D3.2 – Characterization of new flexible players

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Author(s) information (alphabetical)

Name	Organisation	Email
Nikolaos Chrysanthopoulos	Imperial	n.chrysanthopoulos@imperial.ac.uk
Goran Strbac	Imperial	g.strbac@imperial.ac.uk

Acknowledgements/Contributions

Name	Organisation	Email
Christoph Schimeczek	DLR	christoph.schimeczek@dlr.de
Johannes Kochems	DLR	johannes.kochems@dlr.de
Laurens De Vries	TU Delft	l.j.devries@tudelft.nl
Ingrid Sanchez	TU Delft	I.J.SanchezJimenez@tudelft.nl
Hugo Algarvio	LNEG	hugo.algarvio@lneg.pt
António Couto	LNEG	antonio.couto@lneg.pt
Tiago Pinto	ISEP	tcp@isep.ipp.pt
Ricardo Hernandez-Serna	TNO	ricardo.hernandezserna@tno.nl
Dimitrios Papadaskalopoulos	Imperial	d.papadaskalopoulos08@imperial.ac.uk

Document information

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1.0	30.06.2021	Public	Report with detailed technical and economic characterization of the behaviour and capabilities of actors in the electricity market.
2.0	05.01.2024	Public	A revised edition of the report enriched according to sectoral updates related to the energy crisis and project developments in WP4 and WP5

Review and approval

Prepared by	Reviewed by	Approved by
Nikolaos Chrysanthopoulos Goran Strbac (Imperial)	Silke Johanndeiter (EnBW)	Ana Estanqueiro (LNEG)

Executive Summary

The subject matter of this report is the analysis of the electricity markets' actors' scene, through the identification of actor classes and the characterisation of actors from a behavioural and an operational perspective. The technoeconomic characterization of market participants aims to support the upcoming model enhancements by aligning the agent-based model improvements with the modern market design challenges and the contemporary characteristics of players. This work has been conducted in the context of task T3.2, which focuses on the factorization of the distinctive operational and behavioural characteristics of players in market structures. Traditional parties have been considered together with new and emerging roles, while special focus has been given on new actors related to flexible technologies and demand-side response. Among the main objectives have been the characterization of individual behaviours, objectives and requirements of different electricity market players, considering both the traditional entities and the new distributed ones, and the detailed representation of the new actors.

The second and last edition of this report is published amidst a transformative landscape, following the landmark agreement on electricity market reform that marks a concerted effort to adapt to the current challenges. Since is first edition, there has been a momentum of strategic initiatives like the REPowerEU plan, which seeks to rapidly reduce dependency on fossil fuels, the EU's emergency measures framework that provides immediate relief from soaring energy prices, and the comprehensive revision of the Strategic Energy Technology (SET) Plan, aligning it with the ambitious goals of the European Green Deal. Despite the transformative nature of all those initiatives, the actors' behaviour aspects and operation principles that were covered in the performed analysis have not been affected and the modelling approaches that were unfolded in T4.2.1 and followed this basis can be considered resilient and robust.

The report begins by presenting an overview of roles and actors of electricity markets through an exhaustive review of existing and developing representation and modelling approaches. The Harmonised Electricity Market Role Model (HEMRM) of ENTSO-E, ebIX and EFET, a commonly accepted role model is explored, while other frameworks such as the Universal Smart Energy Framework (USEF) and the Smart Grid Architecture Model (SGAM), and ontologies like the Open Energy Ontology (OEO) and the Smart Energy Aware Systems (SEAS) ontology are examined regarding the scope of the players and their roles. The HEMRM offers a harmonized and complete role representation, ensuring at the same time some degrees of freedom with respect to market design. The USEF focuses on the realization potential of flexibility with storage and demand response being at the center of its market organization proposal. The SGAM develops a technically robust approach around smart grid architecture while it inherits roles from HEMRM, and the ontologies provide the insight on the vocabulary required in representing the electricity market in models. Although these approaches originate from different starting points and follow their own evolvement path, they contain systematic ways under which actors have been identified and relationships have been examined on an effort of representing the electricity markets through the incorporation of actors in models. Therefore, the review of all those initiatives has provided a useful insight on how the issue of identification, analy-

sis and representation of actors has been tackled before and enabled the development of definitions and structures around actors.

The relation between the technological progress and the actor scene is an extra aspect considered as the groups of actors and interactions that exist are influenced by the emergence of new technologies, while at the same time new technologies are the outcome of R&D efforts of stakeholders. Definitions in the context of TradeRES of the actors and their roles are provided, while actor classes are identified. The main classes of actors considered are the Prosumer, the Producer, the Supplier, the Aggregator, the Trader, the ESCo, the Operator and the Regulator. The classes have been allocated into the four layers considered, namely the social, the physical, the aggregation and the market layer, while they have been used to provide a structure to the technoeconomic analysis that follows in two dimensions, namely the operational and the behavioural one. The actor classes are also considered under two broad categories, one focussing on the pre-existing and very common parties and another one where the emerging entities are concerned. Apart from the distinction between traditional and new actors' categories, the influence of technology on the assets' operation and consequently on actors' behaviour is considered. The technologies that actors can exploit for achieving their goals affect their positioning in the environment and the way of interaction. Therefore, part of the analysis has been also the mapping of actor classes and technologies relationships. Those relationships of actors and technologies have been considered from the scope of current and envisaged editions of agent-based models as well as from the overall vision of TradeRES project and depict the outcomes of the actor-related survey that was conducted inside the consortium. Similarly, the relationships of the actor classes with operational and behavioural aspects have been examined with respect to their intensity, completing that way the qualitative characterization of actors.

From the operational dimension point of view, we find that prosumers are strongly related to inflexible demand as well as demand side response attributes, with demand profiles being among the important ones. Load shedding and demand shifting are also found to be of high relevance in that class of actors, while energy saving appears to influence the operation. Storage and electric vehicle attributes exhibit strong relationships with prosumers, while industrial prosumers and energy communities seem to be connected with both controllable and non-controllable operational aspects. Energy communities are considered also in the role of a local network operator as they have been related, although mildly, to network parameters. Large generation is strongly affected by capacity and power limits, while the capacity factor and the generation profile seem to be among the most important aspects. Regarding distributed generation, emphasis is given to non-controllable generation and specifically to the generation profile. For the storage, either large-scale or distributed, attributes such as the energy limit, the charging/discharging limit and charging/discharging efficiency appear to matter. The aggregator is also among the class of actors that are affected by demand response attributes, renewable generation and storage characteristics since flexibility aggregation makes use of these technologies. The operators of the transmission and distribution systems have non-negligible connections to network operational attributes as they are affected by the topology, the line characteristics and the technical limits. From the behavioural perspective, prosumers seem to be driven mainly by utility maximization and cost minimization, producers incorporating the firm and investor aspects of microeconomics and along other business entities being more focused on profit maximization. While market operators mainly minimize costs, regulators focus on maximizing welfare including environmental, social and sustainability concerns by setting the legislation standards that affect several actors.

Both dimensions have been exploited for the proper characterization of actors that enable the incorporation of contemporary trends to the agent-based model formulation phase, where the objectives of players and the constraints will be enhanced. The Actor-ID cards that have been deployed are four-block tables that summarize the description, the main technologies, the operational attributes and the behavioural aspects for each actor class. The key findings of the analysis are presented through the cards and the main characteristics of the actors are pointed out.

The necessity emerging from the modelling needs of the “Local Energy Community” case study to design models that are oriented for simulation of markets and interactions, led to a requirement for an extensive review and solid foundation of the local environment, with the transactive energy paradigm integrating well within. Therefore, the second edition of report, in its last section delves into the innovative frameworks that are empowering prosumers and reshaping the energy landscape. A wide spectrum of emerging transactive energy approaches is analysed from the lens of actors’ characterisation. The evolution, ownership, and governance notions are discussed and the business models that underpin these approaches and affect the behavioural and operational shaping are also considered. The multifaceted benefits and challenges these developments pose to stakeholders, are also considered, and provide a reflection of the intricate interplay between innovation, regulation, and market dynamics.

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1. Introduction

1.1 Scope of the deliverable

This deliverable focuses on electricity markets' actors and, by considering their participation from a behavioural and an operational point of view, aims to perform their technoeconomic characterization that is to be used for the proper alignment of players' modelling. The exhaustive analysis of the spectrum of stakeholders can be considered an important step as it enables the identification of the behavioural objectives and operational requirements of the different parties involved in the markets and allows the better understanding of the interactions' dynamics that need to be incorporated in the modelling part of TradeRES project. This work has been conducted in the context of task T3.2 - *Factoring the distinctive operational and behavioural characteristics of new flexible players in market structures*, which precisely consists of the factorization of the distinctive operational and behavioural characteristics of players in market structures, with special focus on new actors related to flexible technologies and demand-side response. Among the main objectives of the task are the analysis of (i) individual behaviours, (ii) objectives and (iii) requirements of different electricity market players, considering both the traditional entities and the new distributed ones, as well as the detailed representation of those new actors. For covering those needs, a two-step methodology has been adopted, where first the identification and then the characterization of players take place. The identification part that has been supported by a review of the regulation, the institutions and the organizations in EU, a widely accepted market role model, an energy system framework and a smart grid architecture model connected to market models and ontologies that cover electricity markets. On the other hand, the characterization follows the findings of an actor-related survey that focused, from a qualitative point of view, to the relationships between the actors and (i) the technologies, (ii) the operational attributes and (iii) the behavioural aspects. For the survey development, key elements of other deliverables and important aspects found in the literature related to electricity market modelling and individuals/collectives' behavioural analysis, have been used. The survey has supported the identification of relationships from the scope of current and envisaged agent-based models as well as from the TradeRES project vision and therefore paved the way for the more model-oriented analysis that followed on WP4-related activities. This second edition has integrated recent developments in the sector and has been influenced by relevant advancements made within the project. More specifically, energy justice and democratisation, as the key policy principles motivating the prosumerism approach and the endorsement of energy communities have been discussed after the contemporary trends and policy interventions have been reviewed. After the analysis of the broad actor scene, special emphasis has been given to the local environment, covering from the traditional business models and extending the analysis from prosumer needs to stakeholder impact. The focus on the local environment is oriented primarily from the Local Energy Communities case study, which deals with lower level of market simulation conceived within TradeRES project that requires high-resolution representation of local actors. The development of models and the interpretation of results of other higher-level cases can also benefit.

1.2 Structure of the deliverable

The deliverable initially provides an overview of the roles and the actors found in electricity markets by reviewing existing and developing approaches. This part is covered in Section 2, where after a short introduction of the current electricity market framework, the recent policy updates and core policy drivers such as energy justice and democracy, the Harmonised Electricity Market Role Model (HEMRM), other frameworks such as the Universal Smart Energy Framework (USEF) and the Smart Grid Architecture Model (SGAM), and ontologies like the Open Energy Ontology (OEO) and the Smart Energy Aware Systems (SEAS) ontology are examined regarding the players and their roles. The relation between the technological progress and the actors' scene is an extra topic considered since the groups of actors that exist may be influenced by new technologies, while at the same time new technologies are the outcome of R&D efforts of stakeholders.

The identification of the actors and their roles in electricity markets is performed in Section 3, along with their classification that aims to provide a structure to the subsequent technoeconomic analysis. After providing the definitions that have been adopted for some key terms, the process of actors' identification that is held via the consideration of two broad categories, one with the pre-existing and very common parties and another one with the emerging entities, the traditional and the new actors' categories, namely, begins. Then the presentation of the main classes of actors, such as the Prosumer, the Producer, the Supplier, the Aggregator, the Trader, the Energy Service Company (ESCo), the Operator and the Regulator is given. The section concludes with the influence of technology on the actors, and specifically on their emergence and further specification with respect to their operation, behaviour and overall interaction with the rest of the system.

In Section 4, the technoeconomic analysis is performed. The analysis takes place with respect to two dimensions, the operational and the behavioural one. Both have been identified as the main dimensions required for a properly structured characterization of the players, since they cover the core parts needed in the modelling phase for the formation of the objective function and the constraints. To summarize the key findings of the analysis and point out the main characteristics of the classes of actors, a novel approach inspired by the demo identification cards used in BRIDGE initiative, has been adopted. Aiming to serve as a quick reference point, the so-called TradeRES Actor-ID cards that are presented in Section 5, include the most important information related to each of the actors and serve as a facilitator for further integration of players' characteristics in upcoming phases of the project.

Section 6 focuses on the local environment and uncovers a spectrum of emerging transactive energy approaches, highlighting the significance of Collective Self-Consumption (CSC), the fostering of Local Energy Communities (LECs), and the development of Positive Energy Districts (PEDs). It further explores the operational intricacies of Microgrids (MG), the efficiency of Smart Local Energy Systems (SLES), the self-sufficiency of District Self-Balancing (DSB), and the potential of Local Energy Markets (LEM). An in-depth analysis of these systems offers insights for the involved actors and the influence of ownership structures and governance attributes to their final shaping and representation, outlining key behavioural and operational factors. The section also presents a variety of business models, each with unique operational, financial, and engagement strategies designed to harness the benefits of transactive energy while navigating the complexities of the energy transition. From financial incentives and regulatory compliance to technological deployment and market acceptance, the section provides a comprehensive overview of the forces shaping the future of energy consumption and production at the micro-founded local environment. Finally, the deliverable concludes in Section 7 with some key remarks and extensions of the second and final edition.

1.3 Relationship with other deliverables and tasks

This deliverable uses several other preceding deliverables and tasks for gathering inputs and identifying key aspects in a wide range of related subtopics, varying from existing models and their coupling to market design principles.

The concepts tackled here are also closely relevant to other tasks of WP3 - *Market Design and Regulation for ~100% Renewable Power Systems*, in the sense that systems, products, services and markets are designed and developed with actors being the underlying driving force. Therefore, either from the system's performance point of view or by considering products and markets for core and ancillary services, stakeholders' behaviour, which arises from needs, is directed by incentives, is restricted by rules and is finally formed through repeated interaction of potentially strategic nature, is on the centre of the undertaken analysis.

Particularly, this deliverable heavily relies on information of other WP3 deliverables[1], such as D3.1 - *Performance specifications for a (near) 100% RES system* and D3.5 - *Market design for a reliable ~100% renewable electricity system*, while simultaneously receives inputs from WP2 and WP4 tasks, related to either the centralised or decentralized (agent-based) modelling approaches adopted in TradeRES project. Finally, it needs to be mentioned that the work conducted in T3.2, which is summarised in D3.2, has paved the way for the representation of actor types and behaviour through novel modelling techniques that have been the subject matter of subtask T4.2.1 - - *Identification of input/output and possible interfaces between models* and of the corresponding deliverable D4.4 - *New actor types in electricity market simulation models*. The focus of the local environment emerges from the needs and requirements of T5.2 - *Local Energy Communities: Case Study A*, a task that has motivated modelling work in T4.2.1 and qualitative analysis in T3.2, which is reported in this edition of the deliverable report. For that reason and due to the concurrent progression of the tasks, there has been a bidirectional flow of information, requirements and results between those tasks, especially during the second phases of T3.2. Finally, the work performed has paved the way for the a second and more coherent edition of D5.2, the deliverable that is about the "Performance assessment of current and new market designs and trading mechanisms for Local Energy Communities (Case Study A)".

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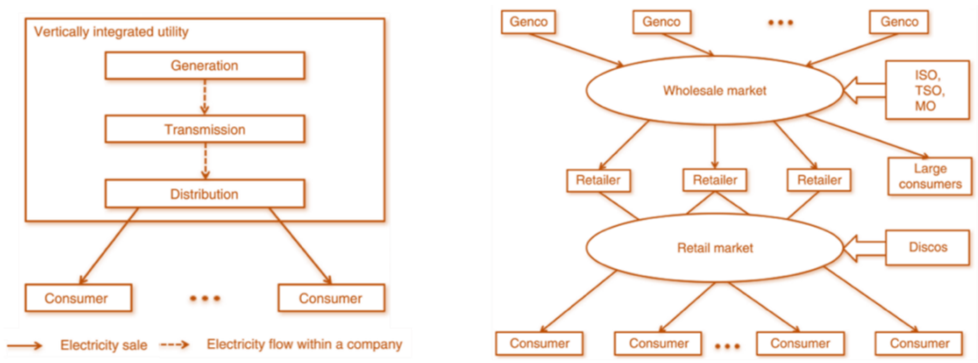
[1] All deliverables referenced in this report are publicly available at: https://traderes.eu/documents

2. Overview of roles and actors in electricity markets

2.1 Policy background and electricity markets

In accordance with the Paris Agreement and its objective to keep the global temperature increase to well below 2°C and pursue efforts to keep it to 1.5°C, the European Green Deal is an ambitious policy package with a wide range of actions and measures for the containment of climate change [1]. Among the most highlighted proposals is the emissions' reduction target which has been set to at least 55% below 1990 levels by 2030 and the long-term goal for climate-neutrality by 2050, which can be achieved through the transition to a sustainable and circular economy with net-zero greenhouse gas emissions.

With the energy system being at the centre of the undergoing transformation, the Clean Energy for all Europeans Package includes ambitious rules and puts forward the legislative parameters to reconsider for responding to contemporary challenges and maintaining the lead in the global energy transition for the coming years [2]. Its main goals are the prioritization of energy efficiency, the intensification of renewable energy sources (RES) take-up, the provision of a stable private investment enabling framework, the strengthening of rights and possibilities for consumers, and the establishment of a smart and efficient market able to guaranty high security of supply standards.



(a) (b)

Figure 1: (a) Traditional electricity supply model and (b) market with retail competition [3].

Given the three legislative packages that the EU has adopted in 1996, 2003 and 2009, respectively, the originally vertically integrated electricity systems, where a national monopoly owned and operated generation units and networks turned to competitive and integrated electricity market structures, with the core differences becoming even clearer through the schematics of Figure 1[2]. Consequent directives set common rules for the in-

[2] In Figure 1b, "Genco" stands for generation companies and "Discos" for distribution companies.

ternal electricity market, allowed new suppliers to enter Member States' markets, and also customers to choose their electricity supplier, while liberalized markets through the unbundling of supply, generation and networks sides and allowed third parties to access markets of increased transparency.

Essential have also been the reforms introduced in the Third Package for the integration of the market and the establishment of the legislative framework, parts of which provide the legal basis for the electricity market of today. Transmission and distribution networks have been also an aspect tackled further during that phase, with the roles of the operators becoming more specific. Noteworthy have been the efforts for cooperation between EU member states' authorities with an early tendency for harmonization. The creation of two entities, the Agency for Cooperation of Energy Regulators (ACER) [4] and the European Network of Transmission System Operators for Electricity (ENTSO-E), namely, has facilitated the design and promotion of policy frameworks, guidelines and network codes. The priority dispatch for renewables, the definition of shorter-term market models for electricity and an overall framework enhancing transparency in price signals for fair participation of different technologies have been among the concepts that promoted RES further. With rules for unbundling generation and supply from transmission networks being already in place, with the retail side being competitive and consumers more protected than before, with the national regulatory authorities being independent and the cross-border infrastructure enhanced, the new legislative proposals that European Commission (EC) introduced, focused on the further exploitation of the RES potential, on strengthening the security of supply, on enhancing energy efficiency in all sectors and on developing contemporary market designs.

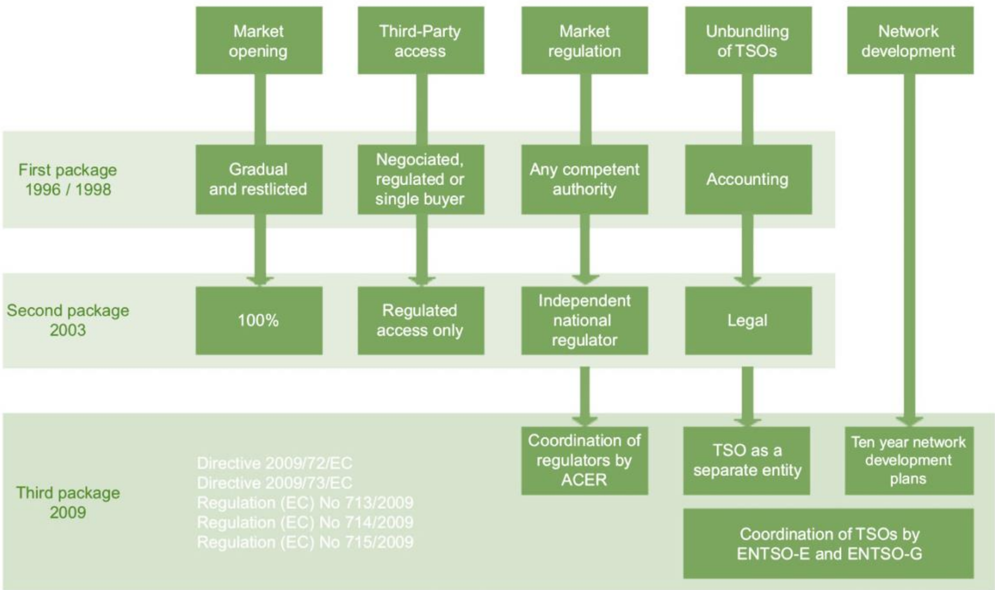


Figure 2: The three Energy Packages formed the basis of electricity market legislation [5].

The recent Directives and Regulations (2019) of EU add the market signalling objective to increase the system's flexibility, enhancing decarbonizing technologies and promoting innovation. Non-discriminatory market access is guaranteed for all resource providers and end consumers, with market-based remuneration being supported even for RES and demand side response (DSR), which is positioned at the centre of energy efficient demand [6]. The notion of aggregation on either the demand or supply side has been introduced for enabling consumers, small and medium-sized enterprises (SMEs) and citizen energy communities (CECs) to participate in the market. The aggregators can perform multiple functions such as assist balance responsible parties through their portfolio optimization allowing minimizing imbalances. Certain goal of the rules set has been the further incentivization of investments in the fields of low carbon generation, energy efficiency, distributed storage and DSR, with clear remuneration processes and equal opportunities.

From a market perspective, the integrated day-ahead and intraday markets are managed jointly by the Transmission System Operator (TSO) and a Nominated Electricity Market Operator (NEMO), while trading should be as close as possible to real time. Decisions ranging from bidding zones' definitions to transmission capacity allocation and congestion management should aim to maximize the economic efficiency, facilitate the cross-border trading and maintain high security of supply standards. All market participants, who should have access to the balancing markets, are set responsible for the imbalances they cause [7], while they can also delegate that responsibility. Beyond certain exceptions, the market-based dispatch includes the RES as well, with priority being restricted only to small previously benefited projects. Long term actions of the TSO and Distribution System Operator (DSO) should target the minimisation of low-carbon generation's curtailment or redispatching, both representing processes governed by non-discriminatory, transparent and objective criteria.

In this legislative framework, design principles for effective, although temporary, capacity mechanisms have also been included, to address the resource adequacy problem in the medium and long run by ensuring that adequate generation resources exist for meeting electricity demand, given the reliability standard that indicates the security of supply level needed [8]. In addition to ENTSO-E's existing tasks and responsibilities, regional coordination centres[3] with clearly defined mission, geographic scope and tasks have been introduced to ensure that the operation of interconnected transmission systems is even more reliable and efficient. A new entity for enhancing the cooperation of DSOs at the EU level, the EU DSO entity[4] has been described along with its rules, procedures and tasks targeting to the completion of the internal market through the promotion of optimal network management and coordinated operation of distribution and transmission systems.

The presented EU regulations together with the more technical regulatory documents, the network codes (NCs), constitute the framework that governs stakeholders' operation and participation in electricity markets. Beyond the differentiation of markets with respect

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[3] Often called regional operation centres (ROCs).

[4] https://www.eudsoentity.eu/

to the geographical scope, ranging from local markets to transnational wholesale markets, another core classification aspect is the timeframe at stake. Based on the market or contract type, transactions may refer to many years in advance (long-term contracts, derivative products in future and forward markets), to the following day (day-ahead market), to a specified short time period (intra-day market) and to real-time balancing (balancing market) [9]. The different timeframes along with the main objective served by each type of market and the key regulative documents are presented in Table 1.

Table 1: Different timeframes, market types and objectives [10].

Managing Risk	**Managing Energy**		**Managing the System**
Forward Market	**Day-Ahead Market**	**Intraday Market**	**Balancing Market**
• Market players managing price risks • Forwards, futures and transmission rights	• Market players balancing their physical positions • Operational planning, capacity allocation, congestion management		• TSO balancing the system in real time • Re-dispatching, frequency control and incidents management
Years ahead to 24 h prior hour of operation	12-36 h prior hour of operation	> 5 min[5] - 1 h prior hour of operation	Hour of operation
Forward capacity allocation	**Capacity allocation and congestion management**		**Electricity balancing guidelines**
Regulation (EU) 2016/1719 [11]	Regulation (EU) 2015/1222 [12]		Regulation (EU) 2017/2195 [7]

2.1.1. Electricity in EU: recent trends and policy updates

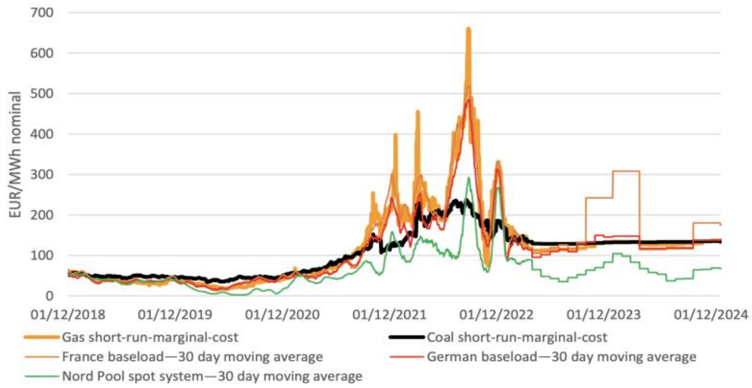
The energy and power sector in the European Union (EU) is currently navigating a period of significant transition and challenge, spurred by the recent energy crisis. This crisis has catalysed an urgent reassessment of energy policies, with an emphasis on enhancing energy security, diversifying supply sources, and accelerating the shift towards renewable energy. The EU's response is multifaceted, including immediate measures to mitigate the impact of soaring energy prices on consumers and longer-term strategies to achieve energy independence and sustainability. Policies are being updated to support the rapid expansion of renewable energy capacity, increase energy efficiency, and reduce dependency on imported fossil fuels, all under the broader ambit of the European Green Deal. This proactive stance reflects a commitment to not only address the immediate crisis but also

[5] Updated. Shorter gate closure times (even zero minutes) exist and are an important step in development of the real-time continuous markets, allowing participants to adjust their balances as close as possible to delivery.

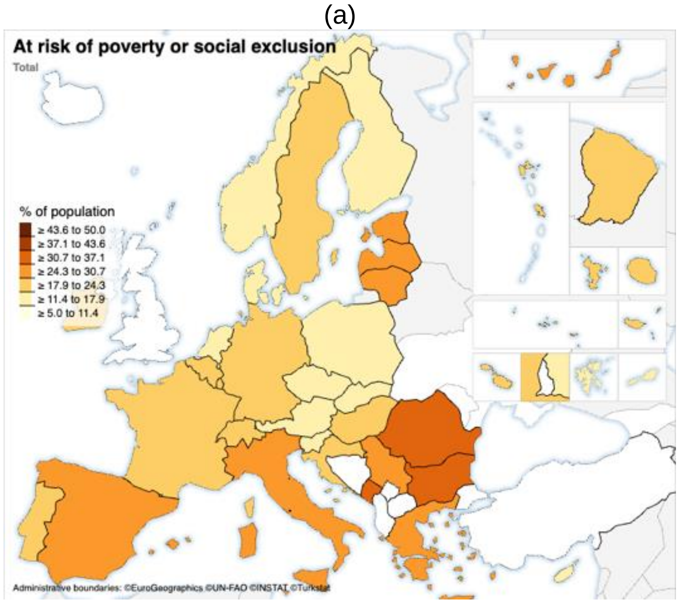
to reinforce the foundations for a resilient and sustainable energy future for all member states.

The unprecedented prices, as seen in Figure 3 (a) [14], that were largely driven by gas prices and prompted the European Commission to establish an emergency framework. The framework, introduced in September 2022, structured interventions around three main pillars:

1. A coordinated effort to reduce peak electricity demand by 5%.
2. The imposition of a price cap on infra-marginal technologies to generate revenue for other measures.
3. Direct consumer support mechanisms to alleviate rising living costs due to increased energy prices.



(a)



b)

Figure 3: (a) Daily power price and short-run marginal costs [14]; (b) Population at risk of poverty [15].

These interventions saw various implementations across EU member states, including direct subsidies to consumers, reductions in energy taxes or VAT, network tariff adjust-ments, and the re-introduction or reform of retail price regulations. The overarching goal was to protect consumers, ensure the continuity of energy supply, and maintain market stability without excessively distorting market dynamics or incentivizing inefficient energy consumption, taking into account the pressure on households in terms of energy poverty and social exclusion risks overviewed in Figure 3(b) [15]. As can be seen in Figure 3 (a), there has been a notable decrease in wholesale electricity prices. During the second quarter of 2023, have been marked by, with the European Power Benchmark averaging 89 €/MWh, which is 53% lower than the same period in the previous year. This trend was consistent across almost all EU countries, with the most significant year-on-year price drops observed in Finland, France, and Spain. Contributing to this decrease in prices has been the increase in electricity generation from renewables, which rose to 46%, and a concurrent reduction in fossil fuel-fired electricity, which fell to 30%. This shift towards renewables was accompanied by a 9% increase in output from combined solar and wind generation, while coal and gas-fired generation saw substantial declines. Alongside these changes, the EU's electricity consumption decreased by 6%, with June 2023 recording even lower demand than the COVID-impacted levels of June 2020 [17].

Figure 4 [16] shows an estimation of the allocated funding of EU countries to shield households and firms from the energy crisis. While these interventions were initially meant to be temporary, they were extended due to ongoing concerns about electricity supply and prices. The situation underscores the need for a balance between immediate relief for consumers and the longer-term goal of a sustainable and competitive energy market in the EU. The crisis has highlighted the importance of accelerating the market's structural reform to incorporate long-term contracting and hedging opportunities for consumers, potentially leading to a hybrid market model that blends liberalized market mechanisms with state intervention and long-term contractual agreements.

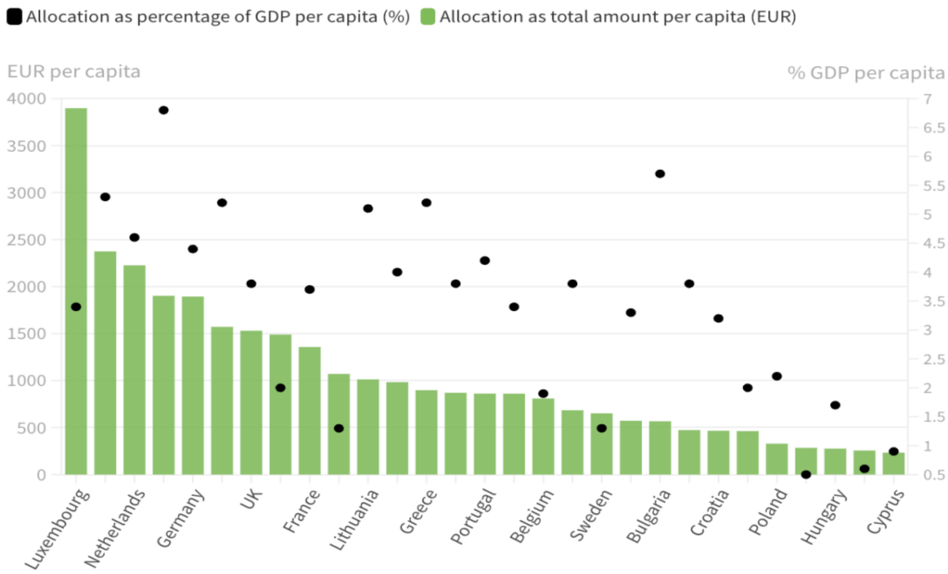


Figure 4: Governments earmarked and allocated funding to shield households and firms from the energy crisis (Sep 2021 - Jan 2023).

These shifts in market dynamics coincide with the European Commission's welcome of the provisional agreement on electricity market reform [18]. This agreement, reached on December 14, 2023, aims to construct a renewables-based energy system to lower energy bills, protect consumers from price spikes, and empower them to benefit from the energy transition. This reform aligns with the European Green Deal and the REPowerEU Plan, proposing a sustainable and independent energy supply for the EU and a cleaner, more competitive European industry through better access to affordable, renewable, non-fossil energy [19].

The reform features revisions to the Electricity Regulation, the Electricity Directive, and the REMIT Regulation. It emphasizes the broader use of long-term contracts for clean power production and introduces non-fossil flexible solutions like demand response and storage into the system. It aims to give consumers a wider choice of contracts, clearer information, and the option to lock in secure long-term prices, while also allowing for dynamic pricing contracts to take advantage of price variability. Additionally, the reform seeks to enhance consumer protections, reduce supplier failure risks, and protect vulnerable consumers, especially during crises.

Moreover, it enables consumers, including businesses and public authorities, to play an active role as prosumers participating in energy sharing. They can invest in wind or solar parks and sell excess rooftop solar electricity locally. It also encourages Member States to facilitate the deployment of renewable energy by consumers through plug-in mini solar systems. For the industry, the reform facilitates the deployment of stable long-term contracts like Power Purchase Agreements (PPAs), obliges Member States to ensure the availability of market-based guarantees for PPAs, and boosts liquidity in markets for long-term contracts. It also introduces Contracts for Difference (CfDs) or equivalent schemes for public support for new investment in renewable and low-carbon electricity generation. In essence, the provisional agreement marks a significant step towards enhancing the flexibility and future-proofing of the EU's power system, supporting the EU's aspirational target of 45% renewable energy by 2030, and aiding Member States in increasing non-fossil flexibility. This agreement now awaits formal adoption by the European Parliament and the Council before it can come into force.

Before the market reform, the Strategic Energy Technology (SET) Plan, the European Union’s cornerstone for the facilitation of the development and deployment of low-carbon technologies, was also revised. The revised SET Plan pivots around ten key action areas encompassing the entire innovation chain—from research to market uptake [20]. It addresses critical sectors like integrating renewables into energy systems, cost reductions, consumer technology, and services, enhancing energy system security, new materials for buildings, and energy efficiency for industries. The Plan spotlights the competitiveness in the battery sector, e-mobility, renewable fuels, bioenergy, carbon capture, and nuclear safety.

Recognizing the interlinkage of digitalization with energy transition, the revised SET Plan puts forth a task force approach to address cross-cutting issues such as the digital transformation of the energy system, ensuring the circularity of clean energy materials, and societal acceptance of the transition. The Plan also underscores the need for a skilled workforce, advocating for large-scale skill partnerships and tapping into various European funds to bolster green skills and jobs.

Key actions are categorized into specific focus areas:

1. **Renewables**: Enhancing the performance of renewable technologies and integrating them into the energy system.
2. **Energy Systems**: Developing new technologies and services for consumers, ensuring resilience and security.
3. **Energy Efficiency**: Creating new materials and technologies for buildings and improving energy efficiency in the industry.
4. **Sustainable Transport**: Achieving competitiveness in the global battery sector and promoting e-mobility.
5. **Renewable Fuels and Bioenergy**: Boosting the use of renewable fuels and bioenergy sources.
6. **Carbon Capture Storage and Use (CCS-CCU)**: Advancing technologies for carbon capture and storage/use.
7. **Nuclear Safety**: Ensuring the safety of nuclear energy operations.

The specific technologies or domains that are related to each key action are:

- Offshore wind, photovoltaics, deep geothermal, ocean energy, concentrated solar power, and solar thermal electricity are all integral parts of expanding renewable energy capacity and reducing costs.
- Energy systems are further developed through positive energy districts and high voltage direct current (HVDC) innovations.
- Energy efficiency is targeted in both buildings and industry.
- The sustainable transport objective is supported by advancements in batteries and renewable fuels, including bioenergy.
- Carbon capture storage and utilization (CCS – CCU) and nuclear safety each have dedicated IWGs to advance technologies and ensure environmental and operational safety.

2.1.2. Energy justice and energy democracy

The SET Plan's comprehensive approach involves a wide array of stakeholders and reflects the EU's commitment to a holistic and inclusive energy transition. Together with the temporary measures and the market reform, show in practice the role of policymaking and regulation in setting the environment within which actors interact. Energy justice and energy democracy are critical concepts in the context of a fair and equitable energy transition. They encompass the principles that energy systems should be fair, inclusive, and sustainable for all.

The following Energy Justice Principles [21] may be of particular interest to policy design, implementation and evaluation:

1. **Availability**: Energy systems must ensure access to adequate, reliable energy resources and infrastructure for all. This includes the provision of energy supply and technologies for conservation, transportation, storage, and distribution.
2. **Affordability**: Energy services must be financially accessible, preventing undue burden, particularly on disadvantaged consumers. This encompasses fair pricing and price stability.
3. **Due Process**: Communities should have the opportunity to participate in energy policymaking and projects impacting them, ensuring fairness and consent in decision-making.
4. **Transparency and Accountability**: People deserve access to clear, accountable information on energy and environmental policies. This principle calls for democratic decision-making and anti-corruption measures.
5. **Sustainability**: Energy resources should be used in a manner that does not deplete them rapidly, avoiding undue environmental harm.
6. **Intragenerational Equity**: Equal opportunities for accessing energy services should be available to all present-day individuals, regardless of their social group.
7. **Intergenerational Equity**: Future generations should also have access to good quality of life and energy services, emphasizing sustainable practices and climate change mitigation.
8. **Responsibility**: All actors, especially those in positions of power, have a duty to protect the environment and reduce the negative impacts of energy production.
9. **Resistance**: Individuals and communities should actively oppose projects and practices that are unjust and violate energy justice principles.
10. **Intersectionality**: Energy justice intersects with broader social justice issues, such as race, class, gender, and power dynamics, and must be considered in this wider context.

A just transition advocates for an inclusive approach to decarbonization, ensuring gender parity, climate justice, and rectification of historical injustices. The language of energy justice provides a framework to address how access to energy is often skewed by social, economic, and political factors. Energy democracy represents the collective call for a participatory approach to energy systems, where communities have a say in decision-making and some degree of control. This concept encourages bottom-up demands for systemic changes, ensuring that energy policy decisions and the structure of the energy sector reflect the will and participation of the people.

Local initiatives, such as energy cooperatives, embody the intersection of energy democracy with community organizing. These cooperatives enable local energy planning and decision-making to align with community priorities, often reflecting broader goals related to the control, finance, and ownership of energy resources. Energy justice and energy democracy advocate for a transition that is not only technically and economically sound but also socially and environmentally equitable. They challenge the energy sector to consider the human dimensions of energy policy, ensuring that the shift towards sustainable practices is also a shift towards greater equity and empowerment for all.

2.1.3. Organisations in EU

Electricity markets are constantly monitored, with the Energy market observation system (EMOS), a system maintained and operated by the Market Observatory for Energy, being the tool that facilitates data feeding and analysis of the Directorate-General for Energy. The ENTSO-E Transparency Platform provides also open and continuous access to pan-European electricity market data for all users, covering for categories such as the demanded load, the generation capacities and dispatches, the transmission and balancing details, the outages and congestion management reports [13]. The European Commission publishes reports on European electricity markets on both a short (quarterly) and long run basis, focusing on the evolution of prices, volumes and countries' interactions and analysing the underlying factors. There is also the EurObserv'ER[6], with its RES barometers and RES policy reports that monitors and analyses the development of renewable energy sectors in the EU, while at the same time evaluates the progression made given the objective set by the European commission. Market reports and outlooks are issued also by intergovernmental organisations and agencies like the International Energy Agency (IEA) and the International Renewable Energy Agency (IRENA). Although the IEA[7] was initially established in response of Organisation for Economic Co-operation and Development (OECD) to the oil crisis, nowadays it has a more energy policy advising role with energy security, economic development, environmental protection and climate change mitigation orientation. IRENA[8], which has been more recently founded, aims on facilitating cooperation, advancing knowledge, promoting RES adoption and enhancing sustainable energy initiatives.

There are also a number of institutions and observatories with subject closely related to the energy sector and electricity markets. One such example is the Energy Watch Group[9] (EWG), an independent non-profit global network of scientists and parliamentarians, which aim to influence political actions towards 100% renewable energy and climate protection. Another one is the International Energy Forum[10] (IEF), an organization consisting of energy ministers from several countries, some of which are EU member states, with a broad mandate covering for many energy issues, such as oil and gas, clean and renewable energy, sustainability, energy transitions and new technologies. The World Energy Council[11], an accredited by the United Nations non-governmental (NGO) and non-commercial organization with a long history, as an impartial global network of many na-

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[6] https://www.eurobserv-er.org/
[7] https://www.iea.org/about
[8] https://www.irena.org/aboutirena
[9] https://energywatchgroup.org/about-us
[10] https://www.ief.org/about
[11] https://www.worldenergy.org/about-us

tional Member Committees that connects energy leaders, industries, governments, innovators and experts across the world, constitutes another example. Many other regional and local energy and greenhouse gases (GHG) observatories exist (Table 2) and play an important role in the implementation of efficient strategies at the local level, with an indicative and not exhaustive list covering for the informal European network of ENERGee Watch project[12] (H2020 funded).

Other notable associations are the European Federation of Energy Traders (EFET), the Union of the Electricity Industry (Eurelectric), the European Federation of Local Energy Companies (CEDEC), the European forum for energy business information exchange (ebIX). EFET[13] is the association of European energy traders in wholesale electricity and gas markets, while beyond its general purpose of promoting and facilitation energy trading in open, transparent and liquid wholesale markets, as a standard setting body, aims to provide standard solutions to common aspects of wholesale energy transactions. Eurelectric[14] is the sector association that represents the common interests of the electricity industry at pan-European level by covering for issues ranging from generation and distribution networks to markets and customer issues. CEDEC[15] represents the interests of medium-sized local and regional energy companies, active in electricity and heat generation, supply, distribution and metering operations, while GEODE[16] focuses particularly on energy distribution. Finally, ebIX[17] is a non-profit European organisation aiming to advance, develop and standardise the electronic information exchange in the European energy industry, by providing harmonised processes for the liberalised downstream electricity, compatible with European and national rules.

Examples of organizations with a more special focus are the REScoop.eu, the European federation of citizen energy cooperatives that aims to represent citizens and energy cooperatives in the European energy debate, the WindEurope, a non-profit organization that represents the wind industry and actively promotes wind energy, the SolarPower Europe, a member-led association that aims to promote solar as the core of a smart, secure and sustainable energy system, the European Association for Renewable Energy EUROSOLAR[18], an independent non-profit association supporting the transition to a sustainable environment-friendly economy based on 100% renewable energy, the World Council for Renewable Energy[19] (WCRE), an independent global network of NGOs, companies and scientific institutes acting in the fields of renewable energy, environmental protection and development aid and European Green Vehicles Initiative[20] (EGVI), a contractual Pub-

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[12] https://energee-watch.eu/
[13] https://efet.org/about-us/
[14] https://www.eurelectric.org/about-us/about-eurelectric/
[15] http://www.cedec.com/en/about-us
[16] https://www.geode-eu.org/
[17] https://www.ebix.org/
[18] https://www.eurosolar.de/en/index.php/eurosolar/head-office-eurosolar-bonn
[19] https://www.wcre.org/index.php/about-us
[20] https://egvi.eu/who-we-are

lic Private Partnership dedicated to promoting and facilitating pre-competitive research on road transport vehicles within the European Research Area and focused on delivering green vehicles and mobility system solutions which match the major societal, environmental and economic challenges.

Table 2: List of regional and local energy and GHG emissions observatories

Regional Energy and GHG Emissions Observatories
Technical Chamber of Greece Energy Observatory [GR]
OREGES – Centre-Val de Loire Regional Energy and GHG Observatory [FR]
Nord-Pas-de-Calais Climate Observatory [FR]
Zlin Region Energy Monitoring Centre [CZ]
SiReNa20 – Energy and Environmental Observatory of Lombardia Region [IT]
Liguria Region Energy and Environment Observatory [IT]
Energy and Environmental Observatory of Kent [UK]
Energy Observatory of the Metropolitan City of Torino [IT]
Local Sustainability Observatory of the Basque Country [ES]
North Sweden “Energiluppen” [SE]
Energyhub.ie, Carlow Kilkenny Regional Energy Observatory [IE]
ROECC – Regional Observatory for Energy, Environment and Climate [BG]
ANERGO – Alba eNERGy Observatory [RO]
OREGES Poitou-Charentes, Regional observatory for Energy and GHG emissions [FR]
ROSE – Regional Observatory for Energy and GHG Emissions [FR]
ORECA Region Sud [FR]
Inventory of GHG of the Basque Autonomous Community [ES]
OREGES Rhone-Alpes Regional Observatory for Energy and Greenhouse Gases emissions [FR]
Hallbarometer, Norrbottens County [SE]
OPTEER – Regional observatory for energy climate and air [FR]

Based on this short overview of trends and policies related to the energy sector and the structures and associations involved, it can be said that there is a significant number of several stakeholders behind this multibillion industry, with each one of them playing their role and serving their interests.

2.2 The Harmonized Electricity Market Role Model (HEMRM)

The Harmonized Electricity Market Role Model has been a continuous effort of ENTSO-E and the associated organizations EFET and ebIX to develop a Role Model capable of representing several domains within the electricity market. The main aim of the initiative that started several years ago, with the first version being launched almost ten years ago, has been the facilitation of the dialogue between market participants with a particular focus on the development of ICT solutions under a common terminology. Although such a model mainly focuses on the information interchange in the electricity market rather than the market structure itself, it has been a structured and organized way to identify roles and interactions.

This way of harmonization has evolved in parallel to the extension of the common information model (CIM) of International Electrotechnical Commission (IEC) into the context of European markets (IEC 62325). That extension set the ground for developing and integrating software applications related to the deregulated energy market's data exchanges. On the other hand, the CIM has been an abstract model of representing all the major objects in an electric utility enterprise typically needed for modelling operational aspects and considers energy, generation and distribution management systems by defining a common vocabulary and creating a basic ontology. The CIM vision of IEC 61970 includes the core with the operational limits and the topology on top of which all other notions (wires, generation, protection, outage, control area, load model, etc.) are developed. Similar to the CIM, which is maintained as a Unified Modelling Language (UML) model, the class diagramming technique has been used to represent the HEMRM. Two of the UML symbols are mostly used, the "actor" symbol that is used for representing a role and shouldn't be confused to the actors of the market, and the "class" symbol is used to define a domain.

Beyond the two structural elements of the Role Model, the role and the domain, there is also the conceptual component of the actor. Based on the description of the model, the roles represent the behaviors deployed by different parties, as perceived from the system's point of view, and may include the external business interactions with other parties. Identified delimited areas, where the consumption, production and/or trade of energy take place, are represented by the domains. Actors, finally, cover for the parties that are active in the market and participate in business transactions. Based on the regularity and legislative framework that has formed the environment, actors undertake one or more roles during their operation. For keeping the Role Model free from any given market instance and independent of business processes specifics, actors do not appear directly in the model so that the electricity market is decomposed into a set of autonomous roles and domains. Although HEMRM does not provide a direct description of the parties, the structured overview of their roles that it provides can be found useful in identifying and categorizing actors. Table 3 presents the roles of HEMRM 2020-01 and interrelates them with three very broad labels that aim to characterize the role's reference. The "Connected Party" label refers to parties that have physical subsistence, the "Market Party" label covers for parties that are involved in market operations and transactions, while the "Operators" label which is analyzed further to "Market Facilitation", "Grid Operation" and "Meter Operation", covers for activities related to the system operation.

Table 3: HEMRM 2020-01 roles

ENTSO-E, EFET and ebIX HEMRM 2020-01		Connected Party	Market Party	Operators		
Number	**Role Name**			**Market Facilitation**	**Grid Operation**	**Meter Operation**
1	Balance Responsible Party		X			
2	Balancing Service Provider	X	X			
3	Billing Agent	X	X	X	X	X
4	Capacity Trader		X			
5	Consumer	X				
6	Consumption Responsible Party		X			
7	Consent Administrator			X		
8	Coordinated Capacity Calculator				X	
9	Coordination Centre Operator			X	X	
10	Data Provider		X	X	X	X
11	Energy Service Company (ESCo)		X			
12	Energy Supplier		X			
13	Energy Trader		X			
14	Grid Access Provider			X		
15	Imbalance Settlement Responsible		X	X		
16	Interconnection Trade Responsible			X		
17	LFC Operator				X	
18	Market Information Aggregator			X		
19	Market Operator			X		
20	Merit Order List Responsible		X	X		
21	Meter Administrator		X			X
22	Meter Operator		X			X
23	Meter Data Administrator		X			X
24	Metered Data Aggregator		X			X
25	Metered Data Collector		X			X
26	Metered Data Responsible		X			X
27	Metering Point Administrator		X			X
28	Nominated Electricity Market Operator			X		
29	Nomination Validator				X	
30	Party Administrator			X	X	X
31	Party Connected to the Grid	X				
32	Producer	X				
33	Production Responsible Party		X			
34	Reconciliation Accountable		X			
35	Reconciliation Responsible		X			
36	Reserve Allocator			X		
37	Resource Aggregator		X			
38	Resource Provider	X				
39	Scheduling Agent		X			
40	Scheduling Area Responsible		X			
41	System Operator				X	
42	Trade Responsible Party		X			
43	Transmission Capacity Allocator			X		

Beyond the actor, role and domain notions, the HEMRM 2020-01 version introduces the resource, the account and the CIM Object. The (harmonized) resource represents grid assets, either on the production or consumption side, that are used in certain processes of the electricity markets. Moreover, the (harmonized) accounts stand for the business functioning objects that are necessary for aggregated reporting and finally the CIM Objects that incorporate to the role model objects from the IEC/CIM standards. Figure 5 presents the most recent version (2020-01) of HEMRM, slightly adjusted and with the highlighted parts containing the roles presented below.

Related to the physical infrastructure at the Accounting Point level (red marked area), the Party Connected to the Grid is the party that contracts for the right to consume or produce electricity by being a Consumer and/or a Producer respectively. An Energy Service Company (ESCo), a party offering energy-related services (insight services, energy management services) but not being directly active in the energy value chain or in the physical infrastructure itself, may be contracted by the Party Connected to the Grid. The Grid Access Provider is responsible for providing access to the grid through an Accounting Point for energy consumption or production, while it is also responsible for creating and terminating Accounting Points. The Energy Supplier with which the Party Connected to the Grid has a balance delivery contract, either supplies electricity to or takes electricity from it at an Accounting Point. Closely connected to the accounting point are two other roles (purple marked), the Resource Aggregator that aggregates resources for usage by a service provider for energy market services, and the Energy Trader that is selling or buying energy, respectively.

With balancing responsibility on one or more Accounting Points (blue marked area), a Balance Responsible Party (BRP) is a market participant or its chosen representative that is responsible for its imbalances, i.e. the energy volume representing the difference between the allocated volume attributed to that party and its final position. It can be a Consumption Responsible Party and/or a Production Responsible Party, with a direct contractual connection to an Energy Supplier. Alternatively, it can be an Interconnection Trade Responsible which is a party recognised for the nomination of already allocated capacity or a Trade Responsible Party who can be brought to rights, legally and financially, for any imbalance between energy nominated and consumed for all associated Accounting Points. Scheduling information can be exchanged with a Scheduling Agent, an entity with the task of providing schedules. Regarding the balancing service provision (orange marked area), the LFC Operator is responsible for the load frequency control (LFC) for its LFC Area or LFC Block, while the Coordination Centre Operator is the party responsible for coordinating activities within a zone (Coordination Centre Zone) related to scheduling, load frequency control, time deviation and compensation of unintentional deviation. By acquiring capacity from Reserve Resources, a Balancing Service Provider provides balancing services to one or more LFC Operators after biding for balancing to a Reserve Allocator who is responsible for specifying the reserve requirements, receiving the bids in compliance with the prequalification criteria, and determining which bids meet the requirements. Finally, it should be noted that the reserve-providing units or reserve-providing groups are considered as resources that are managed by Resource Providers, who provide production/consumption schedules for them.

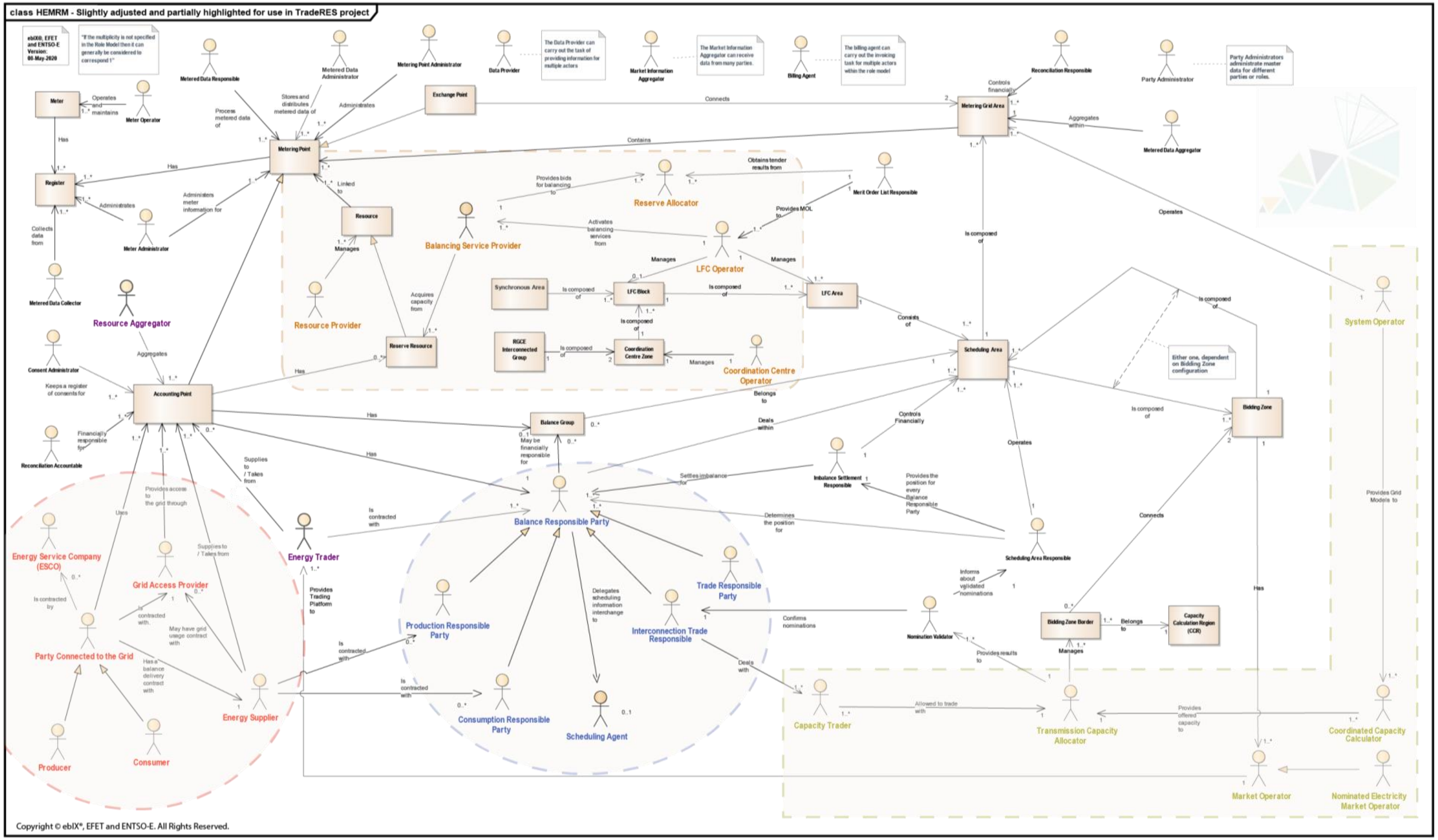


Figure 5: The Harmonized European Electricity Market Role Model (Adjusted/highlighted for demonstration purposes of TradeRES project).

Finally, on the system, market and capacity allocation side (green marked area), Capacity Traders participate in the transmission capacity market, while the Coordinated Capacity Calculator is responsible for calculating transmission capacity, at regional level or above. The Transmission Capacity Allocator manages the allocation of available transmission capacity for a Bidding Zone Border, by offering the available transmission capacity to the market and allocating the available transmission capacity to individual traders. These roles act on behalf of the System Operators, which represent the parties responsible for operating and ensuring the maintenance and development of corresponding systems in given areas. Moreover, System Operators are responsible for establishing the interconnections with other systems and for ensuring the long-term ability of the systems to meet reasonable demands for the distribution or transmission of electricity. On the market side, Market Operators provide the service to match the offers to sell electricity with bids to buy electricity and Nominated Electricity Market Operators (NEMO) are entities designated by the competent authority to organize cross-zonal trade of electricity, i.e. perform tasks related to the single day-ahead or single intraday coupling. Following the developments of the BRIDGE General Assembly 2020 [22], a subgroup of ENTSO-E's Regulation Data Management Working Group was created and worked towards a differential analysis with respect to the ENTSO-E – ebIX – EFET model. The related report [23] focused on flexibility roles and emphasised on the clarification of the Operator role to DSO and TSO, while currently is under discussion with the responsible bodies. Since then, there have been two revisions of HEMRM, namely the HMR2022-01 and the HMR2023-01 with minor alterations of the roles and only a few additions irrelevant to the purposes of the analysis (e.g. Alignment Agent for aligning the forecasts and the Modelling Authority «System operation» / Model Merging Agent «System operation» that relate to data service provision to operators).

2.3 Roles and actors in other frameworks

In the following paragraphs, other contemporary frameworks that have been widely adopted in several applications related to the electricity sector transformation are presented from the roles/actor perspective, aiming to provide a more comprehensive outline for the actor scene and set the ground for further analysis.

2.3.1. The USEF

The Universal Smart Energy Framework (USEF), although focusing on Europe, describes the market for flexibility and aims to become an international standard for smart energy systems. It has been developed by USEF Foundation that consists of seven key players from the industry and offers to all stakeholders, from energy companies to consumers, the needed Framework description, with specifications, designs and implementation guidelines, for accelerating the establishment of an integrated smart energy system. The concept behind the framework involves end-use consumers accessing the electricity market and being able to sell flexibility, which is offered to Operators and Balance Responsible Parties after its accumulation by the Aggregators. Among the key aims of USEF is the specification of the parts that enable the trading of flexible energy use through the market and the crystallization of the new and existing roles along with their interactions.

Among the stakeholders interested in the transformation of the energy system to its smart version with high penetration of RES, USEF considers the following groups [24]:

- the Suppliers, the BRPs and the Producers,
  - Suppliers, BRPs and Producers are foreseen to use prediction models and dispatching algorithms for efficient management of generation assets
  - Suppliers, BRPs and Producers are expected to optimize their client portfolios aiming to adapt the consumption profiles to available RES generation
- the DSOs and the TSOs,
  - DSOs introduce smart meters enabling dynamic tariffs, reduced settlement costs and better insight to end users' load profiles as well as grid load up to the low voltage level
  - DSOs face the challenge of increasing grid capacity demand, which alternatively to grid reinforcements can be tackled by exploitation of flexibility and active network management
  - TSOs are foreseen to play a more active role in the power system since load flow patterns across the transmission grid are continuously changing due to VREs, ensuring that the transmission capacity and the system balance are properly managed
  - TSOs will rely more on smaller generation units and DSR devices that will manage to access markets and through the strengthening of interconnections (as according to the EU Roadmap 2050) shortages and surpluses of power should be balanced out across Europe.
- the Prosumers,
  - Prosumers are envisaged to surpass the position of the passive consumers and participate actively in the energy market
  - Prosumers may participate in a variety of innovative organizations, such as the energy communities that may include wide range of collective energy actions that involve citizens' participation in the energy system.
  - Prosumers have fundamentally different needs than classical end users who are targeted by the incumbent market players and no interest in the limitations of the existing market model
- the Aggregators and the ESCos,
  - Aggregators accumulate flexibility mainly from DSR resources of end users and offer reliable products to various stakeholders, preserving resource owners from exposure to market participation risks
  - ESCos are considered to provide a very broad range of services to end users, included but not limited to information, maintenance and operation of equipment services, without being directly involved in the energy and flexibility supply chain.

When it comes to the market organization, instead of proposing exact business models, USEF adopts a role model approach, by aligning the roles and their names with those of HEMRM. To the extent possible, the USEF role model is in accordance with terminology of pre-existing business models, widely adopted in Europe, and leaves sufficient degrees of freedom in describing the interaction between the market participants and conceptualization of businesses independently to the actors. With the standardization of the flexibility market being at the heart of the USEF role model, the roles defined [24] are the following:

- Prosumer: the end user that not only consumes but also produces energy, with no further distinction on the type i.e. residential, SME, industrial.
- Active Demand & Supply (ADS): demand or supply systems that are actively controlled
- Aggregator: the party that accumulates flexibility and sells it to BRP, DSO and TSO with main goal being its profitability that is achieved through the maximization of flexibility's value and by undertaking the deliverability risks.
- Supplier: the business entity responsible for sourcing/supplying and invoicing its customers, in certain cases including the flexibility's invoicing in cooperation with the Aggregator.
- BRP: the party that is responsible for balancing the supply and demand of its portfolio, which may contain Producers, Aggregators, and Prosumers and can be contracted on the basis of undertaking the imbalance risk of the parties connected to the grid and other business entities.
- DSO: the operator that manages actively and cost-effectively the distribution grid that transports energy on the regional and local level by ensuring system operation and grid maintenance
- TSO: the operator of the transmission system that transports energy transregionally and transnationally from centralized Producers to industrial Prosumers and DSOs and is responsible for short-term system adequacy and balance.
- Producer: the party that feeds energy into the grid through investing in and efficiently operating its assets and thereby providing the required energy security of supply being ensured.
- ESCo: the party that offers energy-related facilitating and enabling services that can offer value to Prosumers, e.g. better insights into prosumer's consumption and production, improved operation and remote maintenance of their assets.
- Common Reference Operator (CRO): the operator that is responsible for the Common Reference information system, which includes details about connections and congestion points of the network.
- Meter Data Company (MDC): the entity that acquires and validates metered data and is involved in the settlement processes of the flexibility and wholesale markets.
- Allocation Responsible Party (ARP): the party responsible for establishing and communicating realized volumes either on consumer or aggregation level that are used on the settlement processes.

USEF positions the Aggregator in the centre of the value chain, mediating between the Prosumer and the three potential customers of flexibility services, namely the BRP, the DSO and the TSO. The analysis of the value proposition of specific services, reveals aims

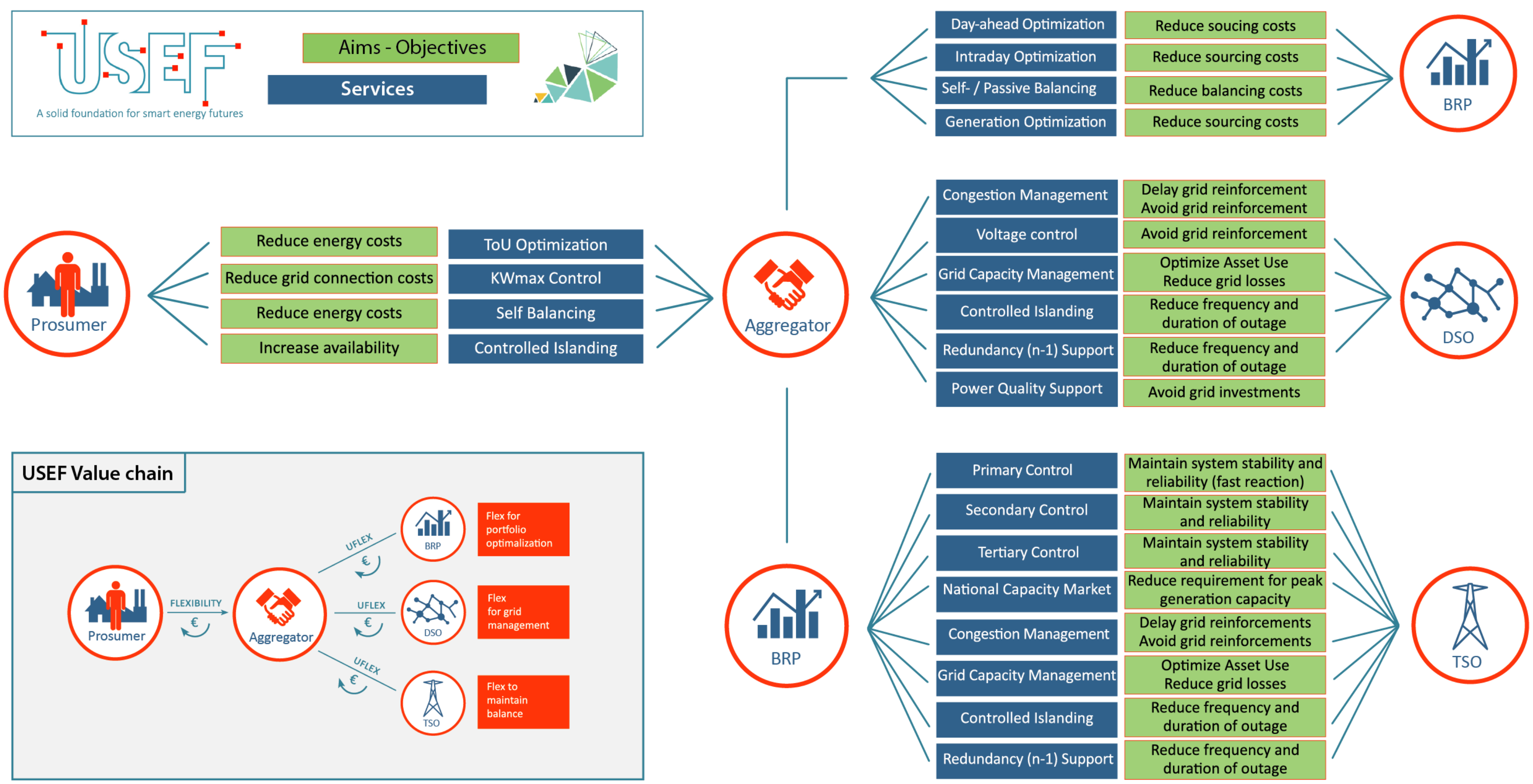


Figure 6: USEF Value chain along with services and values that represent aims and objectives.

and objectives in the context of the TradeRES project through the values offered to the aforementioned actors. More details can be seen in the schematic of Figure 6, where USEF's value chain with the related elaboration on the proposed services is presented. For the Prosumer, USEF identifies the reduction of costs related to energy procurement and grid use, and for the BRP reduction of sourcing and balancing costs is the main interest. The DSO aims to delay or avoid grid reinforcing investments, to optimise the operation of assets while trying to minimize losses and to reduce the frequency and the duration of load shedding actions. Finally, among the TSO's objectives, are the maintenance of the stability and reliability of the system, the reduction of capacity requirements for the system adequacy, the differing of capital-intensive network reinforcements and the improvement of security of supply measures with the reduction of outages' frequency and duration.

2.3.2. The SGAM

The Smart Grid Architecture Model (SGAM) is a reference model that has been developed by three European Standardization Organizations responsible for developing and agreeing on standards so that a wide range of products and services can meet certain safety and quality requirements. These are the European Committee for Standardization (CEN), the European Committee for Electrotechnical Standardization (CENELEC) and the European Telecommunications Standards Institute (ETSI).

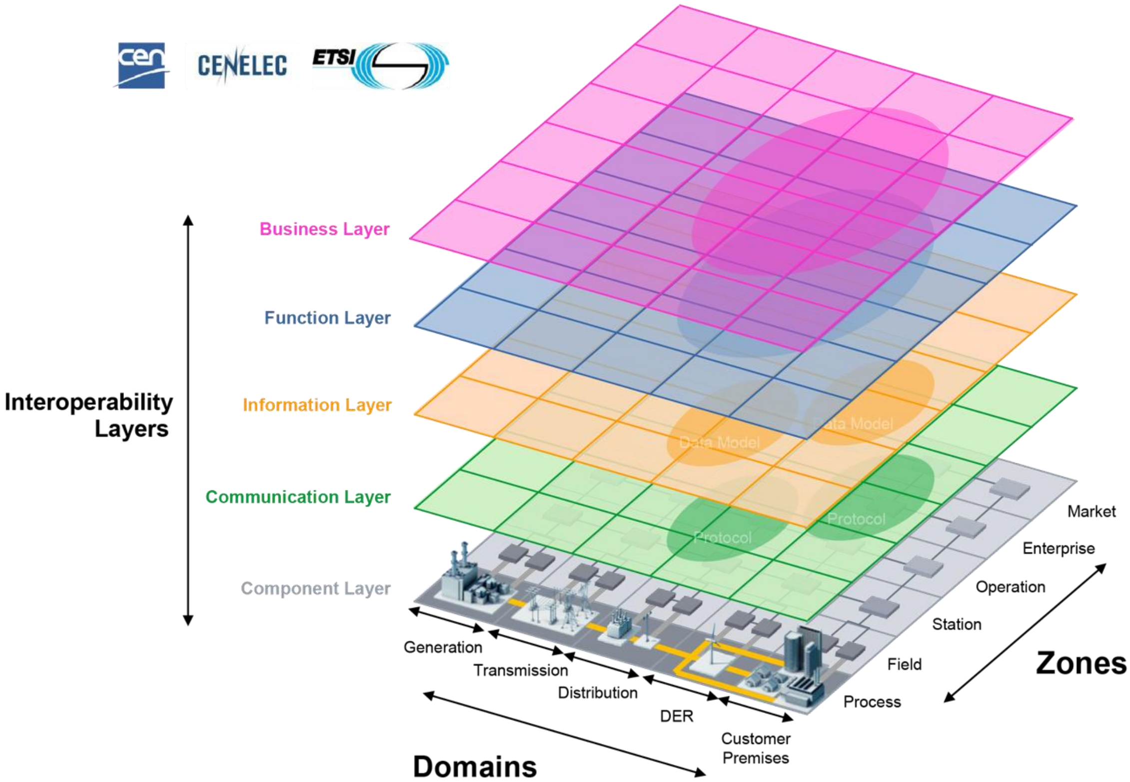


Figure 7: The three dimensions of the SGAM framework.

The model aims to provide a systematic approach for tackling complex interdisciplinary systems, such as the smart grids, by offering a universal, consistent, flexible, interoperable and technology neutral framework.

The framework itself builds on pre-existing material such as the NIST Conceptual Model [25], the European Conceptual Model [26] and architecture standards for creating a comprehensive model capable to support the design of smart grids by representing several viewpoints. The five interoperability layers of SGAM that stand for Business, Function, Information, Communication and Component, span the perpendicular to the Smart Grid Plane dimension. The Smart Grid Plane is formed by setting up the hierarchically ordered levels of power system management against the electrical energy conversion chain. This first dimension stands for the Zones and includes the Process, Field, Station, Operation, Enterprise and Market, while the latter is for the Domains and contains the Bulk Generation, Transmission, Distribution, DER and Customers Premises components. The three dimensions of the SGAM framework are presented in Figure 7 [27].

The SGAM Interoperability Layers are based on categories identified with respect to three drivers, a technical, an informational and an organizational one. Starting from bottom to top, the basic connectivity, that is related to the Component Layer, belongs to the technical driver and consists of all the mechanisms required for establishing physical and logical connections between systems. The network interoperability includes the mechanisms for messages exchanging between systems and across networks, together with the syntactic interoperability that is about the interpretation of data structures of messages for the Communication Layer. On the informational driver side, the concepts contained in the data structures are understood and combined with the business knowledge related to specific interactions, so that the Information Layer is formed by the combination of the semantic understanding and the business context. The business procedures are the part of the organizational driver mapped to the Functional Layer and this is the level where the alignment of the operational business processes and procedures takes place, independently of systems, components and actors. Finally, the Business Layer covers the strategic and tactical objectives shared between businesses and the political and economic objectives that are embodied in regulation and policies.

The business layer is the one that includes the market model and consequently this is where the actors are defined. The relations between markets, products and processes belong on this top layer of the framework, and although the exact market and business models are not in the scope of the analysis, the business services together with the linking interfaces form the business architecture. As it is mentioned in [27], SGAM through this layer can be used to map regulatory and economic (market) structures and policies, business models, business portfolios (products & services) of market parties involved. With the representation of business capabilities and processes enabled, the decision making related to (new) business models and specific business projects (business case) can be supported and new market models can be defined by regulators.

Focusing on the roles and actors from the business perspective, SGAM exploits the roles defined by HEMRM in terms of responsibility and considers their allocation to market partiers, i.e. the legal entities that can perform one or more roles, a process strongly interrelated to regulation and legislation. The roles describe the external intended behaviours of parties, under a certain goal, when getting involved in business transactions and interacting with other parties. Since the generic representation of actors that SGAM promotes, enables the actor context to cover for people, systems, databases, organizations and devices, there is a distinction between system and business actors.

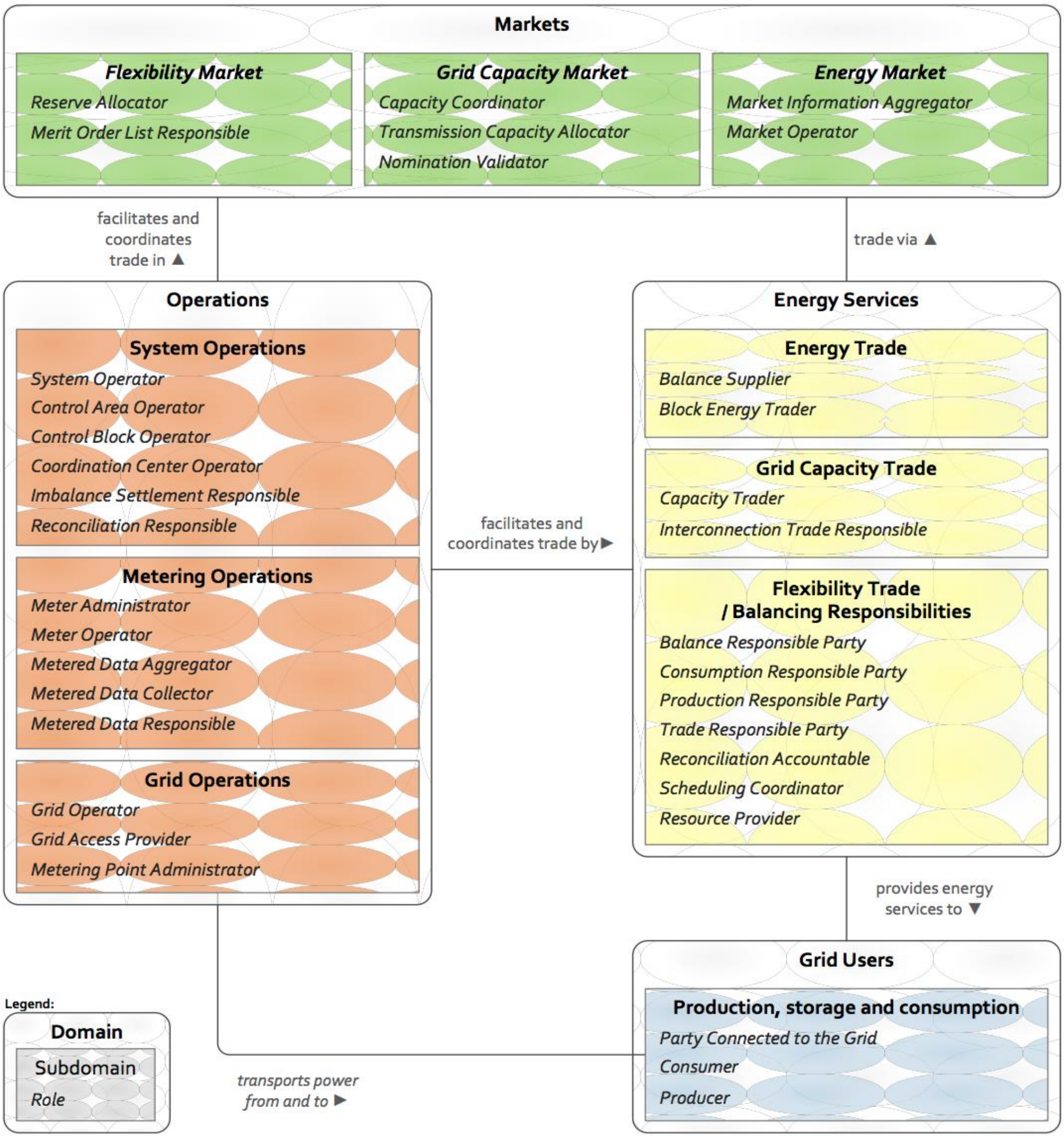


Figure 8: The HEMRM roles included in the European Conceptual Model for the Smart Grid.

While the system actors cover for the functions or devices foreseen in the Interface Reference Model (IEC 61968-1), the business actors are considered to play a role and thus there is a one-to-one correspondence with the roles defined in HEMRM. Given the progress of unbundling in the European electricity sector, some activities are still regulated while others are left to the commercial market and therefore some "smart grid parties" such as DSOs and TSOs are contrasted to "smart market parties" such as suppliers, ES-

Cos, traders, customers etc. Finally, as the transition to the future energy system proceeds, SGAM foresees the update of the list of actors in the model, with new business models being introduced and market models being updated and harmonised across the difference EU market states.

The last part related to SGAM that is worth mentioning, is the relationship between the domains of the European Smart Grid Conceptual Model, which are actually a grouping of roles and actors, and the European HEMRM. There have been four main domains in the European conceptual model of Smart Grids, the Operations, the Grid Users, the Markets, and the Energy Services respectively. In Figure 8, roles are presented along with main domains and subdomains for providing an aligned overview between the models. Specifically about the flexibility trade that is explicitly mentioned together with the balancing responsibilities, the BRP is envisaged to act as the flexibility operator while in the case of direct control of the demand and/or supply the Resource Operator is expected to undertake that role, with the Party Connected to the Grid being the “Smart Customer”.

2.3.3. The SEAS Ontology

Ontologies, as part of a semantic web, are collections of terms and relations between terms that aim to provide a clear understanding of a domain. Primarily, ontologies can serve as the vocabulary for a specific domain and can be used as standardized terminology, while they provide the framework in data related activities such as capturing, annotation, integration and mining. They make data and metadata interoperable and ready to share and reuse in an efficient way by both people and machines. This last property is mainly the reason behind the consideration of ontologies in the project, as in WP2 and WP4 the need for an agreement-based knowledge representation through a vocabulary was already identified.

For the specific domain of interest, there are some ontologies available that offer a wide coverage, such as the Open Energy Ontology [28] and the Smart Energy Aware System (SEAS) Ontology [29], while others have been focusing more on markets, such as Electricity Market Ontology (ELMO) [30], Electricity Markets Ontology (EMO) and certain instances that have been used in European electricity markets (MIBEL, EPEX and Nord Pool) [31], [32]. An overview of the application of ontologies in the energy domain is provided in [33], with respect to agents, the design methodologies and the architectures of multi-agent systems.

The SEAS knowledge model consists of a set of ontology modules, which are in the form of OWL2 DL ontologies. Among the vertical modules for the Smart Grid and Micro Grid domains there is the “Player Ontology” module, presented in Figure 9, that defines business players who can offer services and perform actions that are related to payments. The parties considered are the Aggregator, the Authority, the Balance Responsible Party (BRP), the Balance Service Provider (BSP), the Charge Service Provider, the Charging Station Operator, the Clearing House, the Consumer, the Curtailment Service Provider, the Data Broker, the Data Management System, the Distributed Energy Resources Information Provider, the Distribution System Operator (DSO), the Electricity Trader, the Energy End Customer, the Energy Producer Operator, the Energy Provider, the Energy Retailer, the Forecast Provider, the Generation Equipment, the Home and Building Management System, the Market Operator, the Operator, the Smart Charging Provider and the Transmission System Operator (TSO). Among the Electricity Market classes included in SEAS ontology there is the Day Ahead Electricity Market, the Electricity Capacity Market, the Intraday Electricity Market, the Long-term Electricity Market and the Wholesale Electricity Market.

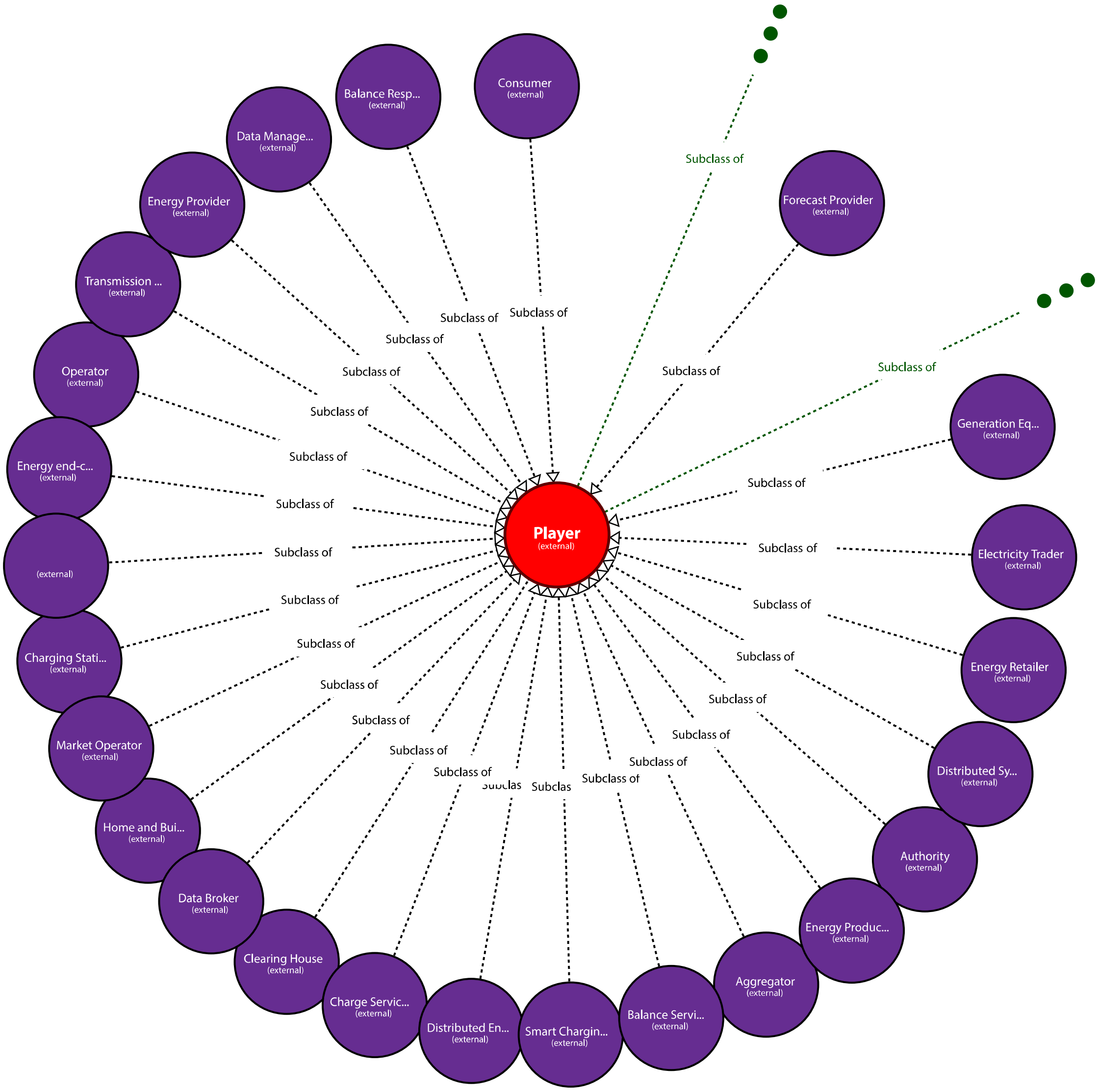


Figure 9: The Player ontology module of SEAS knowledge model.

Some of the Player classes have a one-to-one correspondence with roles from HEMRM while others are focused more on specific and complementary services. Below, following the description of the players, some of the most characteristic classes foreseen in the SEAS knowledge model and have not been introduced already are presented in more detail.

- **Charge Service Provider:** This is the party responsible for provision of e-mobility services to Electric Vehicle users (may include charging, search & find, routing and other services). It operates as a contract party for the EV user, taking care of the authentication and billing process. It provides an access card available for many EVs whose Charging Station Operator has an agreement with the Charge Service Provider and may have some roaming agreement with other Charge Service Provider registered by a clearing house.
- **Charging Station Operator:** This is the party that delivers and manages physical equipment to supply the charging procedure of EVs. It can be generally an investor, owner and operator of the EVs and the private electricity network to which they are connected, which is defined as the charging station.
- **Clearing House:** The Clearing House records all the roaming agreements between the Charge Service Provider and Charging Station Operator (EV service roaming). It facilitates data exchange between roaming partners: authentication, validation of contracts, charge retail records (duration, energy, load…)
- **Curtailment Service Provider:** This party serves as an intermediary between utilities and customers, pooling together groups of customers who participate in demand response programs to reduce energy usage during periods of peak demand. It aggregates load profiles of small and medium consumers to have a better support for the participation in DR events.
- **Data Broker:** This entity is responsible for collecting data from a variety of sources, including the internet, the online sources as well as databases, and other resources such as print documentation and surveys, and selling data packages and information as a product or service to other entities. It can include personal consumer data or business data to serve information needs of private sector and governmental agencies.
- **Distributed Energy Resources Information Provider:** This party provides information of power system variables such as loads and production from renewables, forecasts, information on electric vehicles, etc. It can act as a trusted third party responsible for dispatching information about the consumption between many energy suppliers and sharing a registry for metering data.
- **Energy Retailer:** The party that sells or buy energy to the Energy End Customer and purchases it on the electricity market. It charges the customer based on the flexibility, duration and power. It communicates to the customer the energy metering values, in accordance with the DSO or TSO metering.
- **Forecast Provider:** The entity that provides forecasts of the value of power system variables such as loads and production from renewables or performs and updates the forecasted values about the weather, the prices, the consumption and the generation, which are transmitted to the network operator.

Finally, the Player ontology module is related to other modules of SEAS, such as the System and the Procedure Executor, by being a subclass of those ontologies as it is depicted in Figure 10.

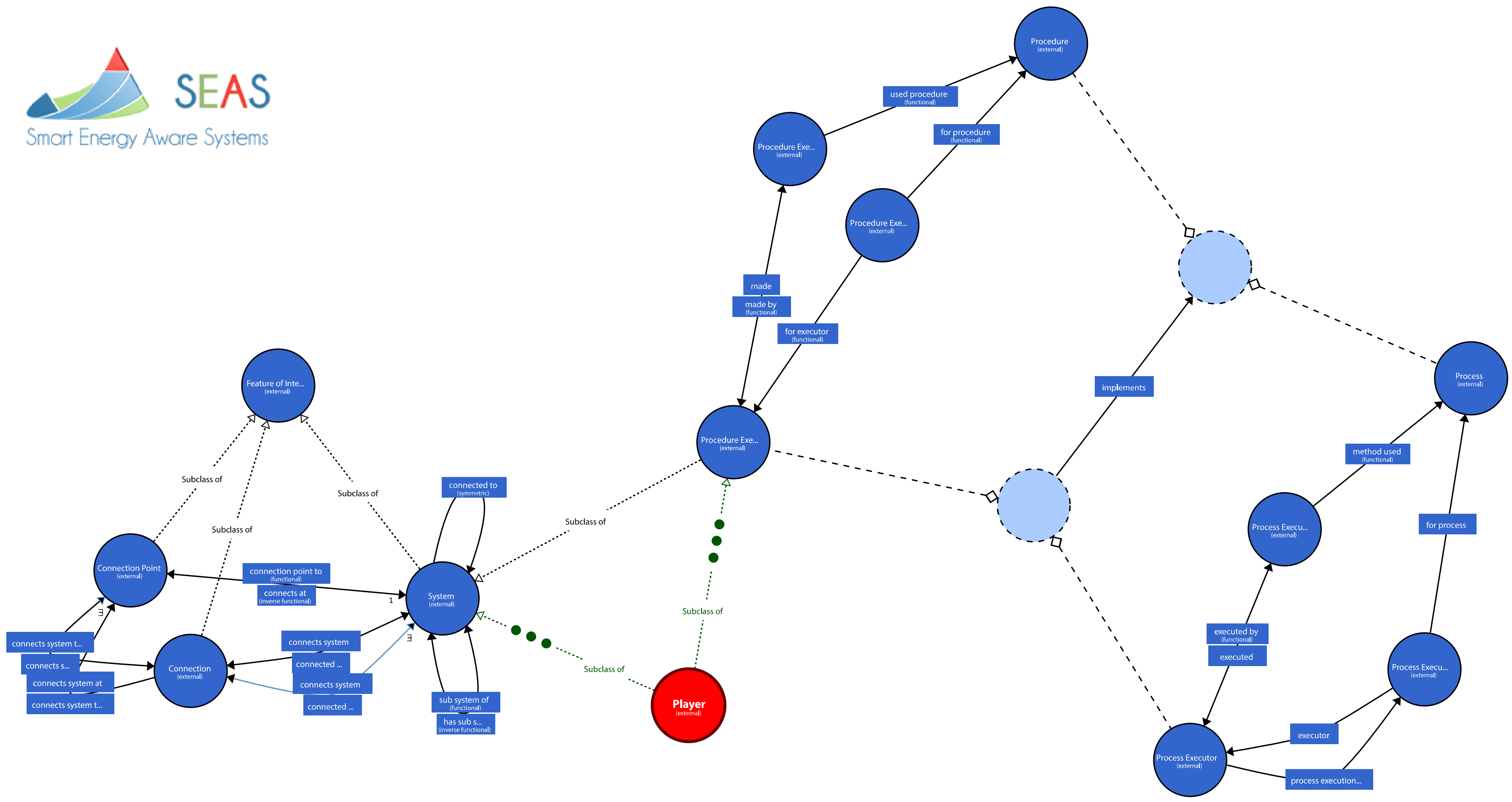


Figure 10: Relation of Player ontology module to other modules of SEAS.

3. Identification and classification of actors

3.1 Definitions of roles and actors

In the previous section, an overview of the parties interested and involved in the energy sector, have been provided from a wide perspective and with special focus on the electricity sector side. Initially, following the policy trends and the regulatory initiatives, the policy making and advising bodies have been described together with the associations and organizations responsible for representing different sectoral interests, indicating the variety of stakeholders. Next, the HEMRM, a commonly accepted role model, provided the context for roles, indicated those on the electricity market domain and covered their evolution during the last decade, through its sequential versions. Other frameworks, such as the USEF, the SGAM and the SEAS model have been examined with respect to the stakeholders, actors, roles and players that each one of them defines and incorporates.

Although this review has offered a good coverage on the multitude of entities currently considered and required for the analysis and implementation of a wide range of contemporary and future use cases and applications, it also pointed out the lack of clear and universal definition of the related terms. Therefore, the need for defining primarily the "role" and "actor" terms for their further use in TradeRES project has emerged, while for clarity reasons definitions of the terms "stakeholder", "player" and "agent" are provided beforehand.

<u>Stakeholder:</u>

From a management theory perspective, given an organization and the specific environment that surrounds it, which consists of parties (other organizations, groups, individual persons) with whom the organization interacts, the stakeholder is a member of that environment and is affected by the organization's performance and can influence it directly or not [34]. Around a firm, the Stakeholder Model [35] identifies the governments, the investors, the political groups, the suppliers, customers, the trade associations, the employees and the communities while the Stakeholder Theory also considers competitors and distinguishes between primary (internal) and secondary (external) stakeholders. Considering the wider environment that results from the union of the specific environments of the interacting organizations within a sector, the set of stakeholders becomes even larger and can include the society at large and the future generations.

A stakeholder is a person, group or organization that has an interest in a system since it is a member of its environment, influences it and is affected by it in a direct or indirect way.

<u>Player:</u>

In game theory, a strategic game captures the interaction of decision makers. In that context, the interacting individuals are considered to be the players of the game, the rules of which define the actions allowed to them to take and their effects [36]. The goals of the players are specified by their objectives, they have preferences over the set of action profiles and what they know before decision making is following the information structure of the game. Based on the game considered the player can represent different type of entities such as individuals, groups, firms, countries, etc.

A player is an individual decision maker that accepts the rules and constraints of the game(s) that participates in and behaves strategically given the information available, his preferences and his objectives.

Agent:

In microeconomics, the basic unit of analysis is the individual economic agent that represents the decision maker and following the classical distinction of activities in consumption and production, typical examples are the consumers and the firms [37]. In micro-founded macroeconomics the agents of the economy are the households, the firms and the central banks, while in certain modelling instances of special focus consumers, workers, voters of commercial banks may appear [38]. In a generalized form of microscale modelling, such as the Agent-Based Models (ABM), the agents may be individual or collective entities such as groups and organization that undertake actions and interact with each other.

An agent is a persistent individual or collective entity with physical, social or economic substance that interacts with other entities in a dynamic system framework and his functionality is considered in the context of an ABM.

The conceptual relation between the terms defined is presented in Figure 11 (a), where the environment with stakeholders forms the broad space and the intersecting sets of players and agents are relatively positioned.

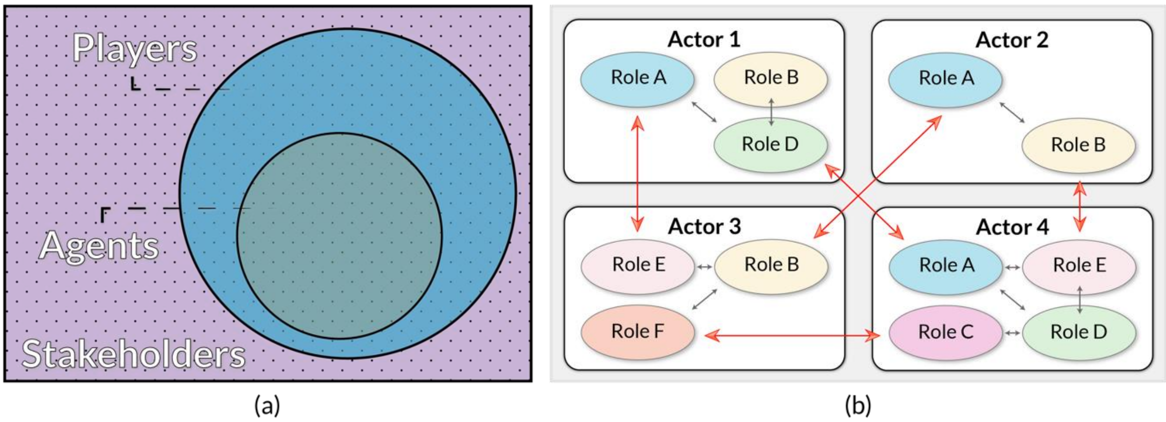


Figure 11: (a) Relative positioning of the "Players" and "Agents" in the "Stakeholders" environment, and (b) interactions between "Roles" and "Actors" on the role model landscape.

About the roles and the actors, following the principles followed in HEMRM for both terms and differentiating from the one-to-one correspondence between roles and business actors in SGAM, the terms are interpreted as follows.

Role:

A role (i) performs specific activities, (ii) has a strict set of functionalities, (iii) operates under certain responsibilities, (iv) has control of specific resources and (v) communicates with other roles.

A role represents the intended behaviour of an entity and is related to specific business-oriented activities that govern its external interactions.

Actor:

An actor can be an individual (user) or collective entity (group, organization) and has ownership of resources, has and develops relations and undertakes one or several roles.

An actor is an entity that has the ability to undertake one or more specific roles for participating in business-oriented transactions and through these roles can interact with other actors.

Finally, the perception behind the definitions provided above is depicted in the schematic of Figure 11 (b), where the internal relations between the roles that the actors incorporate, the relations of actors and the interactions at a role level are presented.

3.2 Traditional and new actors

In the heart of the massive transformation of the energy sector under the low carbon agenda, there is the shift from the supply-driven approach to the contemporary active and bidirectional demand-side participation paradigm, conceptualised by the smart grid and the system of systems approaches. Integral part of any envisaged future instance are the traditional parties that play their significant and structural role on even the new energy architecture along with the new entities that emerge in response to the new set of mechanisms, participating actively in the new market framework and supporting the fulfilment of the policy goals. Exactly those points are analysed in this section, where the enhanced and more active role of traditional entities like the TSOs, the DSOs, the Producers and the Suppliers is presented, and the core involvement of emerging concepts like the Prosumers, the Aggregators and the ESCos is also considered.

3.2.1. Traditional actors (TSOs, DSOs, Producers, Suppliers)

TSOs are entities responsible for the bulk transmission of electric power on high voltage electric network level [3]. The system is operated independently from other electricity market players, in a way that does not favour or penalize one market participant over another. TSOs provide grid access to other parties according to non-discriminatory and transparent rules or codes established in the context of a competitive electricity market environment. The maintenance of the stability and operational reliability of the power system through balancing the load at high voltage level is the primary responsibility of TSOs. Beyond the safe operation of the system, its maintenance and development are also priorities for ensuring the security of supply. Although the exact role of this actor is to be refined in the coming years and decades, the decentralised generation trend along with the weather dependence of production of a greater share of resources are among the challenges faced. Digitization is expected to support the security of supply helping to keep the system balanced and facilitated the better adjustment of the fluctuations in power load. On top of that, the enhanced cross-border cooperation between TSOs and the clarification of responsibilities between TSOs and DSOs will enable the improved and efficient coordination within and across countries making a fully integrated network a reality.

DSOs own and operate or are granted concession contracts to operate the distribution networks, with security of supply and quality of service being among their core responsibilities. The continuously increasing share of RES connected to the distribution level makes the DSOs mission more challenging. Together with the classic role of network operation and development, DSOs have to evolve and become active network managers. Electrification adds to the changing nature of the energy landscape new forms of bidirectional flows (e.g. EVs). Key-enabling technologies such as smart meters, ICT and power electronics, distributed resources and energy storing assets are expected to offer a wider toolbox in contrast to the limited options of extending and/or reinforcing the physical infrastructure that traditionally were available. Beyond arranging a grid connection, providing relevant data while ensuring data privacy, informing customers of disturbances, maintenance works or outages, DSOs have to move towards enhancing system's observability and controllability, focus on smart grid planning and smart asset management, invest on local flexibility mechanisms and customer inclusion, ensure transparency in data access and sharing and manage the system in an active and efficient way exploiting any flexibility potential by acting as neutral market facilitators [39]. As foreseen in the Clean Energy Package and highlighted by E.DSO [40], DSOs and TSOs shall cooperate with each other in planning and operating their networks, by exchanging information and sharing data about the operational aspects of distributed assets and their networks and the long-term investment plans they have. Cooperation is also envisaged for accessing resources such as distributed generation, energy storage or demand response with the main goal being to support the needs of both the distribution and the transmission systems.

Traditionally, the network has been used for merging the generation with the consumption side in a downstream way, with the active parties being the producers and the retailers. Producers, in their typical version are the generating companies that have resulted by the unbundling of utilities process, own generating plants and sell electrical energy. They may also sell services such as regulation, voltage control and reserve that the TSO needs for maintaining the quality and operational reliability of the electricity supply. Producers can own a wide range of number of plants starting from a single plant to a portfolio of plants of different technologies, with the main conventional ones being hard coal, lignite, gas and nuclear generation. Retailers on the other side, buy the electrical energy on the wholesale market and resell it to consumers who may be connected to the grid through different DSOs and do not wish or are not allowed to have more direct access to the wholesale market. Although they do not need to own any power generation unit, retailers can enter into bilateral contracts like the power purchase agreements (PPA) with producers, while in some cases they are subsidiaries of generation companies. Switching from one supplier to another in very short time is promoted by legislation, while DSOs play an important role in handling that process [41].

3.2.2. New Actors (Prosumers, Aggregators, ESCos)

A core part of the decentralization process is the shifting the passive role of the energy consumer to the more proactive behaviour of the prosumer. Small consumers used to buy electrical energy from a retailer, who were able to choose, and lease a connection to the power system from the local DSO. In contrast, prosumers of energy, although initially emerged as the individuals that had also the ability to produce energy locally in a sustainable way, they have turned to the smart and active individual and collective parties that can self-generate energy, participate in peer-to-peer transactions, interact with national energy market actors and exploit the full potential of energy storage, energy conservation, and demand response. In the Clean Energy for all Europeans package end-users have the right to consume self-generated renewable electricity and are empowered to trade the surplus they produce and sell electricity services, other than electricity supply, independently from their supply contract. Moreover, the concept of collective prosuming where active energy citizens act together in collectives such as energy communities is explicitly recognized with the right of prosumers to group and function in the market collectively being granted, although details such as applicable network tariffs have yet to be defined nationally. Provision of additional information is considered a key driver for empowering prosumers and energy communities, with access to dynamic prices through the smart meter infrastructure being considered an important prerequisite. Finally, in the current regulatory framework [6] customers are defined as the wholesale or final customers of electricity, with the latter being distinguished between household and non-household customers given the reference (household, commercial, professional) of their consumption. Active customers are considered the final customers or the groups they create and get involved in a not primarily commercial/professional way of consumption, storage, generation activities and/or participate in flexibility or energy efficiency schemes. On the collective side, citizen energy communities are defined as the legal entities that have as primary goal to provide communal benefits, instead of profits, by providing services related to generation, distribution, supply, consumption, aggregation, energy storage and energy efficiency.

From the regulatory point of view [6], aggregation has been considered as the function of combining load or generated electricity for sale, purchase and auctioning purposes performed by natural or legal persons. At the same time, emphasis is given in the fostered participation of demand response through aggregation and the operation of storage facilities, while the intermediary role that the aggregator can play between customer groups and markets is highlighted. The entity of the "independent aggregator" is defined as the market participant that is engaged in aggregation and is not affiliated to the customer's supplier, with the exact implementation model not being strictly imposed but rather left in the discrepancy of the Member States. Such a model, combined of course with suitable products in all markets, is expected to provide fair and transparent rules that allow aggregators play their intermediatory role in a way that benefits final customers as well.

Aggregators, when considered under the flexibility scope, are the entities that get in contractual agreements with a number of end-users that own directly connected to the distribution level resources, for providing services to the grid and overcoming participation restrictions of other monetization routes. Such resources can be distributed generation assets, controllable loads and energy storage assets that can offer both supply-side and demand-side flexibility services [42]. By aggregating disperse DERs (with or without storage units) in a virtual power plant (VPP) configuration, the aggregated flexible resources can behave as (close as possible to) a conventional power plant with standard attributes, with the combination being sufficiently large for enabling their participation in electricity or ancillary services markets [43].

On the other hand, when it comes to the demand-response resources or energy storage units there is a time-coupling property that can be used for the grid benefit. Since the aggregator can be a grouping of other actors of the system, its exact type and capabilities when represented as a single entity in structured markets or in bilateral agreements with operators are found to depend strongly on the nature of aggregating assets.

For facilitating the transformation of the sector and enabling the aforementioned changes, there is a need for efficiency in a series of activities such as financing, implementation and management, leaving much space for provision of comprehensive energy services to final energy users. ESCos are expected to play an important role in that regard, through a wide range of activities around energy analysis and audits, energy management, project design and implementation, maintenance and operation, monitoring and evaluation of savings, property/facility management, energy and/or equipment supply, provision of services such as space heating and lighting [44]. With all those activities tied to the improved efficiency, the remuneration of the ESCos is proportional to the savings achieved, which are shared between the client and the company. This can be described as performance contracting and the share is related to the level of involvement of the ESCo, which can vary by even including financing and full risk undertaking [45]. Energy services are also offered to final users, by Energy Service Provider Companies (ESPCs) that can be directly linked or affiliated with consultants specialised in energy efficiency, equipment manufacturers or suppliers. The difference with the ESCo, lays mainly on the fact that there are not strong incentives in reducing consumption or achieving certain efficiency levels, since the cost of the services is recovered by the fixed fee or the added value with which the service is offered.

3.3 Classes of actors

In this subsection the classes of actors considered in TradeRES are presented. In Figure 12 the actors' scene is analysed in four layers, namely the social, the physical, the aggregation and the market one. The social layer contains the individuals, the social coalitions and the legal entities that are to different extents involved in the energy sector. In their physical interpretation that is interrelated with the assets they possess, the social individuals and entities turn to the actors that own and operate resources such as distributed generation, energy storage, controllable load, etc. and infrastructure like the network. On top of the physical layer is the layer where business entities are involved in aggregating activities, varying for demand to generation and including suppliers, aggregators and VPPs. Finally there is the market layer where all the financial transactions take place under market structures and actors interact. Three out of the four layers are mapped against the zones of SGAM, with this being depicted in Figure 13.

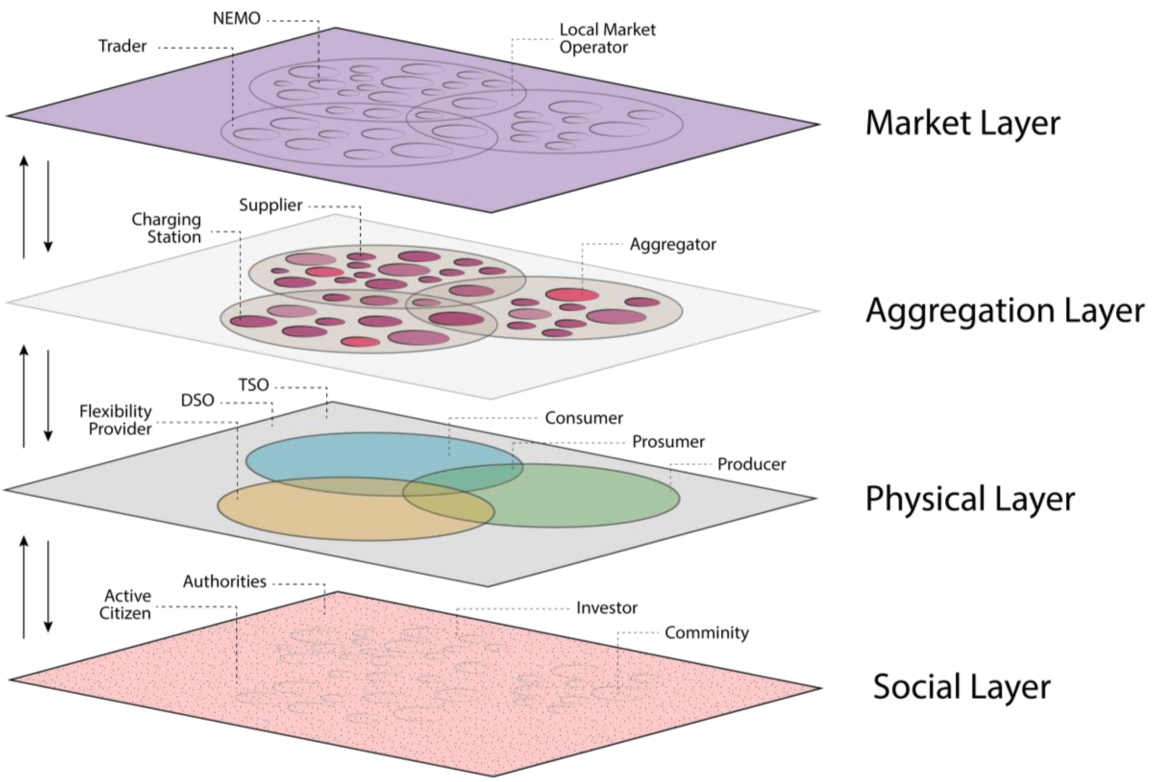


Figure 12: The actors' scene in TradeRES separated in 4 layers.

3.3.1. Prosumer

It is the final user or group of users who consumes, stores, self-generates, participates in flexibility or energy efficiency schemes, in a not primary commercial or professional way. Prosumers are distinguished based on their type to residential, enterprise, industrial prosumers, while the group instance is expressed through the community prosumer. The traditional consumers fall under this category.

3.3.2. Producer

It is the legal entity that owns and operates for commercial purposes, from a single to a portfolio of different and hybrid technologies supply providing assets, such as generation plants, pumped storage facilities, distributed generation and storage assets. Producers are distinguished according to the size of their assets to those who primarily own large generation/ storage assets and to those who own distributed generation and storage assets.

3.3.3. Supplier

It is the entity that buys electricity from the wholesale market or directly from the producers and sells it to the end users. Margins in the supply segment are considered relatively low due to high competition intensity and thus branding, marketing and product differentiation play a role [46].

3.3.4. Aggregator

It is the entity that aggregates a number of end-users and entities that own directly connected to the distribution level resources, like prosumers, producers or any mix of them, for overcoming technical barriers and limitations through the effects resulting by their combination and internalization of operational aspects.

3.3.5. Trader

It is the entity that can represent large energy volumes into the wholesale markets and achieve better positioning and reduced non-energy costs. Monitors all markets, manages the risk of fluctuating energy prices by offering minute-by-minute decisions offers capitalization of advantageous price movements and exploitation of arbitrage opportunities.

3.3.6. ESCo

It is the entity that can act as a facilitator in investments, operations and decision making by internalizing activities that encounter risks and/or can be further improved. Typically offers services through performance contracts through which they obtain a share of achieved improvement.

3.3.7. Operators

It is the entity responsible for the operation of its system, which can have either a physical or an economic interpretation. The TSO is responsible for the trans-national and trans-regional transportation of electricity and for balancing the system, the DSO manages actively the local networks and the grid connections, the wholesale market operator is responsible for collecting the bids and clearing the market at certain time frames, and the local/community market operator is responsible for coordinating the trading at the local level.

3.3.8. Regulators

It is the entity that is legally entitled to supervise the energy industry and is concerned about its sustainability, while maximizing welfare through principles related to cost-efficiency, security of supply and social acceptance. Although it expresses the policy makers' concerns, it aims to balance the interests of all stakeholders, with special focus on the more vital participants of power system, i.e. the generators, suppliers and customers.

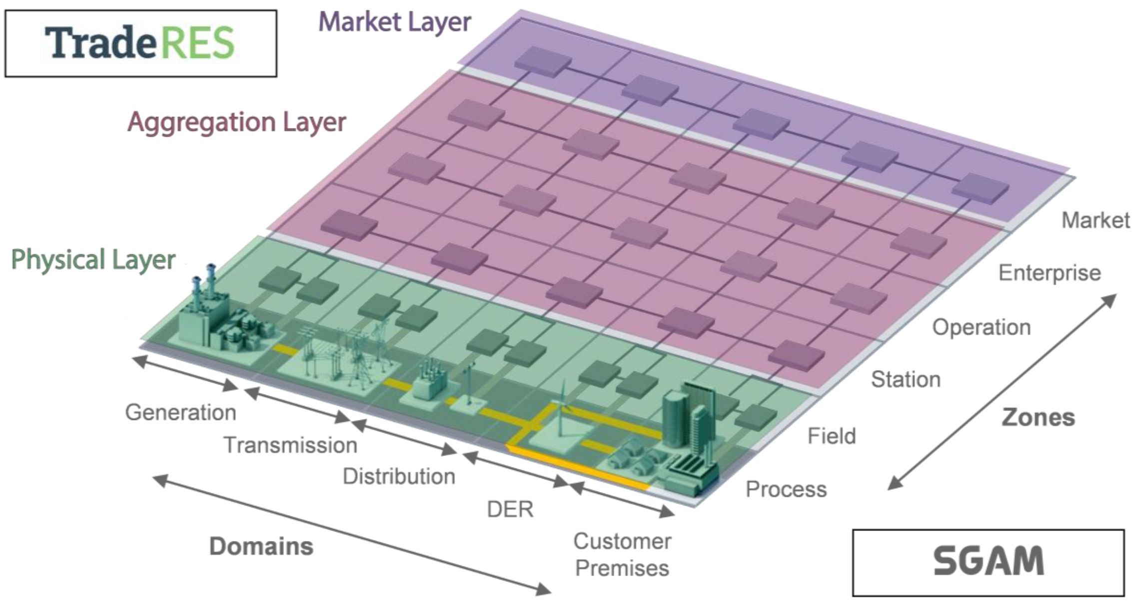


Figure 13: The three layers of the actor scene mapped to the SGAM zones.

3.4 Technology's influence on the actors' scene

The physical layer, as introduced in Subsection 3.3, consists of systems with physical interpretation and forms the basis of any further intellectual development. This cross-domain layer, that incorporates the Process and the Field zones of SGAM, combines assets that span across the electricity supply chain, involving technologies related to generation, transmission, distribution and consumption.

On the one hand, technologies act as enablers and as they go through the lifecycle stages, they drive the emergence of new actors and roles. The four phases of the technology lifecycle are (i) the research and development phase, (ii) the ascent phase, (iii) the maturity phase and (iv) the decay phase. All along the technology evolution there is the adoption lifecycle as well, where the individuals are distinguished with respect to the diffusion of the innovation into the following five groups. There are the innovators, the early adopters, the early majority, the late majority and the laggards. To that extend new or evolving technologies pave the way for new actors, innovators and early adopters that become entrants from the market perspective. On the other hand, technologies influence directly the operation side of assets as they set boundaries due to technical limitation and dictate the interaction of components. The business models, which describe the value proposition, the cost structure and the revenue streams are strongly affected by characteristics and parameters of operation. At the same time the business models set the key activities, the key resources and key partners, with the interactions being related to technological aspects. Therefore, it can be said that there is a bidirectional relation between technologies and actors, with the technologies being promoted by actors and the actors emerging due to the technological evolvements.

Following the developments around the common database of the project that have been reported in D2.1, several technologies have been identified and data related to their cost, their energy potential and their operational parameters have been gathered. On the electricity production side, onshore and offshore wind, photovoltaics of different scales, hydropower facilities, concentrated solar power plants, wave energy installations, open and closed cycle gas turbines fuelled by both fossil and "green" gases, such as green hydrogen, and nuclear power plants are among the technologies considered. Regarding heating and cooling, heat pumps differentiated with respect to their scale, the conversion medium and the temperatures are examined along with electric or gas heaters and boilers, geothermal installations, solar district heating and cooling infrastructure and combined heat and power setups based either on closed cycle gas turbines or biomass or nuclear power. About storage, technologies related to lithium-ion batteries, pumped hydroelectric energy storage, hot water tanks and hydrogen storage are among the reported ones. Carbon capture and storage, polymer electrolyte membrane electrolysis and methanation are some of the technologies mentioned for the utilization of carbon dioxide, the production of hydrogen for being used as an energy carrier and the production of synthetic natural gas from carbon oxides.

All the technologies mentioned above are in different stages of their lifecycle, with some being in the mature phase. Improved and more efficient versions emerge, while undergoing research may lead to new developments of innovative technologies in all the related fields, i.e. generation, storage, demand response and interoperability of systems and sectors. A better insight on the current R&D directions at the European level can be obtained by considering the technologies tackled in research projects of related fellow calls. The BRIDGE initiative, that includes several Horizon 2020 projects on several energy-related disciplines, provides a complete overview. The subjects covered by projects are related to local small-scale storage and next generation energy storage technologies, large scale energy storage technologies, distribution grids and retail markets, transmission grids and wholesale markets, technologies for the deployment of meshed off-shore grids, next generation technologies of renewable electricity and heating/cooling systems, system integration aspects with smart transmission grid and storage technologies under increasing share of renewables, etc. As per the BRIDGE projects brochure [47], the technologies tackled by projects are divided to five main categories, these are (i) technologies for consumers, (ii) grid technologies, (iii) large-scale storage technologies at the transmission level, (iv) small-scale storage technologies connected at distribution level and (v) generation technologies. As far as technologies for consumers are considered, the focus is on demand response, while smart metering and smart appliances follow. In terms of grid technologies, many projects deal with network management, monitoring and control tools as well as microgrids. Regarding storage technologies there is interest in hydro storage, compressed air energy storage and power to gas solutions as well as batteries, EVs and thermal energy storage when it come to the distributed form. About generation photovoltaics along with wind turbines are the technologies considered by the majority of projects, followed by micro-generation, solar thermal, biogas and tidal energy.

It is also interesting to see the wide range of stakeholders participating in the projects and consequently in the BRIDGE initiative. Following the categorization of the BRIDGE projects brochure, there are the consumers including residential, professional and industrial consumers, the regulated operators including the TSOs and DSOs and the regulators as the national regulatory authorities. Moreover, there are the local energy communities including associations, cooperatives, non-profit organisation or other legal entities involved in distributed generation and in performing activities of either a distribution system operator or a supplier or an aggregator at a local level. There are also the electricity markets players, in the category of which broad notions of the energy suppliers, the aggregators and the market operators belong. Generators, retailers and ESCos are considered in the context of the energy supplier, aggregators are foreseen to combine multiple customer loads or generated electricity, while market operators seem to cover for power exchanges, brokers and traders.

The technologies that have been considered to influence the actors, either by driving their behaviour or by dictating their operation, cover for the consumption, the storage, the generation, the network and digitalization part. More precisely, the inflexible demand, the demand side response and the flexible heating cooling are the categories that belong solely to the consumption side. Electric vehicles combine the consumption aspect with the storage one, while battery energy storage systems, heat storage, pumped storage hydropower and power to gas are the energy storage categories involved. A wide range of generating technologies, such as photovoltaics, wind turbines, biomass and biogas, concentrated solar power, geothermal power, other RES, combined heat and power, hydroelectric power, nuclear power, gas carbon capture and storage, open and closed cycle turbines and other non-RES generation alternatives are considered. Finally, distribution and transmission network technologies together with advanced information and communication technologies complete the wide range of identified technologies.

In Table 4 the intensity of relationships between classes of actors of Subsection 3.3 and identified technologies are presented. That association has been made primarily in the context of TradeRES for the needs of the current and further actor-related analysis. On the practical side, the project partners have filled out a table-based survey where they marked the relations with respect to the project's aims and goals. All partners that participated in the survey, through their selections indicated the existence of the relations and captured their importance, while partners that contribute an agent-based model had also the chance to indicate which of the relations are already incorporated in current versions of their models.

The relational table that follows, as well as two similar ones that are on Section 4, have been created through the aggregation of the table-based survey responses. As it was mentioned before, the survey participants, were asked to use two flags, one for indicating a general relationship that is considered of interest in the context of TradeRES and one for marking a relationship already incorporated in the models. Given that this type of indication had a qualitative ground, for the aggregation needs the flags were mapped to real numbers. Due to the higher relative significance assumed for the already modelled relationships a greater number was assumed over the number assigned to the general relationship flag. Thus, with the numerical interpretation available, the aggregation through summation has been made possible and for visualization purposes a green tint scale has been adopted, with the significance following the colour intensity.

As it can be seen in Table 4, prosumers as they incorporate solely consumption, they are related with the demand side categories, while they are connected to distributed generation and storage as well as to electric vehicles. Producers on the other hand, when considered at the large scale are related to wind, photovoltaics and biomass from the generation aspect and to pumped storage hydropower and battery energy storage systems from the storage perspective. Given the intense involvement of distributed assets to the prosumer side, the distributed generation and storage seem to be of less significance when considered independently of the consumption, with photovoltaics and battery energy storage systems being the most noteworthy technologies respectively. Aggregators seem to be another class of actors with intense interest focusing greatly to demand and storage technologies on the one hand and to variable renewables and biomass on the other. The intrinsic feature of this new actor may contribute to increase the market efficiency by helping to unlock a range of flexibility solutions at the generation and consumer level. Finally, the wholesale market operator seems to be strongly related to variable renewables, which are considered to participate at a very high share.

It is worth mentioning that the relationships identified and the highlighted intensity should be mainly considered in the context of the TradeRES project, given its aims and objectives. In other words, the high or low significance of a relation should not necessarily be interpreted in a universal way, since it aims to provide an insight of design directions and the priorities that should be followed within the project. Therefore, actor classes that are not strongly related to technologies, it does not mean necessarily that are not influenced by them (e.g. the DSO), but that they should not be considered and internalised in the project's developments.

Table 4: Relational table between actors and technologies.

BESS: Battery Energy Storage System
CCGT: Combined Cycle Gas Turbine
CCS: Carbon Capture and Storage
CHP: Combined Heat and Power
CSP: Concentrated solar power
DSR: Demand Side Response
EVs: Electric Vehicles
OCGT: Open Cycle Gas Turbine
P2G: Power-to-Gas
PSH: Pumped Storage Hydropower
ICT: Information and Communication Technology

Intensity: High – Low

		Inflexible Demand	DSR	Flexible H&C	EVs	BESS	Heat Storage	PSH	P2G	PV	Wind	Biomass	Biogas	CSP	Geothermal	Other RES	CHP	Hydro	Nuclear	Gas CCS	OCGT	CCGT	Other non-RES	Distribution Network	Transmission Network	ICT
1. Prosumer	**Residential**																									
	Enterprise																									
	Industry																									
	Community																									
2. Producer	**Large Generation / Storage**																									
	Distributed Generation / Storage																									
3. Supplier	**Supplier**																									
4. Aggregator	**Flexibility Aggregator / VPP**																									
5. Trader	**Wholesale Trader**																									
6. ESCo	**ESCo**																									
7. Operator	**TSO**																									
	DSO																									
	Wholesale Market																									
	Local / Community Market																									
8. Regulator	**Regulator**																									

4. Technoeconomic analysis of actors

Given the eight actor classes that have been presented in Subsection 3.3 and the technologies considered in Subsection 3.4, a technoeconomic analysis of actors is performed. This analysis is based on two dimensions that have been identified, one related with the actors' operational elements, which are closely related to their technical limitations, and one focusing solely on the behavioural aspects that drive the decision making of actors and influence their interactions. As a result, each of the dimensions is represented in maximal granularity. Particularly several operational attributes related to the groups of technologies have been included based on an exhaustive review of power system modelling literature, such that each one of them covers a different type of properties that is usually included in modelling. Similarly, our elaboration on the behavioural dimension is based on classical textbooks and the contemporary literature of traditional microeconomic theory, game theory and behavioural economics, representing those fields that study the behaviour of individuals, groups and firms. In the following two subsections the two dimensions are discussed further, with the attributes and aspects presented and explained. This broad approach becomes more concrete and focused through a similar technic as the one described in Subsection 3.4 for the development of the heatmap-style table. Once again, it should be stated that those tables highlight the interest and the focus of the project and although they provide a pretty straight forward indication of existing relationships, they have to be interpreted in the context of TradeRES project.

4.1 Operational dimension

The operational dimension of the technoeconomic analysis aims to shed light on the technical side. In several cases the actors are bound to a single technology or a set of technologies in the sense that a part of their role is the operation of assets and to some extent interactions may take place over a network with some physical infrastructure. Of course, this is accordance with the layered structure that was adopted in Section 3.4, with this technology related part being represented at the physical layer. The physical instance actually has a twofold effect, initially at the very basic level where it sets the nature of the role by providing the main characteristics and later on where it imposes operational constraints. The operational attributes described below aim to provide a wide coverage to the groups of technologies considered, these are the flexible and inflexible demand, the controllable and non-controllable generation, the storage and the EVs, and the networks.

Among the most common parameters when the physical infrastructure is at stake, are the capacity and power limit of the installations (e.g. power plants and network elements), along with the power factors of operation of the metering points. If the demand side is considered, and more precisely the part of the demand that doesn't offer any flexibility, there are two main parameters, the inflexible demand profile that is provided in a time series format and the load curtailment at the specific metering point. Regarding the demand side response, there are mainly two possible cases considered, the first one that refers to cycles of fixed power profiles that can be shifted [48] and the second one where the time when the energy is acquired is flexible and leads to continuously adjusted power.

There is also the power demand that is not realized, where energy is saved either because of long run actions that result in reduced demand or voluntary load curtailment that results in a short run reduction.

The generation can be distinguished by the classes of non-controllable generation, including variable renewables, and to that of controllable generation where the rest of the renewables and the conventional means are included. For the non-controllable generation, the capacity factor of the unit that is used to describe the utilization of the installed capacity by considering the ratio of the actual power produced over the maximum possible output is one of the important attributes. It is followed by the generation profile, which can either refer to a forecast or actual realization and the allowance for curtailment, which can either provide continuous power curtailment or curtailment at the metering point in an on/off basis. Regarding controllable generation, the minimum stable generation limit, the ramp-down and the ramp-up limits of the units, the startup and shutdown time requirements, and the minimum time for changing state of operation are among the characteristics considered [49]. Other important operational aspects have to do with the storage assets and the electric vehicles, which are closely related to the time coupling property imposed by those technologies. Given that energy storage is the subject matter, the minimum and maximum energy limits of the assets certainly play a role, while the charging and discharging abilities together with the efficiency of those operation, are critical parameters [50]. Regarding the network, independently if transmission or distribution is at stake, the network topology is the most critical element, combined of course with the characteristics of lines and nodes. For describing the lines and the nodes, the most common characteristics have been the line length, the conductance and the susceptance, along with the thermal capacity limits and the voltage range for operation in normal conditions.

By observing Table 5, it can be seen that prosumers, independently of their type, are related strongly to inflexible demand and demand side response attributes, with demand profiles being the trivial one. Load shedding and demand shift follow next on high intensity levels, while the energy saving appears more mild but again universal. Storage and electric vehicle attributes present strong relationships with prosumers, while industrial prosumers and energy communities seem to be connected with both controllable and non-controllable operational aspects. Energy communities have been related, although mildly, to network parameters, which may be an indication of their potential involvement in local network operation. Large generation is strongly affected by capacity and power limits, while capacity factor and the generation profile seem to be among the most important aspects. Of course, these are followed by all other generation attributes but when it comes to distributed generation emphasis is given in non-controllable generation and specifically in generation profile. Regarding storage, either large or distributed, attributes like the energy limit, the charging/discharging limit and charging/discharging efficiency appear to matter. The aggregator is also among the classes of actors that are interrelated to demand response attributes and storage characteristics, since from the flexibility aggregation point of view, such technologies are relevant. Finally, the transmission system operator and the distribution system operator have not negligible connections with network operational attributes as their operation is affected by the network topology, the line characteristics and the technical limits.

Table 5: Relational table between actors and operational attributes.

- General
- Inflexible Demand
- Demand Response
- Non-controllable generation
- Controllable generation
- Stortage/EV
- Network

Intensity: Low – High

Actor	Type	Capacity/ power limit	Power factor	Demand profile	Load curtailment	Shiftable fixed cycles	Continuously adjustable power	Energy saving	Capacity factor	Generation profile	Curtailment action	Minimum stable generation	Ramp-down/up limit	Startup/ shutdown time	Minimum up/down time	Minimum/Maximum energy limit	Charging/ discharging power	Charging/ discharging efficiency	Network topology	Voltage limits	Thermal Capacity	Line/node characteristics
1. Prosumer	Residential																					
	Enterprise																					
	Industry																					
	Community																					
2. Producer	Large Generation / Storage																					
	Distributed Generation / Storage																					
3. Supplier	Supplier																					
4. Aggregator	Flexibility Aggregator / VPP																					
5. Trader	Wholesale Trader																					
6. ESCo	ESCo																					
7. Operator	TSO																					
	DSO																					
	Wholesale Market																					
	Local / Community Market																					
8. Regulator	Regulator																					

4.2 Behavioural dimension

The behaviour of actors constitutes an important aspect that affects the interactions that occur in the physical and in the market layer as both have been defined in Subsection 3.3. It is certainly affected by the environment and affects the behaviour of other actors as well, along with the outcome of the system. Behaviour in certain cases coincides with decision making, which may occur with or without the involvement of the decision maker's consciousness. From psychology to classical economics and from behavioural economics to multicriteria decision aiding, tools have been developed to allow the analysis and studies of the behaviour of individuals in a structured manner, enabling its further understanding, explanation and incorporation in models. Given the interdisciplinarity of that dimension, this section aims to present and analyse relevant concepts before introducing the behavioural aspects considered.

Considering the decision-making process, there are four common problematics that actors usually face individually or in sequence of two or more, or in a mixed form [51]. The "choice problematic" refers to the identification of a subset of actions, as small as possible, that contains either the best or the satisfactory actions in terms of optimal or satisficing solutions respectively. Another problematic is the "shorting problematic" in which the actor aims to place actions into predefined categories that are formed beforehand in terms of certain norms that deal with the eventual fate of actions that are assigned to them. The "ranking problematic" refers to the case where the goal is to determine an order over the subset of actions so that they are assigned to equivalence classes that completely of partially ordered. There is also the "descriptive problematic" under which the aim is to make the information related to actions and their consequences explicit so that there can be a systematic and formal description that leads to the qualitative and quantitative descriptions that enable the cognitive procedure of decision making [51].

As the basis of the study of actors' behaviour, classical decision theory sets two basic situations, that of indifference and that of strict preference. The indifference between two alternatives corresponds to the existence of clear reasoning that justifies the equivalence between those actions. Respectively, in the case of strict preference there are positive reasons that can justify clear and significant preference in favour of one of the two alternatives. The situations can be extended further for making the representation of the actor's preferences more realistic by incorporating the weak preference and the incomparability situations. In the former situation there are insufficient reasons for deducing either strict preference or indifference although there is some reasoning in favour of one of the alternatives, while in the latter reasons that could justify any of the other possible relations is absent [51]. There are two major axioms that are related to preferences and these are the axiom of transitivity and the axiom of completeness [52]. Transitivity, which is the fundamental principle, says that if an actor prefers the A over the B and the B over the C, then prefers A over C. Similarly, in the case of indifference if an actor is indifferent between alternatives A and B, and between alternatives B and C, then is indifferent also between A and C. The axiom of completeness, in the classical assumption of the two basic situations, states that the actor that is aiming to make a choice between two alternatives may be indifferent between the two or have a strict preference of the one over the other, or the vice versa. There are also other axioms that assign extra characteristics to the preference and impose convenient properties that enable and facilitate their mathematical representation. Such axioms are about the continuity, the homogeneity and the convexity of the preferences sets. Although the axiom of continuity is of special importance when the mathematical modelling of preferences is considered, the transitivity and the completeness of preferences are the two assumptions that enable an internally consistent ranking of the set of actions. Those two axioms give rise another important concept, that of rationality [53].

More from the social sciences perspective, there are four different types of rationality, the "instrumental rationality", the "belief-oriented" rationality, the "affectual rationality" and the "conventional rationality". The first type refers mainly to the expectation about the behaviour of other actors, the second one is following the ethical, aesthetic and cultural drivers, the third one is concentrating on the effects of feelings and emotions while the fourth one is based on habits. Although it is clear that in reality it would be rare these types to be found individually and combination of types could explain better the behaviour of actors, from an economics perspective rationality is considered in a more restricted setup. Given the required set of assumptions regarding preferences, predictability of actions that attempt to maximise beliefs of actors is limited and therefore rational choice seems closer to the normative than the descriptive approach. Although both approaches provide specific definitions for rationality, the normative theory considers rationality as the mean for achieving the actors' goals through the best arrangements, while the descriptive approach focuses on the pattern of choices and assumes that choices and outcomes can be predicted with sufficient information about the rules and the set of alternatives [54]. A detailed overview and discussion of rational choice theory considerations and limitations can be found in [55] while also other concepts such as the bounded rationality, i.e. the limited ability of the actor to remember and process information, are considered relevant [56].

Rationality also gives rise to the notion of "homo economicus" which refers from an economics point of view to the actor that is considered consistently rational, self-interested and pursues its subjective goals optimally. To that extent the well-being of the actor can be defined by a utility function, which seeks to optimize the following available opportunities. The utility measure, which is not unique and differs between individuals, is the ranking of actions, from the least to the most desirable ones, that is possible due to the axioms discussed earlier. Given the multifactorial sensitivity of utility, there is the "ceteris paribus" assumption that is common when trying to identify the effect of a specific parameter to the satisfaction level finds use when the indifference curves and the marginal rate of substitution of actors are considered. For extending to a more multicriteria framework [51], there is the fuzzy notion of the consequence cloud that incorporates any effect or attribute of interacting with objectives, strategies and value streams actions. Given the consequences, dimensions are required for reflecting the preferences of actors along with scales. The preferences scales can be considered as a more relaxed ranking way that follows a complete preorder of actions. Some typical scales that allow definitions of dimensions for various elementary consequences are (i) the monetary scale, (ii) the discomfort scale, (iii) the complexity scale, (iv) the risk scale and (v) the functional breakdown scale. It is important to mention that through the identification of consequences and the development of the cloud, the decision maker is enabled to specify the criteria with respect to which will take the decisions.

Turning to the several behavioural aspects that have been considered in our analysis, four categories have been defined, namely the self-interest drivers, the non self-interest drivers, the influencing standards and the other characteristics that have more behavioural economics grounds. The self-interest drivers cover for the common goals of actors as perceived in classical economics and include the utility maximization, the cost minimization, the profit maximization and the return on investments. Considering the aforementioned analysis, there is a need for well-defined functions or metrics that enable a consistent measure for the utility, the cost and the profit, respectively. In consumer theory, it is common for utility maximization to take place given a fixed level of spending with the individual buying those quantities of goods that exhaust the total income and for which the trade-off of marginal utilities between the goods is equal to the rate at which the goods are traded in the marketplace [52]. Such concept can be slightly differentiated in a dynamic setup for incorporating time as a characteristic and having a boundary based on consumption instead of budget to meet the needs of the specific good. On the other hand the cost minimization, which is not limited to consumer modelling but is usually found as a social planner objective, sets certain requirements and the aim is their achievement in the least possible cost. Profit maximisation is commonly found in production theory, with firms choosing both their inputs and outputs with the goal of maximizing of their economic profits, resulting as the difference between the total revenues and the total economic costs. Return of investments is most usually considered as the internal rate of return (IRR) and considered in contrast to the weighted average cost of capital (WACC). It is a metric pointing in the same direction as the profit although it is more focused on the timing of the cash flows and approaches the business operation from the investor's side.

From the sustainability perspective there are all those drivers that don't focus on the individuals' well-being directly but see the greater good through individuals' actions. It is common to find such phenomena modelled as externalities, while there are models focusing on the effect of prosocial behaviour that causes actors to experience positive feelings, i.e. the "warm-glow" in which an individual's personal donation to public good makes a positive impact on his utility, independently of how this action influences the social allocation [57]. The environmental aspects possible to include but not limited to the emission of greenhouse gases, to the land use and the pollution of air, water and soil. Societal challenges are more related to the common welfare, to labour issues and to quality-of-life aspects, while the overall perception/acceptance of undergoing developments by local communities is also quite relevant. Sustainability concerns are also of great importance, becoming of high priority in modern societies and developed countries, since they enclose a balanced approach combining economic, societal and environmental aspects. From the economic aspect, these can be related to growth, profit, research and development, from the societal aspect these are related to the standard of living, the education, the labour and the access in equal opportunities, while from the environmental one the use of natural resources, the prevention of pollution and the protection of bio-diversity are the key points. Of course, in between those pillars there are aspects such as the business ethics, the fair trade, the energy efficiency, the green technologies and the renewables that are strongly related with the sustainable development, a top priority in the agenda of decision makers either individuals or organisations.

Moreover, there are the influencing standards that focus on financial, comfort, safety, technical and legislator aspects. The standards refer mainly to the achievement of a corresponding level for satisfying some minimal requirements and are mostly seen as loose behavioural drivers. Finally, there are attributes like the satisficing behaviour, the attitude to risk, the reputation and conscience, the herd behaviour, the framing effect, the loss aversion and several types of bias that have their grounds in behavioural economics and can complement the traditional disciplines. Satisficing behaviour is a decision-making strategy that can be considered as an alternative objective to the utility or profit maximisation [58]. Given the framework deployed before, by considering an agent either the utility or profit are treated more as constraints rather than as ultimate goals, with a certain threshold being set and its achievement leading to satisfaction. Semi-optimality is also an aspect closely related, as under the satisficing behaviour there can be the paradigm where actors can either find optimal solutions through simplified models that end up being satisfactory solutions to the more realistic world. This is closely relevant to the bounded rationality idea, and as it was mentioned earlier limitations including the availability of information, the difficulty of the problem requiring a decision, the cognitive capability of the mind, and the time available to make the decision lead decision makers to act as satisfiers, seeking a satisfactory solution, rather than an optimal one.

Another important subject has to do with how actors deal with risk in an uncertain environment. Extending the utility concept to the expected utility version, attitude towards the risk is combined with preferences. Under the expected utility theory, individuals may be risk-averse [59], i.e. actors would not undertake a fair gamble, which implies that the utility function is concave on wealth. There is also the risk neutrality where the function gets linear and the convex version where actors seek risk. In modern portfolio theory risk aversion is measured as the marginal expected reward that the investor requires for accepting additional risk. There is a trade-off between the expected return and the exposure to risk with the optimal portfolio lying on the efficient frontier, with the capital allocation line being tangent to this point. This later line is the market-based relation between the risk and the returns, in an idealized financial market framework, where decisions are based on risk-return assessments, there is perfect competition and investors are price-takers, there are no transactions costs and borrowing/lending takes place at riskless rates. Loss aversion that captures the tendency to prefer avoiding losses to acquiring equivalent gains is also relevant, with the difference being on the fact that the utility of payoffs depends on previous experiences.

The reputation and conscience are also parameters that drive actors' behaviour, with the importance of the former being also revealed through game-theoretic contexts where in repeated interaction better off equilibria can be sustained by good reputation of players. The herd behaviour has also grounds on the mimic tendency of actors, with groups acting collectively without centralised coordination and the framing effect captures the influence that may have in the decision the presentation of the alternatives [60]. There are several types of bias that may be relevant to the decision-making processes, with the status-quo/activity bias capturing the tenancy of actors to leave things as they are and, on the contrary, to take

Table 6: Relational table between actors and behavioral aspects.

- Self-interest drivers
- Non Self-interest drivers
- Influencing standards
- Other characteristics

Intensity: High – Low

		Utility Maximization	Cost Minimization	Profit Maximization	Return of Investment	Environmental Concerns	Social Concerns	Sustainability Concerns	Financial Standards	Comfort Standards	Safety Standards	Technical Standards	Legislation Standards	Satisficing Behaviour	Attitude to Risk	Reputation and Conscience	Herd Behavior	Framin Effect	Loss Aversion	Status-quo / Activity Bias	Recency Bias
1. Prosumer	**Residential**																				
	Enterprise																				
	Industry																				
	Community																				
2. Producer	**Large Generation / Storage**																				
	Distributed Generation / Storage																				
3. Supplier	**Supplier**																				
4. Aggregator	**Flexibility Aggregator / VPP**																				
5. Trader	**Wholesale Trader**																				
6. ESCo	**ESCo**																				
7. Operator	**TSO**																				
	DSO																				
	Wholesale Market																				
	Local / Community Market																				
8. Regulator	**Regulator**																				

actions mostly for keeping things in motion. There is also the recency bias, which is also known as gambler's fallacy, where actors' expectations are affected more by the more recent outcomes [61].

In Table 6, prosumers seem to be driven mainly by the utility maximization and the cost minimization, producers incorporating the firm and investor aspects and other business entities being more focused on profit maximization. Market operations mainly minimize costs, regulators focus on environmental, social and sustainability concerns while influence the legislation standards that affect several actors.

5. TradeRES Actor-ID cards

Following the concepts analysed so far and the respective developments, this section aims to summarize and highlight the key findings. The creation of identity cards for the traditional and new actors that have been identified as participants in the electricity system and markets, provides a complete high-level overview indicating the main technologies, along with the operational and behavioural characteristics of the actors.

Each of the Actor-ID cards consists of four blocks, one with a short description of the actor, with the types being noted where relevant, another with the key technologies and other two where the operational attributes and the behavioural aspects are distinguished to primary and secondary ones. This classification follows the intensity of the relation as this has been found in Table 5 and Table 6. It needs to be mentioned once again that the relations identified along with their intensity refer the mapping of the actor scene for the purposes of TradeRES project and aim to pave the ground for the enrichment of the agent-based models that follows in WP4.

The Actor-ID Cards 1-8 that follow are one for each of the actor classed that have been identified in Subsection 3.3. These have been the Prosumer, which was distinguished based on its type to residential, enterprise, industrial and community, the Producer including generation and storage, which was distinguishes based on its size to large and distributed, the Supplier, the Aggregator, the Trader, the ESCo, the Operator and the Regulator.

Prosumer

Description	Technologies
The final user or group of users who consumes, stores, self-generates, participates in flexibility or energy efficiency schemes, not primary professional. Types: Residential, Enterprise, Industrial, Community	Inflexible Demand, DSR, EVs, Flexible H&C, BESS PV, Wind, CHP Biomass, Heat Storage, CSP, Distribution network, ICT
Operational Characteristics	**Behavioural Characteristics**
Primary: Demand profile, load curtailment, shiftable fixed cycles Secondary: Continuously adjustable power, Min/Max energy limit, Charging/Discharging power	Primary: Cost minimization, Utility maximization Secondary: Comfort standards, Attitude to risk, Environmental and Social Concerns

Actor-ID Card 1: The prosumer.

The technological influence on the actors' operation and behavior is twofold as it has been elaborated in Subsection 3.4. Technologies act as enablers and cause the emergence of new actors and roles, while they influence directly the operational side of assets by positioning the actor into the system and due to the technical limitations they impose, as well as by giving structure to the business model which frames actors' behaviour.

Producer

Description	Technologies
The legal entity that owns and operates for commercial purposes, from a single to a portfolio of different technologies generation/storage assets. Types: Large, Distributed	Wind, PV, BESS, PSH, Biomass, Hydro, Nuclear, CCGT Geothermal, CHP, CSP P2G, Heat Storage, EVs
Operational Characteristics	**Behavioural Characteristics**
Primary: Capacity/ power limit, Capacity factor, Generation profile Secondary: Curtailment action, Min stable generation, Ramp limit, Up/Down time, Energy limit, Charging power, Charging efficiency	Primary: Profit maximization, Attitude to risk Secondary: Return of investment, Legislation standards, Technical standards

Actor-ID Card 2: The producer.

Supplier

Description	Technologies
The entity that buys electricity from the wholesale market or directly from the producers and sells it to the end users.	Inflexible Demand, DSR, Flexible H&C, EVs, PV, Wind, Biomass, CHP, Nuclear,
Operational Characteristics	**Behavioural Characteristics**
Primary: Demand profile, load curtailment, shiftable fixed cycles Secondary: Continuously adjustable power, Min/Max energy limit, Charging/Discharging power, Efficiency	Primary: Profit maximization Secondary: Return of investment, Attitude to risk, Environmental concerns

Actor-ID Card 3: The supplier.

Extensive discussion on the two dimensions considered in the technoeconomic analysis of the actors has been presented in Section 4, where more details on the operational attributes and the behavioural aspects are given.

Aggregator

Description	Technologies
The entity that aggregates a number of end-users that own resources, like prosumers, producers or a mix of them. Types: Aggregator, VPP	Inflexible Demand, DSR, Flexible H&C, BESS, EVs Wind, PV, Biomass, ICT
Operational Characteristics	**Behavioural Characteristics**
Primary: Shiftable fixed cycles, Continuously adjusted power, Min/Max energy limit, Charging power Secondary: Capacity/power limit, Capacity factor, Generation profile, Curtailment action, Ramp limit, Up/down time	Primary: Profit maximization Secondary: Attitude to risk, Legislation standards, Environmental concerns

Actor-ID Card 4: The aggregator.

Trader

Description	Technologies
The entity that can represent large energy volumes into the wholesale markets and achieve better positioning and reduced non-energy costs.	Biomass, Biogas, PV, Wind, OCGT, CCGT, Nuclear, Hydro, Other non-RES, PSH, P2G, BESS
Operational Characteristics	**Behavioural Characteristics**
Primary: Capacity factor, Generation profile, Curtailment action Secondary: -	Primary: Profit maximization Secondary: Legislation standards, Attitude to risk

Actor-ID Card 5: The trader.

Finally, it is worth mentioning that some classes of actors present more interest than others, since the importance of their role has been highlighted and several operational and behavioural characteristics have been pointed out. Given the analysis that took place, these actors are eligible for improving their representation in agent-based models, with this prioritization being part of the T4.2.1 work. Further details on the actor modelling priorities along with the outcomes of the work related to actors that continues in the project and focuses especially on their representation in models, is expected in D4.4 and its consequent versions.

ESCo

Description	Technologies
The entity that can act as a facilitator in investments, operations and decision making by internalizing activities that encounter risks and/or can be further improved	ICT
Operational Characteristics	**Behavioural Characteristics**
Primary: - Secondary: -	Primary: Profit maximization Secondary: -

Actor-ID Card 6: The ESCo.

Operator

Description	Technologies
The entity responsible for the operation of its system, which can have either a physical or an economic interpretation. Types: TSO, DSO, Wholesale market, Local/community market	Wind, PV, Biomass, Inflexible demand, DSR, BESS, PSH, P2G, Hydro, Nuclear, OCGT, CCGT, Other non-RES, ICT
Operational Characteristics	**Behavioural Characteristics**
Primary: Network topology, Line/node characteristics, Thermal capacity Secondary: Demand profile, Generation profile, Curtailment action	Primary: Cost minimization, Legislation standards Secondary: Safety standards, Technical standards, Environmental concerns

Actor-ID Card 7: The operator.

Regulator

Description	Technologies
The entity that is legally entitled to supervise the energy industry and is concerned about its sustainability	Inflexible demand, DSR, BESS, PV, Wind, OCGT, CCGT
Operational Characteristics	**Behavioural Characteristics**
Primary: - Secondary: -	Primary: Environmental concerns, Legislation standards, Sustainability concerns Secondary: Cost minimization, Social concerns

Actor-ID Card 8: The regulator.

6. Local environment and transactive energy

The analysis that has been reported in the previous sections mainly focused on the broad markets, which is the primary interest of the market designs conceived and analysed in D3.5. Nevertheless, TradeRES also deals with the complexity and interconnectedness of various entities within the power ecosystem at the local level and T5.2, the dedicated task to the “local” case study, aims to analyse, model, and evaluate market settings, interactions between parties and community-based schemes. This section aims to provide the necessary contextual background to T5.2 and report the developments regarding the characterisation of behavioural and operational aspects of the key actors involved in the local environment.

To provide a better understanding of the “local environment”, which in D5.2 is further distinguished into “broad” and “narrow”, Figure 14 presents the local environment through the lens of the transactive energy paradigm. In this context, "transactive energy" refers to a system where economic and control techniques are used to manage the flow or exchange of energy within an existing power system with respect to economic and market-based standard values of energy. At the local level, the ecosystem involves distributed generation and storage, indicating the presence of resources like solar panels, wind turbines, and batteries that are located close to where the energy is consumed. This decentralization is a key aspect of transactive energy, allowing for more direct and potentially real-time transactions between producers and consumers (prosumers).

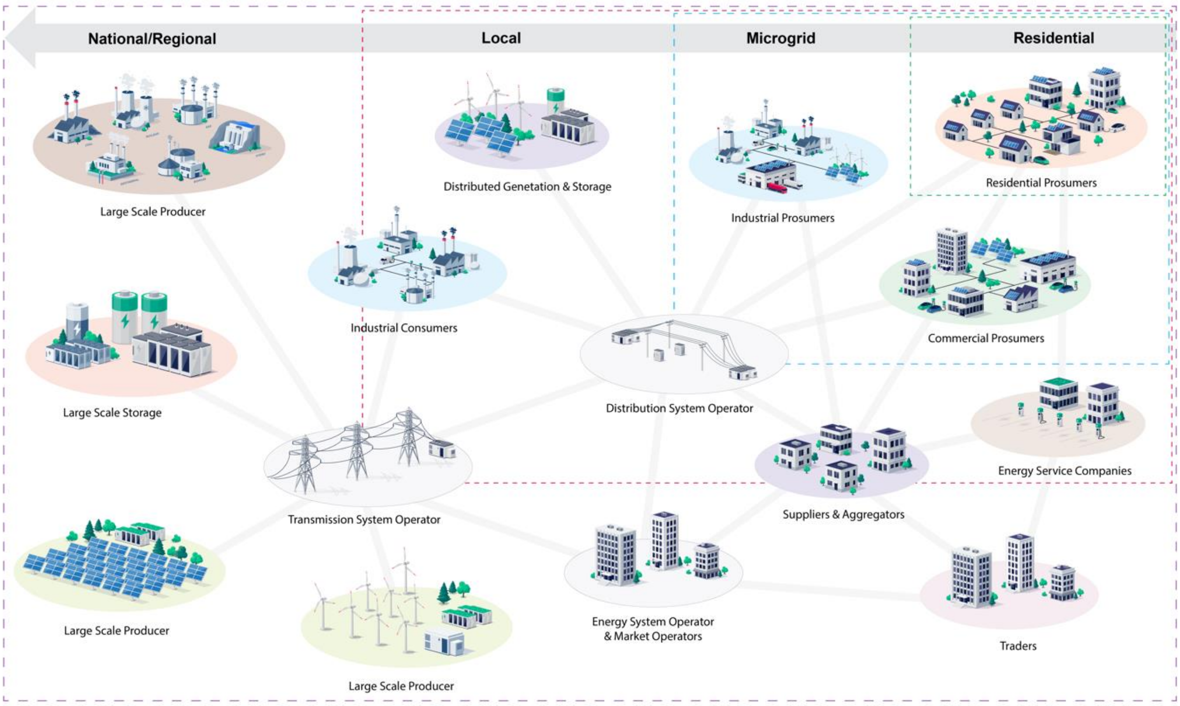


Figure 14: The transactive energy paradigm and the local environment.

Individual prosumers, which could be residential or commercial in nature, are depicted as both producers and consumers of energy. These prosumers can actively manage their consumption and production, and even store energy, participating in the local energy market directly or through aggregators. The DSO plays a pivotal role in the local environment, managing the energy flows and maintaining the balance between supply and demand. The DSO ensures that the physical infrastructure is capable of supporting the dynamic and distributed nature of a transactive energy system. Suppliers/aggregators are shown to be a bridge between the microgrid or local environment and the larger national/regional grids. They could facilitate the local trading of energy, bundling the excess energy produced by prosumers and selling it on larger markets, or purchasing additional energy from the national grid when local demand exceeds supply. The transactive energy paradigm within this local environment is characterized by dynamic and flexible energy transactions, where prices can fluctuate based on real-time supply and demand. This system aims to optimize energy distribution and consumption, making the grid more efficient, resilient, and capable of integrating a higher proportion of renewable energy sources.

6.1 Empowering prosumers

Prosumers, the individuals or entities that both produce and consume energy, are increasingly recognised as a cornerstone for the transformation of the energy system. The empowerment of prosumers marks a significant shift from traditional, centralized power generation to a more distributed model that can enhance the resilience and sustainability of energy systems.

Prosumers can range from households with rooftop solar photovoltaic (PV) installations and battery storage to energy-intensive industrial complexes with distributed energy resources (DERs) and interruptible loads. These active customers take various forms, including homes, supermarkets, office buildings, and industrial sites, each leveraging their unique capabilities for self-consumption and interaction with the grid. Their roles can also extend to financial contributors who, without directly engaging in energy management, provide their rooftop spaces for PV installations, thus participating financially in the energy market. Table 7 **Erro! A origem da referência não foi encontrada.**presents the general needs of residential prosumers that can be drivers of their behaviour and can be useful for the derivation of multi-objective formulations or constraints representing acceptable thresholds.

Technological advancements are crucial in enabling prosumers and, on top of that, characterise them operationally, as seen in Section 3.4. The integration of smart metering devices, electric vehicles (EVs), and smart-charging infrastructure, together with dynamic pricing contracts, has facilitated a surge in prosumer numbers. Technologies like solar PV and batteries have become increasingly common due to the combination of technological maturity and governmental support mechanisms, including subsidies and tax exemptions. Additionally, the emergence of smart chargers and energy management systems has expanded the potential of prosumers to actively manage their energy use and contribute to grid flexibility.

Financial considerations remain a primary motivator for prosumers. The desire to minimize electricity expenses, stabilize costs, and ensure supply security drives prosumers to engage with the energy system actively. The intertemporal setting of the prosumer's decision-making problem may span operational, leasing and investment horizons. Governmental support mechanisms, decreasing technology costs, and the structure of electricity prices and taxes encourage self-consumption and provide opportunities to monetize the stack value of flexibility. However, the phasing out of feed-in tariffs and net-metering schemes is pushing prosumers towards new forms of market participation, such as selling flexibility to system operators, engaging with third-party aggregators, considering the coalition to communal-based schemes or participating in local markets.

Table 7: Energy-related needs of residential prosumers.

General Needs	Description
Energy self-sufficiency	The prosumer wants to fulfil their own energy requirements independently to ensure energy security and supply autonomy.
Control/Independence	The prosumer aims for autonomy from utilities, the state, and other institutions in managing and using their energy systems.
Involvement in the energy system	The prosumer desires to be actively involved in the management and operation of their energy system.
Comfort	The prosumer seeks to use their energy system to enhance personal living comfort.
Respect for the environment	The prosumer's energy system should have a minimal environmental impact.
Profitability/Cost	The prosumer expects the energy system to be cost-effective and to offer financial benefits.
Enthusiasm for technology	The prosumer is interested in experimenting with and utilizing new energy technologies.
Security	The prosumer requires their energy system to be safe and secure, providing peace of mind.

Their integration into the modern power system is multifaceted. On one hand, governmental incentives have propelled the initial adoption of prosumer technologies. On the other, long-term engagement and contribution to system efficiency rely on enabling prosumers to access various revenue streams through their flexibility. Regulatory and technical barriers still exist [62], which, if lifted, could unlock this potential. Some countries have made significant strides in this regard, allowing prosumers to benefit from dynamic pricing contracts and participate in flexibility markets, thereby supporting the overarching goal of an integrated smart energy system.

Following the categorisation of prosumers in the residential, commercial, and industrial segments of Figure 14, which aims to integrate the prosumer entity (consumer and produces actor) within the electricity market and the transactive energy paradigm, Figure 15 presents typical models for empowering prosumers [63]. Each segment showcases different types of prosumers, such as households with solar panels, storage systems, and electric vehicles (EVs), commercial buildings with on-site distributed energy resources (DERs), and industrial sites also equipped with DERs and flexible loads. The interactions between these prosumers and the grid are highlighted, showing how they can generate and inject energy into the grid, shift loads in response to energy prices, and offer flexibility through participation in new and existing energy markets. Notably, residential prosumers are further subdivided into those who consume their self-generated energy and those who invest in DERs at offsite locations, indicating a nuanced approach to energy management and investment within local energy ecosystems.

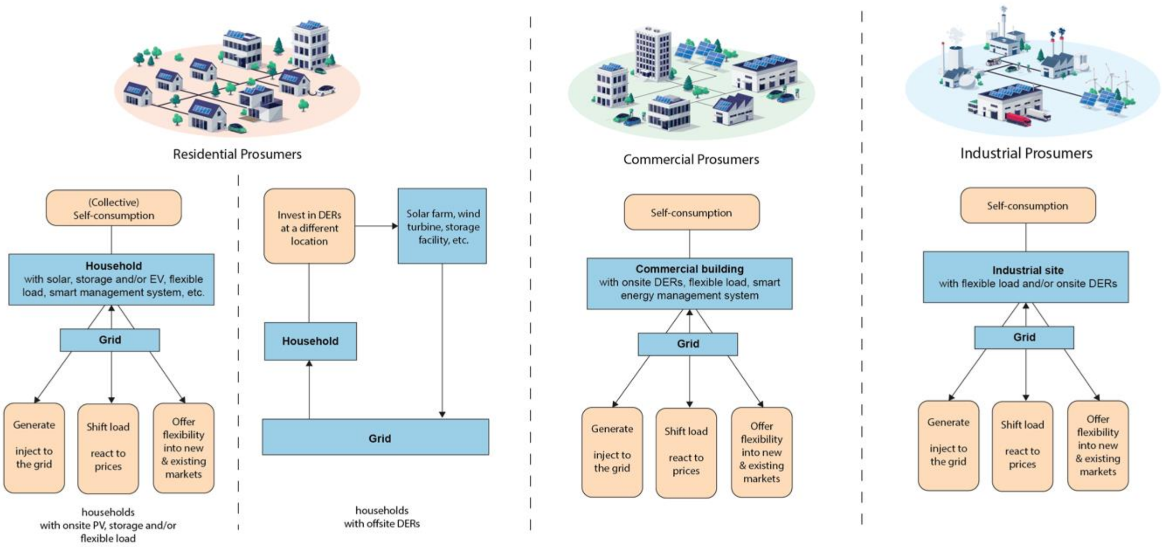


Figure 15: Overview of typical models for prosumers' empowerment.

Finally, it should be stated that prosumers, when analysed in a more localised environment, can be seen as a diverse group whose potential is magnified through the combination of technological enablement, financial incentives, and regulatory frameworks that recognise their value. The evolution of energy policies and market designs will continue to shape the role of prosumers in the modern energy ecosystem. The emerging approaches and the business models discussed in later subsections aim to empower prosumers and support their active participation, which is vital for the energy transition, towards a decentralised, resilient, and sustainable power system.

6.2 Emerging approaches to transactive energy

Transactive Energy (TE) as a concept has evolved significantly in response to changes in the energy sector, especially with the growth of renewable energy sources and distributed energy resources. It refers to the economic and control mechanisms that enable the dynamic balance of demand and supply throughout the electrical infrastructure, with economic value being the key parameter that governs operations. This approach is particularly relevant in the context of the modernising smart grid, which enables more efficient and market-based transactive exchanges between energy producers and consumers.

Under the lens of TE, some innovative approaches that aim to enhance sustainability, efficiency, and community involvement in energy production and consumption are presented below. These approaches can slightly twist the behavioural and operational characteristics according to the specific focus.

6.2.1. Collective Self-Consumption

Collective Self-Consumption (CSC) extends the concept of individual self-consumption to a community level, allowing groups of individuals or entities to consume electricity that they collectively produce. This communal approach to energy generation and consumption provides an attractive proposition for consumers to use energy at more favourable rates and feel empowered by using their own energy. However, CSC often has geographical limitations, which means that CSC schemes typically only cover single buildings or streets, and not larger areas beyond sub-stations. Additionally, CSC schemes face a significant limitation in their inability to participate in flexibility markets, which could otherwise provide opportunities for higher remuneration. Moreover, the recent Opinion of the European Economic and Social Committee[21] emphasizes the critical role of individual and collective energy self-consumption in advancing green and energy transitions and achieving economic and social balance [64]. It highlights the need for local and regional authorities to support "extended collective" self-consumption projects, allowing energy to be used beyond its immediate generation vicinity. This inclusive approach aims to facilitate energy generation and usage for vulnerable populations, combating energy poverty. The Committee also urges the European Commission to endorse non-profit initiatives for the collective procurement of renewable energy installations as exemplary practices.

Collective self-consumption and energy sharing can be regarded as an initial step in establishing decentralized control over electricity trade between producers and consumers, challenging the legal classification of these participants within the system. Rather than being determined by the distribution network or the market, decentralization is characterized with respect to the market players, particularly the energy suppliers. [65] Another crucial aspect that marks energy sharing and communities as contributors to the decentralization of the electrical model is its emphasis on fostering local energy transactions. This characteristic is echoed across various legal structures with differing levels of detail. It is evident that collective self-consumption is deeply rooted in the local context, aligning

[21] The EESC issues between 160 and 190 opinions and information reports a year. 70% are referrals by the Council, the European Commission and the European Parliament. 21% are own-initiative opinions and information reports, while 9% are exploratory opinions generally requested by the country holding the EU Presidency.

with the principles of Energy Justice as it draws focus to the allocation of benefits and responsibilities within the local energy infrastructure. Both the consumer and the producer operate within a closely-knit geographical setting, taking on the localized governance of energy with tangible, physical connections. [66]

The following parties are among the ones related to CSC:

- **Participants/Prosumers:** These are individuals or businesses that generate their own energy, often through renewable sources, and aim to consume it collectively to maximize efficiency and reduce costs; they are the core of CSC.
- **Energy Suppliers/Utilities:** They may facilitate CSC arrangements by offering special tariffs and could benefit from reduced peak demand and increased customer satisfaction.
- **Regulatory Authorities:** Create frameworks to encourage CSC, aiming to boost renewable energy uptake, enhance grid stability, and empower consumers.

6.2.2. Local Energy Communities

Local Energy Communities (LECs) are collaborative initiatives where individuals, businesses, and public entities within a defined locality join forces to produce, manage, and consume energy. These communities are built on the principles of cooperation, sustainability, and collective empowerment. By pooling resources and sharing the benefits of renewable energy generation, LECs aim to foster energy democracy, allowing members to take charge of their energy needs while contributing to the broader transition to a low-carbon economy. LECs often utilize smart grid technologies to optimize energy flows, enhance grid resilience, and support the integration of distributed energy resources such as solar panels, wind turbines, and energy storage systems. They stand as a testament to the potential of collective action in reshaping energy systems to be more responsive to local needs and environmental goals. Some aspects [66] that play a pivotal role in the consideration and characterisation of energy communities are the following:

1. **Energy Allocation Mechanisms:** Energy allocation within communal and cooperative schemes is vital for collective sharing and consumption. Different models, such as long-term net metering and short-term allocations, are used across Europe, each with unique data management and responsibility implications.
2. **Legal Structures for Energy Communities:** The legal form of energy communities significantly affects their operational framework. Certain legal entities, such as cooperatives, have been promoted due to their communal nature and potential for localized energy governance. This legal diversity reflects national priorities and the degree of openness to organizational forms.
3. **Wider Energy Structures:** Legislation may encourage the formation of broader energy community networks, facilitating regional and national associations. This approach aims to strengthen local energy ties and protect against external investor influence, ensuring that economic benefits remain within the community.
4. **Proximity and Effective Control:** The importance of proximity is evident for members or shareholders exercising control over renewable energy projects.

However, the criteria for what constitutes effective control or proximity are not uniformly defined, allowing countries to tailor requirements to their specific contexts.

5. **Autonomy in Energy Communities:** Autonomy within energy communities intersects with membership criteria. Some countries have also imposed restrictions to balance power among members.

Table 8: Point by point comparison of LEC legal schemes in EU legislation.

Renewable Energy Community	**Citizen Energy Community**
A legal entity which, in accordance with the applicable national law:	A legal entity that:
• is based on open and voluntary participation, • is autonomous, and • is effectively controlled by shareholders or members that are located in the proximity of the renewable energy projects that are owned and developed by that legal entity;	• Is based on voluntary and open participation • (autonomous is not mentioned) • and is effectively controlled by members or shareholders that are natural persons, local authorities, including municipalities, or small enterprises (recitals: 'that are not engaged in largescale commercial activity and for which the energy sector does not constitute a primary area of economic activity').
• the shareholders or members of which are natural persons, SMEs or local authorities, including municipalities;	• (recitals: "membership of citizen energy communities should be open to all categories of entities." This means also medium-sized and large enterprises.)
• the primary purpose of which is to provide environmental, economic or social community benefits for its shareholders or members or for the local areas where it operates, rather than financial profits.	• has for its primary purpose to provide environmental, economic or social community benefits to its members or shareholders or to the local areas where it operates rather than to generate financial profits;
• (While not part of the definition, RECS are entitled to produce, consume, store and sell renewable energy, including through renewables power purchase agreements, to share renewable energy within the community, and to access all suitable markets.)	• may engage in generation, including from renewable sources, distribution, supply, consumption, aggregation, energy storage, energy efficiency services or charging services for electric vehicles or provide other energy services to its members or shareholders;

For an EU legislation perspective, LECs include the Renewable Energy Communities (RECs) and Citizens Energy Communities (CECs), which epitomize the modern interpretation of community in the energy sector. The concept of community is intimately linked to shared resources and distributive justice, pivotal in the realm of energy where communities, such as RECs and CECs, emerge as vital constructs. These communities are not just spatial clusters but dynamic entities defined by shared aspirations and a collective approach to energy self-sufficiency, often reflected in their legal structure and governance.

The essence of LECs and CECs lies in their capacity to share benefits equitably, transcending traditional boundaries and embracing the complexity of modern energy demands. They embody a commitment to a sustainable future, one where energy is not only a commodity but also a shared resource that fosters a sense of solidarity and collective well-being within and across communities. Table 8 presents the key points of their definition in EU framework.

Renewable Energy Communities involve various entities like SMEs and citizen households collaboratively generating, storing, sharing, and consuming clean energy. In an REC, there's typically a market player who facilitates and manages the system to offer participants lower energy costs and improved efficiency of DERs. However, RECs face several challenges, primarily due to fragmented regulations across Europe. Despite the existence of a harmonized EU legal framework in the Renewable Directive II, the slow implementation and varied national legislation create barriers. These include administrative complexities, start-up costs, and increased liability. Furthermore, the requirement for RECs to be constituted as legal entities adds to the complexity, with their formation often being a bottom-up initiative, rather than a response to a systemic need.

Citizens Energy Communities are grassroots initiatives where local citizens or groups come together to produce and share energy. These cooperatives are founded on democratic principles, allowing members to participate actively in the energy transition and become more aware of energy systems. This model has gained popularity as a response to increasing public interest in climate change mitigation, often with support from local authorities. CECs represent a direct approach to community-based energy management, enabling participants to take control of their energy needs and contribute to a more sustainable future. However, the cooperative model also comes with challenges, particularly in terms of financial structure and human capital. Many CECs struggle with the complexities of the energy market and the need for effective management and planning to ensure their long-term sustainability and impact.

The following parties are among the ones related to LEC:

- **Community Members:** They invest in and collectively own energy resources, seeking energy independence, lower costs, and sustainability.
- **End-Customers:** These are citizens and legal entities committed to rational and economical energy use to achieve the community's climate neutrality goals.
- **Energy Producers:** Involved in the production and sharing of locally produced energy.

- **Service Providers:** Companies that provide technical, legal, and operational support to CECs, aiming for profitability and growth opportunities.
- **Local Governments:** May support CECs to meet regional sustainability goals and improve energy resilience.
- **Regulatory Bodies:** Play a crucial role in framing the regulations and ensuring compliance.

6.2.3. Positive Energy Districts

Positive Energy Districts (PEDs), or Positive Energy Neighbourhoods, are urban areas or connected buildings that are energy-efficient and flexible, integrating local renewables to achieve net-zero greenhouse gas emissions. They manage an annual surplus production of renewable energy locally or regionally. PEDs incorporate various schemes like co-operatives and CSC within a metropolitan area and extend beyond electricity to include aspects like mobility sharing, heat distribution, and insulation. Typically implemented by municipalities or developers, PEDs face challenges and opportunities due to the scale and diversity of the project. The deployment of numerous DERs and increased electrification can lead to local energy management challenges, causing congestion and other demand-supply complexities.

The following parties are among the ones related to PEDs:

- **Municipalities or Developers:** Often responsible for implementing PEDs due to the scale and diversity of the project.
- **Energy Cooperatives and Communities:** They include a multitude of schemes like cooperatives and CSC, working together within a metropolitan area.
- **Infrastructure Providers:** Involved in providing energy-efficient solutions, renewable energy integration, and infrastructure for mobility sharing, heat distribution, and insulation.

6.2.4. Microgrids

Microgrids are localized grids that can operate independently from the main grid, often featuring their own energy generation, storage, and distribution systems. They represent a smaller-scale version of the standard grid, providing a more manageable framework for integrating Distributed Energy Resources (DERs). Microgrids are particularly useful in remote or isolated areas, such as islands, where connecting to the main grid is impractical or too expensive. Despite their advantages, managing microgrids can be complex due to the variability in load profiles and external factors like weather, which introduce uncertainty into the system. The integration of DERs, while easier in a microgrid than in larger grids, still presents significant challenges in terms of balancing supply and demand and ensuring grid stability. Key regulatory issues [67] include the lack of clarity on microgrid and component ownership rules, which creates obstacles to development and financing. Traditional interconnection standards do not fully address the nuances of multi-property microgrids, such as the need for new interconnection requirements that account for islanding and advanced microgrid control features. Additionally, there is a notable absence of a clear definition and quantification of resilience, which hinders the ability to evaluate the full benefits of microgrids and complicates discussions around compensation. Addressing these issues requires the development of flexible, transparent, and equitable regulatory frameworks that remove disincentives for utilities and facilitate safe, orderly, and predictable integration and operation of microgrid asset.

The following parties are among the ones related to MG:

- **Microgrid Operators/Owners:** These could be private companies, community groups, or public entities that manage the microgrid's assets and operations, looking to provide reliable, localized energy.
- **Technology Providers:** Offer solutions for energy management, storage, and generation, aiming to innovate and capture market share.
- **Investors/Financiers:** Provide capital for microgrid development, seeking returns through operational efficiency and energy sales.

6.2.5. Smart Local Energy Systems

Smart Local Energy Systems (SLES) are about integrating various energy assets and infrastructures in a local area and operating them in a smarter way. SLES automate the use of DERs and the trading of associated asset flexibility in energy and ancillary service markets. Often designed with the assistance of local authorities, SLES aim to adopt a local, granular approach to join assets for increased energy efficiency. Although still in the early stages of development, SLES has shown potential benefits, including alleviating grid congestion, reducing energy costs, and promoting the uptake of renewable energy sources.

The following parties are among the ones related to SLES:

- **Local Authorities:** Assist in designing and implementing SLES for a more granular approach to joining assets.
- **Energy Service Providers:** Offer automated services for the use of DERs and trading of associated asset flexibility.
- **Technology Providers:** Supply the digital and hardware tools necessary for the smart operation of local energy systems.

6.2.6. District Self-Balancing

District Self-Balancing (DSB) is a progressive approach to local energy management, designed to complement existing initiatives and offer additional value [68]. DSB uniquely considers the needs of the entire electricity system, rewarding consumers for sharing renewable electricity, thereby addressing local congestions and shielding consumers from excessive price spikes. It promotes the flexible use of loads, distributed generation, and storage to alleviate areas of congestion highlighted by Distribution System Operators (DSOs). DSB fosters business innovation and market-based solutions to optimize local energy challenges, and it is inclusive, welcoming all energy users without disadvantaging non-participants. By optimizing local climate-friendly investments and protecting against price volatility, DSB empowers consumers, improves system efficiency, and supports decarbonization. DSOs, in recognizing local congestion, should champion DSB initiatives, necessitating transparency and justifying decisions when preferring grid reinforcements over DSB solutions. Market parties play a pivotal role in the deployment and management of DSB schemes, bringing in both public and private resources and enabling DERs to provide diverse services and participate in various markets, thus enhancing their value. Finally, the use of the public low-voltage grid within DSB schemes must be fairly compensated, reflecting the actual voltage level of consumers and ensuring cost-reflective network charges.

The following parties are among the ones related to DSB:

- **Distribution System Operators:** Identify areas of congestion and promote DSB to optimize the grid, thus deferring costly grid reinforcements.
- **Market Players/Aggregators:** Facilitate the DSB scheme by managing DERs, aiming to provide value-added services and participate in flexibility markets.
- **End-Users/Consumers:** Participate in DSB for more efficient energy usage, cost savings, and contributing to a balanced local grid.

6.2.7. Local Energy Markets

Local Energy Markets (LEM) represent an innovative approach to energy distribution that allows the direct trading of energy within localized areas, often in real-time. These markets are designed to empower consumers, giving them the ability to not only generate their own energy, usually through renewable sources like solar and wind, but also to sell excess production to neighbours or buy additional energy as needed. LEMs are enabled by advanced metering infrastructure, smart grids, and digital platforms that facilitate transactions and balance supply and demand dynamically. The goal is to optimize the use of locally produced energy, reduce transmission losses by minimizing the distance between production and consumption points, and lower costs by avoiding traditional utility markups. Additionally, LEMs can contribute to grid stability by providing ancillary services such as frequency regulation and demand response. By integrating distributed energy resources, LEMs support the decentralization of energy production and create a more resilient, efficient, and sustainable energy system.

Actors of the LEM

LEMs can, of course, be considered as ecosystems that integrate various key players, each with distinct roles, objectives, and interactions. These actors range from energy suppliers, network operators, regulators, active and passive participants (prosumers), coordinators, to even the community in different roles. Together, they form a complex web of technical, economic, and social interactions that underpin the functioning and governance of LEMs.

Suppliers that act as intermediaries between wholesale markets and consumers, providing stability in energy pricing and supply, can interact with the market. Network operators, both TSOs and DSOs, aim to manage network constraints and maintain power balance, thus playing a pivotal role in integrating LEMs with the broader energy system.

Regulators and governments set the overarching framework within which LEMs operate, ensuring that societal and community objectives such as decarbonization and energy security are met. Their policies and oversight activities are crucial in creating a conducive environment for LEMs to thrive.

Prosumers or active participants are individuals or entities actively engaged in energy production and consumption. They seek to minimize costs and maximize revenues through the smart management of their energy resources. Passive participants, on the other hand, may not engage actively in the LEM but can still benefit indirectly from its operations.

The role of the coordinator is central to the LEM, acting as an intermediary – the market maker - to promote cooperation and manage the flow of energy, data, and finances within the market. The coordinator's actions ensure that the market operates efficiently and that the diverse needs of the participants are met. Finally, the community is the social fabric that could bind several of the actors together and could also undertake the role of a few of them. To that extent, they could play a critical role in driving local energy initiatives, supporting vulnerable members, and ensuring that the benefits of LEMs are distributed among members in a fair and equal way.

These actors, through their interplay and the structures they create, enable LEMs to offer a range of benefits, such as improved grid flexibility, network stability, energy security, and resilience. They also contribute to more competitive energy pricing, support for renewable energy adoption, and broader societal goals like reducing energy poverty and combating climate change. However, to realise these benefits, challenges such as grid compatibility, growth limitations, regulatory clarity, and energy volatility must be addressed through collaborative efforts, innovative business models, and supportive policy frameworks.

Control and Coordination

LEMs, as a decentralised and micro-founded setting, aim to address a complex interplay between diverse actors with varying goals, resources, and levels of information. The mechanisms for coordinating these active players range from direct to indirect control strategies, influenced by their individual preferences, the cooperative or competitive nature of their interactions, and the structure of information sharing.

Direct control mechanisms involve centralised decision-making, where a primary controller receives detailed data from various units and determines actions to optimize system objectives. This approach is particularly effective in microgrids or when an aggregator owns multiple distributed energy resources. However, it raises significant concerns over privacy and security, especially when it involves personal data from residential participants. Moreover, the computational intensity and single-point-of-failure risks associated with a central controller make direct control less feasible for large-scale LEMs.

On the other hand, indirect control allows stakeholders to retain some level of autonomy, making independent decisions based on provided information. This structure is preferable in scenarios where the individual interests of stakeholders are diverse and not fully aligned. Indirect control is further refined through the lens of competitive versus cooperative frameworks, where stakeholders either vie to maximize personal utility or work towards common goals that provide collective benefits. Information sharing, crucial in this setting, can take the form of mediated, bilateral, or implicit coordination, each with varying degrees of complexity and cost considerations. Mediated coordination involves two-way communication with a central entity that disseminates information, while bilateral coordination sees stakeholders negotiating directly with one another, enhancing system robustness and reducing infrastructure costs. Implicit coordination, where information flow is minimal, offers the most privacy and the lowest cost but may lead to suboptimal system-wide outcomes due to the lack of coordinated decision-making.

Figure 16 presents an example of LEM structure for the varying degrees of coordination [69]. In Figure 16(a), the LEM with the individual residential prosumers who own solar panels and electric vehicles and contribute through generation, load shifting, and offering flexibility is directly managed by a coordinator, suggesting a more centralized approach to integrating their capabilities into the wider energy system. Figure 16(b) introduces a community manager, indicating a semi-centralized model where a community manager facilitates the interaction among prosumers. This model could blend the benefits of central coordination with the autonomy of prosumers, providing a balance between structured energy management and individual flexibility. Finally, Figure 16(c) represents a peer-to-peer network among prosumers, where they directly interact and exchange energy without a central coordinator. This model emphasizes a decentralized approach to energy sharing, where prosumers negotiate and trade among themselves, potentially leading to more localized and efficient use of energy resources.

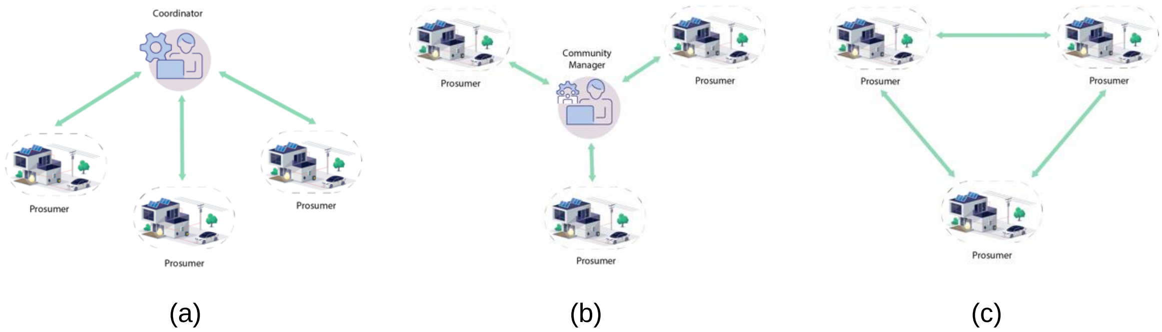


Figure 16: LEM sample structures; (a)

The control and coordination of LEMs, which is rather a market design aspect and is further examined in the local case study (T5.2), present a delicate balancing act between individual autonomy, collective objectives, and operational feasibility, all of which must be navigated carefully to harness the full potential of local energy resources and stakeholder engagement.

In summary, the following parties are among the ones related to DSB:

- **Active Participants**: These can be professionals or non-professionals who own energy resources (such as distributed generation, storage, or demand response capabilities). They aim to reduce personal energy costs and maximize revenues from local generation and flexibility services. They may also seek to minimize their risk exposure to market fluctuations.

- **Passive Participants**: These users do not actively engage in energy trading but are part of the LEM ecosystem. Their objective is to at least not be adversely affected by the market's operation and ideally to benefit from any positive externalities such as improved energy efficiency and lower costs.
- **Coordinators/Market Operators**: These intermediaries facilitate transactions between active participants and the rest of the market. They aim to maximize the collective value within the market by coordinating energy trades and services efficiently.
- **LEC**: It can include both active and passive participants along with local institutions and organizations. The community seeks to derive equitable value for its members and to achieve shared goals such as improved air quality, reduced energy poverty, and enhanced social cohesion.
- **Energy Suppliers**: These entities act as intermediaries between wholesale markets and consumers. Their goal in LEMs is to manage uncertainties in supply and demand patterns to reduce the costs associated with providing stable energy supplies and prices to consumers.
- **Network Operators**: Including TSOs and DSOs, their objective is to manage the energy network effectively, minimize losses, and maintain system balance. In the context of LEMs, they aim to integrate active market participation and manage local energy flows more proactively.
- **Regulators and Government**: These bodies set policies and regulations to ensure fair competition and oversee the operation of LEMs. They strive to achieve national policy goals like decarbonization and to protect the interests of both active and passive market participants.

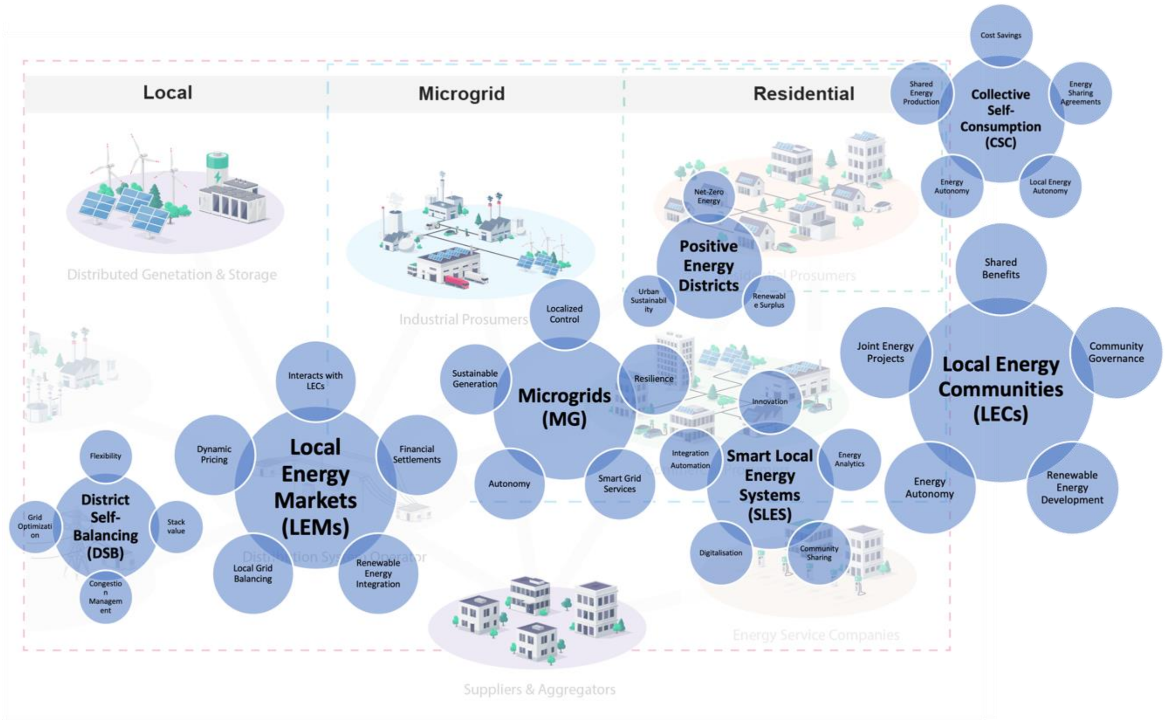


Figure 17: Innovative approaches and their key aspects in relation to the local environment.

6.3 Evolution, ownership and governance

Evolution, governance, and ownership are key aspects that may shape the behavioural characteristics of the formed actors and affect their interaction with others and the broader environment.

The cooperatives' evolution and the generic lifecycle of communities can affect their operational objective and constraints. For the purposes of improved understanding, the phases are presented below. A cooperative emerges out of the desire of a group of individuals or firms to improve their socio-economic position in the context of a non-functioning market. Additionally, they recognize the possibility to benefit from scale economics through coordinated economic action.

Figure 18 illustrates the lifecycle of energy communities together with their transformative capabilities while indicating the behavioural and operational sensitive stages of their development. The cycle reflects the evolutionary phases of cooperatives and community-driven structures [70], which start with their formation to address gaps in socioeconomic structures and leverage collective economic action for mutual benefit. In the Initiation phase, a cooperative is established out of a need for collective action to improve socio-economic conditions. Decisions made here, like setting goals and motivations, have a major influence on behaviours and operations since they establish the cooperative's fundamental purpose and direction.

Social feasibility and technical feasibility stages involve assessing community support and the practicality of the cooperative's objectives. Decisions about skills required and technical assets have a moderate influence on operations, impacting how members will engage with the cooperative and its capacity to meet its goals.

During Capital Raising and Implementation, securing funds and setting up the cooperative's structure are crucial. Decisions made here affect the cooperative's long-term viability and have a major impact on operations, especially regarding who controls the assets and how conflicts are managed.

The Operation stage is where the cooperative's activities grow, and collective benefits are realized. This stage is sensitive to decisions on member engagement and benefit distribution, which can significantly impact operational dynamics and member satisfaction.

Lastly, the Closure stage addresses the end of the cooperative's lifespan or its transformation. Decisions made here, such as how to handle residual assets and the long-lasting effects on the community, can have a profound impact, determining the legacy and final perception of the cooperative within the community.

Throughout all these stages, the intensity of decision-making influences varies, with some decisions having long-lasting effects on member behavior and operational efficiency. Balancing the various influences requires careful governance, transparent decision-making, and the ability to adapt and modify the cooperative's approach as it matures and faces new challenges.

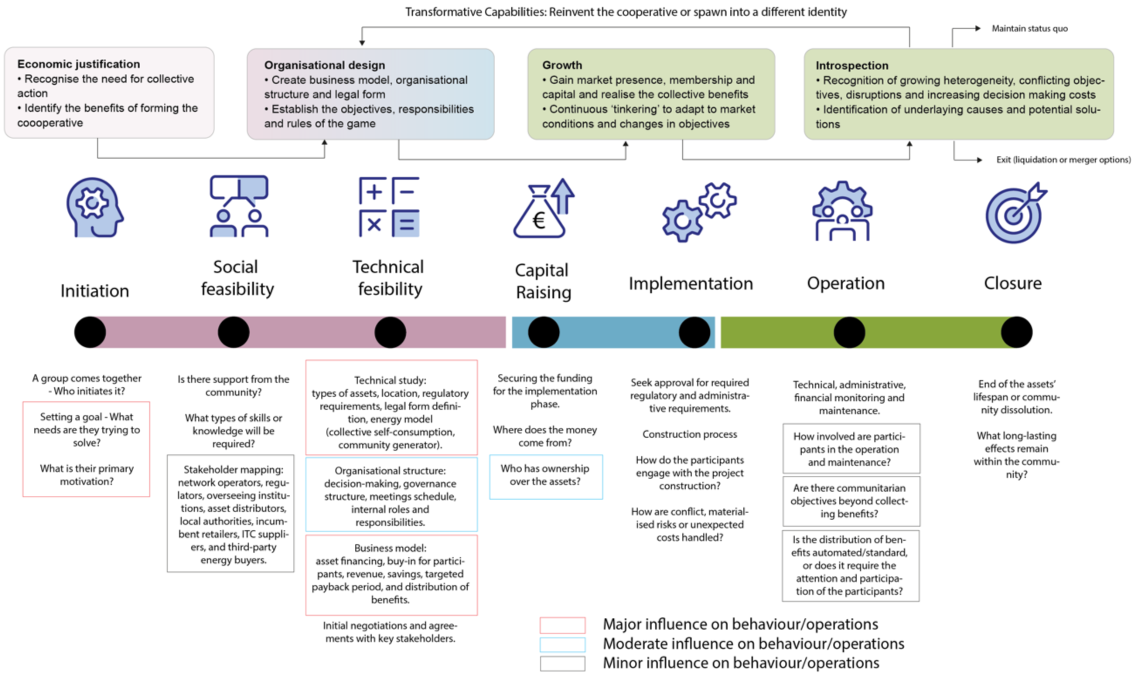


Figure 18: LEC lifecycle and transformative capabilities that influence behaviour/operations.

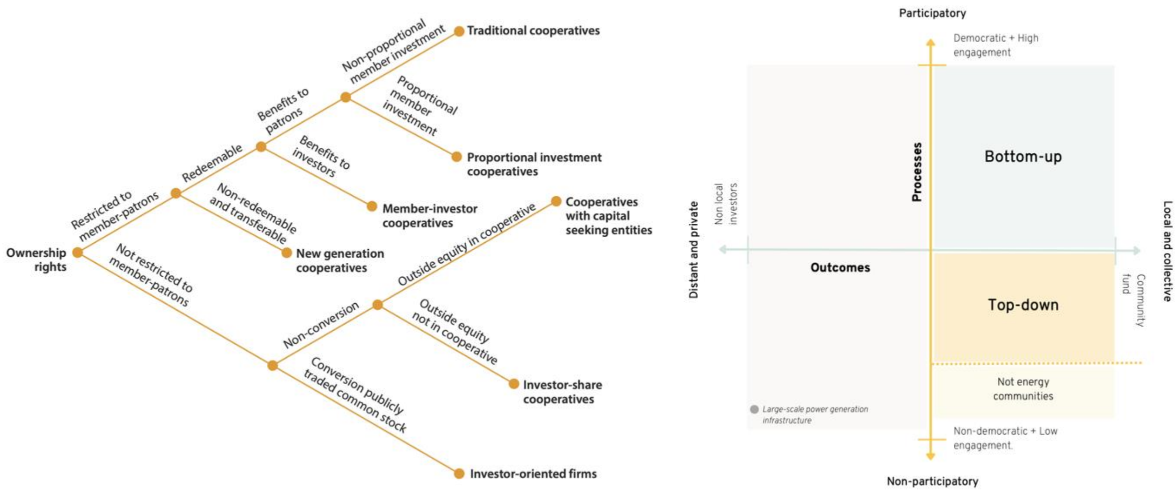
Ownership, management and control rights also play a pivotal role in the representation of the formed actors. Figure 19(a) considers community-based structures and presents a spectrum of cooperative types differentiated by the nature of ownership and control rights. This spectrum [71] is influenced by the evolution of cooperatives as they adapt to changing market conditions and member needs. At one end of the spectrum, traditional cooperatives are characterized by open membership, democratic control, and redeemable ownership rights, with members' capital contributions being proportional to their use of the cooperative’s services. This model is designed to protect members in imperfect markets and is typical of defensive strategies against market volatility.

Moving along the spectrum, we encounter new-generation cooperatives that restrict membership, often with more rigorous selection criteria and patronage rights linked to initial capital investment. These cooperatives may issue non-redeemable and non-transferable shares to secure members' commitment and ensure stability in capital structure.

Further evolution introduces member-investor cooperatives and those with capital-seeking entities, where there’s a blend of member-based patronage benefits and investor-oriented returns. These models might allow for outside equity not rooted in cooperative principles, offering a means to raise capital while attempting to maintain some cooperative characteristics.

At the far end of the spectrum, we find investor-share cooperatives and investor-oriented firms where the cooperative form begins to resemble conventional corporate structures. These may allow for conversion into publicly traded common stock, attracting outside investment and enabling greater capital mobilization, albeit potentially at the cost of diluting traditional cooperative principles of member control and benefits.

The figure underscores the dynamic nature of cooperatives in response to internal and external pressures, seeking a balance between maintaining member-oriented values and pursuing growth and competitiveness through adaptation of their ownership and control structures. These changes reflect cooperatives' attempts to maintain relevance and economic viability in a landscape of increasing competition and technological advancement.



(a) (b)

Figure 19: (a) Ownership-Control rights typology of new cooperative organizations [71], (b) Governance and internal processes [72].

Although governance is a sensitive and complex aspect of communal-based solutions and may have several different instances, there is a direct relation with the ownership rights, the available regulatory frameworks, the members' needs and the anticipated degree of involvement. Figure 19(b) provides a two-dimensional governance landscape for local energy communities, contrasting participatory, bottom-up approaches with non-participatory, top-down models and also related to the generated outcomes.

There is a distinction between local and collective benefits versus private and distant ones. Local and collective outcomes are typified by community funds or initiatives that serve communal purposes, keeping the value and benefits within the local community. As external, often private, entities become involved, the outcome may shift towards a distribution that benefits distant stakeholders, reflecting a market-based allocation of benefits rather than a community-centric one.

On the other hand, there is a degree of participation and engagement within the community. In a participatory, bottom-up approach, decisions are made by community members, ensuring high levels of engagement and democratic governance. These communities typically initiate and control their energy projects, aiming to retain the benefits within the local area. However, as the decision-making power shifts towards external actors—be it local governments, NGOs, or private companies—the processes become less participatory, with a corresponding decrease in community engagement and influence.

Traditional, large-scale energy projects are positioned in the bottom-left quadrant, indicating a centralized, non-participatory approach with outcomes that benefit private, non-local investors. Conversely, grassroots bottom-up energy communities are placed in the top-right quadrant, reflecting their democratic, participatory nature and local, collective benefits.

Top-down energy communities, often initiated by external entities and funded by third-party resources, are located in the bottom-right quadrant. While the intention may be to benefit the local community, these models often lack the participatory processes that characterize bottom-up communities. This raises questions about the extent to which such models can achieve social development and a just transition while preserving meaningful community involvement. Internal governance is critical for a community to share costs and benefits effectively and resolve conflicts. This governance may vary from simple and democratic to complex and undemocratic, and it can operate through social norms, legal rules, or a combination of both. The recognition and support of these governance structures by the state can significantly influence the community's success and sustainability. Finally several governance aspects are presented in Table 9.

Table 9: Governance attributes of cooperative organisations [71].

Attribute	Description
Ownership/Property rights	The nature of claims on the residual assets of the cooperatives – equal amongst members, proportionate to patronage rights or as per equity contributions.
Formal authority structures	The level of formal structure in the organisation for coordination and control – administrative controls, presence of distinct authorities and central staff that affect the level of autonomy of member decisions
Intensity of Incentives	The level of incentives in decision-making at both the organisation and member levels – low level of incentives at the organisation level leads to principal agent problems and low levels at the member level leads to a lack of loyalty.
Administrative Controls for Coordination and information sharing	The level of administrative controls for coordinating the activities within the organisation including overall planning, information processing and transaction governance.
Central Staffing Requirements	The number of staff that is directly employed for performing the different governance functions within the cooperative organisation – affects the operation costs and reduces the distributed value
Partner Selection	Mechanisms in place to define the membership in the cooperative organisation – lack of any criteria leads to an open cooperative with free membership but there may be well defined criteria in place to make it a closed cooperative
Level of autonomous adaptation	Adaptation to changes in market conditions or any shocks directly by members of the cooperative that may be considered unplanned and uncoordinated, for example, a response to sudden price changes.
Level of coordinated adaptation	The level of centralisation and coordination as a collective response to changes in market conditions or adverse events – requires consensus-based and planned decision making
Strength of contract laws	The formality of contract mechanisms in place to govern the transactions of the cooperative, the behaviour of members, co-dependence of member decisions and the interaction of members and the cooperative.
Formalization of Horizontal and Vertical links, and centralisation	The extent to which the association between members, their commitments to the cooperative, the transfer of central functions, production decisions and transaction decisions are formalised through agreements, contracts, incorporation statutes or bylaws.

6.4 Various business models

The business models of prosumers and entities within the local energy environment are strongly related to the shaping of the objectives according to which systems operate, and users interact. Although their derivation and market uptake are subject to inherent dynamics, their potential is framed through regulation, market design and technological improvement and innovation. They are integral to the transition towards more localized and renewable energy systems, facing unique challenges but also offering significant opportunities for the future of energy management.

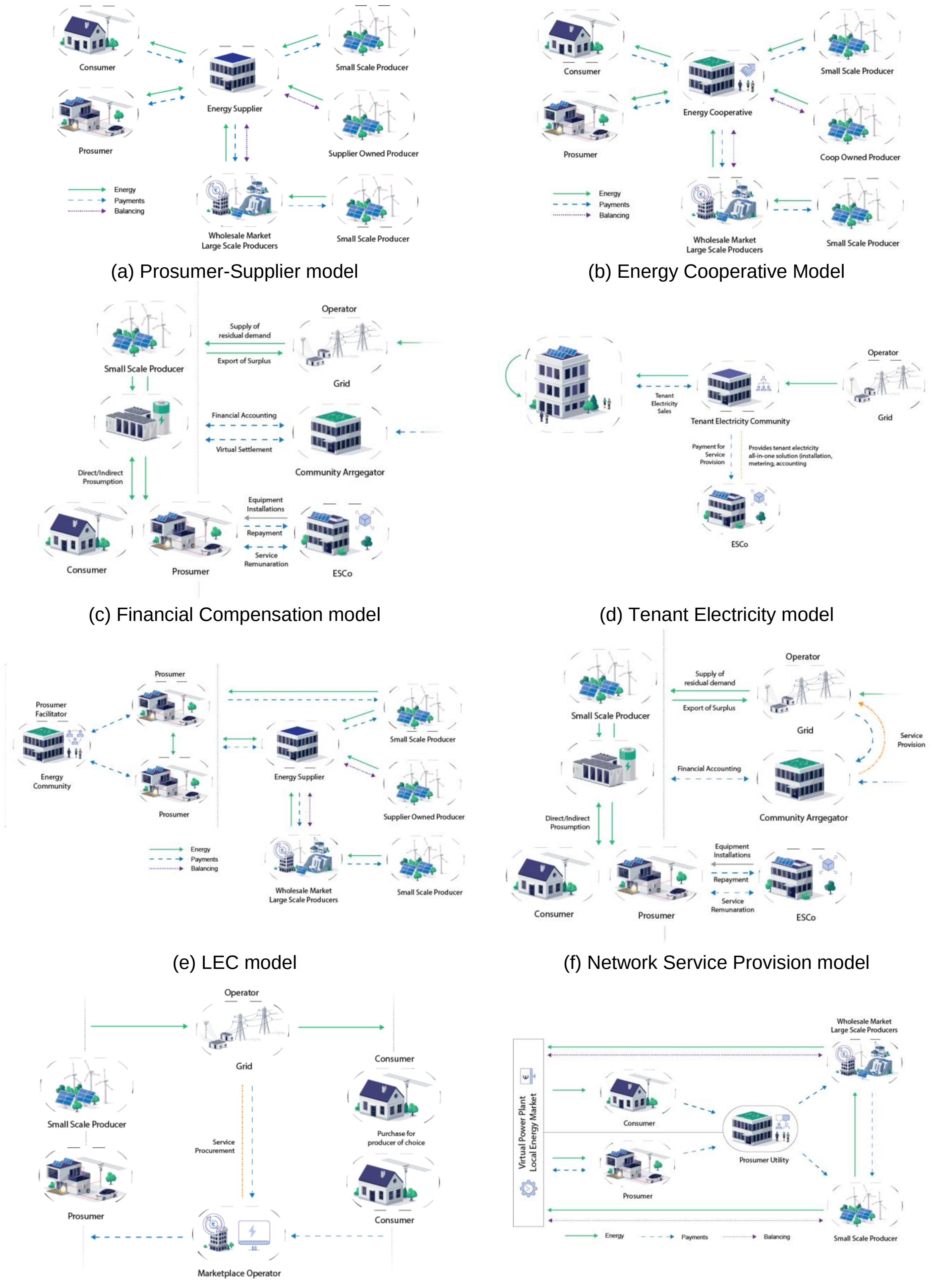
Figure 20 presents eight indicative business model structures for the local environment. Based on those instances and further specification of the technologies and the services, the most common cases of behaviours and operations can be revealed. An example of how the business models are translated to mathematical programming formulations that can be used in local market and communities' modelling can be found in [73]. The modular approach implemented there is ideal for representing the effects different technologies may have on decision variables and constraints and the influence of business model structures and services in the (multi)-objective functions. D4.4 also includes an example formulation, while D5.2 presents the different modelling approaches for the local environment.

First in Figure 20 is the Prosumer-Supplier business models [74], which focus on providing reliable and low-cost energy primarily sourced from large-scale dispatchable and a small mix of variable renewable energy sources. Their revenue streams are mainly from the generation and sale of electricity and gas. However, their more sustainable version focuses on customer-centric energy services, which become a (small) fraction of their operations. This model can be considered the baseline or the 'business as usual' case without specific strategies for managing the increasing variability from variable renewable energy sources (vRES).

Next is the Energy Cooperative business model, which, on the other hand, offers low-profit or no-profit energy generation with a focus on benefiting local communities and cooperative members. The model targets consumers interested in environmental sustainability and community development while facing limitations in expanding beyond regional focus due to their smaller customer base and asset portfolio. Like the other models, cooperative utilities tend to follow a 'business as usual' approach without concrete plans for managing vRES variability on their default version.

The Financial Compensation model, which is presented in Figure 20(c), allows prosumers to virtually bank surplus energy generated, which can be drawn upon when production is low. While these models don't involve physical energy sharing, they enable financial benefits for excess production. On the other hand, they limit the incentive for installed capacities and, by ignoring the temporal dimension, encapsulate an economic rent for the virtual storage that should be covered by the counterparty entities.

Next is the Tenant Electricity model, which enables tenants to benefit from locally produced electricity through rooftop PV systems. Service providers manage the systems and offer increased transparency and convenience for tenants. It can be combined with ESCOs that can deliver energy services and handle financing, installation, maintenance, metering and accounting tasks. This is a typical case where the corresponding actors would primarily aim to maximise self-consumption.



(a) Prosumer-Supplier model (b) Energy Cooperative Model

(c) Financial Compensation model (d) Tenant Electricity model

(e) LEC model (f) Network Service Provision model

(g) Marketplace model (h) LEM / VPP model

Figure 20: Indicative business models focusing on the local environment.

The model where the LEC is in the role of prosumer facilitator is shown in Figure 20(e). The LEC can help users to reduce reliance on grid energy by selling and leasing solar PV systems [75]. The model may be reliant on other energy utility types to supplement the grid-supplied energy when customer-generated supply is insufficient. The model largely focuses on the sale of new systems without accounting for the impacts of vRES on future energy prices and their cost-revenue structure.

The Network service provision model involves aggregating DERs to form community-based virtual power plants (cVPPs), contributing to active network management and grid stability through demand response services or selling reserve capacity [76].

The Marketplace model can involve digital platforms that connect producers, prosumers, and consumers directly and pass the market price signal to consumers. This model can be extended to a LEM setting, where transactions can be place-dependent and the contracts can be smart (blockchain). Revenues may be distributed between all the market participants, not only the prosumers. The benefit of local energy markets based on proximity is that they often do not need to pay fees for their unused upstream distribution and transmission networks [21].

LEM and Virtual Power Plants (VPPs) models provide customers with the ability to maximize the use of their own self-generation assets, such as rooftop solar PV systems. The Local energy markets, closely aligned with community prosumerism, can facilitate transactions within community boundaries via peer-to-peer trading on dedicated platforms and empower small-scale energy producers to sell energy directly to consumers. Control processes and IOT developments enable the creation of VPPs that allow excess generation to be sold and enhance the opportunities for realising the stacked value through the combination of multiple revenue streams.Moreover, the service provision is a very important aspect that is directly related to the value proposition and the revenue streams. Together with the aspects of governance, participation and benefit-sharing can extend to the community-oriented setting that has been previously discussed. The four categories of service-oriented business models presented below are for local energy systems [62] and can be combined and coexist with the previously discussed model structures. For example, the service provision to network operators (local management, balancing services) is related to the network service provision business model shown in Figure 20(f) and the marketplace model in Figure 20(g). The provision of security of supply services can be considered under the energy coop structure of Figure 20(b) or the LEC model of Figure 20(e), while the energy trading with the LEM/VPP model in Figure 20(g). The categories are:

The business model focused on Local Distribution Network Management Services leverages distributed flexible resources to address the challenges posed by the integration of uncontrollable renewables, like photovoltaics and new forms of electrical demand from electric vehicles and heat pumps. These pressures on European distribution networks often necessitate costly reinforcements or expansions. However, by managing active and reactive power, this business model enables the mitigation of thermal and voltage constraints, thereby reducing network losses. The Local Energy Systems (LES) paradigm, through the co-location of resources, further diminishes power flows and losses by aligning local demand with generation, potentially avoiding or delaying the need for network upgrades. Within this category, the business models vary according to the remuneration structures established by DSOs to compensate prosumers for offering their flexibility. Options for remuneration include reductions in distribution use-of-system (DUoS) charges, dedicated contracts between DSOs and prosumers, or through the operation of local flexibility markets. More advanced iterations of this model might involve LECs assuming roles of secondary DSOs through full ownership or partial leasing of distribution network assets, enhancing local energy resilience and management.

The business model focused on the Provision of Local Security of Supply Services represents a strategic shift from traditional, passive approaches employed by European DSOs during emergencies. Historically, DSOs would curtail power to certain low-priority grid sections or rotate blackouts without considering the flexibility that prosumers might offer. This often led to unnecessary and potentially unfair load shedding. With DSR schemes, consumers can actively communicate their preferences and the costs associated with the interruption of their power supply. This allows for more nuanced and equitable emergency management strategies, where different loads can be prioritized based on their importance to consumers, resulting in more efficient and acceptable curtailment approaches. Additionally, in scenarios permitting islanded operations, local micro-generation and energy storage assets can be mobilized to meet demand, thereby minimizing the extent of load shedding. This model not only enhances the resilience of the supply during crises but also aligns outage management with the specific needs and capabilities of the connected prosumers.

The business model based on the Provision of System Balancing Services addresses one of the critical challenges in decarbonized power systems—high balancing demands and associated costs. Distributed flexible resources, characterized by their adaptability, are at the core of this business model, as they are capable of offering various balancing services, such as primary, secondary, and tertiary. These resources can swiftly adjust their energy output or intake—increasing or decreasing production or consumption—in response to real-time system imbalances. This flexibility is a crucial asset, particularly in the context of energy trading activities, where deviations from forecasted levels can occur. By effectively enhancing the responsive nature of these distributed resources, this business model significantly contributes to maintaining the equilibrium of the power grid, ensuring stability and reducing the financial burden of balancing in a greener energy landscape.

The business model based on Local and Wider Energy Trading capitalizes on the shifting dynamics of energy markets due to the large-scale integration of renewable energy sources. As energy prices drop—often to zero during peak renewable production—and become more volatile, prosumers with distributed flexible resources are encouraged to leverage their energy flexibility to take advantage of favourable pricing periods. Traditionally, small prosumers have not engaged directly in wholesale energy markets; instead, they rely on electricity suppliers to manage energy transactions at more stable retail tariffs. However, as suppliers begin to offer dynamic tariffs to harness prosumer flexibility, there is a shift towards more active prosumer engagement in energy trading. The Local Energy Systems (LES) paradigm further expands this concept by fostering direct energy trading among prosumers within local energy markets. This new form of trading aims to establish mutually beneficial energy prices that circumvent the often unfavourable tariffs set by incumbent retailers, which tend to have large differentials between import and export prices. Through direct local trading, LES participants can reduce their reliance on traditional retailers, prompting more competitive tariff offerings from these entities and leading to a decrease in the overall energy costs for those within the LES. This model not only incentivizes the use of distributed renewable energy but also promotes economic efficiency and community empowerment in energy generation and consumption.

6.5 Benefits and Challenges that affect stakeholders

Based on the business model discussion and the presentation of the innovative approaches on transactive energy, it has been clear that LECs and LEMs can play a significant role in achieving more sustainable, efficient, and inclusive energy systems, directly impacting and empowering consumers and prosumers while supporting broader environmental and social goals. The key benefits identified highlight a transformative potential in the way energy is produced, consumed, and managed at a local level. These are:

- **Optimizing Local System Efficiency:** LECs can significantly enhance local system efficiency by optimizing grid use, which involves minimizing peak consumption to defer or avoid grid expansion. This is accomplished through collective actions such as smart grid management and leveraging renewable energy sources.
- **Savings through Collective Self-consumption:** By consuming the energy produced within the community, LECs reduce reliance on external energy sources, which translates to savings on electricity purchases, taxes, and network charges. Collective self-consumption also fosters a supportive ecosystem for sharing or trading energy at more beneficial rates than the standard retail options, as seen in subsidy models like those in France.
- **Avoiding Transmission Network Charges:** Energy communities can accrue savings by consuming energy locally and not feeding excess into the high-voltage grid, thus exempting them from transmission network charges in certain jurisdictions.
- **Selling Flexibility:** Communities can sell flexibility to local system operators as a service, offering an alternative to costly and time-consuming network expansions. This flexibility can stem from DERs and demand response initiatives.
- **Community Benefits and Resilience:** Beyond economic advantages, LECs contribute to the resilience of local energy systems, providing a buffer against adverse events. They also encourage social inclusion, giving ownership to local citizens and fostering community engagement and awareness of energy issues.
- **Financing Services for Energy Communities:** ESCos can offer financing services for renewable assets, enabling energy communities to start with minimal upfront costs and sustain themselves through the sale of locally generated energy. This approach can evolve to include financing for other community assets like batteries, encouraging prosumers to join and contribute their resources.

- **Enhanced Decarbonization:** LEMs contribute significantly to decarbonization efforts by supporting the integration of renewable energy sources into the grid. They offer a pathway to achieving net-zero targets in urban areas, which is critical given that cities are major contributors to CO2 emissions.
- **Energy Accessibility:** LEMs are particularly beneficial in remote regions where investment in energy infrastructure may not be profitable for large market players. By developing independently, LEMs offer access to low-cost electricity in such areas, greatly improving energy availability and quality of life.
- **Supporting Decarbonization in Transportation:** LEMs can extend their influence to the transportation sector by providing electricity for charging stations for electric vehicles, further contributing to the decarbonization of this vital sector.

This diverse array of benefits affects multiple stakeholders. Consumers enjoy lower energy costs and enhanced energy security, while prosumers gain additional revenue by selling surplus energy at competitive rates. Energy communities themselves reap the rewards of collective investments in renewable resources and infrastructure, leading to substantial savings on network charges and improved local system efficiency. Local authorities and governments align with these initiatives to meet environmental policy goals, promote social inclusion, and stimulate economic development. DSOs benefit from increased grid flexibility and stability, which can reduce the necessity for costly grid expansions. Renewable energy developers and ESCOs find new opportunities in these markets for their products and services, fostering innovation and business expansion. Additionally, technology and service providers collaborate with energy communities, offering platforms and expertise to optimize energy production and consumption. Authorities focused on decarbonization leverage LEMs as strategic instruments to integrate renewable energy solutions, aiding the transition to a low-carbon economy and achieving climate targets. Finally, the symbiotic network formed by those stakeholders that contribute to and benefit, individually and collectively, from the evolution of LEMs and LECs, contributes to the paradigm shift in energy distribution and consumption that is well supported by the policy making goals.

On the other hand, the innovative approaches that are meant for the local environment face a series of challenges that stem primarily from the integration and growth within the existing energy system. The traditional grid is often not designed for the bidirectional power flow and the local energy exchanges or the collective generation may lead to additional costs for upgrades and reinforcement. However, with appropriate market models and control mechanisms, network issues such as voltage violations or congestion can be mitigated, promoting a seamless grid connection and even supporting the system with the provision of ancillary services.

The growth of local entities and structures has been somewhat stymied by the lack of comprehensive legal frameworks that fully support the formation of entities and trading in the local environment. Without specific laws or policies in place, the creation and operation of local entities or even structures like LEMs face uncertainty, and in some cases, certain aspects of local trading are forbidden [62]. This legal ambiguity hinders the potential for decentralised efficient trade and service procurement that could contribute significantly to sustainable and renewable energy policies and requires attention and interest from the general population to flourish. The inherent volatility of renewable energy sources poses another challenge, affecting both the stability of energy supply and price volatility. Seasonal and daily fluctuations in renewable energy production, such as solar and wind, necessitate investment in local energy storage solutions to balance generation peaks and lulls. Prosumers with efficient storage systems can decrease their own energy cost and contribute to stability by selling storage rights or providing energy during periods when variable renewable generation is low.

In summary, stakeholders such as prosumers, local energy companies, and distribution stakeholders are directly impacted by grid incompatibility, while consumers face the brunt of regulatory uncertainties and the consequences of energy price volatility. To overcome these challenges, stakeholders must advocate for supportive regulatory environments, engage in the development of efficient energy storage solutions, and foster public interest and participation in LECs and LEMs. As these concepts evolve, these challenges present opportunities for innovation, leading to a more resilient, decentralized, and sustainable energy landscape.

7. Final remarks

This second and final edition of the deliverable on “Characterization of new flexible players”, is the report that summarizes the work conducted in T3.2 and is about the technical and economic characterization of the behavior and capabilities of actors in the electricity market. For that purpose, the analysis has been performed in two dimensions, the operational and the behavioral one, namely, while special focus has been given in the mapping of actors and technologies.

After a short summary of the regulatory framework from the stakeholders’ perspective and an overview of the institutions and organizations that represent different interests in the industry, the widely accepted role model of the electricity market, developed and maintained for several years by ENTSO-E, EFET and ebIX, along with other frameworks, architectures and ontologies have been reviewed. Both the role model (HEMRM) and the other initiatives considered, focus on the actors and their roles in the power system generally and specifically on the electricity market, while each initiative approaches the topic from a different perspective. The HEMRM offers a harmonized and complete role representation, with degrees of freedom with respect to market design. The USEF focuses on the realization potential of flexibility with storage and demand response being at the center. The SGAM develops a technically robust approach around smart grid architecture while inherits roles from HEMRM, while the ontologies provide the insight on the vocabulary required in representing the electricity market in models. The review of all those systematic approaches on the identification of actors and their relationships provided an insight on how the issue of analysis and representation has been tackled, which enabled the development of definitions and structure around actors, adopted in TradeRES project.

Definitions of the stakeholder, player and agent terms have been provided, while the meaning of the role and actor terms has been clarified. Several, traditional and new, classes of actors have been identified, each one of them covering for parties that play a role in the market formation and operation as well as on the system development and management. These classes have been the Prosumer, the Producer, the Supplier, the Aggregator, the Trader, the ESCo, the Operator and the Regulator. The classes have been allocated into the four layers considered, namely the social, the physical, the aggregation and the market layer. Moreover, part of the analysis has been the mapping of actor classes and technologies relationship, since the technologies to which an actor is exposed to and can exploit for achieving its goals affect their positioning in the actors’ environment and the way they interact. The relationships of actors and technologies have been considered from the scope of current and envisaged agent-based models as well as from the TradeRES project vision and depict the outcomes of the related survey. Similarly, the relationships of the actor classes with operational and behavioural aspects have been examined with respect to their intensity, completing that way the qualitative characterization of actors. The results of this technoeconomic analysis are summarised through the Actor-ID cards, which aim to serve as a quick reference source for the key findings of the actor characterization work that is expected to feed the work towards the improved representation of the behavioural and operational aspect into the agent-based models.

The actors' analysis within the local environment underscores the crucial role of transactive energy in empowering a diverse array of stakeholders, from individual prosumers to large-scale local energy communities. The analysis reveals that the evolution, ownership, and governance of these entities are pivotal in shaping their operational objectives and interactions within the broader energy market. Prosumers emerge as dynamic participants, leveraging advancements in technology to manage their energy needs actively. Their influence extends beyond self-sufficiency, contributing to the grid's flexibility and stability through innovative business models and market participation. The empowerment of prosumers marks a transformative shift towards decentralized energy systems that prioritize resilience, sustainability, and community engagement.

Emerging approaches within the local environment, such as Collective Self-Consumption, Local Energy Markets and Smart Local Energy Systems, highlight the potential for optimizing energy generation, distribution and consumption. These models not only enhance grid efficiency but also provide a foundation for inclusive and sustainable energy practices that align with broader environmental and social objectives. The report identifies the key benefits of these local initiatives which act as incentives and behavioural drivers, including increased system efficiency, collective savings, avoidance of transmission charges, and the potential for selling flexibility as a service. Moreover, they contribute to community resilience, offering a more equitable distribution of energy resources and fostering a participatory culture in energy management.

The analysis underscores the transformative capabilities of local energy actors and their business models, which are central to the transition towards a more decentralized, resilient, and sustainable power system. As these entities evolve and adapt to the changing energy landscape, their success hinges on the ability to navigate and influence the regulatory environment, harness technological advancements, and engage stakeholders in meaningful and productive ways.

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