 5.0,  
    "soc_min_kwh": 0.5,  
    "soc_max_kwh": 10.0
```

```
}  
],  
  
"appliances": null,  
  
"tariff_hourly": [  
  { "ts": "2025-09-08T00:00:00Z", "eur_per_kwh": 0.15 },  
  { "ts": "2025-09-08T01:00:00Z", "eur_per_kwh": 0.14 },  
  { "ts": "2025-09-08T02:00:00Z", "eur_per_kwh": 0.13 },  
  { "ts": "2025-09-08T03:00:00Z", "eur_per_kwh": 0.13 },  
  { "ts": "2025-09-08T04:00:00Z", "eur_per_kwh": 0.13 },  
  { "ts": "2025-09-08T05:00:00Z", "eur_per_kwh": 0.16 },  
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  { "ts": "2025-09-08T19:00:00Z", "eur_per_kwh": 0.36 },  
  { "ts": "2025-09-08T20:00:00Z", "eur_per_kwh": 0.33 },  
  { "ts": "2025-09-08T21:00:00Z", "eur_per_kwh": 0.28 },  
  { "ts": "2025-09-08T22:00:00Z", "eur_per_kwh": 0.22 },  
  { "ts": "2025-09-08T23:00:00Z", "eur_per_kwh": 0.18 }  
],
```

```
"scope": "community",  
"objective": "min_cost",  
  
"policy": {  
  "forbid_simultaneous_charge_discharge": true,  
  "enforce_end_soc_equals_start": true  
},  
  
"flexible_loads": [  
  {  
    "type": "HEAT_PUMP",  
    "building_id": "B1",  
  
    "p_heat_kw": 3.5,  
    "p_cool_kw": 3.5,  
    "cop_heat": 3.2,  
    "eer_cool": 3.0,  
  
    "C_kwh_per_deg": 3.0,  
    "U_kw_per_deg": 0.20,  
    "Tin0_degC": 18.5,  
  
    "occupancy": {  
      "values": [ 0,0,0,0,0,1, 1,1,0,0,0,0, 0,0,0,0, 1,1,1,1,1,1,1,1 ]  
    },  
    "comfort": {  
      "occ": { "Tmin": 20.0, "Tmax": 21.0 },  
      "unocc": { "Tmin": 17.0, "Tmax": 22.0 }  
    },  
  },  
]
```

```

    "ambient_degC": {
      "values": [ 10,10,10,10,10,12, 14,18,22,25,27,28, 28,27,25,22, 20,18,16,14, 12,11,10,10 ]
    }
  },

  {
    "type": "HEAT_PUMP",
    "building_id": "B2",

    "p_heat_kw": 4.0,
    "p_cool_kw": 3.5,
    "cop_heat": 3.4,
    "eer_cool": 3.0,

    "C_kwh_per_deg": 4.0,
    "U_kw_per_deg": 0.22,
    "Tin0_degC": 18.0,

    "occupancy": {
      "values": [ 0,0,0,0,0,1, 1,1,1,1,0,0, 0,0,0,0, 1,1,1,1,1,1,1 ]
    },
    "comfort": {
      "occ": { "Tmin": 18.5, "Tmax": 20.0 },
      "unocc": { "Tmin": 17.0, "Tmax": 21.5 }
    },

    "ambient_degC": {
      "values": [ 10,10,10,10,10,12, 14,18,22,25,27,28, 28,27,25,22, 20,18,16,14, 12,11,10,10 ]
    }
  },

```

```

{
  "type": "HEAT_PUMP",
  "building_id": "B3",

  "p_heat_kw": 0.0,
  "p_cool_kw": 8.0,
  "cop_heat": 3.0,
  "eer_cool": 3.5,

  "C_kwh_per_deg": 8.0,
  "U_kw_per_deg": 0.35,
  "Tin0_degC": 22.0,

  "occupancy": {
    "values": [ 1,1,1,1,1,1, 1,1,1,1,1,1, 1,1,1,1, 1,1,1,1,1,1,1,1 ]
  },
  "comfort": {
    "occ": { "Tmin": 10.0, "Tmax": 11.0 },
    "unocc": { "Tmin": 18.0, "Tmax": 24.0 }
  },

  "ambient_degC": {
    "values": [ 10,10,10,10,10,12, 14,18,22,25,27,28, 28,27,25,22, 20,18,16,14, 12,11,10,10 ]
  }
},

{
  "type": "EV",
  "building_id": "B4",
  "max_power_kw": 11.0,
  "energy_kwh": 20.0,

```

```

    "start_h": 18,

    "end_h": 7,

    "crosses_midnight": true,

    "full_by_departure": true,

    "eff_chg": 0.95,

    "batt_kwh": 50.0,

    "soc0_kwh": 15.0,

    "soctarget_kwh": 35.0

  }
],

```

```

"community_assets": {
  "community_gen": [
    { "ts": "2025-09-08T00:00:00Z", "kwh": 20.0 },
    { "ts": "2025-09-08T01:00:00Z", "kwh": 22.0 },
    { "ts": "2025-09-08T02:00:00Z", "kwh": 24.0 },
    { "ts": "2025-09-08T03:00:00Z", "kwh": 25.0 },
    { "ts": "2025-09-08T04:00:00Z", "kwh": 24.0 },
    { "ts": "2025-09-08T05:00:00Z", "kwh": 22.0 },
    { "ts": "2025-09-08T06:00:00Z", "kwh": 18.0 },
    { "ts": "2025-09-08T07:00:00Z", "kwh": 15.0 },
    { "ts": "2025-09-08T08:00:00Z", "kwh": 12.0 },
    { "ts": "2025-09-08T09:00:00Z", "kwh": 10.0 },
    { "ts": "2025-09-08T10:00:00Z", "kwh": 9.0 },
    { "ts": "2025-09-08T11:00:00Z", "kwh": 9.0 },
    { "ts": "2025-09-08T12:00:00Z", "kwh": 10.0 },
    { "ts": "2025-09-08T13:00:00Z", "kwh": 12.0 },
    { "ts": "2025-09-08T14:00:00Z", "kwh": 15.0 },
    { "ts": "2025-09-08T15:00:00Z", "kwh": 18.0 },
    { "ts": "2025-09-08T16:00:00Z", "kwh": 20.0 },
    { "ts": "2025-09-08T17:00:00Z", "kwh": 22.0 },

```

```
{ "ts": "2025-09-08T18:00:00Z", "kwh": 24.0 },  
{ "ts": "2025-09-08T19:00:00Z", "kwh": 25.0 },  
{ "ts": "2025-09-08T20:00:00Z", "kwh": 23.0 },  
{ "ts": "2025-09-08T21:00:00Z", "kwh": 22.0 },  
{ "ts": "2025-09-08T22:00:00Z", "kwh": 21.0 },  
{ "ts": "2025-09-08T23:00:00Z", "kwh": 20.0 }  
]  
,
```

```
"community_battery": {  
  "capacity_kwh": 50.0,  
  "p_charge_kw": 25.0,  
  "p_discharge_kw": 25.0,  
  "eff_charge": 0.95,  
  "eff_discharge": 0.95,  
  "soc_init_kwh": 25.0,  
  "soc_min_kwh": 5.0,  
  "soc_max_kwh": 50.0  
},
```

```
"sharing": { "mode": "pool", "shares_pct": null },
```

```
"config": {  
  "solver": "cbc",  
  "time_limit_s": 30,  
  "mip_gap": 0.01,  
  "penalize_peak": false,  
  "lambda_peak": 0.0  
}  
}
```

