Enabling conditions for the deployment of integrated local energy communities in Europe

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Abstract

The main goal of eNeuron H2020 project (Nov 2020-Oct. 2024, ID: 957779) is to develop innovative tools for the optimal design and operation of local energy communities, integrating distributed energy resources and multiple energy carriers at different scales. This paper presents a review study of the enabling conditions for the deployment of integrated local energy communities (ILECs) in Europe, performed within the project. The enabling conditions are addressed by defining the key actors and their interests in the implementation of an energy community at local level and through a detailed mapping of the enabling and emerging energy and information and communication technologies at both household and community levels. Special focus is also on mapping of the demand-side flexibility technologies to understand the benefits of local flexibility and impacts on the larger systems. In such analysis, the key issues for implementation and adaptation of this new energy paradigm are investigated through covering technological, socio-economic, environmental, and regulatory aspects.

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***Abstract*— The main goal of eNeuron H2020 project (Nov 2020-Oct. 2024, ID: 957779) is to develop innovative tools for the optimal design and operation of local energy communities, integrating distributed energy resources and multiple energy carriers at different scales. This paper presents a review study of the enabling conditions for the deployment of integrated local energy communities (ILECs) in Europe, performed within the project. The enabling conditions are addressed by defining the key actors and their interests in the implementation of an energy community at local level and through a detailed mapping of the enabling and emerging energy and information and communication technologies at both household and community levels. Special focus is also on mapping of the demand-side flexibility technologies to understand the benefits of local flexibility and impacts on the larger systems. In such analysis, the key issues for implementation and adaptation of this new energy paradigm are investigated through covering technological, socio-economic, environmental, and regulatory aspects.**

***Keywords*— Energy hubs, Flexibility technologies, Integrated local energy communities, Renewable energy sources.**

I. Introduction

A. Motivation and Background

Moving towards a carbon-neutral pan-European energy system brings many challenges and opportunities, and a significant progress is necessary so that current energy systems change towards satisfying the needs of society and the economy by becoming as environmentally sustainable as possible. As also recognized by the Clean Energy Package, energy communities represent an efficient and sustainable way for managing energy at local level by exploiting synergies coming from the interplay of multiple energy carriers as electricity, heating, cooling etc, while also promoting end-users' engagement and empowerment [1]. The Integrated Local Energy Community (ILEC) concept can refer to a set of energy users deciding to make common choices in terms of satisfying their energy needs, in order to maximize the benefits deriving from this collegial approach, thanks to the implementation of a variety of electricity and heat technologies and energy storages and the optimized management of energy flows [2].

The establishment and success of an ILEC depend on enabling conditions that include technological, environmental and socio-economic aspects, energy policy and regulation framework, factors relating to individual projects and characteristics of the actors involved [3].

This paper presents the results of a review study of the main enabling conditions for the deployment of ILECs carried out under the scope of the eNeuron H2020 project (Nov 2020-Oct. 2024, ID: 957779). The main goal of the eNeuron project is to develop innovative tools for the optimal design and operation of ILECs, based on the integration of distributed energy resources (DER) and multiple energy carriers at different scales. This goal will be achieved by considering all the potential benefits achievable for the different actors involved and by promoting the energy hub (EH) and micro-energy hub (mEH) concepts. The EH represents the main architectural and operational solution for coupling multiple energy carriers namely the ILEC itself, whereas the mEH represents the prosumer (industrial, commercial, or residential) within the ILEC. Therefore, in the eNeuron ILEC, mEHs cooperate by sharing all energy carriers, with the aim to satisfy the energy needs of the entire ILEC represented by the EH.

B. Aim of the review

The review study has the main objective to define the main attributes and functionalities that would enable the establishment of an ILEC in Europe. Therefore, an overview of the main key actors and their interests in the implementation of ILECs is provided, with the aim to identify the main interactions among actors in the context of ILECs and their possible conflicting interests. On top of that, a detailed mapping of the emerging energy technologies and Information and Communication Technologies (ICT) which

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could be part of an ILEC is conducted, for investigating their role at both household level (mEH) and community level (EH). The analysis also addresses the contribution to the demand-side flexibility offered by the technologies identified, to understand the benefits of local flexibility and impacts on the larger system. Finally, the main issues with implementation and adaptation of this new energy paradigm are investigated through covering technological, socio-economic, environmental, and regulatory aspects.

II. KEY ACTORS

In the energy sector, actors present goals whose realization can be inter-dependent [4]. Several actors present interests in the context of ILECs that may vary with respect to the same actors' interests in the context of the current energy system, because of the new concept proposed within an ILEC.

Within the eNeuron project, 16 main key actors have been identified taking part in ILECs [5-9].

The key actors identified are the following:

- A1: End users, including consumers and prosumers
- A2: Energy producers
- A3: Energy suppliers
- A4: Energy Services Companies (ESCOs)
- A5: Technology suppliers
- A6: Aggregators
- A7: Transmission System Operator (TSO)
- A8: Distribution System Operator (DSO)
- A9: Government, policy makers and regulators
- A10: Balance responsible party
- A11: Storage owners
- A12: No-profit organizations
- A13: Research actors
- A14: Banks, private investors
- A15: Energy cooperatives
- A16: Local Authorities.

Interaction and cooperation among actors play a crucial role in achieving the objectives of an ILEC. Therefore, within the eNeuron project, possible interaction among actors in the context of ILECs have been also identified. The key actor with much more interactions with others is the end user. In detail, in the context of ILECs, it mainly interacts with ESCOs, technology suppliers, aggregators, DSO, balance responsible party, storage owners, no-profit organizations, banks and private investors, energy cooperatives, and local authorities [4,10,11]. The main interactions among actors taking place in the context of ILECs are reported in Table I.

The evolution of the role, interest and responsibilities that potentially affect the key actors as a result of their involvement in this new energy paradigm represented by ILECs, in some cases, has led to conflicts between the interests of individual actors that were not in place in the context of the current energy system. This may entail the need for the actors to adjust their role and objectives in order to make them compatible with the new energy structure and operation proposed by the ILECs. Within the eNeuron project, the main diverging interests among the actors have been derived and the actors involved are reported in Table II [12-14].

Indicatevily, the key actor who has the most conflicts of interest with others are the energy suppliers presenting conflicts with:

TABLE I. INTERACTION AMONGS ACTORS IN THE CONTEXT OF ILECS

	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	A14	A15	A16
A1			X	X	X	X		X		X	X	X	X	X	X	X
A2			X				X	X			X					
A3	X	X		X		X	X	X		X	X	X			X	
A4	X		X		X	X	X	X						X		X
A5	X			X		X	X	X	X			X		X	X	X
A6	X		X	X	X			X	X	X				X	X	X
A7		X	X	X	X			X	X	X			X			
A8	X	X	X	X	X	X	X		X	X		X	X	X		
A9					X	X	X	X								X
A10	X		X			X	X	X			X					
A11	X	X	X							X						
A12	X		X		X			X					X	X		X
A13	X						X	X				X				X
A14	X			X	X	X		X				X			X	X
A15	X		X		X	X								X		X
A16	X			X	X	X			X			X	X	X	X	X

TABLE II. ACTORS WITH CONFLICTING INTERESTS

	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	A14	A15	A16
A1			X			X		X								
A2			X													
A3	X	X				X		X		X						
A4														X	X	
A5																
A6	X		X					X								
A7								X								
A8	X		X			X	X									
A9														X		
A10			X													
A11																
A12														X		
A13														X		
A14				X					X			X	X			
A15				X												
A16																

- End users, when acting as prosumers.
- Energy producers, if the demand can be adjusted with load flexibility. In that case, the peak demand is mitigated, requiring for less profitable power plants.
- DSO, for congestion issues in the distribution grid.
- Potentially with aggregators and balance responsible party, when the entity of the aggregator does not lie with the energy supplier.

III. ENABLING TECHNOLOGIES

The architecture of an ILEC mostly depends on the availability of local resources and technologies, and the corresponding technical standards, market, political and regulatory framework. Enabling technologies play a key role for the deployment and success of an ILEC, and they are mostly related to technologies for facilitating the integration of Renewable Energy Sources (RES), energy storage, sector coupling, as well as ICT.

Within the eNeuron project, 26 enabling energy technologies and 8 groups of ICT have been identified which could be part of an ILEC. Among them the ones contributing to the demand side flexibility have been identified as well [15-21].

The primary source of energy production in an ILEC is renewable energy technologies, which are ideal for decentralized and local generation. However, traditional fossil-based technologies can also be included. The electrical technologies identified include photovoltaic systems, wind, hydro and wave/tidal. The first two technologies are applied both at the household level and at the community level, while hydro and wave/tidal are presented only at the community level. Thermal energy technologies include solar thermal, absorption chiller, and boilers fueled by natural gas, steam, or biomass. While the absorption chiller can be used only at community level, the other ones can be used also at households level. 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 electric vehicles concept. Expecting some types of electrical storage, these have application at both community and household level.

Among the technologies identified, power-to-heat, power-to-hydrogen, the electric energy storage technologies, and the technologies related to electric vehicles, play a very important role in the demand side flexibility of an ILEC.

ICT have been selected considering the ones most used in the context of ILECs. The 8 groups consist of:

- Control and Management Technologies, useful in the decision-making process as well as systems and devices for managing and controlling energy consumption in buildings, companies and factories [22]. Energy Management System / Building Energy Management System, SCADA, Distributed Control Systems, and Programmable Logic Controllers have been around for some time and can be used to facilitate flexibility on the demand side by automating the process. These systems can be adapted at the household and macro-energy hub level.
- Technologies for Analytics, useful in the case of ILECs at comunity and households level, permit to extract valuable information from smart meters, sensors, SCADA systems, etc. [23]. They can be used to understand the past and present status, predict the future and support the decision making.
- Internet of Things, an emerging technology that uses sensors, actuators, and communication technologies to measure and transmit data for fast and optimal decision making [24]. Energy smart meters, sensors, actuators, and sensor networks are key elements at the micro-energy/household level. An extensive network of sensors and meters increases the possibilities of managing energy demand. Greater control enables better regulation and contributes to energy savings.
- Communication Technologies play a key role in ensuring efficient and secure data transfer between energy generation, transmission, and distribution systems. Also, from the perspective of ILECs, communication between the elements of the energy hub (e.g., sensors, actuators, meters, etc.) is crucial. Users' expectations are that communication technologies can ensure fast, reliable, and secure data exchange between system components. Wired as well as wireless solutions have advantages and disadvantages, and most communication systems in the ILECs will be a mix of both technologies. The data transmission methods require the use of communication protocols to organize the data exchange process. These protocols have different characteristics and application areas.
- Data Management Technologies. In the ILECs a lot of data are generated by different data sources: sensors, meters, SCADA, etc. In this context, the Data Management technologies are fundamental to store and make these data accessible on the needs of the micro- and macro- energy hubs. Based on the volume of data source, their velocity and variability, it may be necessary to use Big Data technologies to treat the data properly.
- Computing Technologies. The execution of the several algorithms, necessary to the functionalities of the micro- and macro- energy hubs, requires computational resources. With Cloud Computing it is referred to the provisioning, through Internet, of essential services as storage and computing services, which a user can utilize on demand. On the other hand, where it is necessary to operate in real time mode, some calculations can be transferred to the devices, introducing a new computing paradigm called Edge Computing. Another computing paradigm is the Fog Computing. As the Edge Computing, the processing is moved nearer to the data source, but the intelligence is inserted in the local area network.
- Cybersecurity as a practice of protecting critical systems and confidential information from digital attacks relates directly to IT networks of energy systems. The violation of energy systems put in danger the security of users' personal data but also the security, operation, and reliability of the overall system. Threats can be internal, or external and can arise from anywhere. Therefore, cybersecurity in ILECs is very important to address the potential security – digital attacks [25].
- Blockchain is a shared, immutable ledger that facilitates the process of recording transactions of the community users in a shared ledger within that community. At community / macro-energy hub level, blockchain technology can be used in order to collect data, such as energy production and consumption of community members using blockchain-enabled smart meters. In addition, blockchain technology can contribute to the concept of ILECs through the control of energy networks via smart contracts [26].

Table III reports the energy technologies identified, whereas Table IV reports the ICTs.

For both tables: House-hold Level (HL), Community Level (CL), Demand Side Flexibility (DSF).

TABLE III. ENABLING ENERGY TECHNOLOGIES

Group	Technology	HL	CL	DSF
Electrical	Photovoltaic	X	X	
	MicroWind/Wind	X	X	
	MicroHydro/Hydro		X	
	Wave/Tidal		X	
Thermal	Natural gas boiler	X	X	
	Steam boiler		X	
	Solar thermal for hot water	X	X	
	Absorption chiller		X	
	Biomass boiler	X	X	
Combined generation	Combined Heat and Power	X	X	
	Fuel Cells (electricity/heat)	X	X	
	Geothermal		X	
Transport	Electric Ferries / Boats		X	
Power-to-heat	Heat pump	X	X	X
	Hybrid heat pump	X	X	X
	Electric boiler	X	X	X
	Thermal Storage (sensible / latent/thermochemical)	X	X	X
Power-to-hydrogen	Electrolyzer	X	X	X
	H2 storage	X	X	X
Electricity Storage	Batteries	X	X	X
	Supercapacitors	X	X	X
	Flywheel		X	X
	Compressed air energy storage		X	X
	Liquid air energy storage		X	X
	Pumped-Hydro power plants		X	X
Electric Vehicles	Electric Vehicles (including vehicle to building and vehicle to grid)	X	X	X

TABLE IV. ENABLING ICT

Group	Technology	HL	CL	DSF
Control and Management Technologies	Energy management systems / Building energy management systems	X	X	X
	SCADA		X	X
	Programmable logic controller	X	X	X
	Distributed control system		X	X
Technologies for Analytics	Big data analytics		X	X
	Artificial intelligence	X	X	X
Internet of Things	Smart Meters	X	X	X
	Sensors	X	X	X
	Actuators	X	X	X
	Sensor Network / Wireless Sensor Network	X	X	X
Communication Technologies	Networking devices (e.g., Gateway)	X	X	X
	Communication Protocols (e.g., Modbus TCP, etc.)	X	X	X
	Wireless Communication (Wi-Fi (802.11), GSM (2G/3G/4G/5G), etc.)	X	X	X
Data Management Technologies	Databases (SQL and noSQL)	X	X	X
	Big Data		X	X
	Data Ingestion		X	X
Computing Technologies	Cloud Computing	X	X	X
	Edge Computing	X	X	X
	Embedded Systems	X	X	X
Cybersecurity	Cybersecurity	X	X	X
Blockchain	Blockchain		X	X

IV. KEY ISSUES

During the implementation and adaptation, ILECs must deal with technological, socio-economic, environmental, and institutional issues that can act either encouraging on such systems establishment and growth or limiting in favor of centralized systems [4]. Within the eNeuron project, 24 main key issues have been identified, among technological, socio-economic, environmental, and institutional ones, as reported in Table V [22-26].

From the analysis, it is emerged that the factors that can be potential barriers in the deployment of ILECs are mostly related to the site conditions, support mechanisms, issues related to the grid connection, initial costs and financing, trust and motivation, spatial issues, conflicting interests of parties involved. On the other hand, ILECs can be pro-active for energy efficiency issues, control of climate changes, energy democracy and alleviation of energy poverty.

However, the enabling factors and barriers of a ILEC constantly change according to institutional changes, energy prices and the energy development of the local territories.

TABLE V. KEY ISSUES

Technological	Socio-economic	Environmental	Institutional
Intermittency of local RES generation and demand response schemes application	Paradigm shift through community and end-users' engagement	Emissions reduction	Trust, motivation, and continuity
Lower energy efficiency concerns	Economic incentives mechanisms	Waste management	Energy democracy promotion
Storage connecting, monitoring and operational concerns	Willingness of end-users to invest	Spatial issues	Ownership issues
Local balancing of supply and demand at lower grid level	Coordination and split-incentives		Locality and responsibilities
	Energy poverty alleviation		Support schemes and targets
	Increased energy		(Self-) governance
			Regulatory issues

Local flexibility exploitation and undesired impact on larger energy system Operational resilience of the upper grid	autonomy and security of supply Initial costs and financing challenges		Institutional (re-) design

V. CONSLUSION

This paper describes the preliminary results of a review study performed within the eNeuron project with the aim to define the main attributes and functionalities of an energy community, in order to identify the enabling conditions for the deployment of the new energy entity given by ILECs. The enabling conditions identified deal with the main key actors involved (with their evolution in ILEC), energy technologies, ICT, and demand-side flexibility technologies, and the key issues for the implementation and adaptation of ILECs.

Based on the paper findings, a number of actors are likely to participate within the ILEC ecosystem interacting with each other and developing a different energy value chain each time. This formulates a complex ecosystem where conflicting roles of the different actors may appear. These conflicts need to get addressed by the actors transforming their objectives and business operation accordingly. At the same time, a long list of enabling technologies allow this complex system building and operation. Specifically, through this paper is shown that there is a significant flexibility potential within ILECs that can be exploited within the appropriate regime. For building such an ecosystem some challenges need to be overcame. It seems that as soon as the energy value chain is built without conflicts, then challenges related to the specificities of the site and support schemes i.e., financial, or/and social are the most dominant.

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