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**Swiss Federal Office of Energy**
Energy Research and Cleantech

**Interim report from 20 October 2025**

# PERSIST

## Positive Energy Districts Driven by Citizens

persist

positive energy districts
driven by citizens

https://www.youtube.com/watch?v=wfZaHd_nArE

https://hub.hslu.ch/ta-blog/gridly/

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# Summary

PERSIST aims to achieve a better understanding of how socio-economic, socio-cultural, and socio-political factors shape PEDs (Positive Energy Districts) and their interrelations with technological, regulatory, and investment aspects across different geographical, cultural, and economic contexts. The project investigates the relevant conditions for PEDs across Europe and identifies the most relevant participation archetypes to develop decarbonization scenarios for an optimized flexible and participative Energy System, in an Urban Living Lab (ULL) setting. PERSIT benefits from a strong network of urban living labs (or specific pilot projects of PEDs) that represent different social practices and regulatory contexts within Europe. We expect to observe different cognitive norms (e.g., social aspirations, expected conform levels, environmental concerns), different energy practices or regulations (e.g., available technology and resources, marketing practices and stakeholders, price structures).

During this year work has been done to define a work system between the partners and the actions to be carried out in each task have been outlined. In addition, preliminary work is being carried out on defining supporting documents for the collection of information to define the factors and schemes that affects PEDs implementation as well as to define the current situation of the Living Labs and demonstrators of the project. In addition, we have conducted an analysis of the open data available to support the characterisation of potential energy flexibility of buildings and review of available tools to support such flexibility.

These activities have been complemented with the development of a common protocol for a socio-economic, environmental and technological impact analysis system and its associated KPIs. Finally, all this work has supported the establishment of documents to map out the processes, activities and/or technologies to be implemented in each living lab or demonstrator, specifying when, how and where. Taking always into account the scope and resources of the project.

The next steps of the work will focus on developing a holistic framework to support the energy transition of PEDs in Europe, with particular emphasis on socio-cultural factors and business models. This will include an assessment of energy culture maturity in the Luzern region, examining the current economic, legal, and societal conditions that may influence PED implementation. To achieve this, data will be collected through national public sources, stakeholder surveys, and expert interviews. The approach will follow the previously defined guidelines for successful PED development and implementation. Finally, the project will evaluate the proposed solutions in comparison to conventional PED development methods, using the established KPIs to measure effectiveness and impact.

# Zusammenfassung

Das PERSIST-Projekt zielt darauf ab, ein tieferes Verständnis dafür zu gewinnen, wie sozio-ökonomische, sozio-kulturelle und sozio-politische Faktoren Positive Energiedistrikte (PEDs) prägen. Ziel ist aufzuzeigen, wie diese Faktoren mit technologischen, regulatorischen und Investitions-bezogenen Aspekten in unterschiedlichen geografischen, kulturellen und wirtschaftlichen Kontexten zusammenwirken. Das Projekt untersucht die relevanten Bedingungen für PEDs in verschiedenen europäischen Ländern und identifiziert die wichtigsten Archetypen für Teilhabe, um in einem Urban Living Lab (ULL)-Setting Dekarbonisierungsszenarien für ein optimiertes flexibles und partizipatives Energiesystem zu entwickeln. Das Projekt wird durch ein starkes Netzwerk von Urban Living Labs (resp. spezifische PED-Pilotprojekte) unterstützt, welche verschiedene soziale Praktiken und regulatorische Rahmenbedingungen repräsentieren. Wir gehen davon aus, dass wir unterschiedliche Normen (hinsichtlich sozialer Ansprüche, Konformitätserwartungen, Umweltbelangen) sowie unterschiedliche Energiepraktiken und -

vorschriften (bzgl. verfügbaren Technologien und Ressourcen, Marketingpraktiken und Interessengruppen, Preisstrukturen) werden feststellen können.

Im ersten Jahr wurde daran gearbeitet, einen strukturierten Rahmen für die Zusammenarbeit zwischen den Partnern zu etablieren und die Aktivitäten/Massnahmen zu beschreiben, die zu den jeweiligen tasks durchgeführt werden. Erste Schritte umfassten die Erstellung von Dokumenten zur Sammlung wichtiger Faktoren und Systemelemente, welche die Umsetzung von PEDs beeinflussen, und die Einschätzung aktuellen Status der Living Labs und der Demonstrationsstandorte des Projekts. Zusätzlich wurde eine Überprüfung offener Daten durchgeführt, um das Flexibilitätspotenzial von Gebäuden zu beschreiben, und es wurden verfügbare Tools identifiziert, die solche Flexibilitätsansätze unterstützen.

Diese Aktivitäten wurden durch die Entwicklung eines gemeinsamen Protokolls für ein sozio-ökonomisches, ökologisches und technologisches Wirkungsmessungssystem und die damit verbundenen KPIs ergänzt. All diese Arbeiten haben dazu beigetragen, Dokumente zu erstellen, die die Prozesse, Aktivitäten/Massnahmen und/oder Technologien beschreiben, die in den jeweiligen Living Labs oder Demonstrationsstandorten umgesetzt werden sollen, wobei immer der Umfang und die Ressourcen des Projekts berücksichtigt werden.

Die nächsten Schritte der Arbeit konzentrieren sich auf die Entwicklung eines ganzheitlichen Rahmens zur Unterstützung der Energiewende von PEDs in Europa, wobei ein besonderer Schwerpunkt auf soziokulturellen Faktoren und Geschäftsmodellen liegt. Dazu gehört eine Bewertung der Reife der Energiekultur in der Region Luzern, wobei die aktuellen wirtschaftlichen, rechtlichen und gesellschaftlichen Bedingungen untersucht werden, die die Umsetzung von PEDs beeinflussen können. Zu diesem Zweck werden Daten aus nationalen öffentlichen Quellen, Stakeholder-Befragungen und Experteninterviews erhoben. Der Ansatz folgt den zuvor definierten Leitlinien für eine erfolgreiche Entwicklung und Umsetzung von PEDs. Abschließend wird das Projekt die vorgeschlagenen Lösungen im Vergleich zu herkömmlichen PED-Entwicklungsmethoden bewerten und dabei die festgelegten KPIs zur Messung der Wirksamkeit und Wirkung heranziehen.

# Résumé

Le projet PERSIST vise à approfondir la compréhension de la manière dont les facteurs socio-économiques, socio-culturels et socio-politiques influencent les Quartiers Énergétiques Positifs (PED) et comment ces aspects s'entrecroisent avec la technologie, la réglementation et les investissements dans divers contextes géographiques, culturels et économiques. Cette recherche sur les PED à travers l'Europe inclut l’identification des principaux archétypes de participation pour élaborer des scénarios de décarbonisation optimisant un système énergétique flexible et participatif, dans le cadre d’un Urban Living Lab (ULL). Le projet bénéficie d’un solide réseau de laboratoires vivants urbains représentant différentes pratiques sociales et contextes réglementaires. Ainsi il serait possible d'identifier des normes différentes (en termes d'exigences sociales, d'attentes de conformité, de préoccupations environnementales) ainsi que des pratiques et des réglementations énergétiques différentes (en termes de technologies et de ressources disponibles, de pratiques de marketing et de parties prenantes, de structures de prix).

Au cours de cette première année, le travail a porté sur l'établissement d'un cadre de collaboration structuré entre les partenaires et sur la définition des actions spécifiques à chaque tâche. Les premières étapes ont impliqué la création de documents pour collecter les facteurs et les schémas influençant la mise en œuvre des PED, ainsi que l'évaluation de l'état actuel des laboratoires vivants et des sites de démonstration du projet. Par ailleurs, une analyse des données ouvertes a été réalisée pour caractériser le potentiel de flexibilité énergétique des bâtiments et des outils disponibles pour soutenir cette flexibilité. Ces activités ont été complétées par le développement d’un protocole commun pour un système d’analyse d’impact socio-économique, environnemental et technologique, ainsi que ses indicateurs de performance associés (KPI).

Tout ce travail a contribué à l’élaboration de documents qui détaillent les processus, les activités et/ou les technologies à mettre en œuvre dans chaque laboratoire vivant ou site de démonstration, en tenant toujours compte de l’ampleur et des ressources du projet.

Les prochaines étapes du travail porteront sur l'élaboration d'un cadre holistique visant à soutenir la transition énergétique des PED en Europe, en mettant particulièrement l'accent sur les facteurs socio-culturels et les modèles économiques. Cela inclura une évaluation de la maturité de la culture énergétique dans la région de Lucerne, en examinant les conditions économiques, juridiques et sociétales actuelles susceptibles d'influencer la mise en œuvre des PED. Pour ce faire, des données seront collectées auprès de sources publiques nationales, d'enquêtes auprès des parties prenantes et d'entretiens avec des experts. L'approche suivra les lignes directrices précédemment définies pour le développement et la mise en œuvre réussis des PED. Enfin, le projet évaluera les solutions proposées par rapport aux méthodes conventionnelles de développement des PED, en utilisant les indicateurs de performance clés établis pour mesurer l'efficacité et l'impact.

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| | |
|---|---|
| SFOE | Swiss Federal Office of Energy |
| PED | Positive Energy Districts |
| PEN | Positive Energy Neighbourhoods |
| LLs | Living Labs |
| GA | General Assembly |
| SC | Steering Committee |
| CC | Consortium Committee |
| AB | Advisory Board |
| DMP | Data Management Plan |
| RMP | Risk Management Plan |
| WP | Work Package |
| TCL | Thermostatically Controlled Loads |
| KPIs | Keys Performance Indicators |
| DECP | Dissemination, Exploitation and Communication Plan |

# 1. Introduction

## 1.1. Background

During the last years, in order to support the European Strategic Energy Technology Plan (SET Plan 3.2) [1], the program 'Positive Energy Districts and Neighbourhoods for Sustainable Urban Development' was developed. This program promotes and assists the development, implementation and replication of 100 energy-positive neighbourhoods by 2025. Thus, a common reference framework for PEDs and PENs has been elaborated with the aim of anticipating the various dimensions and aspects related to their implementation. Within this framework, a common PED/PEN definition was defined as follows:

*'Positive energy districts are energy-efficient and energy-flexible urban areas or groups of connected buildings which produce net zero greenhouse gas emissions and actively manage an annual local or regional surplus production of renewable energy. They require integration of different systems and infrastructures and interaction between buildings, the users and the regional energy, mobility and ICT systems, while ensuring the energy supply and a good life for all in line with social, economic and environmental sustainability' [1].*

During the last year different projects have been conducted in order to study and test PEDs to support urban energy transition ) [2]. Nevertheless, it was observed that studies begin to address the technical, economic and social aspects of PEDs, but limited analysis is available on the characterization of PEDs [3]. In addition, it is also highlighted by the European Union that there is still a need to demonstrate fully interoperable solutions that include greater energy efficiency along with better integration of local resources within the district (i.e. renewables, heat sources, etc) [4].

Within the framework of the project PERSIST, the relevant conditions for PEDs across Europe will be investigated, identifying the most relevant participation archetypes to develop decarbonization scenarios for an optimized flexible and participative Energy System, in an Urban Living Lab (ULL) setting. The consortium benefits from a strong network of urban living labs (or specific pilot projects of PEDs) that represent different social practices and regulatory contexts within Europe. This network of ULLs will be used to co-create, test and evaluate the impact of the changes on technical artefacts, social practices, rules and regulations, increasing the possibilities of multiplication and scaling up of solutions.

Within this framework the project:

- **Analyses processes which are internal to relevant social groups,** with a focus on empowerment and activation of citizens not yet engaged, including the impact of digitization of the energy system and the proliferation of social media.
- **Assesses existing / emerging participation models for renewables** (in electricity, heating & cooling, energy efficiency and flexibility) with regard to approach, offer and take-up; external environmental (e.g., openness of institutional or corporate environments, availability of sympathetic interlocutors, access to financial or other sources of support, legal or other obstacles), and internal variables describing the social groups and other demographic variables.
- **Accelerates decarbonization strategies**, through local energy management and promotion of local distributed energy resources (DERs) in PEDs.
- **Improves assets energy efficiency and cost-efficiency**.
- **Tests new business models** for PEDs.
- **Formulates concrete policy recommendations** to public authorities at regional, national and supranational levels, considering the diversity of legal systems and geographies on the basis of decarbonization scenarios for the energy system.

The complex research objectives of PERSIST forbid a simple 'one-research-method-fits-all' approach to yield accurate and replicable results. Therefore, we pursue a mixed-methods technique, i.e., combining qualitative and quantitative research methodologies and across various disciplines. In recent years there has been an increasing consensus that, when tackling complex multi-layered problem settings, mixed methods research yields sounder and more cohesive results. Moreover, there is evidence that especially if research is to produce results with practical implications – a core aim of PERSIST – the mixed methods technique is more reliable in terms of pragmatic success and replicability [5].

## 1.2. Project objectives

PERSIST aims to achieve a better understanding of how socio-economic, socio-cultural, and socio-political factors shape PEDs and their interrelations with technological, regulatory, and investment aspects across different geographical, cultural, and economic contexts. From the project, it is expected to observe different cognitive norms (e.g., social aspirations, expected conform levels, environmental concerns), as well as different energy practices or regulations (e.g., available technology and resources, marketing practices and stakeholders, price structures).

The main objectives in which Swiss team will be focused are:

- **OBJECTIVE 1:** To establish an effective management structure and support clear decision making within the consortium.
- **OBJECTIVE 2:** To support on the creation of "energy flexibility as a service" (EFaaS) mechanism via connected buildings that serve as an energy community, participate in local energy trading, improve neighbourhood power grid, and enhance resiliency in the system.
- **OBJECTIVE 3:** To develop a holistic and comprehensive framework for energy transition of PEDs in Europe, from the socio-cultural and business perspective, developing an energy transition action plan and assessing energy culture maturity in the region of Luzern (related to WP4).
- **OBJECTIVE 4:** Understand the differences of context around Europe and how PED can be replicated within Living Labs.
- **OBJECTIVE 5:** Set-up of a dissemination strategy of the project activities in Switzerland and Europe to promote the involvement of stakeholders with the project and its activities and to share project insights to relevant stakeholders.
- **OBJECTIVE 6:** Conduct a monitoring campaign for a real use case to compare the developed solutions to conventional methods for building PEDs and to enable statements on the added value of this new approach using quantifiable and reliable KPIs related to the expected benefits.

# 2. Approach, method, results and discussion

## 2.1. Approach and Method

This reporting period marks significant progress across all seven work packages of the project, despite challenges related to budget adjustments and timeline shifts among partners. The data management plan, risk management plan, and the dissemination, exploitation and communication plans have been completed, providing a solid foundation for continued project implementation.

Important advancements were made in data collection, methodological development, and framework definition. WP2 successfully gathered international data on funding schemes supporting consumer-level investments, enabling the development of evidence-based recommendations in the next phase. WP3 and WP4 delivered key methodological and planning outputs, including heating disaggregation methodologies, flexibility characterizations, and an energy transition action plan for PEDs. These deliverables position the project to continue its evaluation of building-level grid services and country-specific PED readiness.

The project also strengthened its practical and experimental dimension. The definition of socio-eco-technological specifications for living labs (WP5) and the initiation of solution testing and tool adaptation in demonstration sites (WP6) support future impact assessment, replication, and scale-up works. While WP5 experienced a 12-month delay and WP6 was affected by budget reductions on the Swiss side, mitigation measures are in place, and forward plans are clearly defined.

Overall, the project remains on track to deliver its upcoming milestones, including the final report in WP1 and policy recommendations in WP7. The coordinated efforts across partners continue to build a robust knowledge base, practical tools, and actionable frameworks that will inform effective PED deployment and support long-term energy transition strategies across Europe.

## 2.2. Project activity overview

The following provides a more detailed overview of the activities of the project as a whole:

For WP1 the Hochschule Luzern (HSLU) has revised the work plan to reflect recent budget reductions and to align with the national timelines of the project partners. An Advisory Board has been appointed to support strategic oversight. Both the Data Management Plan and the Risk Management Plan have been completed. The next key deliverable is the Final Report, which is currently in development.

The Riga Technical University (RTU) as leader of WP2 has completed the collection of data from participating countries to assess existing schemes that directly or indirectly support consumer-level investments in long-term transition assets. The forthcoming phase focuses on developing recommendations and replicable models aimed at improving the effectiveness of these funding mechanisms based on the collected data.

The Østfold University College (HIOF) as leader of WP3 has established two heating disaggregation methodologies applicable to residential and public buildings. The characterization of flexibility options and corresponding energy consumption patterns has also been finalized. The Gridly tool (developed by HSLU) has been applied to model potential local electricity markets in Switzerland and Norway. The next steps involve assessing the potential of buildings to provide grid services and enhance overall sustainability and reliability.

In WP4 the Technical University of Cluj-Napoca (TUCN) has finalized the Energy Transition Action Plan and the Energy Efficiency Guidelines for PEDs. Upcoming activities include evaluating business and financing models, technological developments, legal frameworks, and the readiness of citizen-driven approaches to PED deployment in each participating country.

Regarding WP5, the University of the Basque Country (UPV/EHU) has completed the socio-eco-technological specifications for the living labs, establishing a shared framework for scenario identification. This work was finalized with a 12-month delay. The monitoring and impact assessment protocol has also been completed. The next phase will focus on assessing the living labs' impacts within an urban context.

In WP6 HSLU has commenced on testing partner solutions across the study cases. Adaptation of the Gridly tool to the Spanish and Portuguese contexts is currently underway. The upcoming focus is on developing recommendations for PED demonstration in diverse settings and establishing methods for scale-up and replication. Reduced Swiss funding has caused delays in this work package.

The Universidade de Coimbra (UC) as leader of WP7 has begun the dissemination, exploitation and communication plan has been finalized. Next steps are focused on developing a report with the policy recommendations.

## 2.3. Swiss context

This section analyzes the Swiss context through its economic, political and cultural aspects in relation to energy. To determine which methods are most suitable for achieving the development of effective positive energy districts, it is essential to first understand the context in which these methods will be applied. In the case of Switzerland, which has a high rate of public participation (frequent referendums) and local autonomy, public acceptance and citizen involvement are crucial factors for the success of PED initiatives; this idea is illustrated in Figure 1.

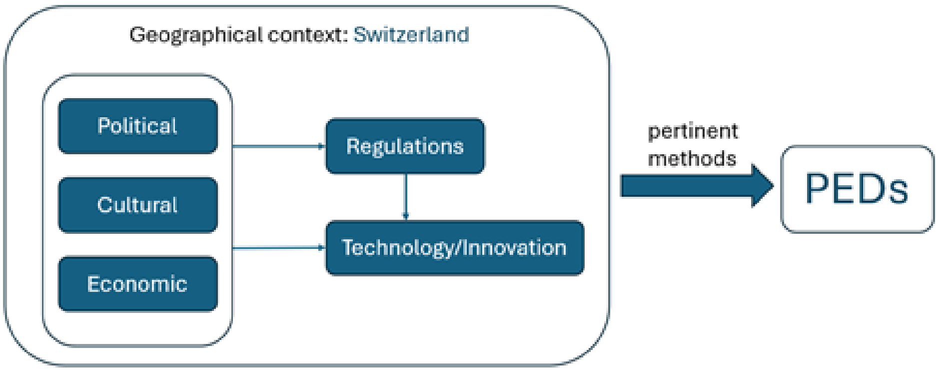


Figure 1: Swiss context for PEDs

Switzerland has one of the highest incomes per-capita in the world and ranks high in economic sustainability and public education [https://www.sgi-network.org/2024/Switzerland/Economic_Sustainability, https://www.aboutswitzerland.eda.admin.ch/en/switzerlands-education-system]. The public seems to be concerned with environmental policies and energetic sovereignty as shown by the accepted referendum on a secure electricity supply from renewable energy sources in 2024; however, regarding emissions: two public referendums related to emissions-reduction targets were rejected (in 2021 and 2025), with a marked divide between urban and rural voters (https://www.swissinfo.ch/eng/business/switzerland-votes-on-controversial-co2-law/46695016). The need to increase energy independence is an important point in Switzerland, as the country does not have fossil fuels and relies heavily on the cooperation with the European Union to satisfy electricity demands. With a healthy economy and concerns in climate protection and energy security, it is not surprising that sustainability-oriented research and innovation spending covers 3.4% of the GDP (2021) (https://www.sgi-network.org/2024/Switzerland/Economic_Sustainability). Additionally, in recent decades, policymakers have introduced several instruments designed to guide Switzerland toward a sustainable future such as:

- **The Agenda 2030**: 17 sustainable development goals of the UN, of which goal 7 is particularly relevant: "Ensure access to affordable, reliable, sustainable and modern energy for all" (https://www.agenda-2030.eda.admin.ch/en/).
- **Paris Climate Agreement**: Participating states must submit and explain a nationally determined greenhouse gas reduction target every five years. Switzerland has set a reduction target of 50 percent by 2030 compared to 1990 levels (https://www.bafu.admin.ch/bafu/en/home/topics/climate/klimapolitik.html).
- **Net-zero target** and **Climate and Innovation Act**: Switzerland aims to achieve net-zero emissions by 2050, meaning it should not emit more greenhouse gases into the atmosphere than can be absorbed by natural or artificial storage (https://www.bafu.admin.ch/bafu/en/home/topics/climate/klimapolitik/ziele-und-strategien/netto-null-ziel-2050.html).
- **Energy Strategy 2050**: The revised law, which came into force in 2018, bases the Swiss energy strategy on three pillars: 1. energy efficiency, 2. renewable electricity production, and 3. the phase-out of nuclear energy (https://www.bfe.admin.ch/bfe/en/home/policy/energy-strategy-2050/what-is-the-energy-strategy-2050.html).
- **The Federal Act on a Secure Electricity Supply from Renewable Energy Sources**: The bill includes funding instruments as well as new regulations for electricity production, transport, storage and consumption (https://www.bfe.admin.ch/bfe/en/home/supply/electricity-supply/federal-act-renewable-electricity-supply.html/).

In this context, a study by Mihailova, D., et al. [https://doi.org/10.1016/j.enpol.2022.112824] regarding Swiss PED preferences shows that mobility is an important aspect to consider, and that the general public has difficulties in envisioning a future that differs from their current way of living. This suggests that promoting energy and environmental awareness, that lead to successful PEDs, greatly depends on creating more interactive ways for citizens to engage with the often-unseen systems that shape the way society will produce, distribute, and use energy in the future (https://doi.org/10.1016/j.futures.2020.102528Get rights and content).

## 2.4. PEDs in CH and links to LECs/LEMs

Given the situation of Switzerland, especially the present risks in energy security and the net-zero target, PEDs present an appealing solution as they have the characteristics of generating surplus local renewable energy (RE) with net-zero emissions. In Switzerland, several PED-related projects have emerged, but are not widely implemented. For example, the PEDvolution project focuses on PED conceptualization, implementation and tool development; one of the demonstrator sites is the so-called Hard community: a non-profit, self-managed cooperative in Winterthur, Switzerland, in which all property and business owners are shareholders (https://journals.sagepub.com/doi/full/10.1177/27723577251352737, https://pedvolution.eu/). The results obtained from the Hard community so far offer encouraging evidence by demonstrating the feasibility of achieving a net-positive energy balance, but they highlight the importance of a synergistic approach that combines advanced technical solutions with active community involvement. Another relevant project is the Pedsets project, an interdisciplinary research initiative investigating the application of PEDs and similar concepts that lead to sustainable neighborhood decarbonization in Switzerland (https://www.zhaw.ch/de/engineering/institute-zentren/ine/nachhaltige-energiesysteme/pedsets). These projects, as well as Persist, are helping Switzerland transition from isolated demonstrator initiatives toward the practical implementation of fully operational PEDs, but there are still several challenges to overcome.

Apart from increased community involvement and supportive policy frameworks, on one side there is a need to increase smart technology and energy efficiency in buildings to reduce overall consumption, and on the other side there is the need to increase and improve active management of RE generation. In Switzerland, solar energy has an important role in the generation of locally produced energy in urban settings (https://www.swissgrid.ch/en/home/newsroom/blog/2023/energy-should-be-produced-where-consumed.html). A report by ZHAW (https://digitalcollection.zhaw.ch/server/api/core/bitstreams/8e608b25-66a0-42dc-aa0e-4c2c3973c53d/content) assumes that 44TWh will have to be covered by solar production in 2050, but to achieve this the current expansion rate must be increased (Rohrer, 2020). Considering that in Switzerland more than half of the population live in rented buildings with several dwellings (https://www.bfs.admin.ch/bfs/en/home/statistics/construction-housing/dwellings/rented-dwellings.html), it seems natural for several users to join forces and form communities for self-consumption (*Zusammenschluss zum Eigenverbrauch*, ZEVs) or local electricity communities (*Lokale Elektrizitätsgemeinschaften* , LEGs) to invest together in PV systems and smart energy technologies. Switzerland first introduced ZEVs in 2018, followed by the authorization of virtual ZEVs (vZEVs) in 2025; the establishment of Local Energy Communities (LEGs) is planned for 2026. In general, these organizations enable groups of consumers and prosumers in a nearby area to collectively produce, trade, and consume locally generated electricity, typically from PV generation; LEGs will increase the potential area for local trading, and allow for more diverse members, i.e. building types (https://www.lokalerstrom.ch/betriebsmodelle/leg). These associations provide the regulatory framework for collective and local energy generation and consumption, which is fundamental for the development of PEDs. These communities are often facilitated by digital platforms that manage data exchange, billing, and energy optimization. However, decision-support tools to assist during the design and configuration phase of ZEVs/LECs remain less common, despite their potential to guide informed and effective decisions about their setup.

## 2.5. Gridly: An interactive decision-support tool for local electricity communities

Gridly is an interactive tool designed to help decision-making in relation to electricity communities and the resulting electricity markets. These are referred to as ZEVs. vZEVs and LEGs in the Swiss context, and as energy communities (ECs) for the general European context. The tool allows to test different configurations of a potential or existing ECs, and observe the resulting changes in local electricity market (LEM) dynamics. The following parameters can be modified: the season(yearly version is also possible); the size of the EC (number of members); the percentage of members with photovoltaic systems (PV), i.e. with the capacity to generate electricity locally; whether members with PV also have a battery; and the amount of capacity and willingness to shift load demand to moments of high PV generation or low load demand. The results which are obtained include the daily average load and generation profiles for the season (or the year); the savings obtained by being part of a EC as opposed to not being part of it; the amount of grid independence obtained, i.e. how much electricity was consumed locally instead of having to be imported or exported to the main grid; and a graphical illustration of the trades happening between the members of the EC. The tool considers a centralized electricity market with fairness assumptions and in this first version, static tariff systems.

## 2.6. Flexible services provided by electric heating

The goal of the flexibility analysis is to quantify time-shiftable electric heating demand in residential buildings and assess how this latent flexibility can support system objectives such as peak reduction, congestion relief, and improved local self-consumption of renewables.

In practice, these services rely on controlled load reshaping over intra-day horizons (hour-scale), subject to personal comfort, building physics, and heating technology.

Because total household electricity combines space/water heating with non-heating uses such as EV charging and appliances, any estimate of available flexibility must first isolate the heating component of demand. Without that separation, the analysis risks overstating what can be shifted (by mistakenly including inflexible end-uses) or understating it by missing heat-storing potential.

### 2.6.1. Heating disaggregation

Sub-metered heating data is scarce, and heating behaviour is highly idiosyncratic across homes (building size/age, occupancy and schedules, thermostat set-points, heating technology). Consequently, simple proportional rules or static temperature thresholds are inadequate for reliable disaggregation.

We therefore adopt a data-driven approach that learns the heating signal from historical time series of whole-home electricity, augmented with weather and calendar context. Our work builds on two Swiss datasets: HEAPO (whole-home electricity for ~1400 residential buildings in the greater Zürich area, out of which 72 homes have sub-metered heating ) and RAPT (a high-resolution dataset from five homes in the greater Lucerne area). Hourly records from 2017–2024 are cleaned and aligned with the nearest hourly weather station temperature.

The analysis focuses on residential buildings; a complementary analysis on non-residential buildings in Verdal, Norway, is currently being pursued with HIOF. The resulting disaggregation is the prerequisite for the subsequent flexibility study, where only the estimated heating portion is considered shiftable under building and comfort constraints.

We approach the disaggregation as a supervised machine learning problem, i.e., build a historical model that maps the hourly total electrical load to the hourly heating component. For each house, inputs are 24-hour vectors of (i) total electricity (in kWh) and (ii) outdoor air temperature, plus day-level context (month, week, day-of-week, and a holiday flag broadcast across the 24 hourly values). Targets are the corresponding 24 hourly heating values in kWh. Only complete days are retained. To enhance convergence of the model, continuous features such as the hourly values are standardized using training statistics; metadata are left unscaled. This yields tensors of shape [N, 24, C], where C is the number of continuous channels plus the broadcast metadata.

The predictive machine learning model is a small convolutional neural network (CNN) tuned to capture the intra-day structure. A 1×1 channel mixer projects inputs to a hidden higher-dimensional layer, followed by residual 1-D convolutional blocks with Gaussian-Error Linear Units (GELU), LayerNorm and dropout for normalization, and moderate dilation (kernel size 5-7). A 1×1 head produces 24 hourly estimates, passed through a Softplus fuction to enforce non-negativity. We train using the AdamW-optimizer, gradient clipping, and mean-squared error (MSE) in kWh per hour as the optimization target, while tracking mean-absolute error (MAE) in kWh. The convolutions are non-causal by design: each hour may use its neighbouring hours within the same day to derive a better estimate of the heating component, as the objective is disaggregation given the total electrical load, not pure forecasting.

### 2.6.1.1 Prediction of heating load in out-of-sample houses

When generalizing to unseen houses with no prior history, we train the CNN without house embeddings and evaluate with a group split - train on 64 out of the 72 random houses in the training set, evaluate the model on 8 unseen ones - to approximate cross-building knowledge transfer of the model. The inductive bias builds upon temperature dependence and universal day-to-day patterns encoded by the convolutions and metadata. This configuration is deliberately parsimonious to be deployable where only whole-home metering and weather are available.

Model training setup: 100 epochs, batches of 128 randomly selected daily datapoints, kernel-size of 9; hidden channels [128, 128, 64, 48]; dilations [1, 2, 1, 1]; dropout 0.1. AdamW parameters: learning rate of $5\times10^{-5}$, weight decay of $1\times10^{-5}$.

Empirical results using the group split without embeddings: Training and validation curves for both MSE and MAE decrease smoothly across 350 epochs (Figure 2). Validation metrics of prediction accuracy: MSE 0.24 kWh, and MAE of 0.23 kWh across hours. The moderate error is expected in cross-house knowledge transfer due to structural variability (building properties, heating controls, occupant behaviour). Despite this, the model captures the main temperature-driven dynamics and day-to-day structure, providing usable heating estimates for downstream flexibility with appropriate uncertainty-aware caps.

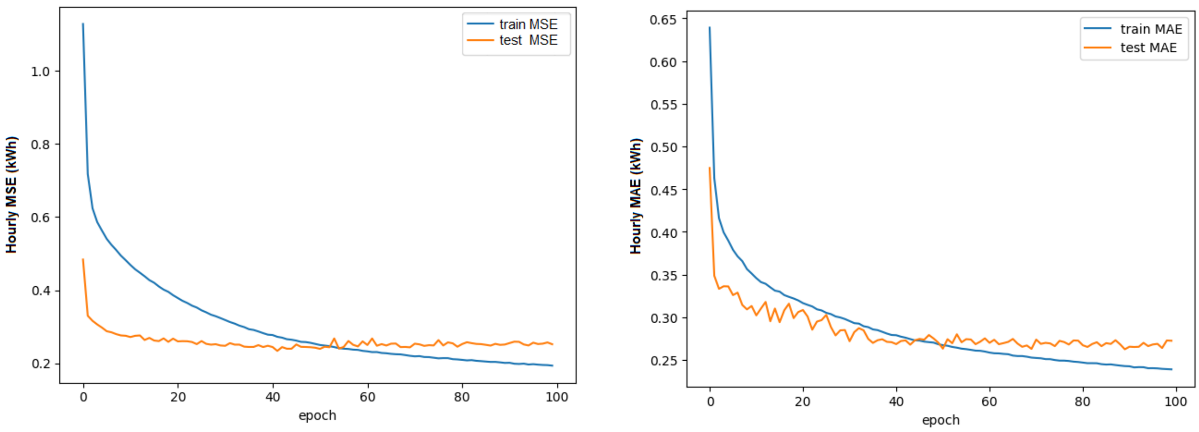


Figure 2: Training and validation curves for both MSE and MAE

### 2.6.1.2 Prediction of heating load in houses with available data

When house identification and sufficient history exist, we augment the CNN with learned house embeddings projected into the first latent layer as a bias. This captures persistent, home-specific traits (building-physics, thermostat habits, heating technology) without any hand-crafted categories or extracted features. Evaluation uses a time-based split (train up to 2023-07-10; validate on 2023-07-11 to 2024-02-11), which tests how well the model learned home-specific features i.e., the accuracy of the learned embeddings. Model training setup: 300 epochs; batches of 64 randomly selected daily datapoints; kernel-size of 7; hidden channels [128, 256, 256, 32]; dilations [1, 1, 1, 1]; dropout 0.1; house-embeddings of dimension 12. AdamW parameters: learning rate of $1\times10^{-4}$, weight decay $1\times10^{-5}$.

Empirical results using house embeddings and time split: Learning curves again show monotonic improvement over 300 epochs (Figure 3). Validation metrics of prediction accuracy: MSE is at 0.15 kWh, and MAE of 0.19. Compared to the cold-start setting, both errors are lower, consistent with the hypothesized benefit of embeddings that encode persistent house traits, and with the inherently easier within-house temporal generalization.

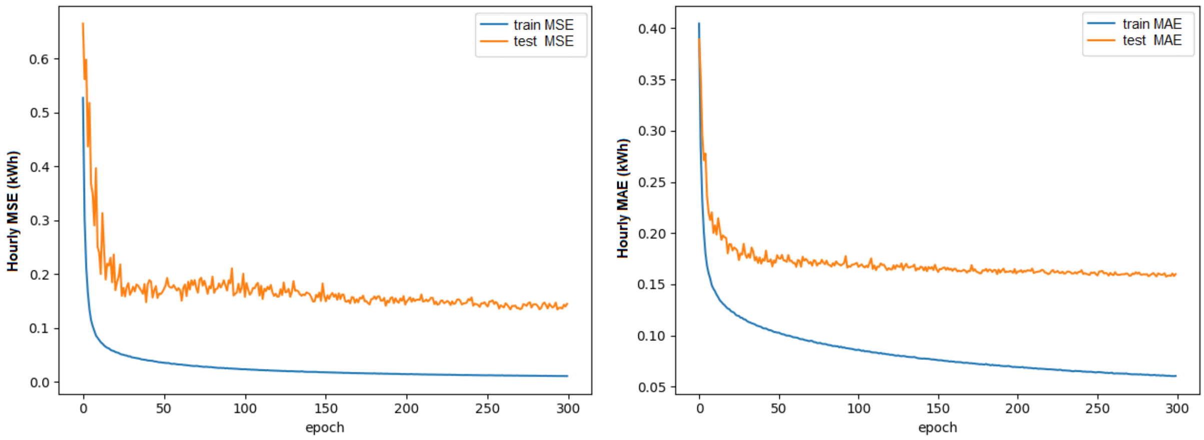


Figure 3: Learning curves again show monotonic improvement over 300 epochs

#### 2.6.1.3 Interpretation of results

For the downstream flexibility analysis, the time-split + embeddings configuration is preferable when house history exists, enabling tighter uncertainty bounds and more confident shiftability estimates. Under “cold-start-estimates", the group-split performance supports initial deployment, but flexibility extraction should be conservative until house-specific data allow adaptation (e.g., by enabling the use of embeddings and fine-tuning).

#### 2.6.1.4 Perspective

The guide future development, we identify several promising directions for improving the model’s accuracy and applicability:

- Feature enrichment: Incorporation of additional signals with broad coverage (humidity, solar irradiance, wind, precipitation) and calendar features (e.g., school breaks) if they improve out-of-sample error without harming coverage.
- Uncertainty & calibration: Estimation of predictive uncertainty via e.g. Bayesian models to propagate confidence into flexibility estimation and the derived decision rules.
- Semi-supervised modelling approach: Leveraging the large amount of unlabeled data in the HEAPO dataset (the remaining 1330 houses without submetered heating) to learn relationships between total electrical load and temperature, before applying supervised fine-tuning via, e.g., masked-hour reconstruction or sequence autoencoding. This should improve the generalization capability of the model and stability on unseen building types.

## 2.7. Co-creation methods

Following the initial design of the tool by a multidisciplinary team at HSLU as part of SWEET LANTERN project, within PERSIST project, work has been done to further develop, test and validate the Gridly tool. Firstly, a collaboration has been established with Smart Region Lab to integrate the tool into the visualisation tables. The objective was to provide additional functionalities to the tables and facilitate its test and dissemination at events and workshops. At the same time, collaboration with Winterthur has been ongoing to introduce real local data into the tool to validate it with a real context, serving as a first case study and, simultaneously, as an example on which to work during the co-creation processes (see Figure 4).

A participatory phase aimed at testing, evaluating, validating, and refining the tool is currently underway. This co-creation process is structured around three key dimensions: (1) the quality, relevance, and visualization of the data presented within the tool; (2) the tool's utility in supporting the initial stages of establishing an energy cooperation initiative such as raising awareness, fostering engagement, and enhancing understanding of ECs or LEMs, as well as its potential to support their management (e.g., fair energy sharing, forecasting community growth); and (3) the definition of the target user groups and the scope of application of the tool.

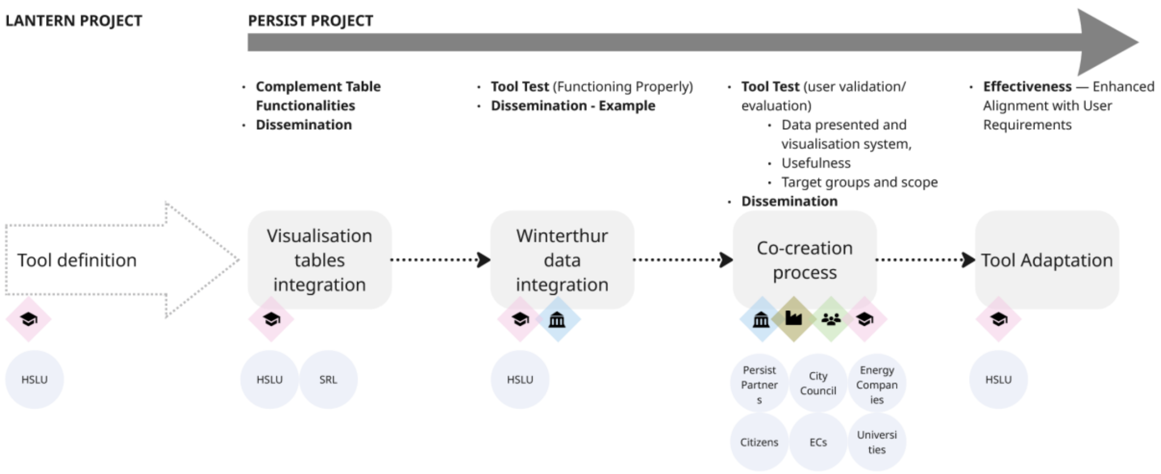


Figure 4. Summary of steps of the tool co-creation process, sectors involved, organisations and objectives of each step.

This process has been carried out with different actors with diverse backgrounds, experience in the sector, and from varied local contexts around Europe. So far, stakeholders from academia (Switzerland, France, Germany, Romania, Lithuania, Portugal, Spain, Norway), public administration (Romania, Switzerland, Spain), the private sector (Switzerland) and civil society (Spain, Switzerland) have been involved. Three events have been held to present and work on a collaborative manner with participants on the tool. Four more are expected to be conducted before the end of the year (see Table 1 and Table 2):

**CONDUCTED EVENTS:**

| Event | Date | Place (city and country) | Number of participants | Sectors represented | Fields of expertise of participants | Type of activity conducted |
|---|---|---|---|---|---|---|
| Project General Assembly PERSIST | 10-11 June 2025 | Cluj (RO) | 15 | Academia<br>Public administration<br>Private sector | Energy<br>Legal/politics<br>Economic<br>Social<br>Engineering | Presentation, test, and open discussion |
| Congress-SSH Energy 2025 | 16-17 June 2025 | Zurich (CH) | 9 | Academia<br>Public administration<br>Private Sector | Energy<br>Urban/Architecture<br>Engineering<br>Legal/politics | Presentation, test, and open discussion |
| Congress-Urban | 1-2 September 2025, | Dübendorf (CH) | 25 | Academia<br>Public administration<br>Private sector | Energy<br>Urban/Architecture<br>Engineering | Interactive Workshop (presentation, |

| | | | | | | |
|---|---|---|---|---|---|---|
| Future Forum | | | | | Legal/politics | test and evaluation) |

Table 1. Summary of events conducted for tool co-creation purposes

**PLANNED EVENTS:**

| Event | Date | Place (city and country) | Sectors invited to the event | Type of activity conducted |
|---|---|---|---|---|
| Meeting | 24 October 2025 | Manzanares el Real (SP) | Civic society (Energy Community) | Interactive Workshop (presentation, test and evaluation) |
| Local Energy Party | 14 November 2025 | Pamplona (SP) | Academia<br>Public administration<br>Private sector<br>Civic society | Interactive Workshop (presentation, test and evaluation) |
| Meeting 1-1 | 14- November 2025 | Pamplona (SP) | Civic society (Energy Communities) | Interactive Workshop (presentation, test and evaluation) |
| Meeting | 24 November 2025 | Pamplona (SP) | Academia<br>Public administration<br>Private sector | Interactive Workshop (presentation, test and evaluation) |

Table 2. Summary of events planned in the following months for tool co-creation purposes

In the first two events conducted, it was decided to hold sessions in which, after a **presentation** of the tool, there would be an **open discussion** among the participants to resolve any questions about the tool and to provide feedback on it (its usefulness, data that is missing, who the participants believe could use it, etc.). Starting with the third event, it was decided to systematise the evaluation system through an **interactive workshop** in which, after the **presentation and testing** of the tool, participants **worked collaboratively** on a series of aspects: most interesting information, pros and cons, usefulness, limitations, what is missing, and who are the potential target groups. In addition, following each workshop, an internal evaluation is being conducted to identify potential improvements and implement necessary adaptations on the dynamics, thereby enhancing the workshop effectiveness in subsequent sessions.

## 2.8. Main results

### 2.8.1. Gridly implementation in interactive data tables

The implementation of Gridly in the Smart Region Lab (SRL) interactive data tables was done to present the simulation results interactively, enabling users to configure ECs, observe outcomes, and compare scenarios in a clear and intuitive way. This work benefited greatly from the support of the Smart Region Lab, whose mission includes integrating interactive data visualization with digital platforms to enhance user engagement and understanding (https://sites.hslu.ch/smartregion/smart-region-lab/).

The visualization and user interface (UI) layer of the Gridly tool, referred to in the codebase as the "energy community simulator", was implemented as an interactive web application. Its structure is defined through a JSON configuration scheme that controls the user interface text, chart labels, and explanation elements across multiple modules. This modular design allows easy translation, customization, and future expansion of the interface without modifying the underlying simulation logic.

The front-end guides users through the configuration of the EC customizable parameters, the execution of simulations, and the interpretation of results. Input controls enable the adjustment of variables such as community size, season, photovoltaic (PV) adoption, presence of batteries, and smart device penetration. Each input is accompanied by descriptive tips that explain the effect on the simulation, thereby helping non-expert users to understand the data provided by the tool.

Once a simulation is executed, the tool dynamically generates a series of visual data tables and charts that summarize key performance indicators:

- Average cost per household and cost comparison between community and non-community scenarios.
- Average daily energy profiles, depicting load and PV generation over a 24-hour cycle.
- Trading network diagrams, which visualize internal energy exchanges among members and with the main grid.
- Energy flow charts, presented as interactive pie charts showing production allocation (self-consumption, battery use, LEM sales, grid export) and consumption sources (from PV, battery, LEM, or grid).
- Outcome dashboards, displaying community-level indicators such as autarky (self-sufficiency), market activity, and average savings.

The interface is organized around a selector panel that lets users toggle between different result views. There are error and warning messages to ensure transparency in case data is incomplete or inconsistent. The visualization components were implemented using front-end technologies such as JavaScript/TypeScript, with data visualization libraries such as D3.js or Recharts, and connected to the simulation engine via an API. This separation allows for responsive updates and scalability in future versions.

Overall, the visualization and UI components of Gridly transform raw simulation data into clear, interpretable insights. They play a central role in making the tool interactive, transparent, and practical for decision-making and stakeholder communication. A screenshot of the user interface is provided below in Figure 5.


Figure 5: Gridly user interface

## 2.8.2. Gridly results and analysis with Winterthur data

The Gridly tool has been tested on a combination of real and synthetic data from households in the city of Winterthur. The load data consists of 600 household smart meter hourly profiles for the year 2024. For each household, the daily profiles of each month are averaged into a single load profile to make simulations manageable. To represent Swiss demographics, where 60% of the population live in multiple-household buildings (https://www.bfs.admin.ch/bfs/en/home/statistics/construction-housing/dwellings.htm), 6 households are considered per building. Each building represents a single member in the simulation; this is achieved by aggregating 6 load profiles per building. The PV data is synthetic PV data from *renewables ninja (https://www.renewables.ninja/)* obtained from around the Winterthur area. This way, for each residential building that is assigned a PV system as per the simulation parameters, there is an assumed 20kW PV system. If the simulation parameters specify that the buildings with PV also have batteries, then a 10kWh battery per building is modelled. The PV and battery values were chosen to match realistic capacities that could be installed in a building – as per the Swiss annual report on statistics for solar power for 2023. The tariff scheme considered is static, with fixed consumption and feed-in tariffs based on Stadtwerk Winterthur tariffs.

To analyze the case of Winterthur, the simulation was run 250 times for the season of spring, with and without battery and varying the following parameters:

- EC size (number of buildings): between 10 and 100 (steps of 10).
- Percentage of houses with smart devices: between 10 and 90 (steps of 20).
- Percentage of buildings with PV systems: between 10 and 90 (steps of 20).

The aspects that were analyzed were:

- Percentage of PV generation that was not self-consumed, that was traded locally, i.e. $supply\ sold = \frac{G_t}{G_l}$, where *G_t* is the amount of electricity sold in the LEM, and *G_l* is the amount of PV generated electricity left after self-consumption.
- Percentage of demand that was not met with self-consumption that was met through internal trading, i.e. $demand\ covered = \frac{D_t}{D_l}$, where D_t is the amount of electricity bought from the LEM, and *D_l* is the amount of load demand that was not met with self-consumption.
- Cost benefit of being part of a LEC, this was calculated by considering the consumption, feed-in and internal trading prices as:

$$cost\ benefit = 1 - \frac{cost_{LEC}}{cost_{noLEC}}$$
$$= 1 - \left[\frac{(D_l - D_t)Grid_{price} + D_t P2P_{price} - (G_l - G_t)FeedIn_{price} - G_t P2P_{price}}{D_l Grid_{price} - G_l FeedIn_{price}}\right]$$

Figure 6 shows the amount of left over locally produced electricity after self-consumption that is sold in the LEM (as a percentage), as expected, the biggest factor that influences this result is the percentage of PV present in the EC. When there are only very few buildings with PV there is no competition for selling electricity as there is so little that the demand is always higher than the production and all of the generation can be sold internally.

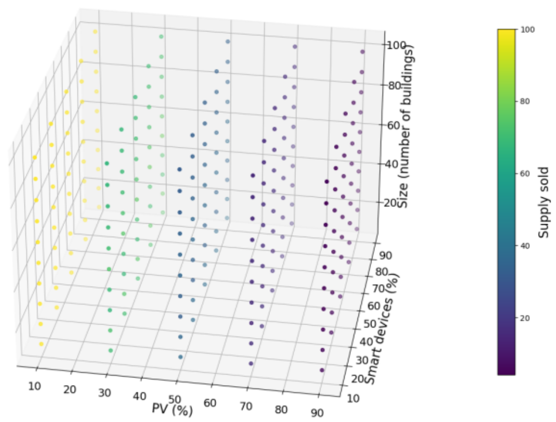


Figure 6: Percentage of PV generation that is not self-consumed that is traded locally

However, when there is too little PV, then more of the demand needs to be met through the external grid. Figure 7 shows that for the Winterthur case, when 30 to 50% of the buildings have PV systems, the most demand can be covered locally. After that there is so much generation that there are not enough local buyers of electricity, and thus a significant amount must be sold to the external grid. Fig. N also shows the importance of smart devices, as increasing the percentage of households with smart devices creates a noticeable increase in the amount of demand that can be covered locally by shifting loads to moments of high PV generation.

Figure 8 shows an aggregated score which was calculated as a weighted sum of the three indicators that were considered (normalized): $score = 0.5(\widetilde{demand\ covered}) + 0.2\ (\widetilde{supply\ sold}) + 0.3\ (\widetilde{cost\ benefit})$. Greater importance was given to the "demand covered" aspect, since reducing the amount of electricity imported from the external grid also lowers the associated $CO_2$ emissions from fossil-fuel-based generation. Furthermore, it was considered that for the members of a EC the cost benefit was more important than reducing the amount of electricity exported to the external grid and thus was given a higher weight.

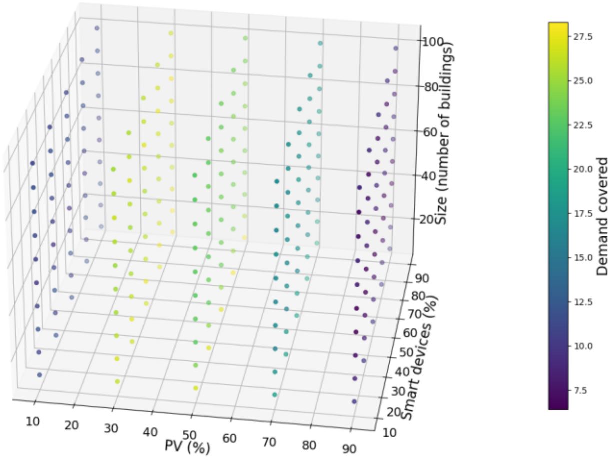


Figure 7: Percentage of demand that cannot be satisfied by self-consumption that is traded locally

Figure 7 and Figure 8 are similar, since for now dynamic tariffs are not considered, but these results may change if they are introduced as the influence of smart devices will become more noticeable.

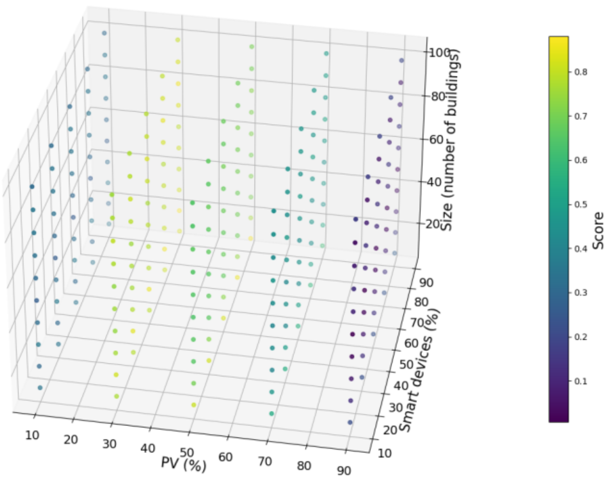


Figure 8: Aggregated score considering percentage of supply and percentage of demand traded locally and cost benefit.

The results with and without battery storage showed a similar trend: having 30–50% of users equipped with PV systems was most beneficial. The main difference was that the cost advantage of participating in a EC was generally smaller when batteries were present than when they were not. It should be noted that the cost comparison is between being part of a EC and not being part of one, in general when there is no battery present there is more local demand that can be covered by trading and so the cost benefit seems to be higher when there is no battery than when there is a battery; however in the absolute sense, having a battery is always beneficial to lowering the cost, as can be seen in Table 3

Table 3: Absolute cost comparison (CHF) for 50 buildings between having PV (50% of buildings) with and without battery and being part of a LEC or not, in the Spring season.

| PV | | | No PV |
|---|---|---|---|
| | **No LEC** | **LEC** | |
| **No Battery** | 101.7 | 79.51 | 152.98 |
| **Battery** | 93.78 | 75.4 | |

### 2.8.3. Workshops and analysis of results (SSH days WS and Dübendorf WS)

Below it is presented a description of the results of each of the events held with external actors:

**At the session in Cluj** (GA), attendees showed interest in the tool. They indicated that having an application that allows them to **simulate what happens** within the community is relevant. It could be used to support EC definition and further development, both for **DSO and EC managers**. Thus, attendees' questions focused mainly on the possibility of replicating it in their contexts (whether the tool is **open access and free**, what **minimum data is required** to implement it in another context, and whether it could **include more than just PV** as a source of local renewable energy). They also emphasised that, despite their interest, this type of energy sharing system is not yet possible in many countries due to current **regulations**. Another barrier they encounter is the number of tools being developed and that city councils are starting to use. The more tools, the more problems. There is also concern about the **anonymisation of data**, who has **access** to it, and they stress the need to work on **data security**.

**At SHH Energy 2025** (SHH), attendees showed great enthusiasm for the tool, highlighting its **usefulness** in their respective contexts. One attendee even expressed interest in exploring the possibility of including it in one of the European project proposals they were preparing. Questions were also directed at the **requirements for replication**, such as whether it is **open access and the minimum data required** for replication. In this case, the issue of regulations was not addressed, as most of the attendees were from Switzerland, where the new Energy Law allows energy sharing between individuals within a Local Energy Community.

**During the workshop at the Urban Future Forum** (UFF), the results are more detailed. As in previous cases, there is a positive response regarding the usefulness of the tool, especially **for DSOs, EC Managers, and Municipalities**. In this regard, both the **visual aspect** (user interface, dynamism and interactivity of the tool) and the **data provided** (knowing what it brings to me) are highlighted as positive and useful, as well as its value at the local level for **customer engagement**. However, certain limitations of the tool have been identified. These include problems related to the **scope of the tool**, mainly its connection to the grid and other LEMs (how it is managed and organised) and the time-frame considered in the simulations (short term). The main characteristics that are missing and could be added in the future are related to several dimensions. On the one hand, in terms of the **variables** it considers, it is indicated that it could be of interest to include electric **mobility** and **HVAC** systems (e.g. heat pumps) and make **battery and PV size adjustment** possible (currently it is either yes or no). It is also questioned whether it is necessary to present the results **by season** or not. On the other hand, regarding the selection of the Energy Community and its size, it is noted that it would be useful to use **Geographic**

**Information System (GIS)** and be able to **select a specific size and area of the Community**. There is also discussion about the understanding of the results, which, in order to better communicate them, would need to include **sensitivity analysis** or incorporate **incentives analysis** or **comparisons with other scenarios** such as the current situation or with LED hubs. It is also noted that, the **value for citizens** is not clear, making it necessary to pay more attention to specifying whether the results refer to the community in general or households, creating an explanatory manual for the tool or including prices applicable to different communities, for example. Another section that is observed to be missing and that could be of support in understanding how EC works is the **stakeholders roles** (who needs to be involved, how many people, what citizens have/need to do, etc.). Finally, there is debate about its **scope, target audience and adaptability** (how the tool adapts to each type of target group).

| | Pros | GA | SSH | UFF | Limitations | GA | SSH | UFF | What is missing | GA | SSH | UFF |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Data provided - user interface** | Know what EC brings to the user | x | | x | User value unclear | | | x | User value explanation | | | x |
| | Energy allocation in local market simulation | | | x | Scale of resuls not indicated (EC or household) | | | x | Actors roles explanation | | | x |
| | Interactive | | | x | | | | | Indicate scale of results (EC or household) | | | x |
| | Dynamic | | | x | | | | | Guidelines | | | x |
| | | | | | | | | | Adaptablity to target group | | | x |
| | | | | | | | | | Results indicated by season or yearly | | | x |
| **Variables considered** | | | | | Connection to grid/ other LEMs | | | x | Mobility variable | | | x |
| | | | | | Variables considered | | | x | HVAC system variable | | | x |
| | | | | | No georeferenced | | | x | Battery size | | | x |
| | | | | | | | | | PV size | | | x |
| | | | | | | | | | Integrate other RES | | | x |
| | | | | | | | | | Georeferenced (GIS) | | | x |
| | | | | | | | | | Select specific area or size of EC | | | x |
| | | | | | | | | | Include incentives variable | | | x |
| | | | | | | | | | Scenarios comparison | | | x |
| | | | | | | | | | Include sensitivity analysis | | | x |
| **Target groups** | DSO | x | | x | | | | | Start with municipality | | | x |
| | EC managers | x | | x | | | | | | | | |
| | Municipalities | | | x | | | | | | | | |
| **Replication / tool use** | Open access | x | x | | | | | | Data access | x | | x |
| | Define minimum data required | x | x | | | | | | Data anonymisation | x | | x |
| | Legal framework limitations | x | | | | | | | Data security | x | | x |
| | Analyse EC future scenarios | x | | | | | | | Real time EC management | x | | |
| | Useful tool for own context | x | x | x | | | | | | | | |

Table 4: Summary of the inputs obtained through the first three events held (GA, SSH and UFF)

## Discussion, conclusions and outlook

Thanks to the feedback received from the various stakeholders to whom the tool has been presented, it has been confirmed that the Gridly tool is of interest for ECs and potential LEMs. In particular, it is considered to have great value as a tool for DSOs, EC managers and municipalities in the energy management of ECs.; both to anticipate possible future scenarios (growth capacity of ECs, need for batteries, strategy to increase profit levels, etc.) and for the planning phase of ECs. In order to better align with the real-world challenges and the concerns of the mentioned stakeholders, a few adjustments and additions need to be made to the tool. On the one hand, electric mobility and electric heating functions should be included as additional modules. On the other hand, increasing customization features, such as the inclusion of geographic information system (GIS) data for the EC members, and having the ability to input data such as real battery and PV capacities as well as tariff data (including a dynamic tariff option) would help to provide a more realistic and complete picture of the situation in ECs. The inclusion of GIS data would allow to simulate different areas or existing buildings, taking into account location-specific patterns of energy production and consumption. In order to decide which adaptations are most important to make, it is necessary to define who is the target audience, so that modifications are tailored to the needs of that actor.

Despite the high level of interest in the tool for EC management, its current applicability in European countries is limited by their current legal framework. For this reason, until the regulation for a fair energy trading system between local agents is allowed, the tool is considered to be limited to awareness-raising and engagement activities. It serves to understand the possibilities and scope that could be reached with ECs or LEMs, both for local actors and policy makers. It could support the necessary regulatory changes that may occur to facilitate the implementation of this type of energy coalitions.

On the other hand, reducing the number of tools used by local agents is a priority for the team. Therefore, work is currently underway on a new proposal in which different complementary tools, including Gridly, developed by different international agents are combined to create an Applied Solution Package (ASP). A coherent, interoperable suite that couples citizen engagement, system simulation, and explainable governance dashboards to provide modular, standards-oriented interfaces (open APIs, common data model) that let cities/DSOs adopt any component standalone or as a bundle and plug into existing data lakes or tools.

# 3. National and international cooperation

## 3.1. Cooperation with HIOF

As part of the collaboration with HIOF, a dataset was shared from the municipality of Verdal, Norway covering 22 non-residential buildings: six schools, five kindergartens, six institutions (medical or otherwise), and five office buildings. For each building, hourly whole-building electricity demand is available for the entire year 2024. The dataset does not include sub-metered end-uses or verified information on existing PV installations, batteries, or controllable devices, except for the heating load of two buildings. This non-residential portfolio is distinct from the Swiss residential data and is used in the following subsections for (i) Gridly-based community simulations and (ii) exploratory heating disaggregation and flexibility analysis.

### 3.1.1. Gridly results and analysis

Using the dataset described in Section 3.1, the Gridly tool was tested with load data of the 22 buildings in Verdal, Norway. Since none of these buildings were residential households, this represented a distinctly different dataset, requiring several adjustments to the tool as well as some assumptions, since there was no information provided about possibly existing PV systems.

- The following assumptions were made: The considered LEC includes all 22 buildings, none of the profiles were aggregated in this case.
- Only the kindergartens are considered to have PV installed, all with the conservative capacity of 40kW.
- When the battery parameter is enabled, the assumed battery capacity is set to 20 kWh.
- No load shifting capacity is considered, i.e. no smart devices are considered.

The PV profiles were obtained from *renewables ninja (https://www.renewables.ninja/)* from around the Verdal area. The tariffs used were based on tariff information obtained from Energifakta Norge (https://energifaktanorge.no/regulering-av-energisektoren/regulering-av-nettvirksomhet/).

With the previous assumptions, the simulation results showed that the considered installed PV was too little to satisfy the load demand of the community; while the prosumers (kindergartens) were able to greatly benefit from self-consumption, the rest of the buildings only very slightly improved their electricity prices since there was no local generation left to trade. Table 5 presents the total demand and generation of the community for the different seasons, along with the amount of electricity that could be traded both with and without battery storage among the prosumers. As can be seen, during winter all the locally generated electricity is consumed. Even in the summer, the best season for trading, the generation is too little to make a significant impact for the members that are not prosumers.

| | Total Demand (kWh) | Total Generation (kWh) | Total Traded (kWh) | |
|---|---|---|---|---|
| | | | No battery | Battery |
| **Winter** | 84159.1 | 171.3 | 0 | 0 |
| **Spring** | 53510.7 | 1353.0 | 285.7 | 184.4 |
| **Summer** | 34078.8 | 1903.8 | 867.4 | 684.1 |
| **Autumn** | 56797.7 | 642.1 | 112.6 | 62.7 |

Table 5: Total demand, total generation and total traded energy during the different seasons considering an energy community of all buildings, with kindergartens being prosumers.

Nevertheless, the prosumer buildings greatly benefit from the installation of PV systems, as shown in Figure 9. In the case where they form a LEC with the other buildings, they profit from generating electricity. The last building from left to right shown in Fig. N has considerably higher consumption than the others, in all seasons it self-consumes all the generated electricity and cannot sell in the LEM, which is why the price with and without LEC is nearly identical. This nearly identical price with and without LEC also applies to all the other buildings considered.

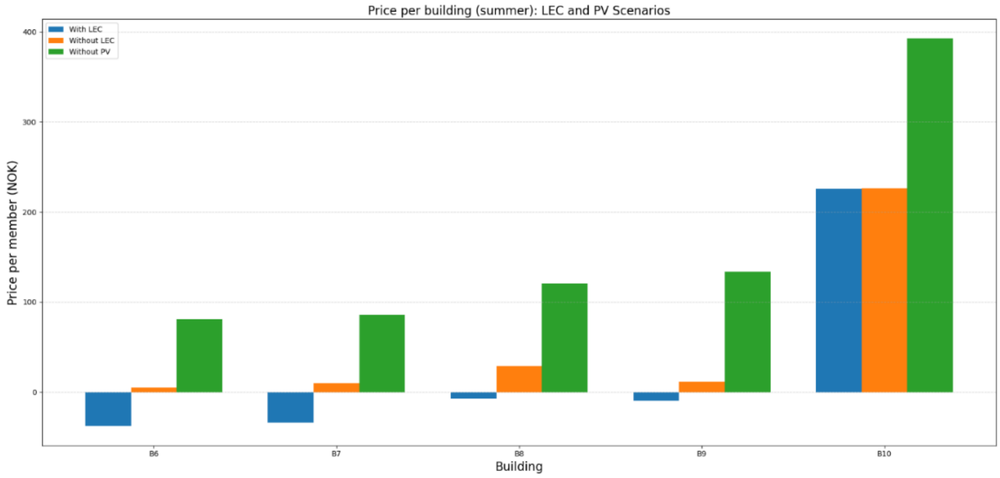


Figure 9: Electricity price for kindergarten buildings for the cases of: not having PV (current case), having PV but not being part of a LEC, and having PV and being part of a LEC with the other buildings considered (negative values indicate profit).

However, it is interesting to note that the proposed LEC does not seem to suffer from the typical mismatch between high PV generation and load that LECs made up of purely residential buildings have, as can be seen in Figure 10. This is a great incentive to creating LECs with combinations of non-residential buildings and residential buildings.

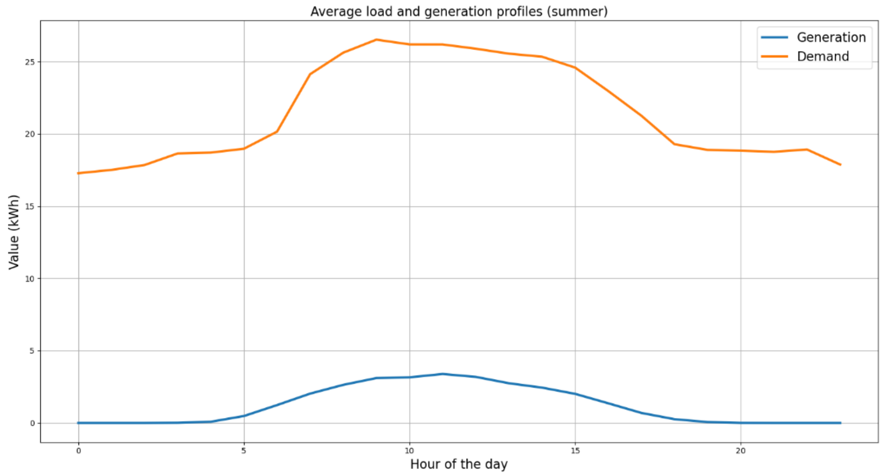


Figure 10: Average daily load and generation profiles (under assumed PV characteristics).

Since the site (Verdal) is not characterized by high solar radiation, a future analysis should be conducted to determine the optimal amount of PV capacity to install. This would require additional information on which buildings are suitable for installation, the available roof or surface area, and the corresponding budget constraints. Furthermore, developing average load profiles for each building type would help to better understand and mitigate the generation–demand mismatch within the community.

### 3.1.2. Heating disaggregation

The partnering research team from HIOF is currently developing a heating-disaggregation model for non-residential buildings (offices, institutions, schools, and kindergartens). As part of this collaboration, they provided whole-building total and heating electrical load data for two institutional buildings whose usage patterns differ substantially from Swiss residential homes. Their ongoing model development is complementary to our work, and the following section focuses on the integration of the institutional building data into the heating-disaggregation model developed in Section 0. The following table provides an overview over the supplied heating data:

| **Dataset** | **Buildings** | **Timespan** | **Total/Heating Load** | **Max.** (kWh) | **Mean** (kWh) | **Std. Dev.** (kWh) | **Regional Temperature ($10^{th}$ - $90^{th}$ percentile)** |
|---|---|---|---|---|---|---|---|
| **Verdal, Institutional** | 2 | 2024-2025 | Total | 267.7 | 57.2 | 59.0 | -15 °C - +25 °C |
| | | | Heating | 185.8 | 31.6 | 37.5 | |
| **Zürich & Lucerne, Residential** | 72 | 2017-2024 | Total | 29.5 | 1.15 | 1.8 | -8 °C - +33 °C |
| | | | Heating | 26.8 | 0.9 | 1.4 | |

*Descriptive statistics of the Verdal and Zurich/Lucerne datasets*

The institutional buildings provide a valuable extension to our Swiss residential corpus. Larger non-residential buildings in local energy communities can achieve higher absolute savings and help absorb excess supply, making them important participants in local markets. Understanding the heating-related consumption allows to improve energy-flexibility estimates and is therefore of high practical interest.

To support this broader perspective, we incorporate the load data of Verdal's institutional buildings into the previously derived heating-disaggregation model of Section 0. The substantial difference in the magnitude of the load profiles - nearing one order of magnitude – and their structure allows to expose the model to a wider range of building sizes and electricity usage patterns. Additionally, the climatic contrast to Central Switzerland will enhance the model's robustness to different weather conditions, with Verdal experiencing winter temperatures up to 10 °C lower.

#### **3.1.2.1** Generalization Studies

To assess the generalization ability of the heating-disaggregation machine learning models, we include the data of the two provided institutional buildings in the training and evaluation of the disaggregation models. As the data is significantly limited, we avoid performing the cross-building prediction outlined in Section 2.6.1.1, i.e., training the model on the data of one building, and evaluating it one the other. Instead, we evaluate how well the model performs when it is calibrated to a sample of historical load-disaggregation data from both buildings and then used to forecast heating load for a held-out period. Specifically, we calibrate the model using the disaggregated electrical load from January to July 2024 and then predict the heating load for August to December 2024 given just the total load. The model architecture and training procedure remain the same as in Section 0.

### 3.1.2.2 Model Performance on Institutional Buildings

For the institutional buildings, calibrating the model to their historical data and decomposing the load for the held-out period yields a mean absolute error of 1.5 kWh. Relative to the mean heating-load level of 31.6 kWh, this corresponds to a 95% accuracy in separating heating from non-heating demand. For comparison, when the same model was trained and evaluated on Swiss residential homes only, it achieved a mean absolute error of 0.1 kWh against an average heating-load level of 0.9 kWh, corresponding to an 89 % decomposition accuracy.

### 3.1.2.3 Perspective

The results indicate that the model can reliably decompose heating demand for large non-residential buildings when provided with a short calibration period. This is notable because institutional buildings differ substantially from residential homes in magnitude, operating schedules, and sensitivity to outdoor temperature, yet the model still maintains high accuracy after calibration. These findings suggest that the approach naturally extends from households to larger community actors whose heating profiles are more structured and operationally driven (e.g., fixed opening hours, heating thresholds, predictable holiday schedules).

Going forward, expanding the dataset with additional institutional and residential buildings from both regions, and exploring methods such as unsupervised domain adaptation to leverage the large volume of unlabeled electrical-load data, provides a clear path for strengthening the model's generalization capabilities.

Improving the reliability of heating-load estimates directly supports more accurate flexibility assessments for local energy communities, especially those with a diverse mix of residential and non-residential participants.

# 4. Publications and other communications

Throughout the year, various activities have been carried out to disseminate the actions undertaken in the project and publish the results obtained. Some of the results of the work carried out in the first year of the project are being published in 2025 in scientific journals or presented in conferences. It is worth noting:

**Journal Articles**

1. **Application of Living Lab Concept: Where, How and for What Is Being Used in Europe to Support Energy, Social and Environmental Transition,** Sustainability, 2025-03-19,. Contributors: Alba Arias; Claudia Pennese; Olatz Grijalba; Yousra Sidqi

Abstract: Due to the current climate situation, it is necessary to apply new methods that support environmental, social, and energy challenges to respond to global emergencies. In this regard, Living Labs have increased their popularity as a strategic tool to promote innovation from the local level and proximity. This study aims to detect the patterns, trends, and coherence of the so-called Living Labs. For this purpose, a characterisation of Living Labs has been undertaken that focuses on energy, environmental, and social issues in Europe to support urban transition. It concludes that Living Labs do not have a single solution. They are highly influenced by the current European trends and promoted topics. They can be multi-dimensional (digital and physical), multi-scale (from small, such as the product, to large, such as the territory) and multi-purpose. It is determined that there is an absence of working in real-life environments and some of the Living Lab's principles. Among the topics, the most common ones are social inclusion, environment, energy, health, and IoT. The implemented scale in a building and the product on the application scale are the most frequent ones. Urban Living Labs are identified as a niche opportunity because of their low current development.

In addition, the team is currently working on an additional publication in scientific journals, which will be submitted before March 2026:

2. **Gridly: A Decision-Support Platform for Local Electricity Market Design.**
   Expected to be published in special issue Urban Futures: Strategies for Decarbonized, Resilient, and Equitable Cities in Springer Nature's in the Discover Cities journal.

Abstract: The current energy transition in Switzerland has led to the rise of Local Electricity Communities (LECs), where members jointly manage generation, consumption, and trading of electricity. To support the design and evaluation of such systems, we present Gridly, an interactive decision-support tool for analyzing the configuration and performance of LECs and their associated Local Electricity Markets (LEMs). Gridly allows users to explore different community setups by adjusting key parameters, including seasonality, community size, photovoltaic (PV) penetration, battery adoption, and demand-shifting potential. For each configuration, the tool computes and visualizes metrics such as average load and generation profiles, community-level cost savings, degree of grid independence, and internal electricity trading flows. The underlying model assumes a centralized market structure with fairness-based allocation and static tariff conditions. By enabling rapid scenario testing and intuitive visualization of market outcomes, Gridly facilitates a better understanding of how community composition and behavioral flexibility influence local energy economics and sustainability. This first version serves as a foundation for further developments, including dynamic tariff schemes, distributed market mechanisms, and integration with real-world datasets.

3. **Beyond Temperature: Leveraging Household Survey Insights for Enhanced Heating Load Disaggregation**. Expected to be published in *Energy and Buildings,* Elsevier.

Abstract: Accurate disaggregation of residential heating loads from total household electricity consumption is a key challenge for understanding end-use energy behavior and enabling targeted efficiency measures. While most previous studies have explored heating load disaggregation in public and commercial buildings, where usage patterns are relatively consistent, residential environments present high variability due to diverse building types, personal behaviors, and available control methods. These complexities have limited the applicability of existing approaches to household buildings.In this work, we propose a hybrid data-driven framework that integrates electrical load measurements with information from a survey of X households to improve heating load disaggregation accuracy in residential settings. The survey data includes variables such as heating system type, automation level, usage schedules, and occupant comfort preferences, which are used to inform model structure and feature selection. Preliminary results indicate that incorporating behavioral and system-level metadata significantly enhances both the interpretability and accuracy of heating demand estimation across diverse residential contexts. This research highlights the importance of combining quantitative load data with qualitative household insights to advance next-generation residential energy modeling.

**Conferences**

1. **Interactive engagement tool for Local Energy Community, market and user's interconnectivity,** Urban Future Forum, 1-2 September 2025, EMPA, Dübendorf (Switzerland)
   Contributors: Yousra Sidqi; Tania Lopez; Alba Arias; Martina Rechsteiner; Manuel Christen, Enrico Bissig

Summary: In this workshop HSLU together with the Future City Alliance organized an interactive, practice-oriented workshop for a diverse stakeholder group. During the workshop, various scenarios were simulated, and the strengths and limitations of the tool were discussed. Participants also contributed valuable ideas for future development. The discussions clearly showed that Gridly serves as a platform for dialogue, participation, and informed decision-making

During the session, the tool was presented and participants test it. This tool aims to solve the energy sale and purchase allocation problem in LECs, while considering fairness constraints in the proposed solution. In contrast to many previous works, which employ an open market, where bidders and sellers are matched based on their pricing preferences, this tool proposes a centralized matching mechanism with a fixed price, to maximize market efficiency. The objective of the workshop is two folded: On the one hand, it was to present the work carried out while on the other hand, together with the participants in the workshop, to analyse the tool, evaluate its usefulness and scope, discuss strategies for its implementation but also how it can be improved to ensure its value and guaranteeing its utilisation among communities.

2. **Understanding Energy Models and the Role of SSH,** SSH Energy 2025, 16 y 17 Junio 2025, Zurich-ETH Zurich, (Switzerland)
   Contributors: Yousra Sidqi; Alba Arias; Philipp Schütz, Manuel Christen, Enrico Bissig

Summary: Energy system models explore possible transformation pathways for the energy system. While they aim to provide robust, science-based decision support, their impact on societal decision-making is often limited. This is due not only to ontological limitations of models themselves but also to challenges in translating model insights for decision-makers and effectively integrating stakeholder knowledge into the modelling process. Social Sciences and Humanities (SSH) research offers valuable perspectives and expertise to address these challenges. Likewise, using models and model results as tools may open new avenues of research for SSH scholars. However, integrating SSH and modelling remains difficult, largely due to a lack of mutual understanding. SSH researchers may be unfamiliar with modelling approaches, making engagement with models difficult. Many modelers in turn lack a clear grasp of what SSH research can offer—and what it cannot. This session creates a structured space for SSH researchers to learn about energy models, critically engage directly with modelers, and explore concrete avenues for collaboration. By combining a paper session—introducing the basics of energy modelling and fostering discussion on SSH contributions—with a hands-on micro-workshop—exploring integration through an interactive visualization tool—participants will move from understanding to action.

**Other dissemination activities**

In parallel with this, other activities have been performed to disseminate the PERSIST project and its activities, such as:

<u>Presentations/Mentionings</u>

- **Smart Country Convention 2025**, Berlin 30. September – 2. October
- **DUT Projects Event 2025,** 30 Sep – 3 Oct 2025 Milan (Italy)
- **Project website** launch (https://www.uc.pt/persist/about-persist/) where all publications and reports are published.
- **PERSIST Project social media** (https://www.linkedin.com/company/persist-dut/posts/?feedView=all) publications
- **HSLU social media publications**
- **Future City Alliance social media publications**
- **Future City Alliance Gridly Project- Link integration on their website**

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