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SHARED UNDERSTANDING OF LOCAL ENERGY COMMUNITY TERMINOLOGY: A CATALYST FOR INTERDISCIPLINARY COLLABORATION AND STAKEHOLDER ENGAGEMENT

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Local Energy Communities (LECs) are an essential component of the clean energy transition in Europe. However, differences in terminology and interpretation across disciplines and among stakeholder groups present challenges to their effective development and operation. This paper explores three key concepts frequently encountered in LEC research and practice: prosumers and self-consumption, flexibility and demand response, and uncertainty. We provide both a Power Systems and an Operations Research (OR) perspective on each term, highlighting how varying definitions can lead to misunderstandings and misaligned decision models. By promoting greater clarity and shared understanding of these terms, we aim to support more effective interdisciplinary collaboration and the development of robust decision support tools for the design and operation of LECs.

Keywords: *Energy community, interdisciplinary collaboration, stakeholder engagement.*

1. INTRODUCTION

The European Union (EU) has ambitious plans for the transformation of the energy sector to provide secure, sustainable, competitive, and affordable energy for all Europeans. Modern fossil or nuclear power plants convert fuel to electricity with an efficiency of 30–40 % [1], [2]. Transporting electricity from power plants to homes and businesses incurs further losses of 1–4 % on the transmission level and 2–23% on the distribution level [3]. Therefore, decentralised decarbonised electricity generation forms part of the clean energy response to climate change and can reduce greenhouse gas emissions, improve supply security, and enhance resilience.

An essential element of the new electricity market design is active participation of empowered consumers. It aims to integrate higher proportions of renewable energy, allow prosumers (participants who both consume and produce electricity) to sell their excess self-generated electricity back to the grid, and allow them to benefit from cheaper electricity during off-peak periods. Interested citizens can group together to form a local energy community (LEC). LECs are called Advanced Energy Communities in the US, Smart Communities in Japan, and are gaining traction in Europe [4], [5].

The EU legislation is moving at pace to ensure a clean and fair energy transition at all levels of the economy. The Clean Energy Package makes the EU's electricity market more interconnected, flexible, and consumer-centred. The Electricity Market Directive is consumer-focused and outlines requirements for Member States and Regulatory Authorities to develop frameworks that allow for consumer participation in energy markets [6]. There are two definitions of an energy community: Citizen Energy Community (CEC) is defined in the Electricity Market Directive [6], and Renewable Energy Community (REC) is defined in the Renewable Energy Directive [7]. In both cases, the communities are autonomous legal entities based on open and voluntary participation with the purpose of providing environmental, economic, or social community benefits for their shareholders or members rather than financial profits. They are entitled to generate, consume, store, and sell renewable energy and may be allowed to participate in cross-border electricity exchanges.

2. RESEARCH CONTEXT AND MOTIVATION

Despite the progress made, variations in the interpretation and application of LEC-related concepts remain a major challenge. The European framework allows Member States considerable flexibility in shaping tailored definitions and support measures of LECs [8]. However, EU countries are at different stages in transposing EU legislation [9] and adopt various approaches to REC, CEC, and collective self-consumption [10]. Regulatory challenges exist in defining the general meaning, the main activities, control and operation, membership, ownership and boundaries of LECs [10]. Meanwhile, scientific literature presents multiple related concepts, such as community energy storage, community microgrids, energy sharing, smart energy community, prosumer community, energy hub, community wind, community solar, virtual power plant, energy cooperative, etc. While "energy community" and "community energy" are the most commonly used terms in research – they tend to focus more on economic objectives rather than social goals, primarily referring to the community as a place [11]. In line with this idea, de São José, Faria, and Vale [12] distinguish between place-based and non-place-based communities. Additionally, another widely used term in research is "integrated community energy system" [12].

Furthermore, LECs unite multiple actors, such as consumers and prosumers, local authorities, distribution system operators (DSOs), service providers (e.g., Energy Service Companies (ESCOs)), and property investors [13]. These stakeholders may have controversial objectives and interpret LEC-related concepts differently. Even within the research community, different disciplines have multiple perspectives and priorities, which pose a challenge for true multi- and inter-disciplinary research. Therefore, addressing terminological inconsistencies is essential for creating a foundation for more effective communication and alignment of goals among diverse stakeholders.

In this paper, we explore some of the terminology that occurs in LEC research and practice. We select a subset of terms, with provision of a power system and Operations Research (OR) and analytics perspective and interpretation of each term. We aim to enhance shared understanding of these terms, create insights into how the disciplinary perspectives may complement each other, or give rise to mutual confusion and misunderstanding.

3. METHODOLOGICAL APPROACH TO GLOSSARY DEVELOPMENT

The SEC-OREA (Supporting Energy Communities – Operational Research and Energy Analytics) team responded to the call to create "Novel Computational Approaches for Environmental Sustainability" in the CHIST-ERA (European coordinated research on long-term Information and Communication Technologies (ICT) and ICT-based scientific challenges) 2019 call. Focusing on developing algorithms and analytics to serve the needs of emerging LECs, the team aims to provide decision support tools for the design and operation of LEC. Multiple skills and sets of knowledge are needed for the successful and sustained participation of LECs in EU energy markets.

The project is broken into work packages targeting just some of the associated disciplines and activity areas: (1) Energy Analytics that aims to extract insights and understanding relationships between weather, renewable energy source (RES) generation, and electricity demand; (2) Optimisation algorithms to capture the interaction of stakeholders with competing perspectives such as the LEC and DSO; Optimisation algorithms to solve the energy dispatch problem taking into account the variability of RES; and Power Systems. All the approaches are designed to assist LECs in understanding the business, regulatory and power system's perspectives, and to make good decisions about how to design and operate their LEC infrastructure.

The SEC-OREA team is composed of researchers from Business Analytics, Operations Research and Power Systems disciplines. Business Analytics and Operations Research use quantitative approaches to enable better decision making. Business Analytics uses data modelling to understand relationships in empirical data. Mathematical modelling represents decision actions and the objectives and constraints of different decision makers and stakeholders in a form that appropriate algorithms can solve.

OR has an established history of modelling and solving energy optimisation problems [14]. It takes a formal approach to specifying a problem statement for the optimisation problem to ensure that the problem inputs, outputs, data, and assumptions are stated. The problem statement is then formulated in mathematical notation with precise definitions for all concepts, symbols, and data parameters or distributions. See, for example, the approach to solving the Unit Commitment problem in [15]. The OR approaches simplify assumptions, such as that all data parameters are known with certainty. These models and approaches can be extended to incorporate uncertainty, such as [16]. Understanding uncertainty is a significant challenge for LECs that may not have adequate business or data analytics expertise, or access to high-quality empirical data to create appropriate statistical or machine learning models.

The SEC-OREA project tries to complement the analytics and algorithmic expertise of the team with power systems insights. In that way, complementary perspectives can be encoded in the mathematical models, which, when solved, should provide more insightful and useful recommendations for LECs. However, this comes with a significant challenge as each discipline has its own methodological approaches and terminology and naming conventions.

4. EXAMPLES OF TERMINOLOGICAL AMBIGUITY

4.1. Prosumers and Self-consumption

The EU legislation per se does not include a definition of the term "prosumer". However, the term generally refers to energy consumers – typically connected to the distribution grid – who also produce and/or store electricity at their premises [17]. While prosumers are often associated with RES, using RES is not a strict requirement. The rapidly evolving concept of prosumers includes the ability to sell surplus electricity and provide various energy services, either individually or through collective structures such as energy communities [18], [19]. Ertz et al. [20] propose a contemporary definition of prosumers, highlighting their contribution to economic, social, and environmental goals and underlining their broader impact beyond individual energy production: "prosumers create value for themselves and others independently or in collaboration with organisations, communities or peers."

As the role of prosumers continues to expand, the EU has introduced the concept of the active customer within its legal framework to provide clarity and support inclusive participation in the energy transition. According to the EU Electricity Market Directive [6], an "active customer means a final customer, or a group of jointly acting final customers, who consumes or stores electricity generated within its premises located within confined boundaries or, where permitted by a Member State, within other premises, or who sells self-generated electricity or participates in flexibility or energy efficiency schemes, provided that those activities do not constitute its primary commercial or professional activity."

Notably, active customers are not required to generate electricity themselves – participation in flexibility or energy efficiency schemes is also sufficient – and where generation is involved, it is not limited to RES.

A distinct group within this framework is the renewable self-consumer, who primarily generates and consumes renewable energy at their premises, most typically from solar panels. According to the EU Renewable Energy Directive [7], "renewables self-consumer means a final customer operating within its premises located within confined boundaries or, where permitted by a Member State, within other premises, who generates renewable electricity for its own consumption, and who may store or sell self-generated renewable electricity, provided that, for a non-household renewables self-consumer, those activities do not constitute its primary commercial or professional activity". Thus, self-consumption refers to the consumption of energy at the same location where it is generated.

The EU Renewable Directive [7] also introduces the term "jointly acting self-consumers", as "a group of at least two jointly acting renewables self-consumers who are located in the same building or multi-apartment block". Often, the term "collective-self consumption" is used to describe jointly acting self-consumers [21]. Some authors use the term "collective self-consumption" to refer to community-level energy consumption, where a portion of the electricity is consumed collectively within the community [22], [23].

From an analytics and optimisation perspective, these definitions and sets of assumptions have implications when designing a related mathematical optimisation model and solution approach. The OR provides a resource allocation framework by creating an appropriate mathematical model of the decisions, objectives, and constraints. Traditional OR approaches have focused on the perspective of DSO and TSO (transmission system operators), mainly focusing on cost minimisation [16], [24]. More recently, as the number and type of actors in energy markets have grown, the concerns and objectives of individuals or groups of are included in the models [25]. Incorporating the competing objectives of prosumers and energy communities alongside those of established system operators leads to more challenging mathematical models. Creating a shared interpretation of the remit and objectives of the actors in an ever-changing regulatory landscape is a challenge, but it is necessary to ensure valid assumptions are encoded in the mathematical models.

4.2. Flexibility and Demand Response

The literature uses multiple similar but slightly different terms when referring to system flexibility, such as demand-side flexibility, demand response, and flexibility services. The EU Regulation on Improving Electricity Market Design defines flexibility as "the ability of an electricity system to adjust to the variability of generation and consumption patterns and to grid availability, across relevant market timeframes" [26]. Sources of flexibility can include demand response, energy storage, and other non-fossil flexibility solutions [26].

Consequently, the literature tends to focus either on quantifying the available flexibility potential that flexibility resources can offer or on the flexibility requirements necessary for stable system operation [27]. Degefa et al. [28] review existing definitions of flexibility and propose three essential criteria that a consistent definition should include: the type of flexibility, the duration of its activation, and the incentive for activating the flexibility resource. They also identify several categories of flexibility resources: demand-side (shiftable in advance, delay, or both), supply-side, stationary storage (standalone or with generation), mobile storage (e.g., electric vehicles), and operational flexibility (e.g., dynamic line rating) [28]. Furthermore, flexibility services refer to products delivered by flexibility resources, which can be offered as ancillary services in existing markets or under alternative arrangements [28], [29].

The EU Energy Efficiency Directive emphasises the role of demand-side flexibility as an important energy efficiency measure [30]. At the same time, the EU Electricity Market Directive [6] market defines demand response as "the change of electricity load by final customers from their normal or current consumption patterns in response to market signals, including in response to time-variable electricity prices or incentive payments, or in response to the acceptance of the final customer's bid to sell demand reduction or increase at a price in an organised market, whether alone or through aggregation". Although the terms "demand-side flexibility" and "demand response" are sometimes used interchangeably, demand response typically focuses on consumer actions triggered by price signals or incentives [18, 31].

Thus, when discussing LECs, it may be more accurate to refer to demand-side flexibility, as this term better captures the diverse behaviours and technologies involved at the community level. Referring to flexibility services may be more appropriate at a higher level or in advanced community models where LECs act as service providers.

In both cases, OR mathematical optimisation models can be formulated to support the participation of LECs in these markets. An optimisation technique called Mixed Integer Linear Programming (MILP) is used by [32] to optimise collective self-consumption of an energy community of prosumers, traditional consumers, and distributed storage units by scheduling members' loads and implementing a Demand Side Management. A MILP model is also proposed in [33], whose authors explore three different objectives for the different types of ECs. They note individual households do not offer sufficient flexibility for any significant grid enhancement, but collectively in an EC their aggregate flexibility has the potential to operate as an aggregator and provide flexibility directly to the DSO.

4.3. Uncertainty

The last concept we address in this paper is "uncertainty". There is inherent unpredictability in factors affecting energy generation, consumption, and management. This unpredictability arises from various sources, including fluctuations in renewable energy generation due to changing weather conditions, variations in consumer behaviour influenced by lifestyle and occupancy patterns, shifts in market dynamics such as energy prices and policy regulations, and potential inefficiencies or failures in energy systems and storage technologies [34], [35]. However, "uncertainty" is interpreted and treated differently by different actors in the clean energy transition.

For example, within the Operations Research mathematical modelling and optimisation communities, "uncertainty" is given a mathematical definition to bound the values that specific parameters can take. When there is no uncertainty in the problem parameters, computationally efficient techniques such as Linear Programming are used to find optimal solutions in the deterministic case. More advanced computational approaches are needed when the parameters are uncertain. Stochastic Programming offers an optimisation framework to address uncertainties and can be used in energy generation, consumption, and market dynamics problems. Uncertainty is incorporated if the parameter statistical distributions are known by creating sample scenarios from the probability distributions. This enables decision-makers to develop contingency-based energy management strategies that account for variability in factors such as renewable energy output, consumer demand, and price fluctuations [36], [37]. Stochastic Programming models are bigger as they include additional constraints for the set of scenarios, and are, therefore, more challenging to solve than deterministic Linear Programming models.

Robust optimisation is another optimisation technique that considers uncertainty in the model parameters but captures uncertainty differently. The goal of this approach is to ensure that optimal decisions are robust to fluctuations in the model parameters, even for their worst-case realisations. An uncertainty set defines the range of variation of the uncertain parameter. Uncertainty can be characterised in the form of a box, polyhedral, or ellipsoidal uncertainty sets based on the shape of the variation of the uncertain parameters. When the model simultaneously accounts for the worst-case realisation of all uncertain parameters, the optimal solution might be highly conservative and computationally expensive. In order to control the degree of conservativeness, the decision maker can allocate a budget for the uncertainty [38] in the parameters by imposing a cap on the number of parameters that can fluctuate within their specified bounds. The corresponding uncertainty set is called the budget uncertainty set. Sometimes, uncertain parameters like photovoltaic (PV) solar power supply and electricity demand may exhibit a spatio-temporal correlation between them, allowing for further reduction of the uncertainty space, easing the computational burden of the problem. Uncertainty sets of correlated parameters can be constructed using data-driven approaches by defining the boundaries of the spread of the data points in the form of a convex hull based on the actual empirical distribution.

This OR treatment of uncertainty in Robust Optimisation leads to conservative solutions from a power systems perspective that ensure the power system operates reliably under fluctuations in power supply and demand once they fall within the range of the uncertainty sets.

The effectiveness of legislative efforts towards energy transition and decarbonization depends on how policymakers address uncertainty [39]. Scott et al. [39] examine how different methods of representing long-term uncertainty affect the evaluation of renewable support policies. They find that relying on deterministic or scenario-based approaches can lead to overly restrictive policies, whereas stochastic optimisation offers more accurate insights despite higher computational requirements. Furthermore, uncertainty in policy, RES support mechanisms, and market prices can hinder investment decisions [40], [41] and particularly the employment of LECs and citizen involvement [42]. At the same time, TSOs and DSOs face uncertainties in both planning [43] and operation [44], [45] of power systems. Velásquez et al. [43] distinguish between two types of uncertainty: aleatory uncertainty, which stems from inherent variability in natural processes (e.g., wind speed or human behaviour), and epistemic uncertainty, which arises from a lack of knowledge and can potentially be reduced through further research. At the same time, Bessa et al. [44] focus on decision-dependent uncertainty, which describes the state of electric devices (available or unavailable).

5. CONCLUSION

In this paper, we have explored just three of the terms that occur in LEC research and practice: prosumers and self-consumption, flexibility and demand response, and uncertainty. Our dual perspectives from the power system and OR show that providing as much definition of the term as possible can assist the two disciplines in appreciating the scope and focus of the research problem. Without agreeing on definitions and sharing understanding, the concepts and research direction may be misaligned. This can lead to wasted effort and poor decision recommendations for LECs.

By creating a shared understanding, each discipline can bring its strengths and expertise to bear in a complementary fashion, aligning the efforts of multiple disciplines, in this case, power systems and OR, can enhance the outputs and solutions provided to support LEC participation in the clean energy transition.

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