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LASAGNE

digital frAmework for SmArt Grid and reNewable Energies

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The authors bear the entire responsibility for the content of this report and for the conclusions drawn therefrom.



Summary

The energy transition needs microgrids. To support them, smart meters will have to gather data from households to predict/plan energy consumption/production.

We propose a novel AI-powered smart meter concept, dubbed Grid Edge Device (GED), that will be enhanced with collaborative AI algorithms to forecast power usage/production. These algorithms will be the backbone of smart self-adaptive digital services for the electricity market. In essence, we will build a “digital framework for Smart Grid and Renewable Energies” (LASAGNE) and involve four stakeholders: System Integrator, Independent Software Vendors, Edge Equipment Vendors and Need-Owners. LASAGNE will be empowered by marketplace features allowing stakeholders to enact their business process.

To handle the energy transition in a socially acceptable way, we will consider both social and business perspectives in the development of our GED-based system.

Microgrids provide neighbourhoods with solutions to actively engage in the energy economy. Networked low- and mid-level GEDs will bring the machine learning-based (ML) intelligence needed to build context-aware (i.e., specific to operating conditions and settings), self-adaptive (i.e., capable of reacting to changing conditions) energy applications for improved power network stability and energy transaction flexibility.



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Abbreviations

B2C	Business-to-Consumer
C2C	Consumer-to-Consumer
DCE	Discrete Choice Experiment
DSO	Distribution System Operator
DT	Digital Twin
E2C	Edge-to-Cloud
EEV	Edge Equipment Vendors
EV	Electric Vehicle
GED	Grid Edge Device
HP	Heat Pump
HVAC	Heating, Ventilation, and Air Conditioning
ICT	Information and Communications Technology
IoT	Internet of Things
ISV	Independent Software Vendors
LSO	Local System Operator
ML	Machine Learning
NOW	Need Owner
PoC	Proof-of-Concept
SI	System Integrators
TAM	Technology Acceptance Model
TSO	Transmission System Operator



1 Introduction

1.1 Background information and current situation

Smart Meters are called smart but in reality are just digital meters. While the current generation of smart meters is designed to remotely monitor the overall electricity consumption of a measurement point, the next generation will hold a much wider role that ranges from measurement, gateway to controller in different grid applications. In addition, future smart meters will support extra smart capabilities at both local household and microgrid levels:

- Monitoring and forecasting appliances' power consumption (heat pumps, EV charging stations, HVAC etc.)
- Planning for optimal renewable power generation (in particular PV Systems) and storage, through consumption predictions.
- Providing communication channels to exchange data related to the above monitoring and planning activities.
- Enacting power negotiation and transactions within the microgrid and with the power grid.

Endowed with above functionalities, we define these new smart meters Grid Edge Devices (GED).

With the complete liberalisation of the power market, it is expected that stakeholders (listed below) will request access to the functionalities of GEDs in order to pursue their objectives. At present, there is no proposal on how these stakeholders can use the smart meters and GEDs collaboratively. Regulations and diversity of stakeholders complicate the mass-market roll-out.

Microgrids (Fig. 1) offer the regulatory framework and the economic incentive to support decentralised renewable energy sources and provide neighbourhoods with solutions to actively engage in the energy economy. Intelligent microgrids (microgrids empowered with GEDs) would be based on AI mechanisms capable of forecasting power usage/production. These algorithms will be the foundation to build end-user context-aware and self-adaptive energy applications such as power network stability services and power transactions/flexibility negotiations. Unlike other projects like MuLDeR, where the intelligence is confined in the GEDs, LASAGNE aims to develop a context-aware "ecosystem" where the intelligence is provided through networked Low-GED (L-GED) and Mid-GED (M-GED), as shown in Fig. 2.

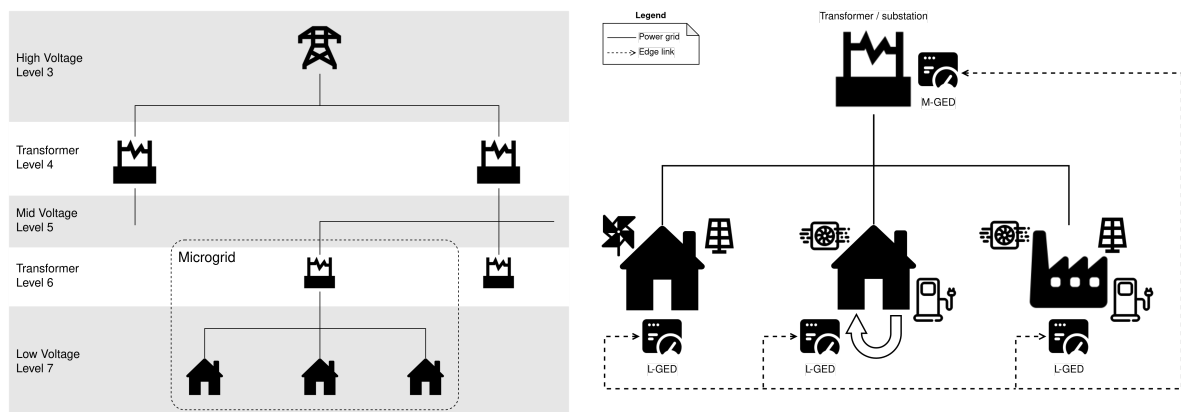




Fig. 1: A microgrid is deployed within a grid cell and spans mid- to low-level voltages (level 5 through 7). A microgrid with households and factories employing several power sources (solar, wind, geothermal) and appliances (heat pumps, EV charging stations, HVAC, etc.).

Fig. 2: L-GED and M-GED are able respectively to act on behalf of households and microgrids. L-GEDs and M-GED learn and anticipate the consumption/production of electric power at low (household) and mid (microgrid) levels and are then able to trade within the network of GEDs for energy exchange.

The added value of context-awareness is that the intelligence can self-adapt to changing operating conditions. Context-awareness will rely on collaborative ML algorithms which allows GEDs to adapt their intelligence according to their context.

1.2 Purpose of the project

We propose to develop a digital framework for Smart Grid and Renewable Energies (LASAGNE). The LASAGNE project's vision and contributions are schematised in Fig. 3. The project targets the three main areas of the call for proposals: energy & ICT infrastructure, social sustainability and energy marketplace. In the first area, LASAGNE aims to develop a framework based on collaborative ML-based algorithms applied to low and mid power production/usage forecasts. These algorithms rely on a coordination model. While such prediction tools already exist for high voltage levels, they have not yet been explored for medium/low voltage levels (microgrid, household).

The outcome of this research will be a toolset for building end-user context-aware, self-adaptive energy applications. To validate this toolset in a real concrete use case, CLEMAP and TVINN will develop a specific application that will be completely detailed for dissemination. On the social sustainability side, a programme acceptance study will inform a communication campaign to empower end users, so that they will engage consciously in the renewable energy transition. This dimension of social acceptance, which is a strong point of our project, is crucial to ensure its success. Indeed, the classic business to consumer" (B2C) business model will be surely called into question in the years to come and will be, possibly, replaced by "consumer to consumer" (C2C) business models(), since these consumers will also be producers. Indeed, these new and very numerous players in the electricity grids are today called "prosumers". This is where social acceptance comes in: to enable prosumers to adhere to the management rules of the microgrid and to encourage strong joint collaboration..

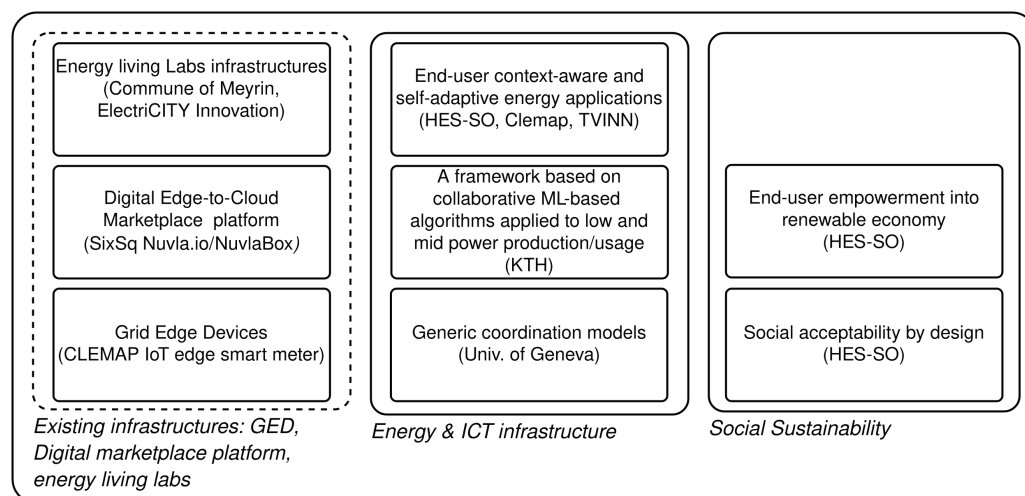


Fig. 3: Project's vision and contributions.



1.3 Objectives

LASAGNE targets three generic objectives:

1. Empower and motivate the stakeholders, detailed in Section 3, to engage in local green-economy business models via personalised GED's adoption.
2. Develop a digital framework embedding collaborative machine learning-based electricity consumption/production forecasting and collective interactions and coordination among GEDs.
3. Promote a digital marketplace platform, as a federating backbone, where the stakeholders meet to collaborate in the energy application business sector – that is, implement their legal agreements, deploy their technical solutions and realise financial flows.

LASAGNE expects to develop a digital framework for Smart Grid and renewable Energies supporting:

1. Social attributes that make the user community share the same social values and therefore fully play the game of cooperation within the microgrid.
2. Collaborative learning algorithms for local and global consumption/production at medium and low voltage levels. These algorithms will rely on a coordination model based on intelligent digital twins, incorporating social attributes *by design*.

2 Description of facility

The projects' fulcrum is the smart microgrid concept (Fig. 2) and the related technologies: ML, DT and coordination algorithms. In order to validate the project's technical feasibility and test the above mechanisms, we deployed testbeds in the following physical facilities (so-called "living labs"):

- "Ecoquartier Les Vergers" in Meyrin, Switzerland, and
- ElectriCITY's "Hammarby Sjöstad 2.0" in Stockholm, Sweden.

In Les Vergers, we are deploying an edge network composed of several GEDs endowed with a proof-of-concept (PoC) energy forecasting mechanism based on the original CLEMAP's software stack. The goal of this first installation is to collect energy consumption/production data and provide useful insight in usage patterns.

In Hammarby, an existing edge application deployment is contributing usage data to be incorporated for analysis in the project's workflow.

3 Procedures and methodology

LASAGNE tackles the challenges of the transition towards renewable energy at three R&D levels: technology, adoption and market. Indeed, our *modus operandi* first individuates the novel technologies that fit the scenario of the "smart microgrid" development; then, ensures that those potential technologies receive the best end user reception through extensive preliminary social acceptance studies; finally, addresses new business models, their related applications and technical means (the so-called "LASAGNE framework") to help stakeholders cooperate in the foreseeable energy market scenarios.

To evaluate the LASAGNE framework, we rely on existing infrastructures (the dashed-line box in Fig. 3):



1. The [CLEMAP IoT Edge smart meter](#) as GEDs.
2. The [Nuvla.io/NuvlaBox](#) edge-to-cloud marketplace developed by [Sixsq](#), as Digital Platform Provider.
3. The existing microgrids infrastructures: [ElectriCITY Innovation](#) in Stockholm and [Les Vergers Ecoquartier](#), in Geneva.

LASAGNE caters to four stakeholders:

1. System Integrators (SI) such as utility companies and microgrid administrators.
2. Independent Software Vendors (ISV): developers of context-aware and self-adaptive energy applications.
3. Edge Equipment Vendors (EEV): GEDs providers.
4. Need Owners (NOW): households and microgrid owners or administrators.

For the four above stakeholders to work together seamlessly, a digital marketplace platform is needed. The LASAGNE project will rely on the [Nuvla.io](#) edge-to-cloud (E2C) platform which provides the desired marketplace features and the needed mass-market scalability. In addition to its edge-to-cloud functionalities, the digital Nuvla.io/NuvlaBox platform will provide a federating backbone where the four stakeholders can easily interact and implement their legal agreements and financial flows. Finally, stakeholders are also under obligation to handle the transition in an economic and socially accepted way: indeed acceptance constitutes a potential barrier for the adoption of this new GED-based technology – assessing this aspect is far from obvious. The success of the energy transition depends on a mix of technological improvements and behavioural adaptations. Our goal is to take into account both social and business perspectives when designing GED-based systems.

4 Activities and results

Technology layer

In the energy market's demand for flexibilities (e.g., to improve grid management or the ability to connect fluctuating generators), we investigate how different energy resources can be utilised to support both local grid (DSO services) and national energy systems (TSO services). The aggregated capacity and flexibility from the participating facilities, for example in a microgrid, can both support the energy system and generate revenues that can be shared with the participant resource owners.

In order to increase flexibility in generation and/or storage and/or consumption, we adopt a two-pronged approach:

1. Resources aggregation (e.g., EV chargers, Energy Storage, solar energy production, etc.) at low- and mid-power levels. The ultimate objective is to enable Systems Integrators (SIs) to improve the “conditions” of flexibility negotiations, excess or lack of resources thanks to reliable forecasts. This is an important business case to SIs since they can create revenue streams and energy savings.
2. Peak shaving via reliable forecasting at low- and mid-power levels. SIs can prevent peaks of usage/production by collaborating and negotiating resources and flexibility transactions with other actors (SIs, households, etc.). This functionality is particularly related to the stability of the grid.

As for reducing energy consumption, LASAGNE aims to reduce peak consumption/production and distribute the load over the duration of the day. This functionality will increase the grid stability and avoid expensive grid overhauling. Thanks to collaboratively enhanced information, these load shifts



are expected to be better handled. For example, in the EV charging environment, context awareness and forecasting methods could improve load management and charging control by up to 50% compared to the current approaches, thus resulting in savings for all involved users.

To support the LASAGNE goals, we will develop new ICT infrastructure services:

- A digital framework embedding collaborative machine learning-based electricity consumption/production forecasting and collective coordination among Grid Edge Devices (GEDs).
- A marketplace platform which provides a federating backbone where the four above-mentioned stakeholders can easily interact, deploy their technical solutions, implement their legal agreements and financial flows.

The GED, whose candidate architecture type has been identified as the Raspberry Pi3 or 4, is under active testing, in the lab as well as in the field, to understand its limits and potentials. In parallel, a proof-of-concept microservice-based edge application stack, endowed with collaborative ML-based intelligence, is under development.

Market Layer

As a means to enact LASAGNE's objectives, we promote a digital marketplace platform where the four stakeholders meet to collaborate in the energy application business sector.

The main rationale behind is to reduce the costs for energy services, without reduction of quality. Thus, by providing resource aggregation and peak shaving mechanisms for microgrids, we aim to optimise energy consumption and allow users to monetize their energy surplus.

Since renewable energy economies depend on market flexibilities, we will test and define what type of energy resources are appropriate for different energy markets. The potential market segments are

- Local flexibility markets where DSOs procure flexibility via a marketplace platform. We also investigate the potential for bilateral contracts with DSO or microgrid operators.
- TSO markets for ancillary services like frequency balancing services and upcoming non-frequency-related services like reactive power management.

Our envisioned market dynamics involves new market players and roles:

- Prosumers, such as housing associations and credit unions, that consume, produce and store energy under a coordinated, collaborative trading model that shifts loads from peak demand and reduces electricity costs.
- Aggregators who seek optimising the usage of their energy assets through the aggregation of flexibility from managed microgrids while enabling users to monetize energy surplus.
- Local system operator (LSO), responsible for managing the digital market platform.

In order to realise our vision, the regulatory framework has to evolve towards reducing the barriers to the adoption of new energy market services. LASAGNE's ambition is to show what is legally possible, highlight where and when the legislation is an obstacle to development, demonstrate the potential benefits of regulation changes and influence future legislative adjustments.



Adoption Layer

By investigating the social acceptance of the GED-based IT systems, this project will help understand which functionalities (“attributes” in DCE terminology) are likely to be accepted by end users and thereby drive design GEDs based IT systems which have the highest probabilities to be adopted by the population. Thus, the findings of this project will provide indications about the solutions that receive highest social acceptance, among those that are both technically feasible and economically viable. To this purpose, we completed an extensive ethnographic survey over a sample of citizens. The two main expected outcomes of this research are:

- The identification of the types of consumer groups that are most likely to use new energy services;
- The conditions under which our market model can enable the co-creation, in a human-centric fashion, of energy-related utility services.

Also, the involvement of our three commercial partners (CLEMAP, Tvinn and SixSq) allows us to capture the industry perspective about the acceptance of innovative smart metering technologies. Last but not least, another benefit of our analysis will be a broad overview of the economic aspects underlying the “micro smart grids”, especially in relation to social aspects such as the digital divide and energy poverty.

5 Evaluation of results to date

With reference to the project’s roadmap detailed in the proposal, we completed the two following milestones:

1. **M1 – Technical feasibility of attributes validation report grounded on internal auditing protocols:** we did a comprehensive study based on ethnographic techniques to identify the salient attributes related to the social acceptance of smart microgrid communities. Focus groups have already been organised with supply-side experts. The main conclusion is that the passive consumer of electricity becomes, within an energy community, a prosumer playing an active role. Our results are confirmed by the recent scientific literature on smart microgrids, according to which the social dimension is as important as the technological dimension. The annex “Milestone #1 report” gives further details. Two related research papers will be published soon – see Section 9.
2. **M2 – Coordination model, digital twins (DT) and design of distributed collaborative ML methods are implemented on an experimental edge-to-cloud (E2C) architecture:** We completed the coordination model and its implementation, developed different types of DTs working on behalf of consumers, producers, as well as specialised DTs dedicated to forecasting and peak shaving. We developed a series of algorithms for contract negotiation regarding quantity of energy. We tested a series of ML methods in order to identify the best ones for the energy domain, and we started the development of federated learning both centralised and decentralised through the coordination platform. Actual data feeds the DT algorithms as well as the ML methods. For the details, see annex “Milestone #2 report”.

On the energy market side, we are investigating the potential application scenarios in both the *flexibility* and *frequency* segment: we are mainly targeting heat pump (HT) management and electric vehicle (EV) charging.

On the system integration side, we are currently drafting the blueprints of:



- The GED's microservice architecture, as sketched in Fig. 4 and 5. As this design aims to accommodate a complex NuvlaEdge/Docker-based multi-container ensemble on resource-constrained appliances, the main challenge is to make all these technologies work seamlessly.
- The supporting management E2C framework that would allow operators to easily deploy LASAGNE applications on their infrastructure through a Web/Cloud portal.
- The marketplace platform offered to end users for the contract management and execution of their chosen microgrid applications.

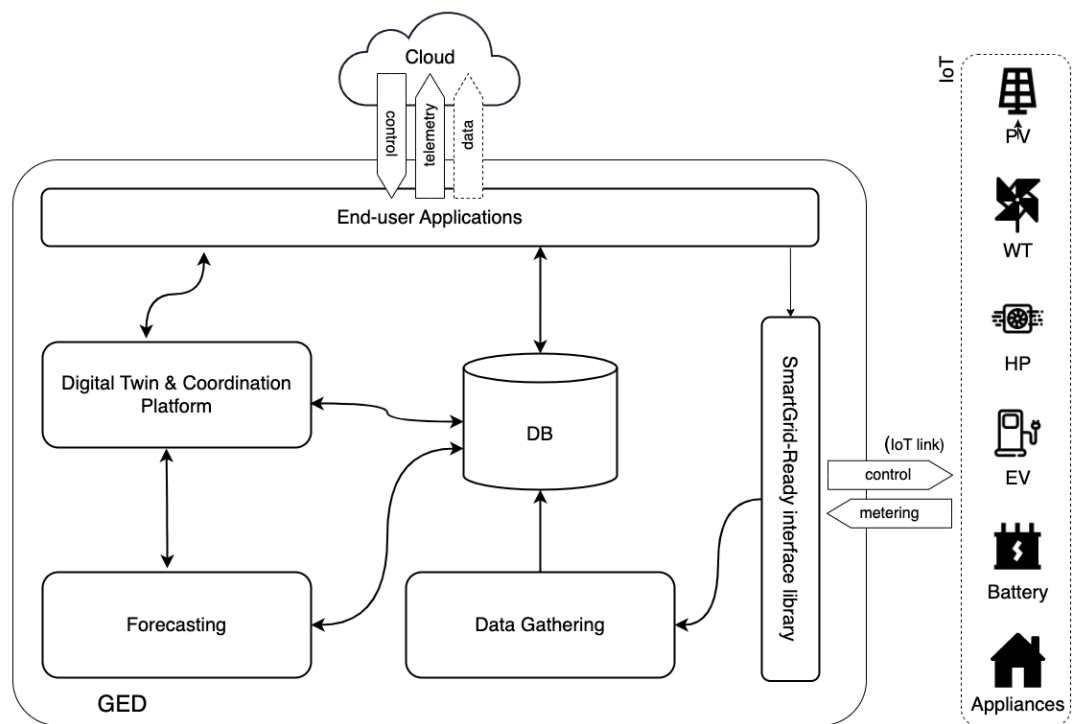


Fig 4: The GED's architecture: component view.

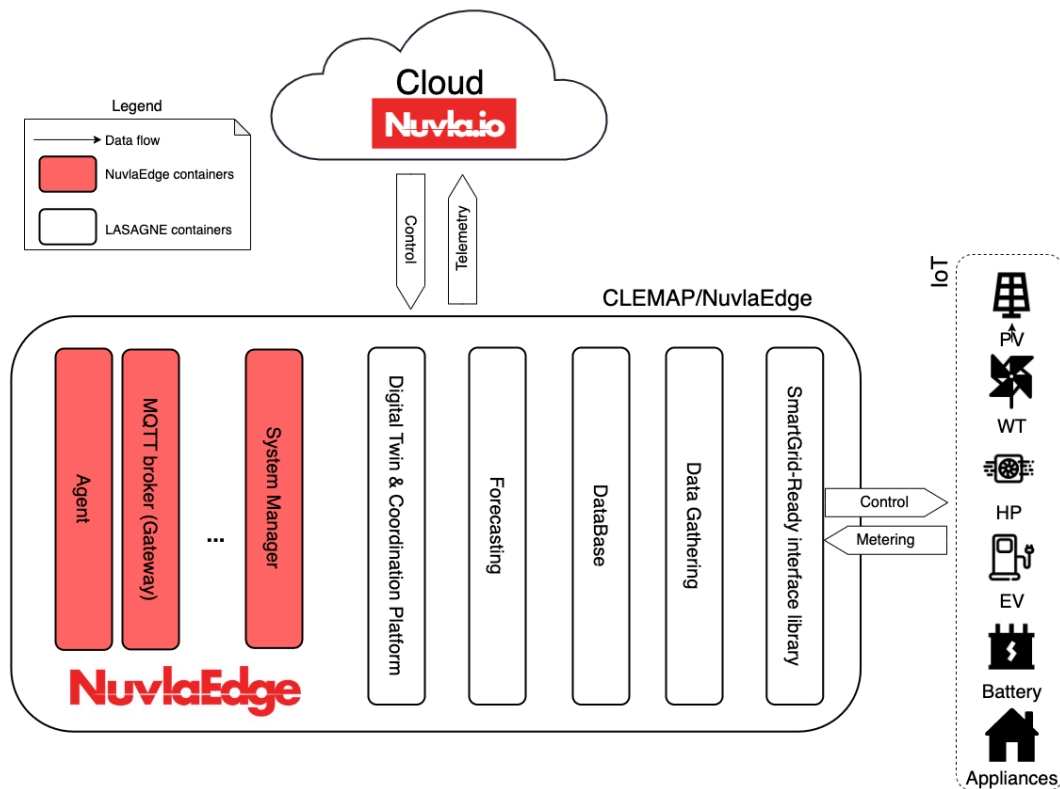


Fig 5: the GED's architecture: microservice view with NuvlaEdge integration.

On the field test side, in addition to the two original living labs, two other entities (the CODHA/Rigaud credit union with the support of the municipality of Chêne-Bougeries, and the Polygones credit union with the support of the municipality of Meyrin) accepted to collaborate with us: a first prototype GED deployment will follow soon at CODHA/Rigaud, whereas the collaboration terms with Polygones have to be finalised yet.

6 Next steps

The project is on track: the next year will see extensive work in several project areas.

- The social acceptance investigations (WP2) will be extended to the third living lab (CODHA/Rigaud) that recently joined the project. We plan to conduct focus groups in an existing microgrid community (the Polygones credit union in Meyrin, Switzerland) to collect precise data about “the prosumer experience”. Our study will be based on a discussion guide developed from the qualitative survey.
- The Edge coordination/DT mechanism (WP3) will incorporate the outcome (privacy, etc.) from the acceptance study above. A first microservice-based prototype GED will be endowed with coordination/DT-based energy forecasting capabilities.
- Power trading/aggregation applications in the energy flexibility and frequency markets will be defined (WP4).
- The marketplace platform (WP4) will be designed and its development started as soon as possible. This work encompasses the definition and development of the Need Owners’



context-aware, self adaptive "flexibility & power trading/aggregation" application as well as its integration in a prototype GED managed through the Nuvla/NuvlaBox platform. In parallel, we will start discussing appropriate marketplace governance policies (WP1).

- Prototype GED testing and evaluation will continue in our living lab deployments (WP5).

Two milestones are expected to be completed by spring 2024:

- **M3:** A fully developed application for power and flexibility negotiation;
- **M4:** A prototype E2C marketplace platform capable of handling the prospective use cases.

7 National and international cooperation

LASAGNE is a European transnational effort whose development is enacted with the help of an advisory board (AB). At the national level in Switzerland, we are discussing cooperation plans with the following entities:

- Polygones: Microgrid infrastructure in Meyrin, where a first meeting took place on May 6th 2023. Polygones agreed to put the LASAGNE platform under trial. The first deployment will take place in January 2024
- OCEV (Office Cantonal de l'Environnement – Geneva): A first meeting took place on May 17th. The goal is to test the LASAGNE platform in the context of e-vehicles charging stations.

We also look forward to participating in upcoming special events:

- LASAGNE will be presented in this event: [Energy Data Hackdays 2023](#). A "LASAGNE challenge" will be proposed to the participants.

8 Communication

June 14th, 2023:

Giovanna Di Marzo Serugendo – Presentation at SAIROP AI Insight Event – <https://www.sairop.swiss/events/sairop-ai-insight-event-distributed-ai-for-continuum-computing-services> – Distributed AI for modelling and engineering continuum computing services. Two case studies from smart and sustainable cities.

May 16th, 2023:

Giovanna Di Marzo Serugendo Presentation at Uni3 – Innovation numérique et intelligence artificielle – enseignement, recherche et applications dans divers domaines (climat, urbanisme, énergie).

March 9th, 2023:

Giovanna Di Marzo Serugendo - Presentation at SIG (Utility company in Geneva) – LASAGNE digital framework for SmArt Grid and reNewable Energies.

February 8th, 2023:

Presentation in public seminar, titled: "Systèmes multi-agents: modélisation de systèmes complexes et développement de services à base d'intelligence artificielle distribuée / Un outil numérique pour modéliser et développer des systèmes complexes : les systèmes multi-agents."

In "Opportunités et défis de l'intelligence artificielle" Conférences scientifiques 2023, Collège de Saussure, Geneva, February 2023, Giovanna Di Marzo Serugendo



Video: <https://youtu.be/cW2DJZAS-wE>

Web: <https://www.culture-rencontre.ch/conferences-scientifiques-2022/>

February 2023:

Presentations in seminar at AI Days @ HES-SO:

“AI applied to smart grid and renewable energies”, Mohamad Moussa

“Combining NLP and trust to automate access to relevant and transparent knowledge on agricultural markets”, Abir Chebbi

January 5th, 2023:

MSc class in AI for IoT, University of Lyon, France: “First and second-order emergence - from natural systems to spatial services and artificial collective adaptive systems”, Giovanna Di Marzo Serugendo

January 2023: Seminar in the project Strategies and tOols for Incentivization and management of flexibility in Energy Communities with distributed Resources (RESCHOOL, an EU-financed project with 16 partners from 7 countries with the goal to develop tools that will increase active participation of communities in energy markets and enhance the relationship with other stakeholders. Campus Montilivi- Universitat de Girona, Girona, Spain. Website: <https://www.reschool-project.eu/>

December 15th, 2022:

Presentation in a corporate seminar at SITG's steering committee “LASAGNE digital frAmework for SmArt Grid and reNewable Energies”, Philippe Glass

November 2022: Presentation in seminar for representatives from Vinnova, Sweden's innovation agency. Hammarby Sjöstad, Stockholm, Sweden. Website: <https://www.vinnova.se/en/>

November 2022:

Presentation in the seminar on “Smart cities, digitalization and datafication of urban spaces and governance”, organised by the Institut français de recherche sur le Japon à la Maison franco-japonaise, Tokyo, November 2022. Title of presentation: “Smart cities – research projects involving living labs in various European cities”, Giovanna Di Marzo Serugendo

Web: https://www.mfj.gr.jp/agenda/2022/11/24/2022-11-24_apres_la_smart_city/

October 2022:

Presentation in the research seminar: “First and second-order emergence - from natural systems to spatial services and artificial collective adaptive systems” at TU-Dresden, Giovanna Di Marzo Serugendo

September 2022:

Presentation in seminar at UNIGE Data Science Day.

Title: “Multi-agent systems: a digital tool for modelling and developing complex systems”, Giovanna Di Marzo Serugendo

Web: <https://datascience.unige.ch/en/research/uniges-data-science-days>

Poster: “Lasagne – implementation of smartgrid in the form of a coordination system of digital twins”, <https://archive-ouverte.unige.ch/unige:164521>

August 2022:

Seminar in the project System change with locally shared energy (financed by the Swedish Energy Agency), a project with 9 partners from Sweden aiming to develop energy community pilots and



address important issues linked to social barriers, legislation, business models, and upscaling. Hammarby Sjöstad, Stockholm, Sweden. Website: <https://www.ri.se/en/system-change-with-locally-shared-energy/system-change-with-locally-shared-energy-focus-areas>

May 2022:

Seminar for partners in the project Transforming Cities Through Positive Energy Districts (TRANS-PED), (JPI Urban Europe). A project with 12 partners from 3 countries developing a governance approach for positive energy district stakeholders to better realize deep changes to cities. Urban Future 2022, Helsingborg, Sweden. Website: <https://trans-ped.eu/>

April 2022: Presentation in seminar for ElectricCITY's members and partners (businesses, academic institutions, public authorities). Hammarby Sjöstad, Stockholm, Sweden. List of actors: <https://electricityinnovation.se/om-oss/?lang=en>

9 Publications

Accepted for publication in Conference Proceedings:

- M.Moussa, N.Abdennadher, R.Couturier and G.Di Marzo Serugendo. "A generic-based Federated Learning model for smart grid and renewable energy". Accepted in ISPDC'2023.
- E.Fragiere, S.Sandoz, N.Abdennadher, M.Moussa, G.Di Marzo Serugendo and P.Glass. "Improving the Social Acceptability of Microgrids", 1st International Conference on Renewable Energy and Sustainable E-Mobility (RESEM-2023).
- E.Fragiere, S.Sandoz, N.Abdennadher, M.Moussa, G.Di Marzo Serugendo and P.Glass. "Fostering "Energy Communities": An Ethnographic-SECI Approach to User-Centered Residential Micro-Smart Grid Adoption", 11th International Conference on Smart Grid (icSmartGrid2023).

Submitted for publications in journals:

- Y. You, Q Xu, and C. Fischione. "Hierarchical Online Game-Theoretic Framework for Real-Time Energy Trading in Smart Grid," submitted to IEEE Transactions on Smart Grid in January 2023, second round review.
- Y. You, Q Xu, and C. Fischione. "Cluster-Driven Attentive Federated Transfer Learning Framework for Short-Term Residential Load Forecasting," to be submitted to IEEE Transactions on Smart Grid in June 2023.

10 Appendix

[Milestone #1 report](#)

[Milestone #2 report](#)