Elicitation and Formalization of Local Energy Community Stakeholder Requirements in Austria

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Abstract: Local energy communities (LECs) are quickly gaining popularity and have considerable potential to benefit their participants as well as the overall energy system, but they may also have a destabilizing effect if implemented in an uncoordinated fashion. Project ECOSINT aims to develop a unified and modular information and communications technology (ICT) architecture for seamless, large-scale integration of LECs into the overall energy system in to ensure that their benefits can be fully lifted. Following a holistic approach, this process involved the elicitation and formalization of requirements from all involved stakeholders as a basis for the development of this architecture. This paper outlines, how these requirements have been collected and formalized using state of the art methods. Furthermore, the requirements are presented and examples of the results of the formalization process are given.

Keywords: Local Energy Community, LEC ICT Architecture, LEC Requirements, Erneuerbaren-Ausbau-Gesetz, ISO/IEC/IEEE 15288, System of Systems, SGAM, ECOSINT

1 Introduction

As the world shifts towards renewable energy sources, LECs, which collaborate to generate, exchange and store energy, are becoming increasingly popular. In Austria, this development is facilitated by the political goal of becoming carbon neutral by 2040 and made possible on a legal basis by the renewable energy expansion act (Erneuerbaren-Ausbau-Gesetz, EAG), the national implementation of the revised European Union Renewable Energy Directive (RED II) and Internal Electricity Market Directive (IEMD), which provide the common framework for the promotion of energy from renewable sources in the EU [1]. This legislation has been met with rapid adoption, with 145 new LECs in the first half of 2023 alone.

As pointed out in [2], LECs can potentially bring benefits to the energy system, but are also associated with certain risks. To ensure reliable operation of the overall energy grid during and after this transition phase, it is necessary to thoroughly consider the mass integration of such LECs. The ECOSINT project, which has already been described in [3] and [4], follows a holistic approach that encompasses all relevant stakeholders involved in the set-up and operation of LECs. Its primary goal is to develop an ICT architecture that allows for large-scale integration into the overall energy system.

A requirement is defined as "*a condition or capability that must be present in a product, service, or result to satisfy a contract or other formally imposed specification*" in the IEEE 1490 guide

[5] and shapes the final product. It is, therefore, the first step in this process to bring together these stakeholders and to gather, discuss, and harmonize their various requirements, both from an outside view on and an inside view of the LEC. This paper presents the requirements that have been collected and outlines the process of eliciting and formalizing them so that they could serve as a basis to develop the necessary ICT architecture described in [4].

2 Related Work

The comparatively favorable legislative conditions for LECs in Austria attracted interest from companies, practitioners, and the research community alike. Although there is a large body of literature on systems engineering in general, due to the novelty of LECs, work on systems engineering and requirement gathering specific to them is still limited, especially work that considers the specificities in Austria. This section is intended to give an overview of research projects concerning energy communities with Austrian scope or affinity[1].

Project LocalRES develops “a planning tool oriented to enable citizen participation” and “a Multi-Energy Virtual Power Plant (MEVPP) approach to optimize in real time different energy vectors and different energy and flexibility services”. SENDER aims for “improving the quality of load forecasts and providing access to load flexibility, which will allow to improve frequency stability, congestion management and increased RES integration”. The objective of project ORANGE is, “to explore future mechanisms that create incentives to ensure cooperative energy supply concepts also under grid-friendly conditions”. CLUE “dealt with the implementation of LECs in four European countries (Sweden, Scotland, Germany, and Austria). The aim was to acquire knowledge about optimized design, planning, and operation of such energy communities and to develop a toolkit for the planning and operation of LECs”. SONDER “aims to develop a scalable, multi-service, and multi-level approach aiding the implementation of local and regional energy communities”. The SOL-E projects aims to pioneer the “development of an energy community based on solidarity in the city of Graz.” NETSE developed a “tool, that provides the optimal technical configuration and control strategies, e.g. in order to regulate loads and integrate energy storage systems” and finally, the #EEG+ project aimed “to create guidelines for the implementation of Plus Energy Communities for decentralized energy supply solutions in the context of mixed-use districts and buildings in new and refurbishment projects”.

While this list provides only a partial overview, it illustrates the volume and diversity of related research projects. What differentiates ECOSINT from other projects is its holistic approach, encompassing all relevant stakeholders while also considering the effects on the overall energy system and how LECs may improve its resilience.

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[1] More information on these projects can be found at www.localres.eu (LocalRES), www.sender-h2020.eu (SENDER), projekte.ffg.at/projekt/4746343 (ORANGE), www.project-clue.eu (CLUE), www.project-sonder.eu (SONDER), projekte.ffg.at/projekt/4672911 (SOL-E), projekte.ffg.at/projekt/4290516 (NETSE) and projekte.ffg.at/projekt/4425019 (#EEG+).

3 Methodology

The advancement of technology and the emergence of new and innovative Smart Grid (SG) applications like LECs have made it possible to address environmental concerns, energy efficiency, renewable integration, etc. This provided new opportunities but has increased the system's complexity further, supplementing the challenges of designing and using these systems. LECs are a class of SG application that can be termed a System of Systems (SoS), as the set of systems "*interact to provide a unique capability that none of the constituent systems can accomplish on its own*", as defined in ISO/IEC/IEEE 21839:2019 [6].

Systems Engineering (SE) is "*an interdisciplinary approach and means to enable the realization of successful systems*" [7], dedicated to designing and managing complex engineering systems. SE is adopted by different industries as the standard method especially when dealing with complex system [8]. As defined in the PMTE (process, methods, tools, and environment) paradigm [9], finding/creating a suitable methodology for SE needs to consider not only the methods but the process, tools, and environment as well. Understanding this interrelationship (see Figure 1) helps enabling a successful implementation. Furthermore, knowledge, skills, and abilities of the involved stakeholder (people) as well as the capabilities and limitations of the technology further affect this interrelationship and should be considered.

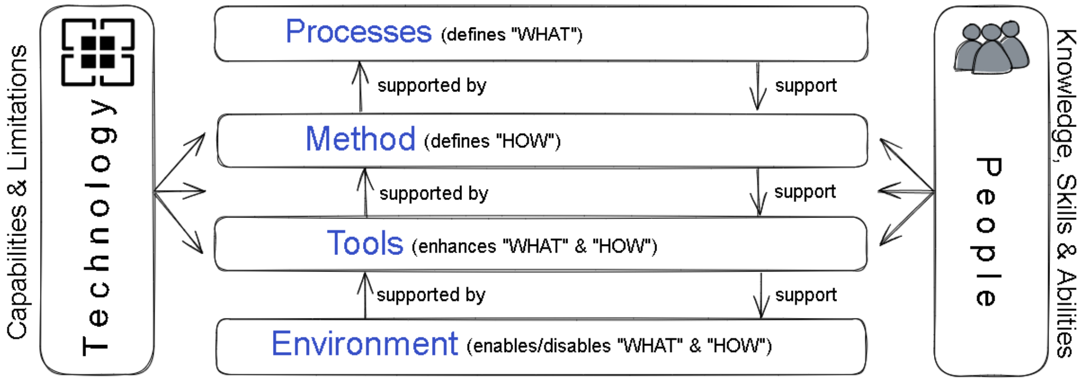

Figure 1: The relationship between process, methods and tools for SE and the effect of technology on them [11].

To address the complexity of modern system engineering, the SE community has been very active in defining international standards, guides, and best practices to make the adoption easier. Two prominent and closely related such standards are ISO/IEC/IEEE 15288 [10] and ISO/IEC 29110 [11]. Both have a concept of a lifecycle that is defined in [11] as "*an abstract functional model that represents the conceptualization of a need for the system, its realization, utilization, evolution, and disposal.*" The lifecycle outlines the stages that the system can go through depending on the process and methods carried out by its stakeholders.

ISO/IEC/IEEE 15288 describes various lifecycle processes of an entire system and is a well-known and widely adopted standard in the industry, while ISO/IEC 29110 is focused on Very Small Entities (VSEs) and defines a subset of requirements and process suitable for their lifecycle phases. In our analysis for suitability of standards, based on the complexity, size, PMTE, technology and people KPIs, the former is found to be more suitable due to it also being well-known, widely adopted, and adoptable.

The SEBoK [12] uses the ISO/IEC/IEEE 15288:2023 standard to define the *Vee Model* (see Figure 2) that establishes six lifecycle phases for an engineering system. After the *exploratory* stage, the *concept* phase is dedicated to finding the stakeholders' needs, comparing alternatives, and defining the roadmap. The *development* phase is dedicated to developing the systems that can solve the identified needs of the stakeholders. The *production* phase deals with manufacturing, testing and validation while the *utilization* phase describes the system being used by the end user. The *support* phase occurs when the system is maintained for its continuous operation. The last phase is the *retirement* phase, and it occurs when the system is disintegrated. When system is ready to move from one phase to another, it must satisfy specific criteria defined as the *decision gate*. The system moves to the next phase if it satisfies the criteria otherwise, it remains in the current phase with possible actionable activities to make it ready for the transition.

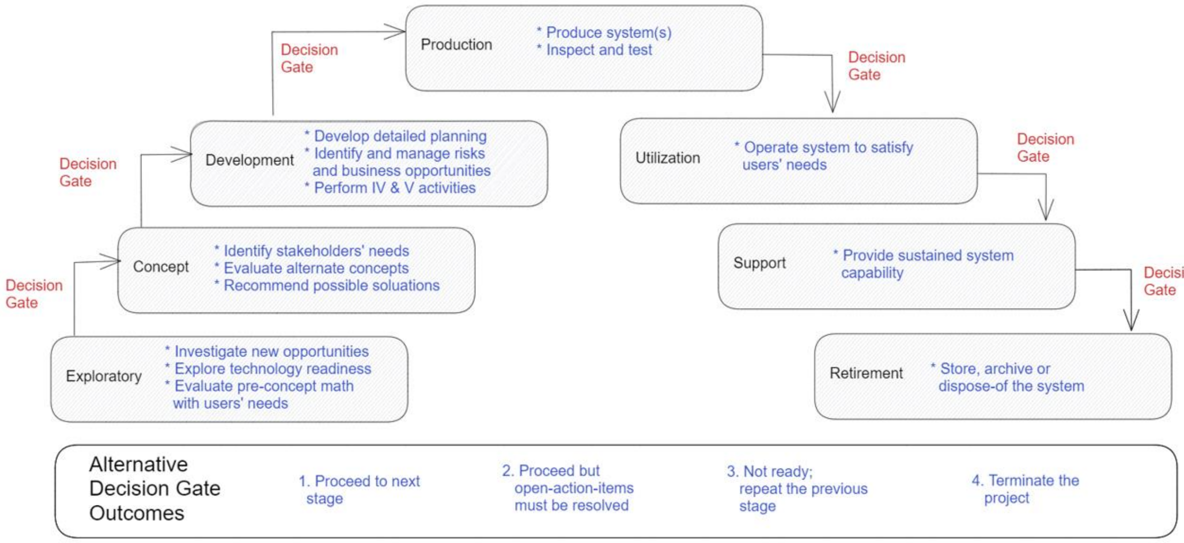

Figure 2 SEBoK Vee Model rendering ISO/IEC/IEEE 15288 lifecycle process [13]

Additionally, the standard also defines thirty major activities performed during the life of a system. These activities are grouped into four categories: agreement (two activities), organizational project-enabling (six activities), technical management (eight activities) and technical process (fourteen activities). With the focus on the *concept* phase (SEBoK Vee Model), the developed methodology, for this part of the work, is based on the first two *technical processes* (1. Business or mission analysis process and 2. Stakeholder need and requirements definition process). The methodology defines the steps to collect and process the inputs sequentially. At first, the focus was on identifying the stakeholders and various classes in which they appear in the use cases, along with lifecycle phases. Stakeholder interests are already reflected to some extent in the composition of the consortium of project ECOSINT. Leveraging the existing understanding of the energy sector and social landscape in the consortium, the stakeholder group is extended for the sake of completeness. Subsequently, representatives for each class of stakeholders were found and invited to a series of workshops[2] to elicit their respective requirements regarding LECs. These workshops

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[2] see https://ecosint.at/?p=339 and https://ecosint.at/?p=393

involved brainstorming and reflection sessions and were aided by preconceived input and custom templates to ensure purposeful progress and appropriate outputs.

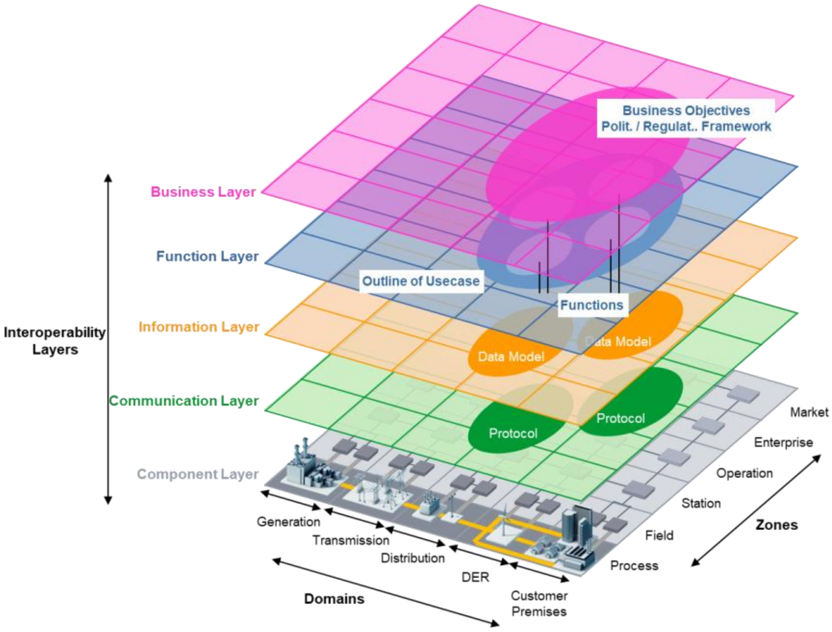

Figure 3: IEC SDR 63200 Smart Grid Architecture Model (SGAM) [13]

The next step involved analyzing and processing the recently acquired requirements to establish context and scope. This includes constructing the operational concept, prioritizing requirements, characterizing the operational environment and stakeholders, and conducting trade-off analyses. These requirements can be broadly classified into type, such as the design requirements, the functional requirements, the implementation requirements, the interface requirements, the performance requirements, and the physical requirements [14]. The analysis and modeling adhere to well-known EU and international standards and paradigms. The primary modeling methodology follows IEC 63200 [13], also known as the Smart Grid Architecture Model (SGAM) shown in Figure 3, utilizing the formal notation and semantics of UML and SysML. The specialized software Sparx Enterprise Architect[3] is employed for modeling, adhering to the Model-Based Systems Engineering (MBSE) paradigm. MBSE, unlike Documents-Centric Systems Engineering (DCSE), creates and utilizes models as the basis for systems engineering. These models are then used for design and development as well as for communication among multidisciplinary teams and stakeholders. This is achieved through a common visual language and framework representing system requirements, design, and architecture, thus reducing misunderstandings, and promoting collaboration. This methodology facilitates a comprehensive analysis of ICT system requirements for energy communities, spanning from initial conception to system disposal.

4 Mission Analysis

As mentioned in the Methodology section, we relied on ISO/IEC/IEEE 15288 to guide our efforts. This standard comprises the so called “Mission Analysis process” and this chapter

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[3] https://www.sparxsystems.com/

summarizes our efforts for performing a mission analysis concerning LECs. We used this to guide our discussions and workshops with stakeholders, as described in subsequent chapters.

On the highest level, all efforts concerning community energy generation arguably come from the desire to keep Earth habitable. Humankind depends on certain atmospheric conditions and keeping global warming below 2.0°C (or better 1.5°C), in comparison to pre-industrial levels, is crucial. The increasing temperatures can be attributed to the increasing concentration of CO_2 (and other greenhouse gases) in our atmosphere. These changes are caused by human activities and to stop it, we must severely limit our use of fossil fuels. This is usually referred to as “climate neutrality” and indeed, with the European Green Deal, the goal of the European Union is to become climate-neutral by 2050. Some countries have set even more ambitious goals, e.g., Austria by 2040 or Germany by 2045. Climate neutrality means, that a net-zero emission balance concerning greenhouse gases is reached. This does not necessarily prohibit all emissions, but the remaining emissions would have to be neutralized by carbon sequestration or offsetting measures.

Reaching climate neutrality requires transformations in all economic sectors. Electrification[4] and the transition to renewable energy sources (like wind and solar) is a crucial part of this transformation. This is where community energy comes into play. There is significant momentum in large-scale wind and solar projects, but enabling individual households to participate in this process will also play an important role, because to reach the ambitious goals, all existing potentials need to be leveraged. Energy communities should enable citizens to actively participate in the energy transition, promote the acceptance of decentralized production and supply and mobilize private investment. While there is a diverse and long tradition of community involvement in energy generation and the European Union also sees economic and social benefits in those communities, the primary purpose of energy communities can, in the end, be attributed to the existential risks of climate change.

Legally, the revised European Union Renewable Energy Directive (RED II) and Internal Electricity Market Directive (IEMD) provide the common framework for the promotion of energy from renewable sources in the EU [1] and introduce the concept of energy communities. The transposition into national law is ongoing, but with the ”Erneuerbaren-Ausbau-Gesetz” (EAG), it is already possible to establish renewable energy communities (”Erneuerbare-Energie-Gemeinschaften” in German language, or short ”EEGs”) in Austria.

Austria aims for net-zero power generation until 2030 and with renewable energy communities, the hope is to encourage further expansion of household photovoltaic (PV) systems[5]. Owners of household PV systems that participate in a renewable energy community can supply energy to the community. This is incentivized via reduced grid usage fees (”local tariff”) and tax exemptions. In Austria, the distribution system operator (DSO) also owns and manages the

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[4] Electrification is the replacement of technologies that run on fossil fuels with ones that run on electricity. It is estimated that electrification can cut primary energy consumption by 40% [17].

[5] Austria aims to expand its power generation capabilities by 27 TWh until 2030, of which 11 TWh should come from photovoltaics [16].

metering infrastructure and must supply the energy community with consumption data (in 15-minute resolution, on the following day, as mandated by the EAG).

The community members see, how much energy they consumed from their main electricity supplier and how much they consumed from (and/or supplied to) the community. As [2] states, “Energy communities can bring a host of benefits to the energy systems. They can support system operations by providing flexibility services locally and alleviating the need for traditional network upgrades.” However, the energy system is complex and highly dynamic, and every intervention (especially when scaling up) is associated with potential risks, for example, the risk of intensifying grid stress, the risk of negatively influencing grid reliability, the risk for market distortion and even the risk of social and/or environmental inequity. To ensure the reliable operation of the overall energy grid in the future, it is necessary to proactively think about the mass integration of such LECs. The ECOSINT project, which has already been described in [3] and [4], developed an Information and Communications Technology (ICT) architecture that allows for such an integration. Following the outlined methodology, a series of workshops was held to gather the requirements on this architecture from all related stakeholders.

5 Workshop 1: “Requirements of and on LECs”

The first workshop in 2021 focused on general requirement gathering. It was held in an online format and brought together representatives from a variety of relevant stakeholder groups such as prospective founders, operators, and members of LECs, hardware vendors, service providers, energy providers, grid operators, researchers, regulators, and sociologists. In accordance with ECOSINT’s holistic approach, no prior limitations, or distinctions, such as between functional and non-functional requirements were made.

Following a series of short impulse presentations introducing ECOSINT and the first examples of LEC projects, a first breakout session split the participants into three groups to discuss and collect their respective requirements from an inside view, an outside view, and a supporting/accompanying view. These were subsequently presented to the reassembled audience. A second breakout session forming the same groups provided an opportunity to consider, build upon and respond to the requirements brought forward by the other groups. Finally, the responses were presented, and the results were summarized. Interspersing the event was a series of short polls, asking participants which contributions they expect LECs to make towards the energy transition, how realistic the requirements of the other groups seem to them and finally to prioritize the requirements that have been gathered during the event.

Group one consisted of municipalities, operators, service providers, and members. Their requirements can be itemized and briefly summarized as follows:

- Avoidance of bureaucracy. LEC operation should be offered as a service, and legal requirements (such as the need to form associations) should be kept to a minimum.
- Possibility for citizen participation. Citizens should have opportunities to actively participate, to promote acceptance and awareness.
- Diversification of expansion. Energy generation should not be limited to PV, but the inclusion of other renewable energy sources should also be encouraged.

- Cost savings. The cost savings gained by LEC membership must not be canceled out by operational expenses.
- Maximization of expansion goals. It should be encouraged, that available resources (such as areas for PV panels) are utilized to their full extent.
- Avoidance of limiting factors for expansion. If there are limiting factors, an effort should be made to bypass them (e.g., alleviating grid restrictions by adding storage capacity).
- Privacy and security. The fact that more detailed monitoring of energy consumption may lead to increased traceability (and therefore decreased privacy) should be counteracted and all personal data that is stored needs to be stored securely.
- Simple messages in public communication. Complex topics should be explained and communicated as concisely and comprehensibly as possible to ensure mass appeal and to leverage existing goodwill.

Group two consisted of DSOs, energy providers, solution providers and hardware providers, whose requirements have been expressed as follows:

- Interoperability. For successful mass adoption, interoperability regarding hardware, software and communication is indispensable.
- Harmonization of tariffs. New tariff models that enable use cases such as joint usage of storage with the energy provider and for peak shaving are needed.
- Sustainable operation. Systems should be set up to be sustainable in the long term. E.g., provisions for replacement should be in place prior to major components such as storage systems reaching the end of their service life.
- Adherence to the costs-by-cause principle. An effort should be made to ensure that cost transparency is maximized and that new mechanisms cannot be exploited (e.g. by a party being rewarded for solving issues that have been induced by the same party).
- Live data. 15-minute interval data (provided by smart meters via PLC) is sufficient for billing, but for real-time control within LECs, live data is required.
- Replacement value calculation. A consensus needs to be established on how to handle missing data points (i.e., how to calculate replacement values for these data points).
- Multiple use of measurement data. It should be avoided to measure the same data multiple times (by multiple systems) for different systems, systems should rather share this data. E.g., if available, the customer interface of a smart meter should be used rather than an additional metering device.
- Low-threshold participation. LEC membership should be as easy as possible. This could be achieved e.g., via support from service providers, one-stop-shops, and offers from cooperatives. It should also be associated with a minimum of bureaucratic hurdles.
- ”How to“ Energy Community. Best practice examples and supporting materials such as model contracts should be (freely) available.
- Unified system architecture. For mass adoption and economic viability, a unified and modular system architecture is required.

Group three brought together research institutions, sociologists, economists, and regulators. They communicated the following requirements:

- Infrastructure. An infrastructure is required that enables practical and efficient LEC operation and grid friendliness. Season-specific parameters need to be considered.
- Use cases and business case(s). Concrete use cases and business cases need to be established to define commonalities and foster a common understanding.
- Robustness. The overall system needs to remain robust and negative effects on the grid need to be avoided.
- Standardized data exchange. Data must be exchanged reliably and using standards.
- Data for simulation. Field data needs to be made available to enable and improve simulations (e.g., to investigate possible interactions between LECs).
- Prioritizing utility over profit. While economic viability needs to be ensured, the utility should be prioritized. This may also motivate prospective participants who prioritize ecological benefits and for whom money is a lesser consideration.
- Simple start. For a quicker start, to gather practical experience, and to formulate best practice examples, initial projects should focus on obvious aspects and currently available technologies and devices, rather than wait for possible future developments.
- New forms of tariffs. New tariffs and/or tariff structures are needed to reflect the paradigm shift that LECs represent and thereby ensure that technical and economic possibilities are not stifled by bureaucratic hurdles.
- Tools. To gauge their potential prior to establishment and for their operation, new (software) tools are needed.

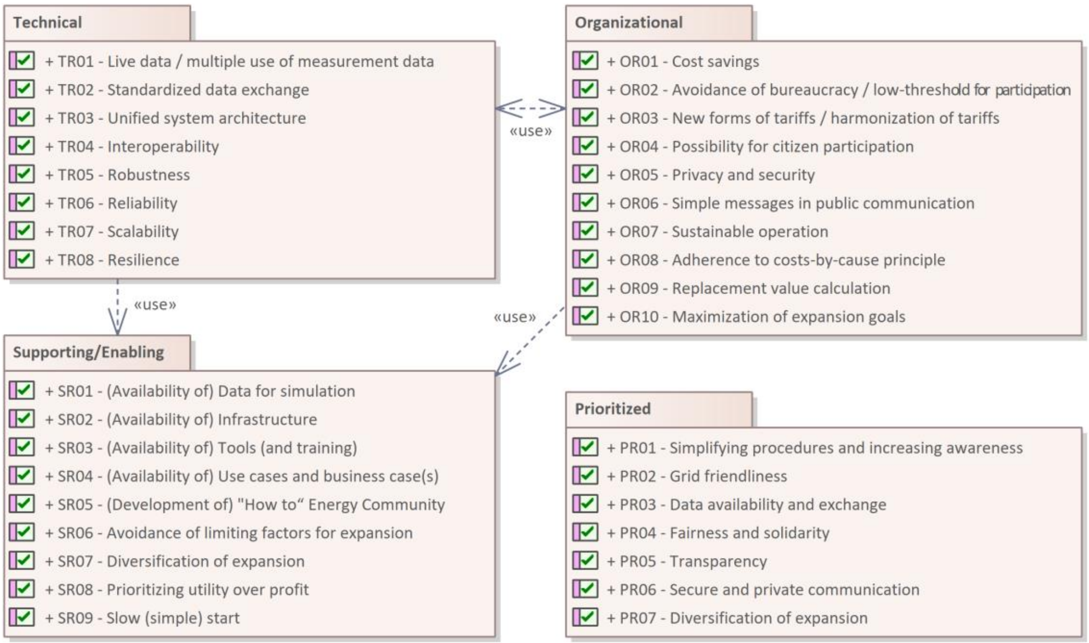

Figure 4: Requirement categorization, dependency interrelationships and prioritization

The final poll of the workshop asked participants to prioritize the requirements that had been presented and yielded the following result:

1. Simple handling (Avoidance of bureaucracy / Low-threshold participation, ”How to“ Energy Community)

2. Grid friendliness (Robustness, Sustainable operation, Maximization of expansion goals, Avoidance of limiting factors for expansion)
3. Interoperability
4. Data availability and exchange (Live data / Multiple use of measurement data)
5. Fairness and Solidarity (New forms of tariffs / Harmonization of tariffs, Adherence to costs-by-cause principle, Prioritizing utility over profit)
6. Transparency (Simple messages in public communication, Possibility for citizen participation, Replacement value calculation)
7. Privacy and security
8. Diversification of expansion

A more formal model of the requirements with dependency and derivation relationships as well as a summarized and prioritized list is presented in Figure 4. Following the approach outlined in ISO/IEC/IEEE 15288, the collected requirements were grouped into technical, organizational, and enabling requirements, subsequently focusing on the technical requirements which have been considered most relevant regarding the software architecture of LECs. A basic overview of how the prioritized requirements can be mapped to the original requirements is given in Figure 5.

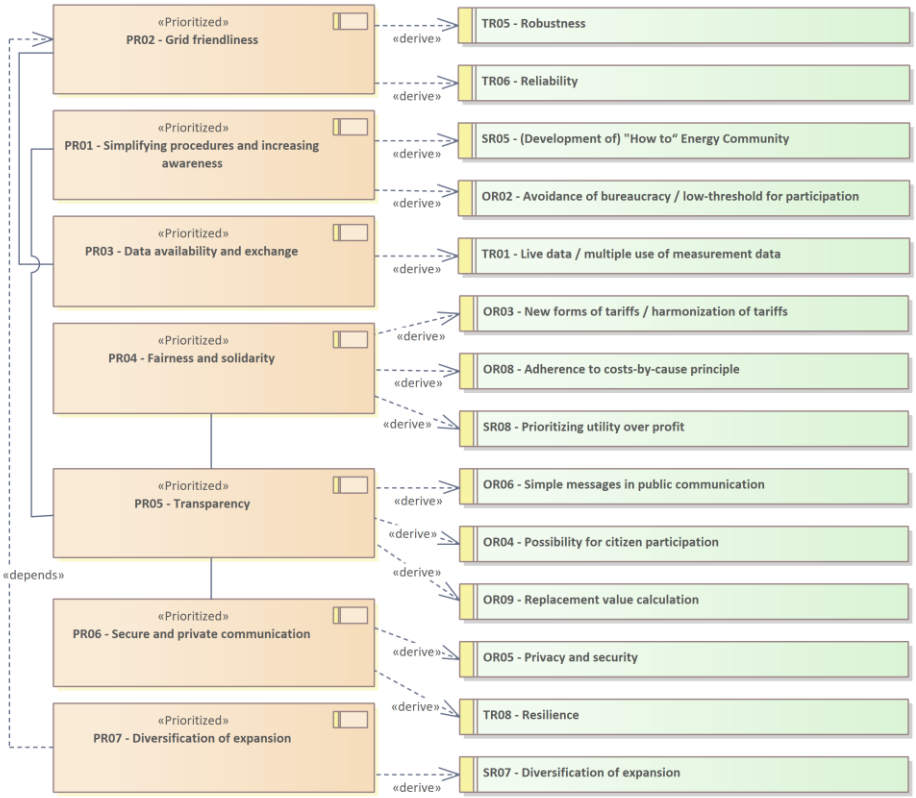

Figure 5: Details of the prioritized requirements extracted from the initial 27 requirements

6 Workshop 2: “ICT Architecture for LECs”

The second workshop, which was promoted similarly to the first workshop and to which all previous attendees were invited, was held in 2023 at the 12th Symposium on Communications for Energy Systems (ComForEn) as a hybrid event, combining physical and online participants.

Here, the audience comprised predominantly research institutions, regulators, and service/solution/hardware providers, many of which had attended the first workshop and thus were already familiar with project ECOSINT and its goals.

The workshop followed a similar structure to the preceding one, opening with an input session that consisted mainly of a presentation of the status of the development of the architecture and how it was influenced by the previously gathered input. The goals of this were to recap the prior event, to inform first-time participants, and to verify that the results so far appropriately reflect the needs that have been previously communicated. A first breakout session gave participants the opportunity to formulate feedback to this presentation.

This feedback consisted mainly of a confirmation that the modeling of the existing structures as well as some related assumptions (e.g., concerning details about the platform which is used by the energy industry to exchange data in Austria) were accurate. The architecture was also deemed to be generally adequate, although some minor oversights (such as the omission of a component in an overview) were pointed out and a need for clarification of some technical details was identified.

The second input session consisted of a presentation of possible topics on which to focus for the remainder of project ECOSINT. Again, the participants were divided into mostly homogeneous groups to discuss the presented topics and to formulate corresponding feedback. Among the different groups, the topics of flexibility (esp. regarding EV charging and heat pumps), data spaces (a topic which is also advanced by projects such as GAIA-X, the International Data Spaces Initiative and the European Data Strategy) and communication infrastructure/architecture (particularly infrastructure for live metering) were identified as the most critical issues on which to focus.

7 Business use cases

During the workshops and various discussions with stakeholders and within the project consortium, it became clear, that most of the discussions could be attributed to three main business use cases:

- *Self-consumption optimization*, meaning that energy that is generated within the energy community should preferably also be consumed within it.
- *Grid-friendliness*, meaning that the amount and timing of energy consumption and/or storage strategy (if batteries are present, either in the households or as a collectively owned asset) is managed according to the availability of grid resources. This is especially useful for bigger and shiftable loads like EVs or heat pumps.
- *LEC-internal energy trading*, meaning that members of an energy community can trade energy among each other.

While we intend to give a more detailed, formal presentation of our use cases in a future paper, our simplified, work-in-progress representation was loosely based on IEC 62559-2 [15]. As the scope of this paper is to present the gathered requirements and the formalization process, only the description of the first business use case “self-consumption optimization” and a discussion of how it ties in with the requirements is provided as an example.

As can be seen in Table 1, this use case relates to several prioritized and non-prioritized requirements.

Self-consumption optimization	
Use Case ID	UC01
Objective	Preferably consume energy that is generated within the energy community within the energy community (minimizing grid use, savings costs via local tariffs).
Beneficiaries	Energy community participants (via cost savings)
Actor(s)	• Energy community participants • Smart meters • Controller(s)
Trigger	Continuous
Preconditions	Live consumption and production data from all energy community participants available.
Assumptions	• Feed-In tariff is lower than energy tariff from the grid. • Local energy transmission cost is not prohibitive.
Result	A higher amount (than without the formation of the energy community) of the consumed energy within the community comes from local generation.
Normal flow	1. Energy community participants report consumption and production data. 2. Controller(s) calculate(s) the current power balance (i.e., production minus consumption). 3. Balance is announced and energy community participants (can) react on it.
Related requirements	• PR02 • PR03/TR01, broadly TR04, TR08 • OR01, broadly OR04, OR10

Table 1: Tabular business use case description for "self-consumption optimization".

Increasing the amount of self-consumed energy lowers the amount of energy, which is fed into and drawn from the grid, thereby reducing overall load, which can be considered grid friendly and consequently corresponds to PR02.

If appropriate incentives are given, this may further be improved by reacting to grid signals to consume/provide energy if possible. As a prerequisite, consumption and production data needs to be gathered and made available to one or several controllers, which relates to requirements PR03 and TR01.

In a broader view, it also requires interoperability between various systems and/or controllers (TR04), especially when reacting to grid signals. Relying less on the grid and more on local generation improves self-sufficiency and if storage is present, it may even be possible to operate independently for extended periods of time. This frees up grid capacity and therefore, in combination with more active grid-friendly behavior, helps to improve its resilience (TR08).

Assuming that the price of energy that is drawn from the grid is higher than the refund for energy that is fed into the grid and that overhead costs are not prohibitive, savings can be generated from this price difference and OR01 is met. Given that LECs include private households and not only corporate entities, OR04 is intrinsically met. Lastly, by incentivizing the local production of energy, it also contributes to OR10 to some extent.

8 Results and Outlook

In this paper, we presented the requirements regarding LECs (both from the view of the overall environment in which they operate and from the view of LECs themselves) that have been collected during the ECOSINT project. Furthermore, the methodologies and tools which were used to systematically gather and formalize them as well as the process by which they were incorporated in the development of a corresponding ICT infrastructure for LECs were discussed. The requirement gathering process (representing the first step of the outlined methodology) resulted in 27 formalized requirements that could be clustered into 3 categories (technical, organizational, and supporting). As exemplary requirements from the technical category, “standardized data exchange” or “resilience” can be named. The organizational requirements include aspects like “cost savings” or “avoidance of bureaucracy” and lastly, the “availability of data for simulation” is one example for the supporting category.

The 27 requirements can also be condensed into seven prioritized requirements, which can then be cross-referenced with three business use cases, namely, self-consumption optimization, grid-friendliness, and LEC-internal energy trading. Finally, Figure 6 shows a ranking of these business use cases by properties deduced from the requirements.

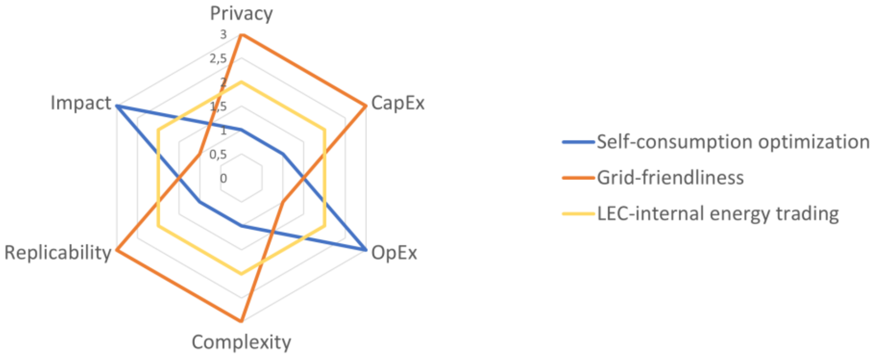

Figure 6: Key parameter assessment and ranking of the main business use cases (1= lowest, 3=highest)

All these considerations were taken into account to make informed design decisions regarding an ICT architecture for the mass integration of LECs into the energy grid (as described in [4]).

Based on the presented results and looking beyond the ICT architecture, future work could explore using a scenario-based approach, introducing stricter formal methodologies, or utilizing SGAM more widely to enhance the scalability and replicability of the proposed architecture. Additionally, as mentioned in Section 7, it may prove helpful to elaborate on high level use cases and stakeholder groups.

Author contributions

OL organized the workshops and documented the requirements. JK defined the formalization process. SL researched and gathered related work and formulated business use cases. All authors contributed to the requirement formalization process. JK and OL formulated the Introduction. SL wrote the Related Work and Mission Analysis Sections. SL and OL formulated the Business use cases Section. JK wrote the Methodology Section. OL wrote the Workshop 1 and 2 Sections. All authors collaborated on the Results and Outlook Section and read and approved the final manuscript. The overall contributions are OL (1/3), JK (1/3) and SL (1/3).

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