eneuron

Optimising the design and operation of local energy communities based on multi-carrier energy systems

BEST PRACTICE BOOK

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Table of Contents

Introduction

eNeuron at glance

LECs and ILECs: state of the art

The ambitious energy and climate goals set by the European Commission (EC) for 2030 require the commitment beyond the conventional electricity sector, decarbonising across different sectors through an integrated approach appears to be a valid and viable path for the future as this was outlined in the ETIP-SNET's Vision 2050[1]. Integrated local multi-energy systems within integrated local energy communities (ILECs) are recognised as a promising alternative to centralised energy supply. This concept offers the distribution systems a bottom-up approach to meet local energy needs since they promote efficient use of the available energy. This is thanks to the coordinated interplay of heat, cooling and power technologies, storage and flexible demand.

These communities aim to enhance energy efficiency, sustainability and resilience. However, there are still many challenges in implementing local energy communities (LECs) and ILECs efficiently.

Benefits:

- Use of renewables;
- Energy efficiency;
- Cost savings;
- Energy democracy;
- Community engagement.

Challenges:

- Regulatory barriers;
- Economic barriers;
- Technical barriers;
- Non-technical barriers;
- Scalability.

The multifaceted approach adopted by eNeuron identified challenges in several domains, demonstrating the complexity of implementing ILECs and the importance of non-technical factors that are often overlooked. This best practice book divides barriers, recommendations and lessons learned according to regulatory domains, technical and non-technical domains.

The innovative mission of eNeuron project

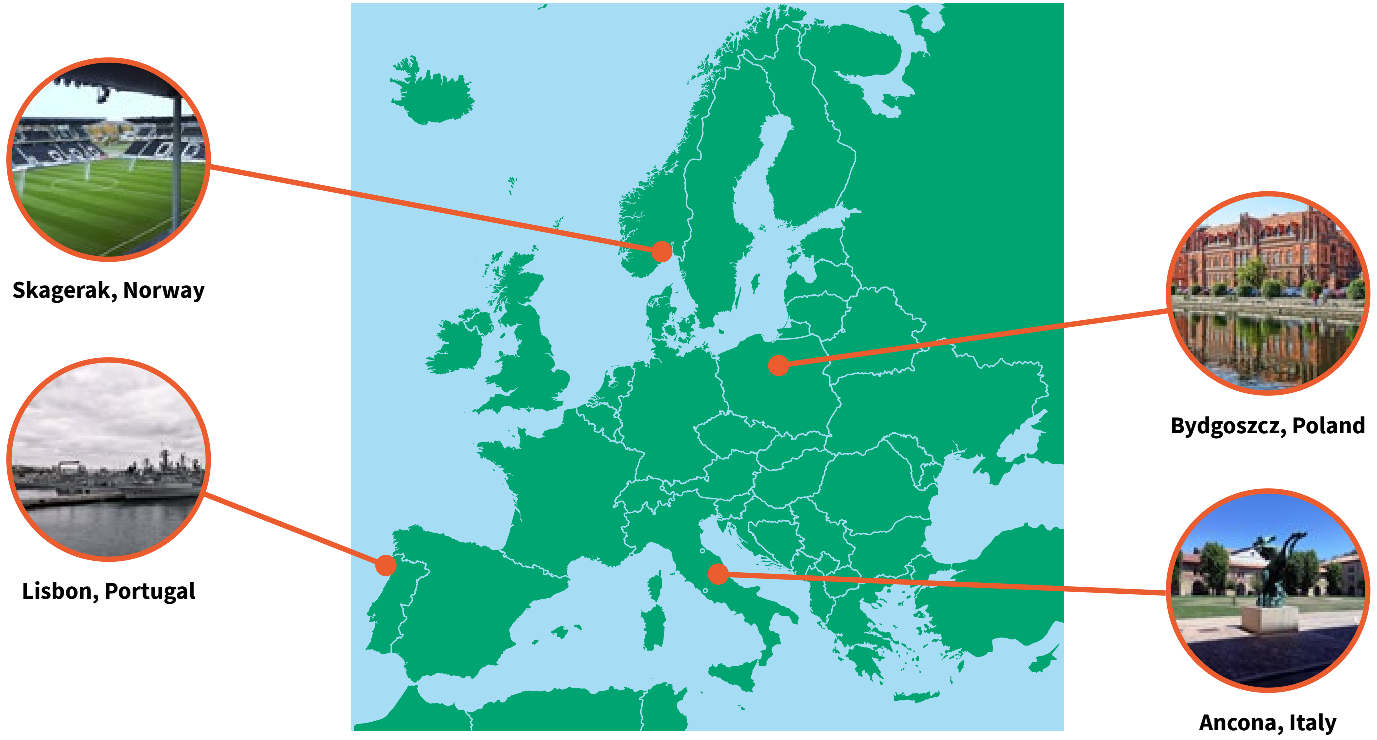
Considering that none of the existing formal definitions of energy communities[2] covers the multi-energy aspects, the H2020 project eNeuron introduced its own definition of an ILEC as:

> *A set of energy users deciding to make common choices in terms of satisfying their energy needs to maximise the benefits deriving from this collegial approach thanks to the implementation of various electricity and heat technologies, energy storages (ESs), and the optimised management of energy flows.*

The integrated nature of ILECs presumes a highly complex interaction of multiple aspects from various energy sectors, which historically functioned more or less independently. Therefore, configuration and development of an optimal ILEC is an extremely demanding task, requiring a sound interdisciplinary knowledge base. The challenge is that such a base is not available, and, in addition, the present picture seems to be very dynamic due to the ongoing energy transition.

To deal with this challenge, the eNeuron project's main goal has been to develop innovative tools for the optimal design and operation of ILECs, integrating distributed energy resources and multiple energy carriers at different scales. This goal has been achieved by bearing in mind all the potential benefits for the different actors involved and by promoting the Energy Hub concept, as a conceptual model for controlling and managing multi-carrier and integrated energy systems in order to optimise their architecture.

The eNeuron ILEC framework has been put to the test at four pilot schemes: a city and its major energy nodes (Bydgoszcz, Poland), a football stadium and its vicinity (Skagerak, Norway), a naval district with its own distribution grid (Lisbon, Portugal), and a university campus across several sites (Ancona, Italy).



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[1] R. Bacher, M. de Nigris and E. Peirano, "ETIP-SNET Vision 2050," 27 June 2018. [Online]. Available: https://www.etip-snet.eu/wp-content/uploads/2018/06/VISION2050-DIGITALupdated.pdf. [Accessed 30 April 2020].

[2] J. Roberts, D. Frieden and S. d'Herbemont, "Energy Community Definitions," May 2019. [Online]. Available: https://www.compile-project.eu/wp-content/uploads/Explanatory-note-on-energy-community-definitions.pdf

1. Insights from the eNeuron pilots

Creating an ILEC requires careful planning and constant monitoring. Key steps include:

Objectives and Scope
The main goal is to achieve specific objectives such as increasing renewable energy production, improving grid reliability, or maximising local energy self-consumption.

Stakeholder Engagement
Success depends on strong collaboration between residents, businesses, authorities, and technology providers to secure expertise and financing.

Regulatory Framework
Compliance with local regulations and clearly defined roles for participants are essential, with a coordinator managing data sharing and revenue distribution.

Technology
Using renewable energy, energy-efficient devices, storage solutions, and smart grid technologies ensures optimal performance and revenue.

Data Management
Smart grid data is used to optimise energy production, consumption and grid performance.

Implementation
Begin with small-scale pilots, expanding as initial results are evaluated, and provide training to onboard new stakeholders.

Monitoring and Evaluation
Set key performance indicators (KPIs) to track energy savings, renewable energy usage, and other metrics, updating strategies based on results.

These steps, followed in the eNeuron project, help scale and replicate successful ILECs in other regions.

Bydgoszcz, Poland

Oveview

The Polish pilot includes eight public facilities, each forming a micro-Energy Hub (mEH), such as schools, sports facilities, a swimming pool, an animal shelter, and an administration building. Most buildings rely on external grids for electricity and heat, with six having their own rooftop PV systems. Five facilities fully consume their PV energy, while the animal shelter stores surplus energy in batteries. The PV systems are metered but not controlled.

Some buildings use equipment like combined heat and power units, heat pumps, and heaters, operated manually by on-site staff. The eNeuron project installed a battery energy storage system (BESS) and a step voltage regulator, which are remotely controlled.

Since the facilities are spread across Bydgoszcz with different communication systems, an energy hub monitoring platform (EHMP) was created. This platform includes a database on a server at IEN and software to collect and store data from the facilities.

Technology and assets installed

- 2 CHP units generating electricity and heat from natural gas, each unit generates 20 kW of electrical power and 38.7 kW of thermal power;
- 6 PV installations with a total maximum output of 270 kWp;
- 5 solar collectors, each collector has a surface area of 2.5 m2;
- 3 heat pumps, each supplying 25.08 kW of heat energy using 6.02 kW of electricity;
- 1 BESS based on lithium-ion technology with a nominal power of 50 kW, and a capacity of 200 kWh;
- 1 automatic step voltage regulator adjusting the output voltage in 9 steps, with a maximum adjustment range of ±10% of the nominal voltage.

Stakeholder engagement

CoB and IEN held workshops with students from local educational institutions, introducing the concept of self-sufficient, sustainable energy communities. They presented the Polish pilot's technical structure, energy resources, and project goals.

The City of Bydgoszcz also organised energy management conferences, attended by local government officials, research units and NGOs. Representatives participated in various conferences to showcase eNeuron tools and discuss the project. At the Bydgoszcz Energy Forum, two discussion panels were held: one for local entrepreneurs and one for residents.

In September, the City of Zamość representatives visited the project's facilities to explore eNeuron's potential. Facility managers gained knowledge in improving energy efficiency, which will be applied to other city-managed buildings. The idea of ILECs has sparked interest, especially in optimising photovoltaic (PV) energy use, which is widely adopted in Poland.

Technical implementation

IEN, along with partners CoB and ENEA Operator, gained expertise in optimising energy conversion systems like PV installations with energy storage and solving integration challenges across different energy carriers.

One issue involved devices with varying communication interfaces, such as heat pumps lacking readout capabilities. This was resolved by modifying an IEN-developed telemechanic controller to measure voltage, current and power. This allowed heat pumps, heaters and an electric furnace to be monitored.

Other assets, like CHP units, had local control systems requiring communication intermediaries for data acquisition. Electricity meter data was gathered via internet connections. A common database was created, fed by various communication software, to consolidate all data.

A key challenge was to develop a software platform to support multiple communication methods and to integrate with the field devices for comprehensive data collection.

Lisbon, Portugal

Oveview

The Portuguese Pilot comprises a local energy system within the Lisbon Naval Base campus, property of the Portuguese Navy. The Pilot site presents the opportunity to optimize the electricity system operation with other energy carriers. LNB is located in Alfeite, near Lisbon, Portugal. It comprises a complex of port infrastructures, facilities, and services to provide logistical support to the naval units moored and anchored at LNB, Marines, Naval Academy, among others.

The LNB has the following carriers at the EH level: electricity, water and natural gas. At the mEH level, energy carriers, such as heat and cooling are also present. In Fig. 2, it is presented an overview of all the energy carriers and assets at the LNB. Regarding the main energy assets, at EH level, there will be a centralized large-scale PV system (870 kWp), water storage tanks and pumps. Still, at EH level, there are significant consumer units, with different profiles, like workshops and offices. At mEH level, some of the units will have generation, consumption, and storage, namely:

- The Sports Centre mEH will have PV and Solar Thermal generation, Natural Gas boilers, Domestic Hot Water (DHW) storage, and share a BESS with the “DT” consumer, that has an EV charger.

- The Residential Mess will have Solar Thermal generation, Natural Gas boilers, DHW storage and heat pump HVAC.

- The Canteen will have PV and Solar Thermal generation, Electric boilers, DHW storage and a V2G EV charger.

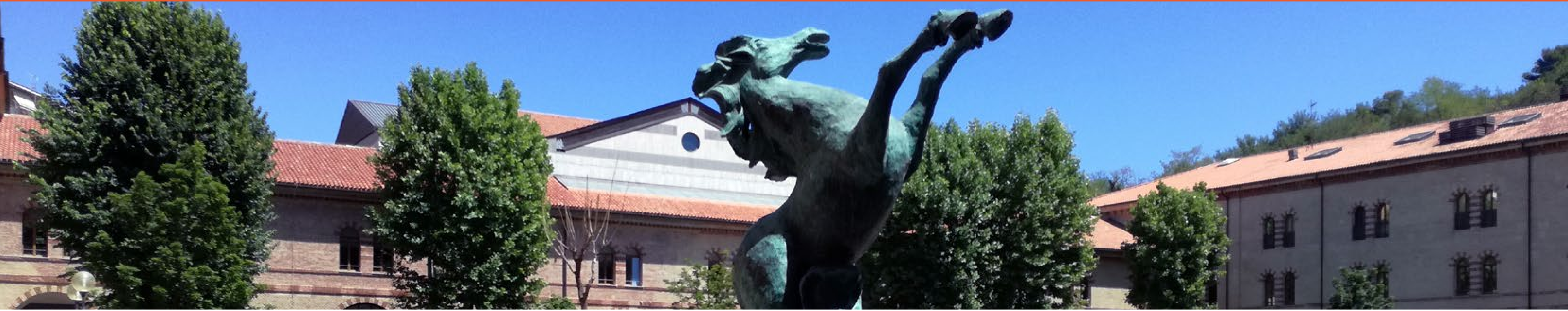
Technology and assets installed

- **Sport Centre CEFA**
  PV 52.8 kWp
  #60 Solar collector 154.8 m2
  #2 Natural gas boilers - 600 kW
  #2 Domestic hot water tanks 3000 l
  Battery Energy Storage System BESS – to kW/75 kWh
  #2 Regular EV charger 22 kW

- **Residential mess**
  #70 Solar collectors 180.6 m2
  #2 natural gas boilers 500 kW
  #3 domestic hot water tanks 7000 l
  Heating, ventilation and air conditioning 22.8 kW

- **Canteen**
  PV 41.4 kWp
  #30 Solar collector 77.4
  #2 natural gas boilers 600 kW
  #2 domestic hot water tanks 3000 l
  #2 Vehicle-to-grid charger 44 kW

- **Water pumping station**
  #2 Water pumps 220 kW
  #2 Water tanks 9700 m3



Ancona, Italy

Oveview

The Università Politecnica delle Marche (UnivPM) is located in the Marche Region, central Italy, with its main campuses in Ancona, the regional capital. UnivPM is recognised as an Energy Hub (EH) with five mEHs: Monte Dago, the faculties of medicine and economics, the sports centre and administration offices.

Monte Dago is a multi-carrier LEC featuring various energy conversion and storage technologies, along with an internal electricity network. A medium voltage (MV) cabinet allows electricity import-export with the national grid. The site's energy needs are partially met by a CCHP unit and eight natural gas boilers (1 MW each). Photovoltaic panels also supply electricity.

In the summer, electrical chillers provide cooling. The eNeuron project has added new storage units, including an integrated hydrogen system and electric batteries, along with EV charging stations, all of which offer grid flexibility. Existing technologies are managed by a local energy service company (ESCo), while the new systems are controlled via the eNeuron solution by ENEIDA.IO, except for the hydrogen system, which operates independently.

Technology and assets installed

- #1 CCHP unit - 600 kWe/700 kWth (heating)/400 kWth (cooling) with an electric efficiency of 42% and a thermal efficiency of 48.4%, whose sum leads to an overall efficiency of 90.4%;
- #2 adsorption chillers (water-lithium bromide-based) with a cooling power of 150 and 250 kWth, respectively, and a Coefficient of Performance (COP) of 0.75 each;
- Electric chillers - 900 kWth;
- #1 Photovoltaic (PV) system of 20 kWp with sun modules having an average efficiency of 19%;
- #1 integrated hydrogen system composed of #1 Alkaline Electrolyser of 23 kW, #2 metal hydrides hydrogen storage tanks with a capacity of 6000 l @std conditions, and #1 Proton Exchange Membrane (PEM) fuel cell of 1 kW – installed during eNeuron;
- #2 Lithium-ion, second-life batteries with a capacity of 5 kWh each connected to an electric load of maximum 2.4 kW and the electric grid via a 3 kW inverter – installed during eNeuron;
- #2 EVs' charging station with a power of 7 kW (single-phase)/22 kW (three-phase), feeding voltage of 230 V (single-phase)/400 V (three-phase), and a grid frequency of 50 Hz – installed during eNeuron .

Stakeholder engagement

UnivPM offers courses for Bachelor's and Master's students, with the Monte Dago site hosting the Faculties of Agriculture, Engineering, and Biological Sciences. The Energy Systems Research Group from the Department of Industrial Engineering and Mathematical Sciences (DIISM) is involved in the eNeuron project, delivering lectures to engineering students and conducting over 10 engagement activities showcasing the Monte Dago micro-Energy Hub (mEH) and the eNeuron toolbox.

UnivPM has also engaged with stakeholders such as DSOs, ESCOs, municipalities, and SMEs to discuss the technical, economic, and bureaucratic challenges of implementing ILECs in Italy. Additionally, the project was presented during researcher events in 2022, 2023, and 2024 to inform the public, although it is clear that awareness of ILECs remains limited.

Technical implementation

The Monte Dago micro-Energy Hub (mEH) includes various energy conversion and storage technologies, some pre-existing and others installed during the eNeuron project. Several challenges were encountered:

- **Integrated hydrogen system:** The alkaline electrolyser needed revamping, and new hydrogen storage and a PEM fuel cell were added. Connecting old and new equipment posed technical difficulties due to different settings and protocols. Finding a hydrogen-specialised company was challenging, compounded by delays from COVID-19 and geopolitical issues. Bureaucratically, Italy's lack of hydrogen regulation made authorising the system difficult, which required several inspections for approval. The current authorisation is the one related to equipment dealing with inflammable gases (hydrogen included).

- **Second-life batteries:** Adapted from the automotive sector, these batteries faced no technical or implementation issues, though safety considerations regarding installation location were crucial.

- **EV charging stations:** Technically, no problems arose during installation or integration with eNeuron. However, contract selection with the DSO was key, and a private ground option was chosen, limiting use to academic staff only. Staff must use their badges to charge their EVs, with the same electricity rate as their home consumption.

Skagerak, Norway

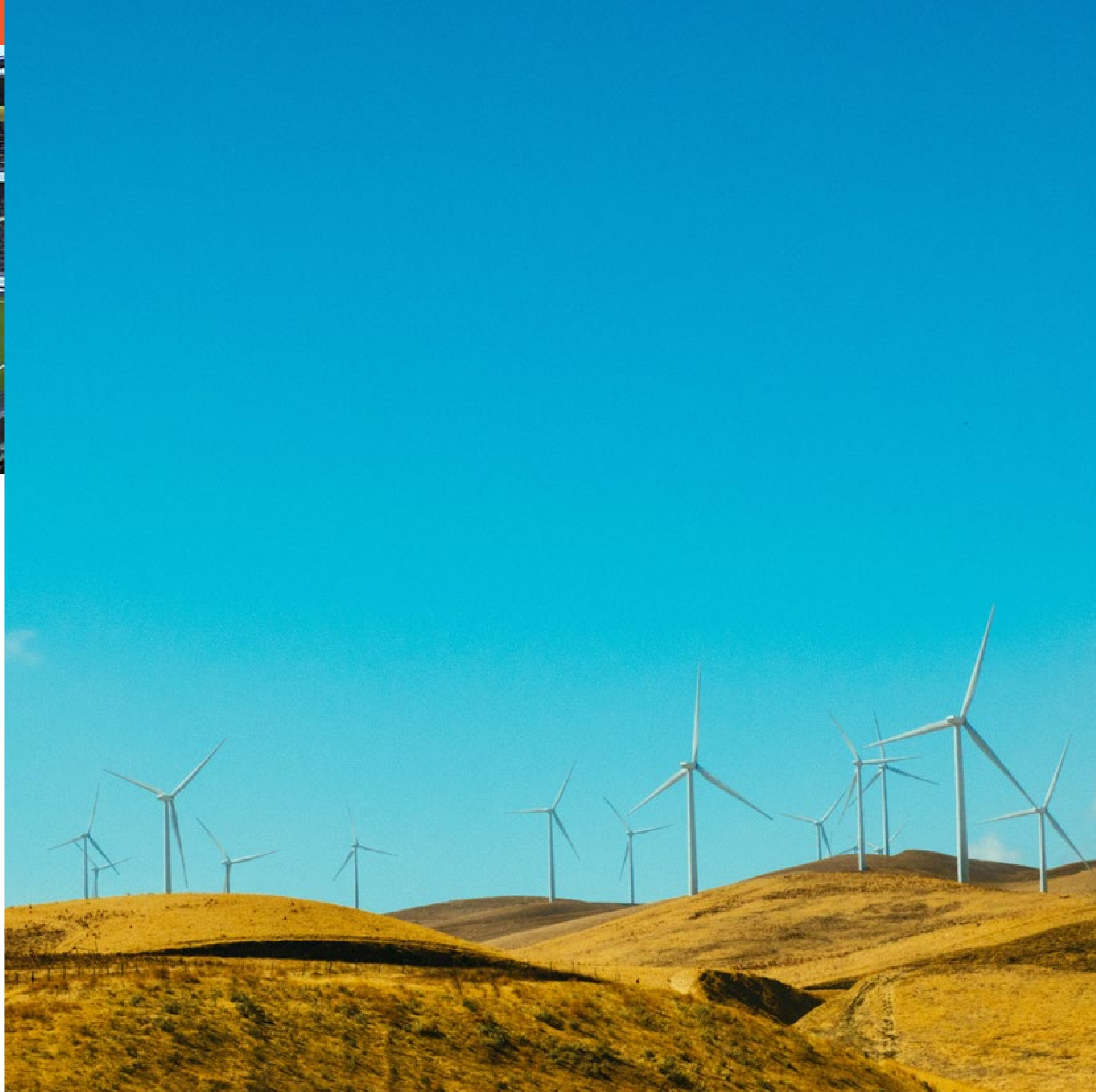
Oveview

The Norwegian pilot site is located at Skagerak Arena. It is a full-scale operational football stadium in Skien, the southern part of Norway.

The Norwegian demo is deployed at industrial-size installation at an operational football stadium, so called “Skagerak Energy Lab” (Energilab), which combines a big scale (800 kW) PV generation plant, with a battery energy storage system (BESS) of 1 MWh and power electronics, thus allowing several operational modes for the unit, including fully islanded operation. Skagerak Energilab is currently a completed and active full-scale research arena for testing and developing future sustainable energy production and distribution of significant size and degree of innovation. Due to existing topology and to minimise construction costs, the generating PV panels and the battery are located at different substations.

Technology and assets installed

- **Local grid:** 230V IT-nett and 400 V TN (PV), 400 V TN-nett (battery).
- **The energy storage:** 1 MWh/800 kW Li-ion battery, delivered by Samsung. Control system: MicroScada
- **PV:** 4300 m² in 2700 polycrystalline panels of types REC295TP2 and REC300TP2 with an installed power capacity of 800 kW(p). Calculated energy production of 660 000 kWh in a normal year.
- **Weather station:** VSN800 Weather Station, ABB
- **Houshold customers:** Number of customers: 42 (two housing cooperatives)
- **Commercial:** Stores, offices, school, gym (nine in total) Skagerak Arena: Football stadium



2. The Regulatory Domain

Policy considerations from the integrated energy community perspective at European level

Society needs energy that is clean, secure and affordable. While ILECS can deliver these goals, the deployment of energy communities in Europe can be delayed by site-specific conditions, grid connection challenges and conflicting stakeholder interests. The barriers identified mainly lie in two interlinked dimensions: regulatory and technical.

Barriers and recommendations

- **Support mechanism – the lack of appropriate financial and regulatory support can hinder ILEC developments**

The support and engagement of the end users is fundamental, but the legal framework especially at the national level needs to follow. Several important steps in this direction have recently been taken. More specifically, citizen and renewable energy communities, active customers and other innovative concepts have been introduced in the “Clean Energy for all Europeans” package[3] and more specifically in The Renewable Energy (RED II) 2018/2001[4] and Internal Electricity Market (IEM) 2019/944[5] Directives. The legal framework, defining the energy communities in these two directives, identifies only main general principles with a wide selection of potential roles and responsibilities, which can be granted and does not explicitly cover the notion of the multi-carrier systems within such a community.

For now, it is up to Member States to define national regulatory regimes and there is an indication of considerable diversity among the forthcoming national models. Following the pan-European legislation, an array of possibilities appears to be open e.g., it can undertake roles of final customers, producers, suppliers or distribution system operators, engaging in energy generation, distribution, supply, ownership and management of batteries, EV charging points, etc. Despite the expectations, the most recent development of the Electricity Market Reform[6] focuses more or less on more stable and predictable energy prices while ensuring efficient market functioning and avoiding distortions of the internal market, and thus does strengthen introduction and development of the energy communities in Europe. The latest version of the Directive 2023/2413 promoting energy from renewable sources[7] does not elaborate on the issue of energy communities.

- **To achieve the planned energy transition, it is important to establish efficient energy markets and support the empowerment of the final consumer**

Efficient energy markets should be fair for all involved stakeholders and this also includes energy communities. They need the right to produce, consume, store and sell renewable energy. These communities should also be able to exchange, within the same community, the renewable energy produced by them and access all the appropriate electricity markets, directly or through aggregation, in a non-discriminatory way.

To pave the way for this transition, the EU requires that the Member States ensure participation of consumers, including through demand response, through investments in particular, variable and flexible energy generation, energy storage, or the deployment of electromobility. Recent European legislation[8] requires that the ENTSO-E and a new EU DSO entity must involve more active citizens and energy communities in the generation, consumption, storage, and sell-off of electricity without facing disproportionate burdens.

- **To implement an ILEC, it is important to adopt a multifaceted approach and to change the current regulatory framework accordingly**

Defining and addressing the main issues with the implementation and adoption of an integrated energy system is vital for its success. By tackling technical, economic, regulatory, social, environmental, and operational challenges, stakeholders can ensure a smoother transition to a more efficient, sustainable, and resilient energy future. This comprehensive approach not only enhances system performance but also fosters economic growth, energy security, and public trust, ultimately contributing to global sustainability efforts.

The project’s analysis of actor interactions revealed significant limitations in the current regulatory framework. Its predominant focus on electricity often impedes the expansion of potential roles that various actors could adopt within an ILEC, highlighting the need for more comprehensive, multi-carrier energy policies.

The study identified several potential barriers to ILEC deployment. This identification can help stakeholders and policymakers anticipate and prepare for potential obstacles in ILEC deployment, allowing for more effective planning and risk mitigation. Moreover, it emphasises the social aspects of energy transitions, such as trust-building and stakeholder engagement, which are often overlooked in technical-focused approaches.

- **The role of storage in energy communities will be fundamental and regulation should not overlook it**

Ownership and operation of the energy storage has probably been one of the most controversial and disputed issues after introduction of the EU Internal Electricity Market (IEM) Directive 2019/944[9], which maintains a position from the previous editions, which do not allow SOs to own, develop, manage or operate energy storage facilities. On the contrary, when it comes to the newly introduced concept of energy communities the same directive permits ownership and operation of storage facilities and EV charging points. This opens new opportunities for energy communities, which so far seem to be mostly overlooked. Storage technology in its various forms is considered as a key enabler of the energy transition and a binding element of different energy vectors. However, it has been concluded that today only a few energy storage applications can justify market-based business cases, and this is why many energy storage technologies have not spread into the market yet. There is a strong expectation that the short-term electricity balancing market is where energy storage will be first

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[3] The European Commission, “COM(2018) 773 final: A Clean Planet for all, a European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy,” 28 November 2018. [Online]. Available: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52018DC0773.

[4] The European Commission, “Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources,” 11 December 2018. [Online]. Available: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2018.328.01.0082.01.ENG&toc=OJ:L:2018:328:TOC. [Accessed 28 February 2021].

[5] The European Commission, Directive (EU) 2019/944 of the European Parliament and of the Council of 5 June 2019 on common rules for the internal market for electricity and amending Directive 2012/27/EU, 2019.

[6] The European Commission , “Electricity market – reform of the EU’s electricity market design,” 2023. [Online]. Available: https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/13668-Electricity-market-reform-of-the-EUs-electricity-market-design_en

[7] The European Commission, “Directive (EU) 2023/2413 of the European Parliament and of the Council of 18 October 2023 amending Directive (EU) 2018/2001, Regulation (EU) 2018/1999 and Directive 98/70/EC as regards the promotion of energy from renewable sources,” 18 October 2023. [Online]. Available: https://eur-lex.europa.eu/eli/dir/2023/2413/oj

[8] The European Commission, Directive (EU) 2019/944 of the European Parliament and of the Council of 5 June 2019 on common rules for the internal market for electricity and amending Directive 2012/27/EU, 2019.

[9] The European Commission, Directive (EU) 2019/944 of the European Parliament and of the Council of 5 June 2019 on common rules for the internal market for electricity and amending Directive 2012/27/EU, 2019.

applied, based on commercial business cases, and it is believed that the need for additional balancing power will be substantiated already within the next five years. From a longer-term perspective (15-20 years) energy storage will become an even more significant part of the electricity system and in particular energy communities, providing more services.

- **Slow adoption of low carbon technologies**

The nature of ILECs involves the interaction between various generation and storage technologies, contributing to decarbonisation. Key to this is the optimisation of energy systems to meet end users' demands sustainably (e.g., increasing renewable energy use) and economically (e.g., improving energy conversion efficiency). However, current ILECs tend to prefer traditional, higher technology readiness levels (TRL) technologies due to factors like the lack of national regulations, which create uncertainty for investors. The complexity of the problem and the variety of the solutions available highlight the need for a holistic approach with customisable optimisation tools to evaluate various decarbonisation technologies.

Hydrogen stands out as a promising technology for different levels, including energy communities [8]. Hybrid solutions, coupling different energy storage forms with intermittent renewables, can enhance renewable energy deployment. Technologies at the transmission level, like AC/DC, will impact distribution networks. When eNeuron began, barriers such as the absence of a regulatory framework hindered hydrogen infrastructure deployment in Europe. Key issues included defining hydrogen infrastructure (e.g., whether an electrolyser is a natural monopoly or competition-exposed activity), industry unbundling rules, and third-party access to infrastructure.

By 2024, significant progress had been made. In December 2023, the European Commission finalised the Hydrogen and Decarbonized Gas Package, a regulation and directive shaping the market for hydrogen transmission, distribution, and storage[10]. This package, part of the Green Deal, includes rules to facilitate the uptake of renewable and low-carbon gases, including hydrogen, while ensuring energy security and affordability across the EU. Despite strong motivation, establishing a new hydrogen infrastructure is a complex and lengthy process, requiring both technical advancements and a new legal framework involving multiple stakeholders.

- **Local energy market mechanisms should be developed further to ensure consumers have access to electricity markets**

According to the IEM Directive[11], all consumers should have access to all electricity markets, where they can both trade flexibility (from demand response, energy storage) and self-generated electricity (from distributed generation). With this specification, the directive opens up the possibility for all consumers to get the actual market price for both electricity and flexibility services. This is a first step towards an open market, where the consumers also pay the actual electricity price. It appears that the establishment of well-functioning local markets is a compulsory attribute of the successful energy transition. Several functions are required:

- Local trading of renewable electricity.
- Trading of flexible resources necessary for ancillary services securing operation reliable system operation.
- Cross-sector market arrangements for sector coupling.

It is likely that the process will happen step by step and require some time to mature. However, there is a limited description of existing local energy market mechanisms, mainly because this is a new trend in the power system and not deployed on a large scale. To handle these changes and study the consequences for stakeholders involved, it is important to evaluate possible business models.

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[10] The European Commission, "Commission welcomes deal to decarbonise EU gas markets and promote hydrogen," 8 December 2023. [Online]. Available: https://ec.europa.eu/commission/presscorner/detail/en/ip_23_6085.

[11] The European Commission, Directive (EU) 2019/944 of the European Parliament and of the Council of 5 June 2019 on common rules for the internal market for electricity and amending Directive 2012/27/EU, 2019.

3. The Technical Domain

Lessons learned on the methodological level

This section focuses on overall lessons learned associated with the technical domain extracted from the activities performed in WP3 "Identification of the 'Local Integrated Energy Community subject and definition of the use cases". The lessons learned concern the methodology used in eNeuron such as the use cases and business models methodology.

The use cases and business models methodology

Local authorithies **Energy market actors** **Technology providers**

Use cases and business models for energy systems are crucial for ensuring system efficiency, reliability, regulatory compliance and financial viability. They provide a framework for addressing complex challenges, integrating new technologies, and meeting the evolving needs of consumers and the market, making them vital lessons learned in the energy sector.

Using the IEC 62559-2 methodology as a standardised template, the project developed 12 use cases. This analysis illustrated the involvement and interactions of all actors in each use case through detailed sequence diagrams. Additionally, each use case included an energy system architecture section, depicting the composition of the energy system. The research identified and also thoroughly described 16 business models using the business model canvas template.

Our advice

This approach allowed for a detailed exploration of key characteristics and processes, including key partners, customer value propositions, key activities, etc. It demonstrates the wide range of business possibilities within ILECs, encouraging innovation and diversification in the energy sector. Moreover, well-defined business models can help attract investors by clearly articulating the value proposition and potential revenue streams of ILECs.

The importance of PESTLE analysis to adapt models to local contexts

Local authorithies **Energy market actors** **Technology providers**

The PESTLE analysis is crucial for business models in energy systems because it provides a comprehensive understanding of the external factors that can impact the industry. By conducting a thorough PESTLE analysis, businesses in the energy sector can anticipate and adapt to external pressures, seize opportunities, mitigate risks, and ensure sustainable growth.

To align the business models with the eNeuron pilots, 7 PESTLE analyses were conducted. These highlighted the relevant political, economic, social, technological, legal, and environmental factors that could impact the implementation of ILECs in different contexts, providing valuable insights for practical application and policy development. They emphasise the need to adapt ILEC models to local contexts, highlighting that a one-size-fits-all approach is unlikely to succeed.

Using the PESTLE analysis, the national contexts in which eNeuron pilots operate were examined. The primary objective was to identify factors that can either facilitate or hinder the development of the eNeuron business models. In the following page, the lessons learned derived from the analyses:

BUSINESS MODEL 1: Flexibility for local balancing and increase of self-consumption for multi-carrier systems

- The Italian government incentivises the deployment of PtH technologies by applying a discount of 65% when replacing the old devices. At the same time, in Italy, there is a lack of legislation for H2 plants and there are barriers to electricity generation or energy storage.
- In Norway, regulation for energy communities is being planned.

BUSINESS MODEL 2: Flexibility harvesting at EH level for services to the upper grid

- In Poland, legislation enabling the functioning of energy communities is being planned. At the same time, regulation for thermal generation, energy storage and RES production is missing.

BUSINESS MODEL 11: Smart meters and sensors manufacturers for optimal energy management and innovative devices manufacturers (ICT or hardware) for control, measuring and monitoring in general

- In Poland and Portugal, the availability and maturity of smart meters for water and especially for natural gas are not as high as for electricity smart meters.

BUSINESS MODEL 12: Blockchain platform providers for local energy markets

- The EU strongly supports rules concerning blockchain technology. The Commission has adopted a comprehensive package of legislative proposals to regulate cryptocurrencies to increase investment and ensure consumer and investor protection. The EU recognises the potential of blockchain and supports the use of blockchain technology in the energy sector, primarily for data protection, with the goal of tackling climate change and supporting the Europe Green New Agreement.
- From a national standpoint (IT, PL, PT, CY, DE, IE, and ES), the regulation is in most cases missing, being planned or unclear. This may lead to fixed prices between consumer and energy utility, instead of dynamic P2P energy trading, since this last one

may have no legal foundation, impacting the energy community operation.

BUSINESS MODEL 13: Reliability services to energy users in case of islanding

- In Norway, thermal generation, which includes technologies like electric boilers, heat pumps, and fuel cells, faces certain regulatory limitations that hinder their full potential. At the same time, the implementation and operation of energy storage installations face several challenges, stemming from complex administrative procedures and the current legal framework. Barriers for RES production are present and mainly consist of: complex administrative procedures for grid connection authorisation; legal uncertainty regarding risk and cost mitigation; lack of funding for less developed generation technologies.

Our advice

> This holistic approach enables strategic decision-making and helps in developing resilient and forward-looking business models. The PESTLE analyses help identify potential risks and challenges specific to each implementation context, allowing for more effective risk mitigation strategies.

Enabling technologies for multi-carriers energy system to support demand-side flexibility

Local authorithies

Energy market actors

Technology providers

Energy planners

Energy communities

Understanding the specific technologies involved in an energy system, along with their roles and advantages, is essential for ensuring the system's efficiency, economic viability, environmental sustainability, technical compatibility, reliability, regulatory compliance, and capacity for innovation.

23 enabling energy technologies and 8 groups of ICTs have been identified for taking part in an ILEC. The primary source of energy production in an ILEC is renewable energy technologies, which are ideal for decentralised and local generation. However, traditional fossil-based technologies can also be included. The electrical technologies identified include photovoltaic systems, wind, and hydro, whereas the thermal ones include solar thermal, absorption chillers, and boilers fuelled by natural gas, steam, or biomass. Furthermore, energy technologies that could be part of an ILEC can be related to combined generation, transport, power to heat, and power to gas, different types of electricity storage as well as technologies related to EVs concept.

Group	Technology	Household level application	Community level application	Demand-Side Flexibility
Control and Management Technologies	Energy Management System (EMS) / Building Energy Managment System (BEMS)	✓	✓	✓
	SCADA		✓	✓
	Programmable Logic Controller (PLC)	✓	✓	✓
	Distributed Control System (DCS)		✓	✓
Technologies for Analytics	Big Data Analytics		✓	✓
	AI	✓	✓	✓
Internet of Things (IoT)	Smart Meters	✓	✓	✓
	Sensors	✓	✓	✓
	Actuators	✓	✓	✓
	Sensor Network/Wireless Sensor Network	✓	✓	✓
Power-to-Hydrogen	Electrolyzer	✓	✓	✓
	H2 Storage	✓	✓	✓
Electricity Storage	Batteries	✓	✓	✓
	Supercap	✓	✓	✓
	Liquid Air Energy Storage (LAES)		✓	✓
	Pumped-Hydro power plants		✓	✓
EVs	EVs (including EV as V28 - V2G)	✓	✓	✓
Thermal	Natural gas boiler	✓	✓	
	Steam boiler		✓	
	Solar thermal for hot water	✓	✓	
	Absorption chiller		✓	
	Biomass boiler	✓	✓	
Combined generation	CHP	✓	✓	
	Fuel Cells (electricity/heat)	✓	✓	
	Geothermal		✓	
Transport	Electric Ferries/Boats		✓	

Table 1. Enabling energy technologies

On the other hand, the groups of ICTs identified include control and management technologies, internet of things, communication technologies, data management technologies, cybersecurity, technologies for analytics, computing technologies, and blockchain.

Group	Technology	Household level application	Community level application	Demand-Side Flexibility
Control and Management Technologies	Energy Management Systems (EMS) / Building Energy Management Systems (BEMS)	✓	✓	✓
	SCADA		✓	✓
	Programmable Logic Controller (PLC)	✓	✓	✓
	Disributed Control Systems (DCS)		✓	✓
Technologies for Analytics	Big Data Analytics		✓	✓
	AI	✓	✓	✓
Internet of Things (IoT)	Smart Meters	✓	✓	✓
	Sensors	✓	✓	✓
	Actuators	✓	✓	✓
	Sensor Network/Wireless Sensor Network	✓	✓	✓
Communication Technologies	Communication Protocols (e.g. Modbus, Profibus, etc.)	✓	✓	✓
	Wired Communication (e.g. Ethernet, Fiber Optical Communication, etc.)	✓	✓	✓
	Wireless Communication (e.g. Wi-Fi 802.11, GSM 2G/3G/4G/5G, etc.)	✓	✓	✓
Data Management Technologies	Database (SQL and noSQL)	✓	✓	✓
	Big Data		✓	✓
	Data Ingestion		✓	✓
Computing Technologies	Cloud Computing	✓	✓	✓
	Edge Computing	✓	✓	✓
	Embedded Systems	✓	✓	✓
Cybersecurity	Cybersecurity	✓	✓	✓
Blockchain	Blockchain		✓	✓

Table 2. Enabling ICTs

The analysis highlights the crucial role of sector coupling and storage to demand side flexibility, as well as the technologies related to EVs and the ICTs.

Our advice

From the analysis of the existing framework, it is clear that it is necessary to strengthen the ongoing actions to support demand-side flexibility, supporting the use of sector coupling and storage as well as defining more targeted interventions for the spread of ICTs.

This comprehensive understanding enables better planning, optimisation, and management of energy resources, ultimately contributing to a more effective and sustainable energy system.

The importance of understanding the dynamics of the actors involved

Local authorithies **Energy market actors** **Energy communities**

Understanding the roles, interactions, and responsibilities of actors in an energy system is fundamental to ensuring its efficiency, resilience, and sustainability.

The project identified 18 key actors within ILECs, ranging from end users to government bodies. Their collaborative interactions are essential for realising ILEC objectives. Conflicts of interest among stakeholders, such as those between energy service companies (ESCOs) and other entities, can obstruct progress. This underscores the complex stakeholder ecosystem in modern energy systems and highlights the need for robust coordination mechanisms and clear communication channels within ILECs, otherwise misunderstandings and delays might occur.

Operators and Utilities	• Electrical Distribution System Operator and (DSO) and Gas Network Operator (GNO) • Electrical Transmission system Operator (TSO) • District Heating Network Operator (DHO) • Balance Responsible Party (BRP)
Actors in the Distributed System	• End users including consumers and prosumers • Electric vehicles owners • Aggregators • Energy Service Companies (ESCo) • Energy storage owners
Framework Settlers	• Government, policy makers and regulator • Local Authorities
Framework Settlers	• Electricity producers • Energy suppliers • Technology suppliers • No-profit organizations (associations, foundations, etc.) • Research actors (universities, private research institutes, etc.) • Banks, private investors • Energy cooperatives

Figure 1. Main key actors grouping based on Stakeholder Characterisation.

Our advice

> This comprehensive knowledge enables better decision-making, supports the integration of new technologies, promotes innovation, and facilitates the transition to a more sustainable and reliable energy future. Such understanding not only helps in optimising the current system but also prepares it for future challenges and opportunities.

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4. The Technical Domain

Lesson learned on implementation and adoption level

This section focuses on overall lessons learned associated with the technical domain extracted from the activities performed in WP4 “Analysis, design and operation optimisation of the local energy systems: emergence of energy hubs”. The lesson learned focus on some technical aspects such as the energy hub modelling and the workflow-based architecture.

Multi-objective problem formulation is a complex and multi-facet research question that is highly relevant for ILECs in minimising conflicts of interest among stakeholders

Local authorithies **Energy market actors** **Technology providers** **Energy communities**

The formulation of multi-objective problems within ILECs is a complex research area due to the need to balance and optimise multiple, often conflicting, goals for sustainable energy management.

ILECs aim to achieve economic efficiency by minimising energy production and consumption costs, reducing environmental impact through lower emissions and increased renewable energy use, ensuring energy reliability and security, and enhancing social welfare by improving community well-being and equitable access to energy.

The involvement of diverse stakeholders, including residents, local authorities, and energy producers, adds to the challenge not only because of different interests and priorities, but also because the use of different languages, which might lead to misunderstandings. Technological integration further complicates the process, as ILECs incorporate renewable energy sources, energy storage systems, smart grids, and demand response technologies.

Additionally, energy systems operate in dynamic and uncertain environments, with fluctuating renewable energy supply, changing demand patterns and market shifts, all influencing decision-making and optimisation strategies.

Our advice

> eNeuron adopted multi-objective approaches in different layers of the ILEC context. This allows different stakeholders with different scopes to be satisfied. However, these approaches must be in harmony with one another as ILECs are supposed to be collegial and consensual when it comes to efficient operation.

Energy hub modelling and configuration are limited in the state of the art when it comes to connection with the markets. To produce realistic and sustainable solutions, ILEC modelling and analysis must consider the markets properly

Energy market actors **Technology providers** **Energy communities**

Multiple limitations and challenges exist in the interaction of EHs with multiple markets. Current studies often overlook extensive market rules and constraints, focusing on internal EH networks without considering the upstream utility grids and associated market model. Therefore, there is a lack of studies that integrate grid distribution models and complex market mechanisms between several EHs.

Most models use historical day-ahead electricity prices, neglecting markets closer to operation like IDM or real-time markets, which are crucial for adjusting supply and demand under intrinsic uncertainty. There is a lack of clear market frameworks and realistic interactions with energy markets or upstream networks.

Thermal and gas networks face challenges, including limited consideration of gas market structures and transactions in EHs, and the exclusion of hydrogen as an energy carrier.

Demand response (DR) is addressed, but ancillary grid services are rarely considered.

Peer-to-Peer (P2P) energy-sharing mechanisms show benefits both for prosumers and the system, but face challenges. Challenges in optimisation algorithms and pricing schemes require convergent mechanisms and the inclusion of models that simulate the behaviour of the flexible resources to identify the available flexibility under different control actions in an accurate way.

Our advice

> eNeuron's approach is to deal with the P2P market in the ILEC environment making sure that through the market the different optimisation layers converge and the flexibility from the different carriers is efficiently used.

Workflow based architecture for the planning and operation optimisation toolbox promotes scalability and modularity as the ILEC can expand allowing different functionalities to be run

Local authorithies **Energy market actors** **Energy planners** **Energy communities**

Research community

The workflow management approach focuses on creating an interaction framework where different tools can communicate through a shared database by using standardised data structures. Once these have been established, usage is relatively easy for regular users and offers flexibility and scalability options as well. Scenarios can be run in parallel modelling tasks whereas it is easy to develop and apply for several users.

The SPINE Toolbox is a Python-based open-source energy system modelling framework for multi-carrier energy systems planning with high level of temporal, spatial and technological adaptability that adopts workflow architecture and supports data exchange among different models. It enables groups of users that are developing local workflows, to collaborate as a team on large-scale problems that require data curation. It also facilitates multiple tools and models through version control of workflow routines and databases for data storage.

One of the main advantages of the SPINE Toolbox is that it is problem agnostic and allows for rapid development of new ad hoc optimisation and simulation models in Python, GAMS, or Julia. It can be used for modelling and simulating a wide range of complex energy systems, integrating electrified transport and the variable renewable energy systems found in ILECs.

Our advice

> eNeuron toolbox follows the workflow architecture approach enabling SPINE database and as such it is capable of delivering more than 50 functionalities through the collaboration of around 10 tools. This way eNeuron offers a holistic approach when it comes to planning and operation of an ILEC with expandability opportunities.

5. The Non-Technical Domain

The regulatory, societal and environmental lessons learned at pilot level

This section focuses on overall lessons learned associated with the non-technical domain extracted from the activities performed in WP7 "Evaluation of results: replicability and scalability". The recommendations provided are classified according to the dimensions considered in the impact assessment.

At a project level, the impact assessment evaluates the tangible benefits of the implementation of the project solutions. The approach followed up by eNeuron split the impact assessment into different dimensions, each with its particular methodology. In this case, five dimensions have been considered: technological, regulatory, environmental, economic and societal.

At a global level, a scalability and replicability analysis (SRA) assesses the potential of the project developments to widen its impact beyond the implementation phase. Such analysis becomes important as it allows us to quantify the scale potential and its replication within other contexts (e.g., other use cases and environment) throughout certain indexes.

→ Regulatory and institutional dimension

The regulatory and institutional dimension of the eNeuron impact assessment covers an analysis of the policies and regulations associated with ILECs at local level within the pilots' countries. Specifically, this assessment identifies drivers and barriers for the development of these schemes (and its associated technologies) existing within the current regulatory framework of Italy, Norway, Poland and Portugal. The regulatory assessment is divided into five stages:

- Literature review: collection of information about the policies which regulate the operation and implementation of LECs-related multi-energy technologies.
- Framework description: overall description of the national regulatory framework on ILECs for each pilot country by using both the literature collected and information provided by the eNeuron pilot leaders.

- Identification of barriers: identification of the main barriers and limitations for the implementation and operation of ILECs.

- Categorisation and comparison: categorisation of the regulatory barriers and limitations identified according to, e.g., legal/non-legal related aspects and comparison of the legal framework and regulatory barriers among pilot countries.

- Formulation of alternatives: deep analysis to find viable solutions to overcome the identified regulatory barriers.

Thus, the recommendations formulated seek to overcome these regulatory barriers to the implementation of the ILEC paradigm and the eNeuron solutions. In the following lines major recommendations are summarised:

Unbalance of the adoption of energy community policies within existing regulatory framework among member states

Policymakers **Governmental Bodies**

The concept of "local energy community" is still novel within some member states and there is not a clear standardised definition for it. Instead, alternative related concepts such as "renewable energy community", "citizens energy community" or "energy community", are defined within the current European regulation. While one of those definitions is taken as the basis for setting out specific regulatory frameworks, other member states just refer to these schemes as "energy communities". Considering such differences, the eNeuron regulatory assessment included a comparison of regulatory policies and barriers between pilot countries which gives insights on the implementation status of the ILEC concept in member states. This is evidenced when contrasting the level of consolidation of policies on energy communities in countries such as Italy or Portugal with Poland. The latter lags in setting out a regulatory framework for these schemes.

Our advice

The comparison of regulatory frameworks indicates that there is still work ahead in some member states to fully integrate the energy community concept. Local authorities are mainly responsible for developing a suitable regulatory framework for energy communities' schemes in which the definition, roles, operation, licensing procedures and financial support appear detailed. Alternatively, policies oriented to energy communities should be integrated into existing regulatory frameworks through amendments. When considering multi-carrier energy systems (as in ILECs), this last proposition is to be implemented beyond the electrical regulatory framework, extending it to the other carriers (thermal, heating and cooling).

Need for implementation of regulatory sandboxes within energy community pilot projects

Policymakers **Governmental Bodies** **System Operators (DSOs)** **Aggregators**

The eNeuron impact assessment found that the pilot implementation phase of EU energy community projects dealt exclusively with the technical domain in most cases.

Therefore, the pilots do not evaluate the regulatory implications of the technical solutions tested. Consequently, the developments of these projects may find several shortcomings when integrated into the energy network.

Our advice

Regulatory sandboxes (with the support of local authorities) in pilots for future LEC-related projects should be implemented in order to have an integral impact assessment of this concept in "real-world" roll-out. Overall, a regulatory sandbox involves the implementation of new legal frameworks under a controlled environment with the purpose of testing their effectiveness. Such sandboxes will help to:

- Evaluate modifications in the boundaries of the role and attributions of the different actors involved in the Energy Community and the energy networks.
- Test new regulations associated to the integration of novel technologies such (hydrogen or fuel cells) in the energy flow at the level of already well-established ones (e.g., carbon, gas, PV or wind).
- Assess the effectiveness of new tax exemptions, grants and loans schemes for energy communities with a city/country from the regulatory and economic point of view both at a system and user level.

Simplification of procedures for implementation of ILECs

Policymakers **Governmental Bodies**

One barrier to ILEC implementation, and more generally to renewable energy projects, is the complicated processes for obtaining the relevant permissions.

Some cases there are several entities involved in this process as well as several legal requirements and feasibility studies (beyond the environmental impact assessment) which increase the complexity.

Our advice

To address this, a special simplified procedure to deliver all needed permissions must be established, considering the following aspects:

- Set a specific authority to be in charge of carrying out the environmental impact studies specialised in RES technology-related projects (which are directly related to energy communities).
- Simplify the permission process for the interconnection of small RES plants according to the size in terms of installed power (by setting specific thresholds).
- Offer free guidance for emerging energy communities projects throughout the process of licensing, permissions acquisition, grid integration and management

Introduction of a set of policies for taxes exemptions, grants and loans for emerging energy communities

Policymakers **Governmental Bodies** **Energy communities**

An important driver for the adoption of emerging technologies is financial incentives for their research, development and post-adoption.

Our advice

As financial incentives are fundamental for consolidating the energy community concept, these should be made available under a special regulatory regime. Below are some recommendations in this respect:

- Implementation of long-term compensation mechanisms able to increase financial forecasting stability of energy communities, and as consequence, reduce long-term risk[12].
- Creation of a standardised regulatory regime within the EU which guarantee loans with minimised interested rate, dedicated grants through a special programme for projects whose scope is to build energy communities (not only limited to pilot or technology development). Thus, not only the adoption of these schemes will be more attractive financially but it will also allow for greater reliability when evaluating the return on investment[13].
- Adoption of local regulations of feed-in tariff favourable for the energy communities within all member states (not limited to RES generation but extending to energy community schemes).

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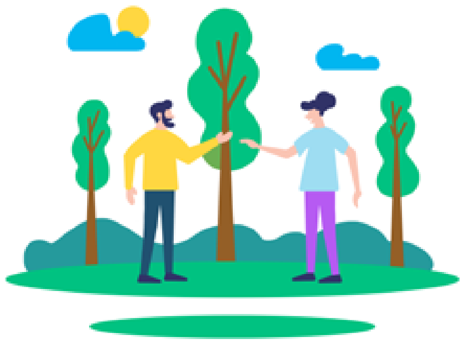
[12] A. Nettelbeck and M. Meitern, "D6.5 Regulatory Barriers Analysis," Renaissance - Renewable Integration & Sustainability in Energy Communities, 2022.

[13] S. Hunkin and K. Krell, "A Policy Brief from the Policy Learning Platform on Low-carbon economy," Interreg Europe, 2022.

→ Environmental Dimension

For the environmental dimension, a methodology commonly used to assess the impact of a project or in this case, the implementation of technological solutions, is the life cycle assessment (LCA). This is a comprehensive method which quantifies the environmental (including resource depletion) and health impact associated with the emissions and resources produced by the implementation of a new technology, project or product through its lifetime[14]. eNeuron implemented an LCA for its operational phase through the widely used software SimaPro which allows the measurement of the environmental impacts as per the impact categories.



Complementation of the Environmental assessment by the integration of landscape (visual) impact assessment

Governmental Bodies

The environmental impact assessment performed within eNeuron is based on a traditional and worldwide accepted approach which is the LCA. As a result, it is possible to quantify certain parameters associated with the carbon footprint impact caused by the solutions (e.g., emission factors, resource consumption, pollution, etc.). Nevertheless, this approach does not include the evaluation of the landscape impact derived from the installation of the new technologies. For instance, in the transition towards energy community schemes, the additional assets (heat pump, PV installation or even wind farms) provoke greater environmental impact not considered in traditional LCAs which are associated to the landscape (e.g., visual impact or terrain occupation).

Our advice

The recommendation in this case is to include a landscape impact assessment during the environmental assessment. In the beginning, the installation of additional assets may have a negative effect on the landscape (specially in cases which their scale and size are significant). In contrast, it may have a more positive effect on the landscape and ecosystem than the fossil-fuel-based generation expansion needed to generate same amount of additional energy. More sophisticated approaches can also include carbon footprint monetisation calculation considering, among others, the extra infrastructure needed for associated ILEC technologies [Flexplan]. These are alternative analysis approaches which, when integrated, will broaden the scope of the environmental impact assessment in future energy community projects.

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[14] European Commission - Joint Research Centre - Institute for Environment and Sustainability, "International Reference Life Cycle Data System (ILCD) Handbook - General guide for Life Cycle Assessment - Detailed guidance," Publications Office of the European Union, Luxembourg, 2010.

→ Societal Dimension

The recommendations in this dimension aim to ensure that ILECs are accepted and adopted. A key element here is to anticipate why local stakeholders may not embrace an ILEC. This involves constantly engaging with them in the actual context of implementation. The recommendations don't draw on a particular eNeuron pilot, but rather from the whole engagement framework.

Drivers of acceptance may differ greatly between different populations, concerning ILEC adoption

Citizens **Energy communities** **Energy market actors**

Indirect beneficiaries of eNeuron would potentially be the adopters of ILECs in local communities. Responses from the questionnaires show both pattens and differences between populations. For example, the positive impact on the social reputation of pilots due to the new energy efficiency measures of eNeuron was highly confirmed in Italy, while in Norway more than two thirds of respondents did not confirm such assumption.

Our advice

It is of outmost importance to empirically validate the assumptions about motivations and interests of target adopters of ILECs. The assumptions made by technicians and companies, as well as empirical evidence from other studies, cannot always anticipate the actual motivation of the target population. This aspect should not be undervalued as citizens and local stakeholders may be distrustful and less interested if their real motivations aren't taken on board.

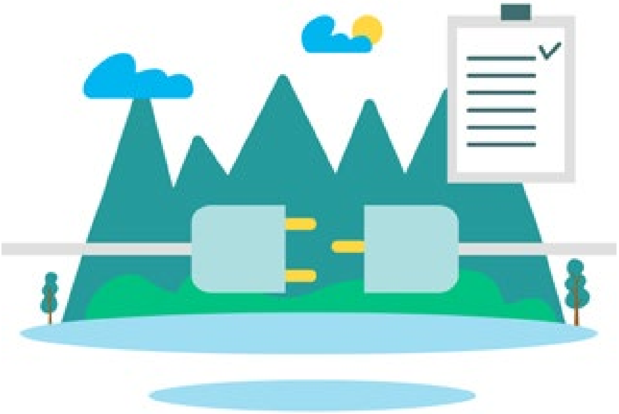
Drivers of acceptance may differ greatly between different populations, concerning ILEC adoption

Local authorities **Technology providers** **Energy market actors**

The eNeuron engagement framework was designed to balance approaches that allow scientific rigour with approaches that support the participation of various stakeholders. The framework design drew on literature on technology acceptance and provided each pilot leader with input on available methods. Nevertheless, the pilot leaders were then engaged in collaborative workshops to give shape to the engagement framework according to their specific existing capabilities and constraints. Eventually, the engagement framework was translated into a roadmap to facilitate the overview of activities for pilot leaders

Our advice

> Partners and representatives who are actually “in the field” of the future implementation should be included in the design process of the engagement framework. This is true for the whole implementation process as such partners can interact and help keep things to plan. Such an approach should be used to adapt best practices and evidence from other projects to the new context of implementation. It would avoid abstract and unwarranted assumptions, and allow the engagement to be fine-tuned according to the reactions of local stakeholders. It is also advised to translate the engagement strategies into hands-on documents, which can work as ‘intermediary objects’ among disparate partners and stakeholders and facilitate engagement.



→ Replicability and Scalability of eNeuron solutions

Scalability and replicability are key to the success and longevity of any project, especially for organisations looking to grow or expand. Scalability ensures a system can increase in capacity while maintaining performance without added complexity. Replicability allows the system to be duplicated across different environments while preserving its effectiveness.

The methodology used in this analysis is similar to that proposed by the BRIDGE initiative and is based on the Smart Grid Architecture Model (SGAM), which includes five key layers: Business, Function, Information, Communication, and Component. By assessing the eNeuron project through these layers, the goal is to identify bottlenecks, suggest improvements and ensure the system’s scalability and replicability.

Standardisation and open access: key drivers for scalable and replicable integrated local energy communities

Citizens **Policymakers** **Energy market actors** **DSO**

Technology providers **Research community**

eNeuron Toolbox

Standardised functionalities, legislation, communication standards and processes play a vital role in the successful implementation of an ILEC. By creating uniform standards for technology, legal frameworks and operational procedures, projects can ensure smoother integration of energy systems and greater scalability. Additionally, promoting open access to new solutions—such as open-source energy management platforms or interoperable smart grid technologies—enhances innovation, encourages collaboration and accelerates the adoption of sustainable energy practices across communities. These factors are crucial in facilitating the replicability and scalability of ILEC models across different regions.

The eNeuron toolbox/KERs demonstrate strong potential for scalability and replicability, largely due to their modular design and integration of mostly open standards across key system layers, including Information, Communication, Function, and Component. By adopting these open standards and ensuring system interoperability, the toolbox can be implemented across different regions and environments. This allows communities to flexibly adapt the solutions to their specific needs while maintaining system efficiency and effectiveness. However, to fully unlock this potential, further harmonisation of legislation across Europe could significantly help.

Our advice

> Adopting open data and communication standards enhances system flexibility, reduces vendor lock-in, and facilitates integration and expansion. It is also essential to prioritize interoperable systems, as ensuring interoperability across different components and technologies enables smoother integration and greater efficiency. Identifying supporting components early, such as evaluating the need for middleware or additional systems upfront, can prevent bottlenecks and ensure seamless functionality. Additionally, it is important to balance flexibility with complexity by avoiding unnecessary layers or components in system architecture, which can simplify scaling and replication.

Conclusions

After 4 years of eNeuron project, the ambitious goal of contributing to a more sustainable and decentralised energy future has been reached. But there is still much road ahead.This document provides insights into eNeuron's project and recommendations for the future work. ILECs represent a forward-thinking approach that, despite the many barriers, proves to be promising.

The continuous evolution of smart grid technologies, the regulatory framework and community engagement strategies is paving the way for broader adoption and success.

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