A Systematic Literature Review of Peer-to-Peer, Community Self-Consumption, and Transactive Energy Market Models

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Abstract

Peer-to-peer and transactive energy markets, and community or collective self-consumption offer new models for trading energy locally. Over the past 10 years there has been significant growth in the amount of academic literature and trial projects examining how these energy trading models might function. This systematic literature review of 139 peer-reviewed journal articles examines the market designs used in these energy trading models. The Business Ecosystem Architecture Modelling framework is used to extract information about the market models used in the literature and identify differences and similarities between the models. This paper identifies six archetypal market designs and three archetypal auction mechanisms used in markets presented in the reviewed literature. It classifies the types of commodities being traded, the benefits of the markets and other features such as the types of grid models. Finally, this paper identifies five evidence gaps which need future research before these markets can be widely adopted.

Keywords: peer-to-peer, self-consumption, transactive energy, market model, electricity trading, energy trading, smart grid, local energy markets, prosumers

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1. Introduction

Fundamental changes are likely to transform energy markets globally in the coming decades. Moving away from large, centralised energy generators, we have already seen an increased adoption rate of distributed energy resources (DER), such as photovoltaic or wind generators and distributed

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storage devices [1]. DERs help countries to reduce emissions and meet carbon reduction targets they have committed to under the Paris Climate agreement [2]. However, the fluctuating and intermittent nature of most renewable energy sources (RES) poses a challenge for network and system operators. Maintaining a balance of demand and supply to guarantee stable operation of the electricity grid poses a greater challenge with lower proportions of dispatchable generation. Simultaneously, a shift to a low-carbon economy due to the growing number of alternatives to fuel-based solutions, such as electric vehicles and heat pumps, is likely to increase the load on electricity grid [3]. Current mechanisms in the energy market are limited in their ability to respond to these new challenges [4]. To avoid high grid reinforcement costs and respond to the changes in load behaviour and volume, new market and balancing mechanisms are needed.

Local energy markets (LEM) have emerged as a new approach to foster integration of more RES and DERs into the electricity grid [4]. The purpose of LEMs is to incentivise small-scale energy consumers, producers and prosumers to exchange energy with one another in a competitive market and improve local balance of demand and supply for energy [5]. In this context, prosumers are defined as small-scale energy users that both produce and consume electricity [6]. Various LEM designs have been proposed. They mainly differ in the type of market mechanisms used and scale of operation. Transactive energy (TE), peer-to-peer (P2P) energy trading and collective or community self-consumption (CSC) are among the most discussed LEM models in the literature.

TE is a concept that has emerged to provide decentralised coordination of supply and demand, and more recently to manage DERs in the electricity grid [7]. Instead of conducting costly grid reinforcement to respond to changes in load, the aim of TE is to manage decentralised resources in an autonomous way using price signals to provide system stability. The GridWise Architecture Council defines TE as "a set of economic and control mechanisms that allow the dynamic balance of supply and demand across the entire electrical infrastructure using value as a key operational parameter" [8].

P2P allows market participants to directly exchange electricity with one another without the need of a middleman, thereby empowering the energy end-users and providing them with an incentive to actively engage with the energy market [9]. Such exchanges between peers are typically accompanied by financial transactions. If no financial transaction is required, this exchange is known as 'energy sharing'.

Finally, the term CSC has its origin in the European Clean Energy Package as 'jointly acting renewable self-consumers' [10]. CSC is defined as "a group of at least two jointly acting renewable self-consumers [...] who are located in the same building or multi-apartment block" [11] or where permitted by member states, participants can be located in different buildings or blocks [12]. In this definition 'renewable self-consumer' refers to energy end-consumers that generate renewable electricity for their own consumption purposes rather than commercial activities [11].

While all three concepts share common features and can be classified as LEMs, they have distinct characteristics in terms of size, operation scale and the main purpose of the market activities. In the current literature, these terms have been used interchangeably, resulting in a lack of consensus on the meaning of the terms and the differences between the concepts. To advance the development of LEM models, a structured overview is needed that shows the current state-of-the-art of this class of models while highlighting the differences between them to provide insights into yet insufficiently explored areas.

Several review and survey articles analyse and discuss local electricity trading from different perspectives. Khorasany et al. [13] review market designs for local energy trading, focusing on scalability, overheads, and how they address grid constraints. Tushar et al. [14] review P2P electricity trading techniques, providing an overview of their key features and benefits they bring to the grid and prosumers. Their focus is on clearing mechanisms of the markets. Similarly, Jin et al. [15] classify and organize the literature on potential designs and market clearing methods, with a focus on local flexibility markets. Sousa et al. [16] review consumer-centric electricity markets such as P2P markets, integrating the behaviour of all market participants, not only prosumers. Zhou et al. [17] review the following key aspects of P2P energy trading: market design, trading platforms, physical and ICT infrastructure, social science perspectives, and policy. Soto et al. [18] analyse P2P markets focusing on the following six components: trading platform, blockchain, game theory, simulation, optimization, and algorithms. Aggarwal et al. [19] focus on optimization models used in the energy trading mechanisms for P2P markets, providing a comprehensive taxonomy on the topic too. Andoni et al. [20] provide a systematic review for how blockchain technology fits in the energy sector and discuss various applications in the sector where blockchain technology can be useful. Similarly, Siano et al. [21] explore the application of distributed ledger technology in TE markets, experimenting with different consensus mechanisms.

This review conducts a systematic analysis of the market models used in the literature. This work uses the *The Business Ecosystem Architecture Modelling* (TEAM) framework [22] to analyse the design of TE, P2P and CSC energy markets. Using the TEAM framework for the analysis of each paper allows this review to extract the same detailed information about each market presented in the literature. This information includes definitions, participants, grid model and structure, market rules (clearing mechanisms, pricing, settlements, choreography) and value generation. This paper develops six archetypal market models from those presented in the reviewed literature. This review presents the state-of-the-art knowledge about details of the markets including the market structure and rules, the market participants and the transfer of value.

The contributions of this literature review are threefold: First we advance understanding of how the terms P2P, TE and CSC are defined in existing literature from an ecosystem perspective. To accomplish this, we identify the use of each concept in the literature and extract information on the transactions and markets from those papers. Second, we assess the state-of-the-art knowledge about the three market models focusing on the market value, the participants involved, the scale at which they operate and their operation. We derive six archetypal market designs and three archetypal price formation mechanisms. Finally, we identify major challenges these markets face and assumptions and simplifications made that prevent these markets from being implemented on a large scale. We provide insights into five evidence gaps in academic literature that require further research for these market models to be adopted at scale.

The remainder paper is structured as follows. Section 2 presented the methodology used for the systematic literature review, including the literature search, decision on paper inclusion/exclusion, and data extraction and analysis. Section 3 presents the results of the analysis and discussion of the results. Section 4 details the research gaps found during the review. Finally, Section 5 provides concluding remarks.

2. Methodology

This literature review followed a systematic process for selecting papers to review and extracting data from those papers. This section details the process used to identify relevant literature, and extract and analyse data consistently from each piece of literature.

2.1. Literature Search

To identify a relevant set of literature we conducted a systematic literature search using the Scopus and Web of Science databases. The search term was *("peer to peer" OR "peer-to-peer" OR P2P) OR ("self consumption" OR "self-consumption" OR CSC) OR (transactive OR TE) AND electricity*. The article title, abstract and keywords fields were searched in Scopus. The topic field was searched in Web of Science, which includes title, abstract, author keywords, and keywords plus. The results were filtered to only include peer-reviewed journal articles. Both databases were searched on 25 March 2020. Scopus returned 759 results and Web of Science returned 587 results. A total of 892 journal articles were returned by the search, after removal of 454 duplicate search results.

2.2. Inclusion Criteria

We first reviewed the title and abstract of each paper against the inclusion criteria listed below. The title and abstract review was completed by one person. Papers were kept in the review at the title and abstract review stage if the reviewer was in doubt. During the title and abstract review 675 paper were removed, leaving 217 papers.

Inclusion criteria:

- The paper is written in English;
- The paper concerns electricity markets;
- The author defines the main subject of the paper as peer-to-peer, self-consumption or transactive uses of electricity – there are no universally agreed upon definitions for peer to peer, self-consumption or transactive energy, therefore papers were included based on whether the author defined their paper as concerning one of these topics;
- The paper analyses either one or more entities which transact or a market; and
- The paper has been published in a peer reviewed journal.

Following the title and abstract review, we reviewed the full text of the remaining papers. The same inclusion criteria was used for the title and abstract review and the full text review. The full text of each paper was reviewed by one person. Where that person had a doubt about one of the criteria, a second reviewer checked it. There were 72 papers removed during the full text review, leaving 145 papers. During the data extraction process a further six papers were removed leaving a total 139 papers in the review.

Number of papers included in the review:

- Total results: 892 (Scopus 759, Web of Science 587, duplicates 454)
- Remaining papers after title and abstract review: 217 (675 removed)
- Remaining papers after full text review: 145 (72 removed)
- Papers included in review: 139 (6 removed during data extraction)

2.3. Data Extraction

Data was consistently extracted from each paper included in the review using a data extraction table. The data extraction table was designed for this study, but is based on *The Business Ecosystem Architecture Modelling* (TEAM) framework [22]. The TEAM framework is designed to analyse a group of businesses which do not have a central coordinator controlling them all, but rely on common ICT infrastructure to interact. This is very analogous to local energy markets. There is not necessarily a central coordinator directing the market and each individual may act in the market as they see fit. However, for the market to function all individuals must agree on common means of communicating bids, creating contracts and proving the contracted energy has been supplied and demanded.

The TEAM framework was adapted by the authors of this study to make it more specific to the P2P, CSC and TE markets this study is analysing. The amendments to the TEAM framework for this study include:

- Additional data about whether the paper author defines the market in the paper as P2P, CSC or TE, and how the author defines those terms.
- Additional data about modelling assumptions used in the paper such as whether there is uncertainty about future events, and whether physical constraints are considered.
- Additional data about the market participants.
- Additional information about the market such as the length of the settlement period and the length of the model run.
- Additional information about the size of the market and the resources available to market participants.
- Consolidation of information about cash flows and risks.

- Removal of information about IT and technology requirements.

A complete list of the data extracted for each paper can be found in Appendix A. Details about how to access the completed data extraction table for this study can be found in Section 6.

Data extraction was undertaken by one researcher per paper. The unit of analysis for data extraction was a market, i.e. all data was extracted for each market presented in a paper. All papers in this review only presented a single market.

Following data extraction the data was checked for validity and completeness. Each data field was checked by one reviewer to ensure data had been extracted consistently for each paper. Inconsistencies found during review were addressed by the researcher who originally did the data extraction for that paper.

3. Results and Analysis

The results of the literature review provide insights into all aspects of P2P, CSC and TE markets. In this section we present the results of the literature review alongside analysis and discussion of the results. Section 3.1 presents the key characteristics and definitions of P2P, CSC and TE markets. Section 3.2 details the value added in the markets and the needs of the market participants. Section 3.3 describes the market participants and the resources available to them. Section 3.4 describes the size of the markets. Finally, section 3.5 details archetypal market designs and price formation mechanisms, along with other design parameters of the markets.

3.1. Key defining characteristics of P2P, TE and CSC

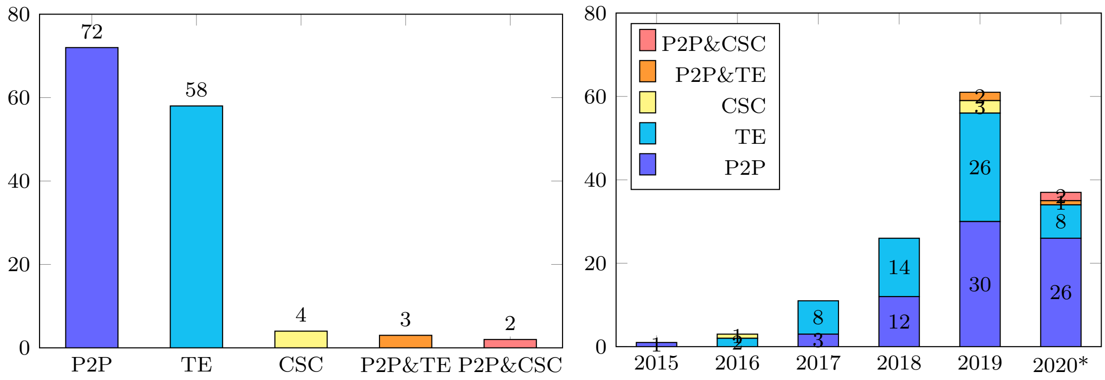
Distributed or local energy markets aim to actively engage energy end-users and contribute to the balancing of demand and supply. This section analyses how the terms P2P, TE and CSC are used and how they have developed over time. An analysis of the definitions or descriptive characteristics of TE, P2P and CSC shows that the classification differs depending on the specific objectives and trading mechanisms a market proposes.

Figure 1 presents an overview of the papers reviewed by term and year. Most of the papers analysed were associated with the term P2P and TE, see Figure 1a. Only a few papers focused on the concept of CSC [23–26] or combined different types of concepts [21, 27–30]. The analysis of the papers by year shows that the concept of LEM has received increased attention over the past years, with the number of papers nearly doubling every year as highlighted in Figure 1b. The revised Renewable Energy Directive [11] was published in December 2018 which can explain the inclusion of CSC from 2019 onward. Finally, the databases were searched in March 2020. Therefore, the results for 2020 only capture a snapshot until that point in time and are not reflective of all publications of that year.

To understand the differences and similarities between the three concepts, we analyse characteristics all three terms used to describe the market models' main objectives. An overview of all characteristics identified and the associated papers can be viewed in Table 1. The characteristics included in this analysis are only extracted from papers that explicitly provide a definition of P2P, TE or CSC or give a clear introductory statement on the main purpose of the concept used. Therefore, not all papers have been considered in this analysis.

A key distinctive characteristic between the models is the scale of participants in the market. In P2P markets, energy trading mainly takes place between small scale participants, e.g. residential energy consumers or prosumers [31–34]. However, some models have trading between larger participants including residents, buildings and microgrids [35, 36]. None of the papers which consider TE nor CSC market explicitly highlight scale as a key characteristic of their models.

The models also differ in their degree of centralisation. However, there is a range of centralisation observable within each model category. In P2P markets, participants can trade energy with each other directly, without a middleman [9, 27, 28, 35, 37–43] or through centralised third parties [27, 44, 45]. CSC markets are generally operated in a more collaborative manner, for example using a non-profit centralised manager [25]. TE market models do not tend to focus on the governance and operation of the market.



(a) Number of papers by market model

(b) Number of of papers by year and market model

Figure 1: Number of papers included in the systematic review

*includes papers published up to 25 March 2020

Locality and typology is an important feature of the different models. A key aim of P2P and CSC markets is to incentivise local energy generation [24, 27, 31, 34, 46–48] and consumption of DERs [27, 39, 55, 56, 56]. In P2P markets, participants can be located on a same distribution feeder or grid [27, 55, 57–61] or engage in virtual energy trading [41, 57]. There are mixed opinions in the literature over scale at which TE markets are feasible. Some papers believe TE markets should be limited to s distribution grid or small geographical area [62–65]. Other papers state that TE markets can operate across the entire electricity network [66–68].

TE markets puts a stronger focus on providing benefits to the electricity grid than P2P or CSC markets. The most frequently used definition for TE in our dataset is the Gridwise Architecture Council definition [21, 79, 95–100]. This definition puts balancing of demand and supply of energy [62, 66–68, 73, 74] and the integration of DER into the electricity grid [49–54] at the heart of TE markets.

TE markets also frequently consider grid constraints [64, 65, 77, 79, 80] to maintain an efficient and secure supply of energy [53, 81]. The aim of these markets is to optimise the load to achieve an energy equilibrium among the participants [50, 63, 75, 76]. Other services provided by participants in TE markets include demand side response (DSR) [71, 72] and the provision of flexibility through energy aggregators [64, 65, 77]. In P2P markets, participants can also engage in DSR and flexibility services [56, 69, 70], and contribute to grid security and stability [36, 78]. In CSC markets, the balancing of energy demand and supply is mentioned as a market service [25, 26], but not in the context of providing real-time grid stability services.

Papers considering P2P and TE markets tend to put much more emphasis on specifying the market structure and design than papers focusing on CSC markets. The concept of P2P energy trading is based around a competitive market structure [46] where users engage in bilateral negotiation of transactions [41, 43, 83–85] making use of contracts for the settlements [34, 86]. In TE markets, participation is generally assumed to be active through bidding [62, 80], price negotiations [71, 101] or auction based market clearing mechanisms [63, 65, 101]. With the goal of decentralising energy markets, TE can be operated as an extension of [82, 87] or replacement [51] for the competitive wholesale market. TE markets can also operate as a sub-system of the existing market structure [54]. TE systems are set up in a market-based environment [49, 65, 72, 73, 76, 79, 82] aligning individual participants interest with those of the wider energy system [67] by using economic incentives [50, 65, 66, 73, 79, 81, 82, 87]. Amongst others, the use of local marginal pricing [54, 75, 88] and the response to price signals [52, 63, 88, 89] have been highlighted as a means of optimising energy load behaviour.

P2P and CSC market models put a strong focus on the market transactions. In P2P markets, prosumers can trade their surplus energy with other participants in the market [27, 61, 70, 78, 90, 92–94]. The aim is to maximise the total welfare of the participants [58, 90] while at the same time

Table 1: Defining characteristics of P2P, TE and CSC.

Category	Characteristics	P2P	TE	CSC
Participation	Small-scale participants	[31–34]	-	-
	Participants from various scales	[35, 36]	-	-
	Participants located in one community	-	-	[24]
Governance	Energy trading without intermediary	[9, 27, 28, 35, 37–43]	-	-
	Energy trading with intermediary	[27, 44, 45]	-	[25]
Locality & Typology	Local energy generation	[27, 31, 34, 46–48]	[49–54]	[24]
	Local energy consumption	[39, 55, 56]	-	[27]
	Close geographical proximity	[27, 55, 57–61]	[62–65]	-
	Virtual trading of energy and different layers of the grid	[41, 57]	-	-
	Operating across various grid layers	-	[66–68]	-
Market services	Provision DSR services	[56, 69, 70]	[71, 72]	-
	Balancing of demand and supply	-	[50, 62, 63, 66–68, 73–76]	[25, 26]
	Provision of flexibility services	-	[64, 65, 77]	-
	Consideration of grid constraints	[36, 78]	[53, 64, 65, 77, 79–81]	-
Market design	Competitive market structure	[46]	[49, 65, 72, 73, 76, 79, 82]	-
	Bilateral market transactions	[41, 43, 83–85]	-	-
	Contracts	[34, 86]	-	-
	Price signals and economic incentives		[50, 52, 63, 65, 66, 73, 79, 81, 82, 87–89]	-
Market transactions	Maximise total welfare	[58, 90]	-	-
	Set own trading preferences	[86, 90, 91]	[67]	-
	Trading of surplus energy	[27, 61, 70, 78, 90, 92–94]	-	[25, 27]

allowing the participants to set their own trading preferences [86, 90, 91]. In CSC markets, energy communities [24] incentivise energy trading within the community [27]. This reduces the dependency on centralised energy providers and create new roles for energy end-users who both produce and consume. Within a CSC setting, prosumers can optimise their energy usage [25, 26] by trading surplus energy [25, 27] and engage in energy aggregation [24], which usually refers to acting as net-metered community.

All three models share characteristics, but each model has a particular focus area. In P2P markets a strong focus lies on incentivising the individual to participate in energy markets, while allowing them to set their own energy trading preferences. In TE markets the main trading purpose is to provide stability services at various levels of the grid, and participation is not limited to small-scale energy users. Both terms are richly discussed in the literature and make use of competitive market structures to achieve their main trading purpose. By contrast, the term CSC has so far seen the least adoption in the academic literature, probably due to its origin in regulation. Most of the characteristics of CSC models focus on the community aspect of local energy markets and its community focused governance.

3.2. Market value proposition

To assess the market value proposition of each model we look at the main needs of the market participants and the commodities being traded. In this section we evaluate the value each model claims to contribute to the market.

3.2.1. Value added in the market

The three models, P2P, CSC and TE, focus on different market objectives. The P2P markets tend to focus on benefits to the individual. The CSC markets aim to maximise the welfare of a community. The TE markets tend to provide a service to the grid, such as balancing, by providing price signals to individuals. The market objective determines the value transfer between market participants.

The market design is determined by the type of market participants and the value transfer between them. During the design of the market several strategic and technical considerations need to be made, namely:

- The first market activity is to define and connect the participants to the market. The market participants need to be willing to adhere to the market rules and share a certain level of information with other participants or third parties.
- The second market activity is to design the transaction. This includes defining the offer/demand of commodities to exchange, the financial flows between parties, the dependency, and the settlement process.
- The last market activity is the distribution of benefits, and costs.

Electrical energy was traded as a commodity in all the markets reviewed which provided that information (130 of 130 papers). In most cases electrical energy was just sold by generators to consumers (102 of 130 papers). In other cases the market paid for flexibility, either alongside a market for the sale of energy (11 of 130 papers) [29, 50, 56, 76, 91, 102–107], or in a flexibility only market (10 of 130 papers) [26, 64, 66, 72, 77, 80, 100, 108–110]. Finally, some markets traded ancillary services such as reactive power, either alongside energy (5 of 130 papers) [30, 67, 68, 111, 112], or as a standalone ancillary services market (2 of 130 papers) [75, 113].

Although electrical energy was always traded in the markets reviewed, it was sometimes combined with other commodities. Combined heat and power markets are found in five of 130 papers [92, 114–117]. One presented combined power and gas markets [118], and one paper presented a combined power, heat and gas market [119].

The source of energy for sale in the markets included small generator, either stand alone (34 of 118 papers) or controlled by a prosumer (84 of 118 paper), and storage devices, either stand alone (14 of 118 papers) or controlled by a prosumer (59 of 118 papers). The primary advantage of acting in a P2P, CSC or TE market for energy generators is either that there is no other method of selling their energy, or where feed-in tariffs (FiTs) exist the P2P/CSC/TE market price is higher than the FiT price. P2P, CSC and TE markets are also less rigid about the types of generation which are permissible. FiT schemes have limitations on the type and size of generation which is allowed [120]. Typically storage is not compensated under FiT schemes.

This literature review shows that the benefit distribution can be split into two main categories. Firstly, benefits can be accrued by the market participants in relation to the market participation and price. Secondly, benefits can be accrued by collective interest. In the first category, all the benefits go to the market participants. The ratio of benefit accrual between market participants depends on market price. Amin et al. [37] introduce the Shapely-Shubik power index to identify the pivotal player and fairly distribute the revenue from market transactions. Morstyn and McCulloch [121] propose a market platform is design which considers different individual prosumer energy preferences and values (e.g. financial, environmental, social, and philanthropic). A set of individually beneficial transactions has been defined in [64] to design a TE market framework for DSOs, aggregators and prosumers. Nguyen et al. [68] propose a TE market considering the welfare outcomes for each participant.

However, in the second category of benefit distribution, all market participants cooperate to achieve the maximum collective interest/welfare. This is the case when the benefit brought by the market is voltage and frequency regulation or grid stability rather than or in addition to a financial benefit. Basnet and Zhong [55] have proposed a P2P market which maximises the total community welfare. An interesting concept of energy collectives has been proposed by Moret and Pinson [25] as a CSC market structure to reflect consumers preferences in the negotiation process. Chen and Hu [116] propose a TE model for collective interests maximisation for interconnected micro-grids. The authors have shown that market participant clustering can enhance the collective interests and increase energy cost saving by 15.34% comparing to a case without clustering.

Energy buyers and sellers both benefit from P2P, CSC and TE markets. Buyers benefit by purchasing energy at below the retail market rate. Sellers benefit by selling energy at above the FiT rate, if one exists, or by selling their energy at all if not [33, 73]. The distribution of the benefit between the buyer and seller depends on the market price (see Section 3.5.2 for more detail on market price). Many papers do not explicitly compare the P2P/CSC/TE market price to retail market and FiT prices. Therefore it is sometimes not possible to determine the benefit of the P2P/CSC/TE market over the traditional market.

Although many papers state that the P2P/CSC/TE market price is lower than the retail market price, they neglect non-energy costs which are included in the retail market price [27, 37, 46, 122]. These include balancing costs[1] and network costs[2]. It is likely that P2P, CSC and TE markets will be subject to some level of balancing and network costs [123, 124], however it may be lower than in traditional markets. For example, CSC markets aim to use electricity locally. Therefore, they may not be subject to the same level of network costs and geographic balancing costs. However, these costs are still likely to reduce the value of these markets for their participants.

Some of the markets reviewed also provided a service to the grid, such as energy balancing[3]. This service is often provided through dynamic pricing leading to load shifting, or storage arbitrage. These services are normally compensated through time of use pricing, i.e. a flexible load is compensated for shifting in time by the fact that they buy energy at a lower price. A storage device is compensated by purchasing energy at a low price and selling it at a high price (arbitrage). These devices are providing a service beyond simply selling energy. They are making adjustments to the supply and demand for energy at short notice. In traditional energy markets these are balancing services. Balancing services are usually procured in a separate market to energy. In liberalised electricity markets balancing services are often procured by a different entity to energy (system operator and energy supplier respectively). Balancing services are normally valued more highly than energy in traditional markets to reflect the fact that the changes to supply and demand are being made at short notice (typically less than an hour).

In traditional electricity markets there are normally minimum bid sizes for balancing markets. Therefore the types of resources which can participate in balancing in P2P markets would not be able to provide those services in traditional markets. Therefore the fact they can be compensated for balancing services at all is additional value to those market participants. However, the fact they are being compensated at only the difference between the purchase and sale cost for storage, and the higher original and lower actual energy costs for flexible loads, means they are probably being under valued in P2P markets. Their compensation will be lower than the market price for energy, compared to above the market price for energy in traditional markets.

One reason these flexible resources are not fully compensated for their true service is that most P2P, CSC and TE market in the papers reviewed are not subject to imbalance charges. Either the papers assume that market participants can perfectly predict their supply and demand for energy and always balance their position on the futures market, or the papers do not consider cash out

[1]Balancing costs are charged to electricity market participants by the system operator. They are used to recover the costs of the system operator and are charged in proportion to a market participant's energy imbalance.

[2]Network costs are charged to market participants by the distribution and transmission network operator to cover the capital and operating costs of the electricity network.

[3]Energy balancing involves shifting supply or demand for energy between settlement periods to keep the overall grid supply and demand for energy in balance.

at all. If the papers considered imbalance charges, flexible resources may be valued more highly, because they are then comparable to the cash out price, rather than the energy price.

3.2.2. Needs of market participants and commodity traded

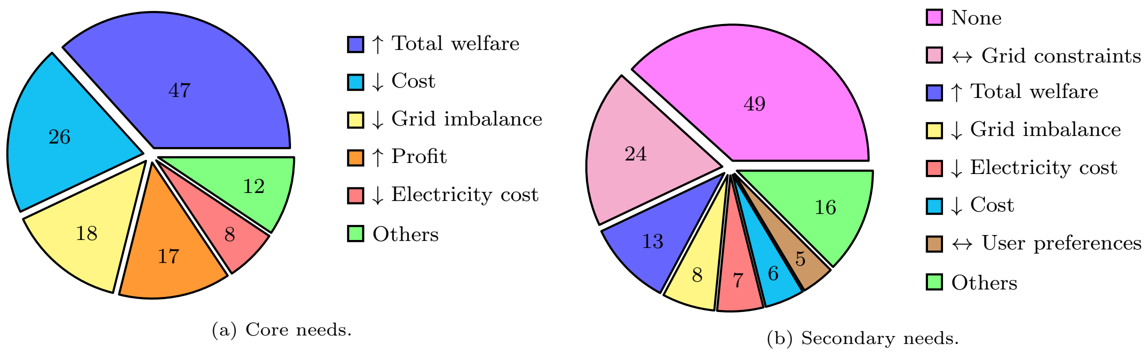


Figure 2: Needs of market participants. ↑ Increase; ↓ Reduce; ↔ Respect.

LEMs are designed to respond to various types of participant needs. These needs range from prosumers increasing their profit, reducing cost and respecting preferences to grid operators reducing grid imbalance and respecting grid constraints. All market models analysed respond to at least one of these needs. About 40% of these models (49 of 128) respond only to a single *core* need, while the remaining models target at responding to an additional *secondary* need too. Table 2 depicts the needs each market model satisfies (categorised by type) by trading a specific commodity. In our analysis, we differentiate between the following terms closely-related to financial benefits: total welfare (also known as economic surplus), profit, cost and electricity cost. We use the term total welfare if a market model provides the end users (e.g. prosumers) with increased profit or reduced cost, depending on their role in the market (seller or buyer). If a market model focuses only on providing one of the financial benefits to the market participants then we use the specific term instead of total welfare. We use the term electricity cost if the market model aims to reduce the electricity cost, which is beneficial to all grid users, not only the market participants.

Figure 2 provides an overview of the *core* and *secondary* needs which market models satisfy. The dominant *core* need (47 of 128 papers) is increasing total welfare of prosumers [43, 46, 59, 67, 106, 125, 132, 135], followed by reducing cost [49, 71, 79, 142, 144, 145] and grid imbalance [64, 151–154], increasing profit [41, 61, 118, 139, 140] and reducing electricity cost [85, 87, 94, 149]. Less common *core* needs include respecting grid constraints [75, 88, 156], reducing grid dependence [158], reducing peak load [77], increasing self-consumption[26, 157] and increasing DER use [81]. Figure 2a provides an overview of the *core* needs of market participants in the reviewed literature.

Approximately 76% of the analysed markets (98 of 128 papers) have a *core* need related to financial benefits (total welfare, profit, cost and electricity cost). This figure rises to 84% if you only consider P2P market models (59 of 70 papers). However, only 68% (36 of 53) TE models and 60% (3 of 5) CSC models have a financial *core* need. This suggests that out of the three types of models, P2P markets are the most financially-driven.

The dominant *secondary* need (24 of 79, about 30%) is respecting grid constraints [40, 42, 45, 76, 85, 104, 113, 134, 141], followed by increasing total welfare [66, 87, 94, 122], reducing grid imbalance [91, 103, 109, 115], reducing electricity cost [29, 69, 95, 147], reducing total cost [47, 88, 89, 154, 155] and respecting user preferences [43, 50, 71, 86, 121]. Other *secondary* needs less commonly cited include reducing electricity consumption [137], reducing energy losses [34], reducing CO_2 emissions [138], reducing grid dependence [107], increasing self-consumption [24, 55, 158], increasing RES use [35, 61, 114], increasing profit [70, 81, 105], increasing return on investment [148] and providing fair cost distribution [106, 150]. Figure 2b shows the breakdown of *secondary* needs. About 60% of *secondary* needs (48 of 79 paper) are related to the grid and environmental concerns.

If we consider both (*core* and *secondary*) needs, most of the P2P models (57%, 40 of 70 papers) only take financial benefits into account, ignoring any grid related needs. This is not the case for

Table 2: Needs of market participants addressed by P2P, TE and CSC market models.

Core needs	Secondary needs	Commodity	P2P	TE	CSC
↑ Total welfare	None	Electricity	[9, 33, 44, 46, 56, 57, 90, 125–130]	[74, 116]	-
↑ Total welfare	None	Flexibility	-	[100]	-
↑ Total welfare	↔ Grid constraints	Electricity	[28, 40, 131, 132]	[28, 72, 98, 133, 134]	-
↑ Total welfare	↔ Grid constraints	Flexibility	-	[67, 73, 111, 112]	-
↑ Total welfare	↓ Electricity cost	Electricity	[59, 69, 83]	-	-
↑ Total welfare	↓ Electricity cost	Flexibility	[29]	-	[29]
↑ Total welfare	↓ Grid imbalance	Electricity	[38, 48, 135]	[115, 136]	-
↑ Total welfare	↔ User preferences	Electricity	[43]	-	-
↑ Total welfare	↔ User preferences	Flexibility	[86]	-	-
↑ Total welfare	↓ Consumption	Electricity	[137]	-	-
↑ Total welfare	↓ Electricity loss	Electricity	[34]	-	-
↑ Total welfare	↓ CO2 emissions	Electricity	[138]	-	-
↑ Total welfare	↑ RES use	Electricity	[35]	-	-
↑ Total welfare	Fair cost distribution	Electricity	[106]	-	-
↑ Total welfare	↑ Self-consumption	Electricity	[55]	-	-
↑ Profit	None	Electricity	[27, 37, 78, 139]	[52, 65, 101, 118]	[27]
↑ Profit	None	Flexibility	[140]	[51]	-
↑ Profit	↔ Grid constraints	Electricity	[41, 141]	-	-
↑ Profit	↔ Grid constraints	Flexibility	-	[76]	-
↑ Profit	↑ RES use	Electricity	[61]	[114]	-
↑ Profit	↓ Grid imbalance	Electricity	-	[109]	-
↓ Cost	None	Electricity	[58, 84, 92, 93, 142–145]	[54, 96, 99, 146]	-
↓ Cost	None	Flexibility	-	[79, 108]	-
↓ Cost	↔ Grid constraints	Electricity	[45]	[49, 104]	-
↓ Cost	↔ User preferences	Electricity	[121]	-	-
↓ Cost	↔ User preferences	Flexibility	-	[50, 71]	-
↓ Cost	↓ Grid imbalance	Flexibility	[91]	[103]	-
↓ Cost	↑ Total welfare	Electricity	[32]	-	-
↓ Cost	↓ Electricity cost	Electricity	-	[147]	-
↓ Cost	↑ Self-consumption	Electricity	-	-	[24]
↓ Cost	↑ Return on investment	Electricity	[148]	-	-
↓ Electricity cost	None	Electricity	[149]	[97]	-
↓ Electricity cost	↑ Total welfare	Electricity	[94]	-	-
↓ Electricity cost	↑ Total welfare	Flexibility	[122]	[87]	-
↓ Electricity cost	↔ Grid constraints	Electricity	[85]	-	-
↓ Electricity cost	↓ Cost	Flexibility	[47]	-	-
↓ Electricity cost	Fair cost distribution	Flexibility	[150]	-	-
↓ Grid imbalance	None	Electricity	[151]	[152]	-
↓ Grid imbalance	None	Flexibility	-	[63, 153]	-
↓ Grid imbalance	↑ Total welfare	Electricity	[60, 119]	[62]	-
↓ Grid imbalance	↑ Total welfare	Flexibility	-	[64, 66]	-
↓ Grid imbalance	↓ Electricity cost	Electricity	-	[95]	-
↓ Grid imbalance	↓ Cost	Electricity	[154]	-	-
↓ Grid imbalance	↓ Cost	Flexibility	[155]	[89]	-
↓ Grid imbalance	↔ Grid constraints	Flexibility	[42]	[80]	-
↓ Grid imbalance	↑ Profit	Electricity	[70]	-	-
↓ Grid imbalance	↑ Profit	Flexibility	-	[105]	-
↓ Grid imbalance	↓ Grid dependence	Flexibility	-	[107]	-
↔ Grid constraints	↑ Total welfare	Electricity	[156]	[75]	-
↔ Grid constraints	↓ Cost	Flexibility	-	[88]	-
↑ Flexible demand use	↑ Total welfare	Flexibility	[36, 102]	-	-
↑ Self-consumption	None	Flexibility	-	-	[26]
↑ Self-consumption	↓ Cost	Flexibility	-	[157]	-
↓ Grid dependence	↑ Self-consumption	Electricity	[158]	-	-
↓ Peak load	↔ Grid constraints	Flexibility	-	[77]	-
↑ Ancillary services	↔ Grid constraints	Electricity	-	[113]	-
↔ User preferences	None	Electricity	-	-	[25]
↑ DER use	↑ Profit	Electricity	-	[81]	-

Legend: ↑ Increase; ↓ Reduce; ↔ Respect the TE markets model type. The majority of TE markets (64%, 34 of 53 papers) do consider grid related needs in one or another form.

3.3. Market participants

In the following section we have a detailed look at the market participants involved in the models. We look at the types of participants engaged in each model taking a frequentist approach and depict the assets market participants contribute to the market.

3.3.1. Types of market participants

Market designs and operating conditions can be distinguished based on the participants involved in the market. We differentiate between seven different types of market participants: pure generators, pure consumers, prosumers, aggregators, retailers, central market operators and grid operators. Figure 3 shows all market participants presented, split by type of market. Some papers are represented multiple times if more than one market model was discussed. Detailed references for the type of market participant considered by each paper can be found in Table 6. The description for each participants can be found in the code book in Appendix A.

Around 94% of P2P markets have prosumers, followed by 55% which have pure consumers, 46% have central market operators and 29% have grid operators. Other market participants represented in P2P markets include aggregators and retailers, with pure generators coming last. This distribution of participants highlights the focus of P2P markets on individual energy end-users and the goal to offer them a platform to trade energy on. However, the consideration of other participants such as retailers, grid operators or aggregators highlights the diverse types of P2P market and their different ways they integrate into the existing energy market structure.

In TE markets, grid operators and prosumers play the most significant role, both being represented in 64% of papers. They are closely followed by pure consumers at 62%. 55% of papers include a central market operator. Around half of all papers include pure generators and aggregators. Finally, with 23%, the least number of papers considered retailers in their market platforms. TE models have a more even distribution amongst the different market participants than P2P markets. This supports the characteristics assigned to TE in Section 3.1 stating that TE market models can operate across various levels of the grid with a diverse range of participants involved.

For CSC markets, over 83% are centered around energy prosumers. A central market operator was mentioned in 67% of cases. Half of the papers considered pure consumers. Retailers, pure generators and grid operators were the least prominent market players. None of the CSC markets included an energy aggregator. This highlights the strong community focus of CSC markets and their centralised nature. It should be stressed that only a small sample size of CSC related papers has been analysed Section 3.1.

All three market models have prosumers, pure consumers and market operators as the dominant participants in the market. In contrast to P2P, TE puts a stronger focus on grid operators, pure generators and aggregators, which supports the findings highlighted in Section3.1 that TE is more

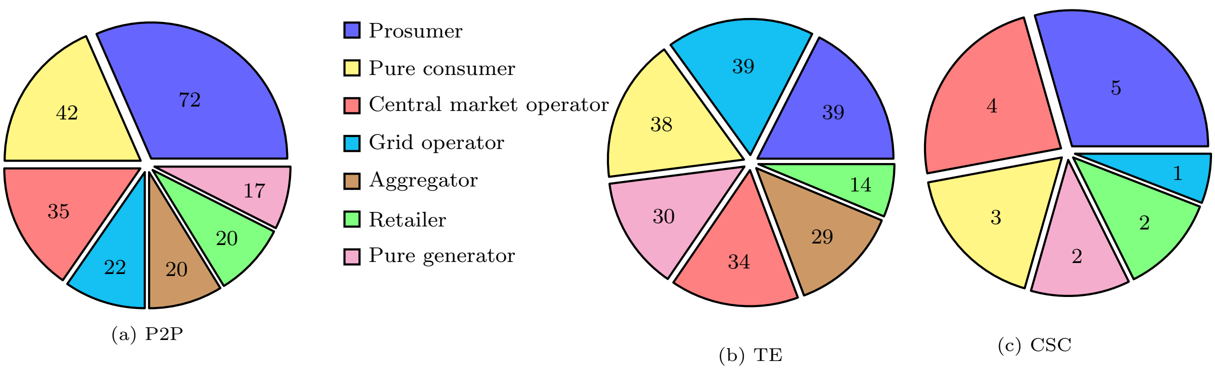


Figure 3: Types of market participants

Table 3: Market participants

Participant type	P2P	TE	CSC
Pure generators			
Entities which only generate energy	[30, 35, 42, 43, 45, 61, 84, 90, 102, 119, 138–140, 142, 144, 148, 156]	[30, 49, 52, 54, 62, 63, 67, 68, 75, 81, 87, 89, 100, 101, 103–105, 107, 109, 112, 114–118, 133, 134, 136, 152, 159]	[25, 26]
Pure consumers			
Entities which only consume energy	[21, 29–31, 34–38, 42, 43, 45, 47, 56–58, 61, 69, 70, 78, 83, 84, 90, 93, 94, 102, 110, 119, 125, 131, 137–139, 141, 142, 148, 149, 151, 154, 155, 158, 160]	[21, 30, 50, 52, 62, 63, 65, 66, 72–76, 87–89, 95–97, 100, 101, 103–105, 107, 108, 112, 114, 115, 117, 118, 133, 134, 136, 146, 152, 159, 161]	[25, 26, 29]
Prosumers			
Entities which consume and generate energy	[9, 21, 27–38, 40–48, 55–61, 69, 70, 78, 83–86, 91–94, 106, 110, 119, 121, 122, 125–132, 135, 137–141, 143–145, 148–151, 155, 156, 158, 160, 162]	[21, 28, 30, 51, 54, 62, 64, 65, 67, 68, 71, 73, 76, 79, 81, 82, 87–89, 95–99, 104, 105, 107, 111, 113, 115, 118, 134, 136, 146, 152, 153, 157, 159, 161]	[24–27, 29]
Aggregator			
Entity that act on behalf of a group of smaller market participants	[21, 30, 36, 38, 40–43, 60, 61, 86, 90, 94, 110, 122, 125, 126, 140, 149, 156]	[21, 30, 50, 64, 66–68, 71, 76, 77, 79, 80, 88, 95–97, 100, 101, 104, 105, 107, 114, 117, 118, 133, 136, 146, 152, 153]	-
Retailer			
Entity that connects to other large markets	[27, 30, 37, 38, 43, 46, 47, 55, 59, 69, 78, 86, 102, 122, 125, 127, 143, 149, 154, 160]	[30, 65–68, 74, 81, 95, 96, 101, 104, 105, 111, 133]	[25, 27]
Central market operator			
Single agent which runs the market or the platform	[27–30, 32, 34–37, 42, 44, 45, 47, 55, 56, 59, 60, 78, 84, 93, 102, 106, 110, 121, 126, 128, 132, 137, 140, 142, 143, 150, 158, 160, 162]	[28, 30, 51, 52, 54, 62, 63, 65, 67, 68, 71, 73, 75, 77, 79, 81, 82, 87, 89, 95, 96, 99, 105, 107, 112, 114, 117, 133, 134, 136, 146, 153, 157, 161]	[24, 25, 27, 29]
Grid operator			
Entity that operates the electricity network and interacts with the market	[21, 28–30, 35, 42, 58, 59, 84–86, 94, 102, 110, 126, 128, 135, 140, 144, 148, 154, 160]	[21, 28, 30, 49, 51, 53, 54, 62, 64, 66–68, 72, 73, 75–77, 79, 80, 82, 87, 88, 95, 96, 99, 101, 103, 104, 109, 111–113, 116, 117, 133, 136, 152, 157, 159]	[29]

focused on providing grid services than incentivising individuals to trade amongst each other. Furthermore, TE is a concept that focuses on supporting the electricity grid, explaining a more equally distribution of different market participants. This is supported by the characteristics identified in Section 3.1 where locality plays a rather small role in TE markets compared to P2P markets. An important observation to make is that the diversity of participants in a market is important for pooling resources and enabling different market mechanisms. However, diversity might also increase complexity when operating the market as a wider range of market behaviours have to be taken into consideration.

3.3.2. Assets of market participants

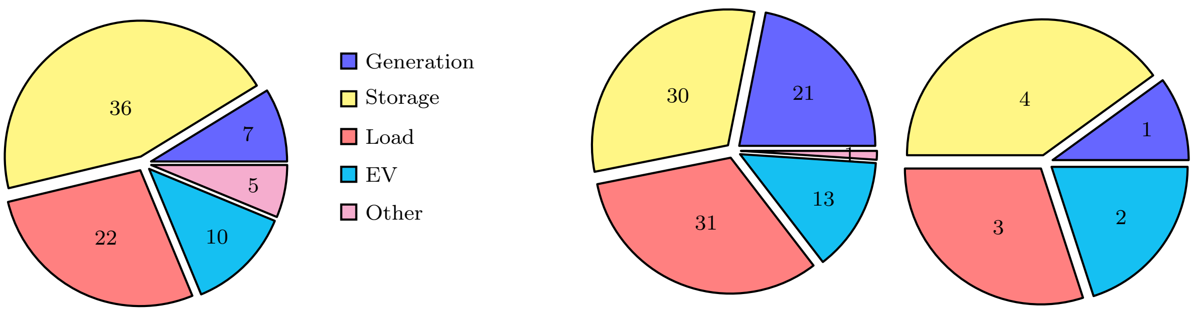
Assets participating in the market were classified as either controllable or non-controllable assets. By controllable assets, we refer to either energy generators or loads that can be dispatched as requested by an energy operator. Loads can be either shifted, curtailed or completely disconnected depending on the specific properties. These assets can provide either power balance or voltage control services. Energy storage systems are considered to be controllable assets. They can either generate or absorb power from the electricity grid. Non-controllable assets are generation units that cannot be dispatched or are intermittent in nature, and loads which are not shiftable or shapeable.

Assets participating in markets directly and indirectly (e.g. through a home energy manager) were considered in this analysis. Figure 4 shows the type of controllable assets split by market type. Nearly 80% of all papers have included or explicitly mentioned controllable assets in their market model. For all market models storage devices and dispatchable loads play a major role. In most markets small scale residential energy storage systems were used with a few exceptions, for example in the cases where community or utility size storage systems [47, 122] or thermal storage units [54, 115, 116] have been considered. All three market models integrated controllable load in their market designs. In P2P and CSC markets, controllable load was usually shiftable appliances [29, 36, 102, 149, 154] or air conditioners [91, 110, 149] and heatpumps [36]. While in TE markets, shiftable appliances were also a key source of flexibility [71, 73, 103, 108, 117], however heatpumps were frequently used as a main source of load control [66, 71, 73, 89, 114, 115, 157]. Compared to P2P and CSC markets, TE markets put a stronger focus on dispachable generation including combined heat and power [54, 114–116] or traditional fuel-based generators [66, 81, 117]. In a few cases P2P markets made use of diesel generators [43, 148, 156]. All three market models considered EVs in their market designs, although not as frequent as some other controllable energy assets. Finally, the term "other" in Figure 5 refers to papers where controllable assets were considered but not explicitly described. An overview of the references that used controllable assets and in what type they were can be viewed in Table 4.

There is a clear difference between the non-controllable assets found in P2P and CSC markets compared with TE markets. Figure 5 shows the type of non-controllable generation units classified in PV energy and other distributed generation (DG). It can be seen that P2P markets mainly considers solar energy generation units. When explicitly mentioned, most markets refer to small-scale solar rooftop PV systems. In a few cases multiple generation units have been considered, which in most cases were based on solar and wind generation [30, 56, 119, 131]. In contrast, TE markets more frequently include other types of DG in their markets. In these cases wind energy is the dominant type of DG [30, 75, 105, 112, 118]. For CSC markets, most non-controllable generation units included PV installations only with one exception [26].

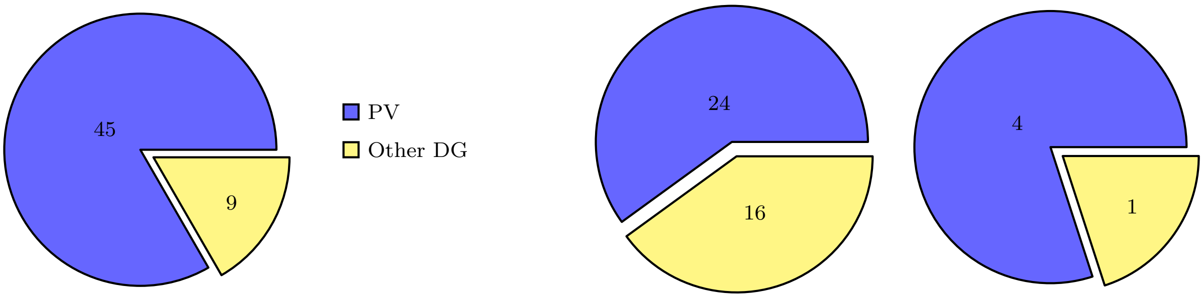
3.4. Market scale

The scale of the market is a key determining factor for understanding the operating conditions of the markets. To understand at which scale each market can operate we first look at the size of models in terms of the nodes or participants involved and second investigate the scale of the participant in each market.



(a) P2P (b) TE (c) CSC

Figure 4: Types of controllable market assets.



(a) P2P (b) TE (c) CSC

Figure 5: Types of non-controllable market assets.

Table 4: Controllable and non-controllable assets of P2P, TE and CSC markets.

Type of control	**Type of assets**	**P2P**	**TE**	**CSC**
Controllable assets	Generation Storage Load	-	[62, 66, 81, 115, 116, 136]	-
	Storage Load EV	[29, 92]	[67, 71, 73, 80, 107]	[29]
	Generation Storage	[30, 148]	[30, 54, 109, 134, 147]	-
	Storage Load	[21, 36, 40, 45, 91, 106, 119, 122, 154, 155]	[21, 88, 99, 100, 104, 105, 112, 118, 146, 157]	[26]
	Load EV	[102, 160]	[103, 108]	-
	Generation Load	[156]	[79, 89, 114, 117]	[25]
	Storage EV	[48, 129]	[64]	[24]
	Generation	[43, 127, 144]	[49, 52, 75, 87, 101, 111]	-
	Storage	[27, 33, 44, 47, 55, 59, 61, 83, 86, 93, 94, 121, 131, 132, 137, 141, 143, 158]	[97, 113, 152]	[27]
	Load	[9, 38, 46, 110, 142, 149, 150]	[63, 68, 72, 95]	-
	EV	[60, 126]	[50, 74, 76, 77, 153]	-
	Other	[41, 42, 84, 128, 138]	[159]	-
Non-controllable assets	PV Other DG	[30, 56, 119, 131, 143, 155]	[30, 49, 75, 81, 82, 104, 112, 115]	[26]
	PV	[9, 21, 27, 29, 31–34, 36–38, 44, 47, 55, 58, 59, 69, 78, 83, 86, 91–93, 102, 106, 121, 122, 125, 127, 129, 130, 135, 137, 140, 141, 148, 156, 158, 160]	[21, 54, 64, 67, 71, 73, 89, 97–100, 113, 116, 146, 152, 161]	[25, 27, 29]
	Other DG	[45, 46, 61]	[62, 74, 101, 105, 118, 134, 147, 153]	-

3.4.1. Participation in market models

This section focuses on analysing the size and scale of the markets discussed in the papers in terms of the number of participants involved. Only papers providing this information have been included in this analysis. Where multiple scenarios have been tested, the scenario with the highest number of participants was included in this analysis. An overview of the number of papers and size of market is given in Figure 6. These numbers were derived from each paper looking at the number of key participants involved or the number of nodes stated. Instead of specifying the number and type of participants, some papers referred to nodes which are usually the number of agents a market is optimised for, e.g. [82, 112, 131]. Most papers design small energy markets with 1-10 participants, followed by markets with 11-50 participants. These two group sizes make up more than half of all papers. Around 16 papers involve 51-100 participants, 13 papers involve 101-500 participants, 5 papers involve 501-1000 participants and 6 papers look at more than 1000 participants. A detailed overview of the number of participants considered in each paper can be seen in Table 5.

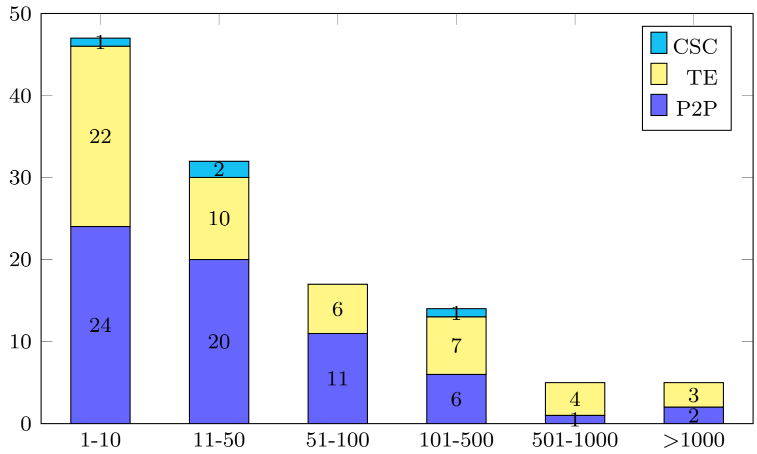


Figure 6: No of nodes/participants in the market.

Most authors built their markets models using small participation numbers, mainly to apply and demonstrate the functionality of their market mechanisms. While this can help to evaluate the performance of a market, it only provides limited insights into to real-life applicability and scalability of such markets. Markets with larger numbers of participants usually focus on scheduling of devices, such as EVs or thermostatically controlled loads [74, 80, 108, 140] rather than individual households optimising load profiles.

For all papers with more than 500 participants the test duration varied between a few hours to maximum one day with one exception where two months were considered [129]. This proves that although the models look at larger scale adoption they are not tested on resiliency and diversity of load. However, where fewer participants have been included in the market longer simulation durations have been tested [37, 82, 159]. Depending on the type and scale of P2P, CSC and TE markets, more research into markets operating at scale with a couple of hundred nodes or participants is required.

3.4.2. Size of market participants

A second characteristic which is important is the scale at which market participants are operating. We divide participants into small scale, building scale, community scale or grid scale. Small scale market participants are predominantly residential/individual energy users. Markets with building scale participants involve multiple buildings trading. Community scale markets do not focus on the individual energy users in the market but rather operate as a community, for example a microgird or through aggregators. In grid scale markets, participants can be of various size operating across an entire national electricity grid. Identifying the scale of market operation helps in understanding the main trading purpose of a market by means of who the market was designed for and its ability to

Table 5: Market scale.

Participation	P2P	TE	CSC
1-10 participants	[9, 27, 31, 33, 38, 40, 44, 46, 47, 56, 58, 59, 61, 92, 122, 125, 131, 138, 142, 144, 149, 150, 155, 162]	[49, 51, 62, 63, 71, 81, 82, 87, 97, 100, 103, 104, 111, 113, 115, 133, 136, 146, 147, 152, 153, 157]	[27]
11-50 participants	[28, 29, 32, 34, 35, 37, 41–43, 48, 69, 85, 106, 126, 127, 137, 139, 154, 156, 160]	[28, 68, 73, 88, 101, 107, 109, 116, 118, 134]	[25, 29]
51-100 participants	[55, 60, 86, 94, 119, 121, 130, 132, 135, 141, 145]	[64, 76, 99, 112, 159, 161]	-
101-500 participants	[57, 70, 91, 93, 102, 143]	[50, 77, 95, 96, 98, 105, 117]	[24]
501-1000 participants	[110]	[67, 72, 74, 89]	-
>1000 participants	[129, 140]	[79, 80, 108]	-

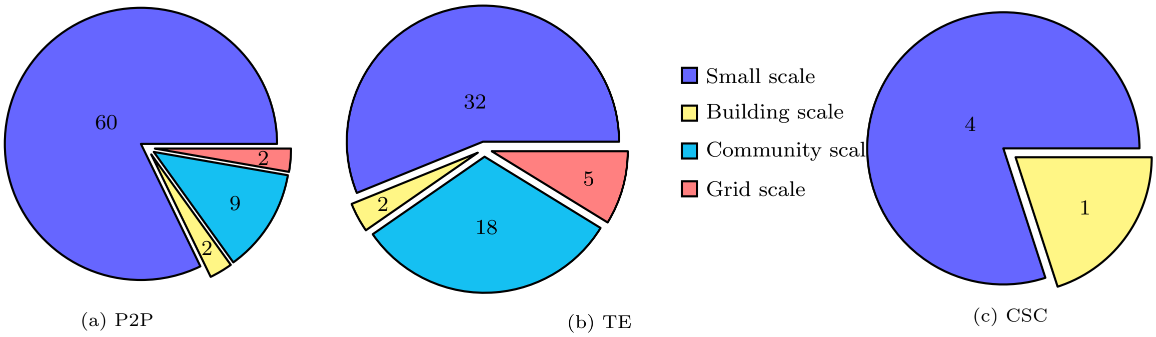


Figure 7: Scales of market participants.

scale in the future. An overview of all three concepts and the scale of market participants included can be seen in Figure 7. Table 6 provides the associated references.

Most papers focus on developing markets for small scale participants. In the case of P2P, nearly all papers except for a few focus on these small scale residential energy users or in some cases EVs, for example [48, 60, 126]. A few papers have considered trading at community scale. These markets usually conduct transactions between microgrids [35, 40, 156], as virtual power plants [41] or with industrial energy users [43, 91, 142]. Similarly papers considering CSC markets only consider small scale energy users in their analysis [24–26, 29]. The scale of users in TE markets is more varied. The majority of papers still focuses on small scale users. Most community scale papers focus on trading amongst microgrids [81, 116, 136, 147] while one paper focused on trading amongst aggregators [77, 134] or through a virtual power plant [109]. The papers classified as grid scale operate at national grid level [30, 75, 104]. In TE markets small scale participants are dominant. However, TE market papers included proportionally more grid scale Markets than papers considering P2P markets. This shows TE markets operate across various levels of the grid, from small scale to grid scale applications.

Table 6: Market participants.

Participant scale	P2P	TE	CSC
Small scale	[9, 28, 29, 31–34, 36–38, 44–46, 48, 55–61, 69, 70, 78, 83–86, 92–94, 102, 106, 110, 119, 121, 125–127, 129–132, 135, 137–141, 143–145, 148, 150, 151, 154, 155, 158, 160, 162]	[28, 50, 62, 64, 65, 67, 68, 71–74, 76, 79, 80, 82, 88, 89, 98–100, 103, 108, 112–114, 117, 118, 146, 152, 157, 159, 161]	[24–26, 29]
Building scale	[27, 149]	[54, 153]	[27]
Community scale	[35, 40–43, 47, 91, 142, 156]	[49, 63, 77, 81, 87, 95, 96, 101, 105, 107, 109, 111, 115, 116, 133, 134, 136, 147]	-
Grid scale	[30, 122]	[30, 66, 75, 97, 104]	-

Table 7: Grid model: grid constraints & power losses.

Grid model	P2P			TE		
	Grid Constraints	Power Loss	Other	Grid Constraints	Power Loss	Other
IEEE 13 bus	[46, 70, 110]	-	-	[67, 77, 93, 134]	[67, 77, 134]	-
IEEE 14 bus	[56]	-	[37]	-	-	-
IEEE 24 bus	-	-	-	[105]	[105]	-
IEEE 30 bus	[36]	-	-	[75]	[75]	-
IEEE 33 bus	[122]	-	-	[95, 111]	[95, 111]	-
IEEE 37 bus	-	-	-	[98, 104, 107, 108]	[98, 108]	-
IEEE 39 bus	[85]	[85]	-	-	-	-
IEEE 55 bus*	[121, 130, 156]	[121, 130]	-	[64]	[64]	-
IEEE 69 bus	-	-	-	[88, 112]	[88, 112]	-
IEEE 118 bus	-	-	-	[105]	[105]	-
IEEE 123 bus	[33, 36, 122]	-	-	[49, 77, 95, 98]	[49, 77, 95, 98]	-
ISO 5-bus**	-	-	-	[68]	[68]	-
CIGRE 6 bus***	[9]	-	-	-	-	-
CIGRE 15 bus⋆	[42]	-	-	-	-	-
SCE 56 bus⋆⋆	[128]	-	-	-	-	-
WECC 240 node⋆⋆⋆	-	-	-	[79]	[79]	-
PJM 5 bus	-	-	-	[103, 104]	[103]	-
Real Network	[141, 162]	[141, 162]	[34]	[76]	-	[96]
Simulation Case	[43, 131]	[43, 131]	-	[82, 87, 104, 113, 118]	[113, 118]	[97, 104, 109, 117]

*:European Low Voltage Test Feeder, ** ISO 5-bus transmission test system, ***CIGRE Benchmark LV Microgrid network, ⋆CIGRE 15bus European benchmark,⋆⋆Southern California Edison (SCE) 56-bus test feeder,⋆⋆⋆CAISO- 240 node WECC

3.4.3. Types of grid models

There is a strong correlation between the market design and the physical network in LEM concepts. The formation of a transaction depends not only on the commercial interests, but also on the ability of the network to support this transaction, such as the impact on grid stability and performance. Due to the link between LEM and low/medium voltage networks, many research works have been devoted to analysing voltage constraints. However, other constraints have been highlighted, including but not limited to phase imbalance, power peaks, upstream generation, transmission capability, and line congestion [36, 46, 56, 122, 131]. Along with grid constraint, power losses have an important impact on the physical implementation of the commercial transaction. 32 papers include a power loss analysis. Baroche et al. [85] proposed a distance unit fee to incorporate the power loss in the transaction. The results showed that this method could smooth the integration of LEM transactions into the physical grid. Guerrero et al. [141] have investigated the impact of P2P transactions on voltage, power loss, and power transfer grid sensitivity. Di Silvestre et al. [162] proposed a power loss evaluation method to be associated with the transaction design. While considering associating the technical aspect of the grid constraints and power losses and the market aspect of the transaction, the proof of concept usually refers to testing and validating the transaction on a physical grid. This is important for benchmarking the results and evaluating the possible integration or the markets into a physical grid. This requires a multidisciplinary background which can limit the literature outputs in this field. Indeed, 48 papers of the 139 papers in this review study have considered the grid testing approach for performing their analysis.

Different grid models have been used in the models presented, including IEEE and CIGRE test feeders, simulation case test feeders, and in some cases, real case test feeders (see Table 7). The diversity of feeder models makes them more adapted for different scenarios. However, this diversity raises questions about the replicability of a proposed approach for an LEM segment in different grid configurations. It is worth noting that the technical aspect of power losses and network constraints integration to the transaction design is out of the scope of this study. A detailed analysis of the above is in [163]. However, this section considers a market layer aspect. It suggests a comparison between the grid models deployment for transaction design and physical grid integration in P2P, TE, and

Table 8: Grid model specifications

Grid model	HV (100-200kV)	MV (1-100kV)	LV (<1kV)	Balanced	Unbalanced
IEEE 24 bus	✓			✓	
IEEE 30 bus	✓			✓	
IEEE 33 bus		✓			✓
IEEE 37 bus		✓			✓
IEEE 39 bus	✓			✓	
IEEE 55 bus*			✓		✓
IEEE 69 bus		✓		✓	
IEEE 118 bus		✓			✓
IEEE 123 bus		✓			✓
ISO 5 bus**	✓			✓	
CIGRE 6 bus***			✓	✓	
CIGRE 15 bus⋆		✓		✓	
SCE 56 bus⋆⋆		✓		✓	
WECC 240 node⋆⋆⋆	✓			✓	
PJM 5 bus	✓			✓	

*European Low Voltage Test Feeder, ** ISO 5-bus transmission test system, ***CIGRE Benchmark LV Microgrid network, ⋆CIGRE 15bus European benchmark,⋆⋆Southern California Edison (SCE) 56-bus test feeder,⋆⋆⋆CAISO- 240 node WECC

CSC markets. Moreover, it shows how the grid models were used and deployed in grid constraint and power loss analysis while performing LEM market analysis and transaction design. Table 7 describes the different grid models while mapping the 139 papers considered in this review. They are categorised by market segment. In each category, papers with power loss and/or grid constraints analysis are highlighted. Among the 139 papers in this review, no CSC markets integrated grid models. This analysis points to a research gap in analysing the link between CSC transaction design, physical grid constraints, and power losses.

As shown in Table 7, many simulation case studies have been described in the literature. This approach can be more adapted to spot out the research output in a specific grid model. However, this can limit the benchmarking of the obtained results. The deployment of real case test feeders also presents the same limits. Despite this, it can be very useful to demonstrate the transaction implementation validity. The replicability for other grid models is questionable. The IEEE test feeder models have been widely used compared to the CIGRE ones. The IEEE 13 bus, IEEE 30 bus, IEEE 33 bus, IEEE 55 bus (European test feeder low voltage), and IEEE 127 bus models have been used in both P2P and TE LEM-based case studies [36, 49, 64, 75, 77, 122, 134, 164]. These models are usually obtained from real networks and adopted to ease wide range of analysis and bench-marking. A brief comparison between the characteristics of these benchmark grid networks is described in Table 8. Two main characteristics can define the model selection: (1) voltage level, and (2) phase balance. In a balanced network, the power system, the loads, and the equipment are designed to operate with phases balanced. However, in an unbalanced network, a voltage mismatch can occur in the three-phase system. The voltage level is used usually for defining the TSO or DSO bench-marking. In the IEEE 141:1983-Clause 3.1.1.2, the high voltage (HV) deals with 100 kV to 200 kV voltage range. The medium voltage (MV) describes all voltage levels between 1 kV to 100 kV. The low voltage (LV) describes all voltage levels less than 1 kV. While the HV and LV are directly linked with transmission and distribution systems respectively, the MV network can be deployed in both transmission and distribution since it is the main contact point between energy generation and consumption.

Recall that the main aim of the test feeder models is to reproduce characteristics of a network within certain regional and technical specificities [165, 166]. Originally, they were designed to address certain academic and research purposes and not to represent the complexity and network full size. The particularity of the design allows each feeder to consider one or certain analysis challenges as power flow studies, optimal equipment placement, integration studies, state and parameter estimation, new control schemes, etc [165]. Due to the scarcity of a realistic and adequate test system, the research community has routinely used the available models for different purposes other than the originally intended one [166]. Our analysis of physical dependencies and power losses with the market link from the 139 papers in this review shows that 17 test feeders have been deployed for validating results for the different market segments. Among the 17 models, only the IEEE 55 bus European test feeder low voltage has been used in grid constraint and power loss analysis in both P2P and TE markets. Obviously, the variety of grid scenarios can limit the adoption of a single test feeder model, thus a guideline for linking market design, integration challenges, and grid model could ease research benchmark and orient future research. Moreover, proposing valuable test platforms for transactive energy market benchmarking purposes in different network voltage levels is also essential to perform adequate benchmarking and properly evaluate the scalability and the total surplus of the P2P, CSC, and TE markets.

3.5. Market operation

In the following section we discuss market operation mechanisms that are an essential part of LEMs. We first introduce introduce six archetypal market designs identified in the analysed papers (Section 3.5.1). We identify three archetypal price formation mechanisms (Section 3.5.2). This is followed by the type of data shared between participants and user preferences considered (Section 3.5.3). We then provide insights into the settlement period and gate closure times used (Section 3.5.4). Finally, this sections concludes giving an overview of the different types of risks considered in the markets (Section 3.5.5).

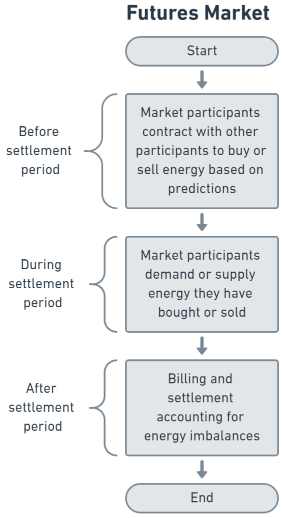
3.5.1. Market design

Six archetypal market designs have been identified in the papers. The market design is the manner in which the price formation mechanisms are strung together to form a complete market (see Section 3.5.2 for more detail on individual price formation mechanisms). Figure 8 shows flowcharts for each of the archetypal market designs. In some cases, such as a futures market (Figure 8a), a single price formation mechanism is used. Whereas in other market designs, such as a mixed decentralised/centralised market (Figure 8c), several different price formation mechanisms might be used in succession over different time periods. In this section each of the price formation mechanisms found in the reviewed literature is described, along with an analysis of how each is typically used. Table 9 shows the price formation mechanism and market design used by each of papers in the review.

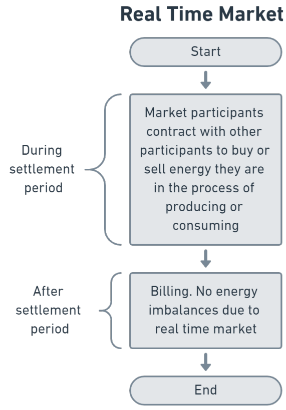
Futures Market: In a futures market all trading happens before the settlement period. During the settlement period market participants attempt to stick as closely to their traded positions as possible. Any energy imbalances resulting from a deviation from the traded position are dealt with during settlement after the settlement period. Single auction, double auction and bilateral negotiation price formation mechanisms are all found paired with futures markets. Futures markets are by far the most common market design found in the reviewed literature. They are also the most similar to the way many existing electricity markets work, e.g. in Great Britain [167]. Figure 8a shows an archetypal flowchart for a futures market.

Real Time Market: In real time markets there is no trading ahead of the settlement period. All trading is done during the settlement period. This allows market participants to update their position in the market throughout the settlement period based on their actual supply and demand for energy. Therefore all market participants should theoretically come out of the settlement period with a balanced position. However, there are reasons why market participants may not have a balanced position, for example if total supply and demand in the market are not matched. Most papers reviewed assumed the markets modelled are linked to larger traditional electricity system which act as an infinite bus and are able to absorb any excess supply and demand. Else the papers assume there is sufficient flexible energy generation or load that price signals in the market are sufficient to balance supply and demand for energy. This allows all market participants to balance their position during every settlement period. Single auctions, double auctions and bilateral negotiations are all found in real time markets in the reviewed literature. Figure 8b shows a archetypal flowchart for a real time market.

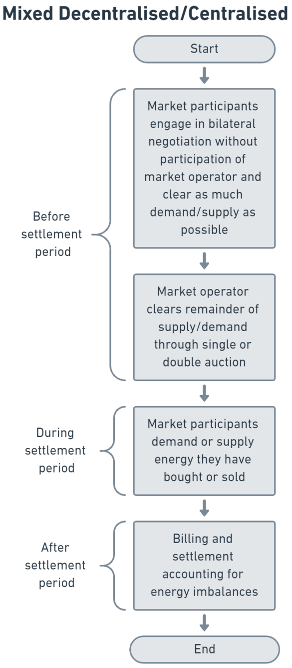
Mixed Decentralised/Centralised Market: In a mixed decentralised/centralised market there is a period of bilateral negotiation where market participants attempt to clear the market as far as possible without intervention from a market operator. The bilateral negotiation is followed by a



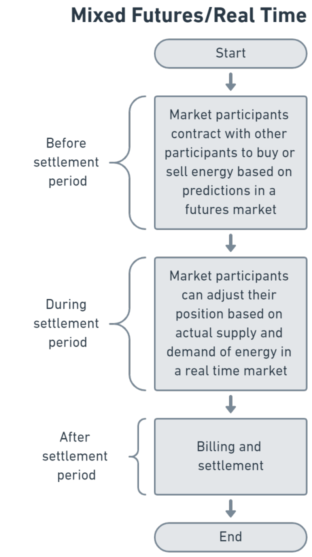
(a) Futures market



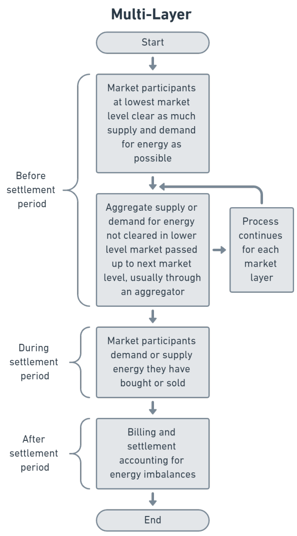
(b) Real time market



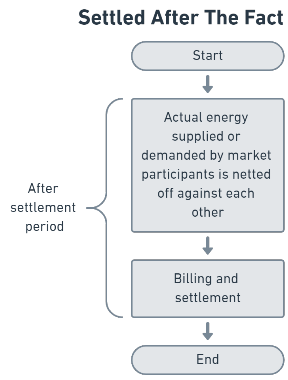
(c) Mixed decentralised/centralised market



(d) Mixed futures/real time market



(e) Multi-layer market



(f) Market settled after the fact

Figure 8: Market design flowcharts.

Table 9: Price formation mechanism and market design.

Price FM	Market design						Type
	F	RT	Mixed C/D	Mixed F/RT	Multilayer	S.A.T.F	
Single auction	[9, 34, 44–46, 56, 85, 90, 93, 106, 110, 119, 121, 129, 131, 142, 150, 151, 155, 158]	[148]	[47]	[128, 140]	[143]	-	P2P
	[51, 52, 66, 67, 76, 80–82, 87, 88, 96, 99, 105, 111, 153]	[74, 75, 117]	-	[50, 54, 62, 68, 73, 118]	[64, 95, 104, 136, 146]	-	TE
	[24, 27]	-	-	-		-	CSC
Double auction	[21, 28, 31–33, 35, 36, 38, 41, 42, 55, 59, 61, 70, 91, 102, 122, 126, 127, 130, 132, 135, 137, 141, 154, 160]	[48, 60]	[37, 149]	[156]	[30]	-	P2P
	[49, 63, 72, 77, 100, 101, 103, 108, 109, 113, 114, 116, 133, 134, 147, 152, 161]	[89]	-	[65, 71, 107, 157]	[79, 115]	-	TE
	[25]	-	-	-	[29]	-	CSC
Bilateral negotiation	[43, 83, 86, 98, 138, 139, 145]	[58]	-	-	-	[69, 125]	P2P
	[40, 97, 101]		-	-	-		TE
	[26]		-	-	-		CSC

* FM – Formation Mechanism; F – Futures; RT – Real Time; C – Centralised; D – Decentralised; S.A.T.F. – Settled After The Fact

centralised auction run by a market operator to clear the remainder of the market. The centralised auction may simply be within the P2P/CSC/TE market, or the market operator might trade with a larger traditional market in order to further clear the P2P/CSC/TE market. Both single and double auctions are used for the centralised part of the market in the reviewed literature. Figure 8c shows a archetypal flowchart for a mixed decentralised/centralised market.

Mixed Futures/Real Time Market: In a mixed futures/real time market there is some trading ahead of the settlement period based on predicted supply and demand for energy. There is then further trading during the settlement period during which time market participants can correct their position in the market due to any energy forecasting errors. Mixed futures/real time markets are found with both single and double auctions in the papers reviewed. Figure 8d shows a archetypal flowchart for a mixed futures/real time market.

Multi-Layer Market: Multi layer markets are markets settled at multiple levels. For example there may be multiple markets at the bottom level which is cleared internally first. An aggregator within each of these markets then participates in a higher level market to clear an excess supply or demand in the lower level markets. Multi-layer markets are found with both single and double auctions in the papers reviewed. Figure 8e shows a archetypal flowchart for a multi-layer market.

Settled After The Fact: In a small number of cases there was no trading before the end of the settlement period. In these papers market participants were paid or charged for energy they supplied or demanded after the settlement period. In these markets there is no price formation mechanism. Figure 8f shows a archetypal flowchart for a market settled after the fact.

3.5.2. Price formation mechanism

Price formation is the mechanism by which market prices are discovered. Exchange takes place within the context of a market institution, the rules that specify which messages (e.g., buyer bids, seller asks) are permitted, which agents are allowed to communicate messages, and how agents transact. Market institutions thus define price formation processes. Table 9 shows the price formation mechanism used in each of the papers reviewed.

Many diverse market institutions exist, from bilateral individual search between buyers and sellers, to the "posted price" institution that is used in most markets for consumers goods, to a wide array of auction designs [168]. These different institutions are suitable in different markets depending on the nature of the goods or services exchanged and the physical and economic context. For example, if the transacted items are common value goods, they will have the same value for each agent (e.g., financial securities, timber, oil and gas drilling leases), but each agent may have incomplete information (and may have different degrees of incomplete information) about the nature of the item, so the agents may form different expected values. In contrast, private value goods have different values for each agent depending on their individual, subjective preferences, but agents do not know the preferences and valuations of other agents. Efficiency, or maximizing welfare creation through exchange, is likely to require different market institutions in these cases.

In the papers reviewed for this survey, five main categories of market institution were employed and tested: single auction, double auction, system-determined mechanisms, negotiation-based mechanisms, and equilibrium-based mechanisms.

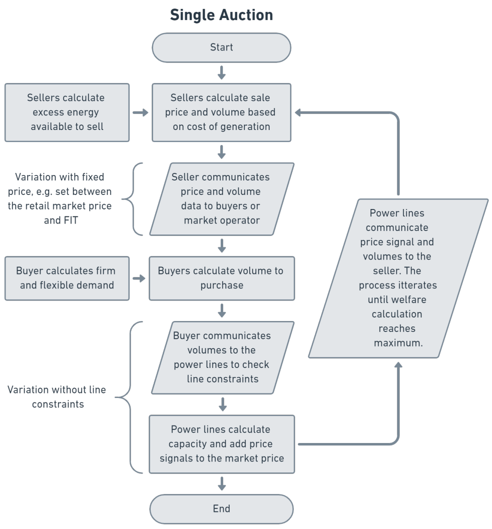
Single auction: In a single auction, only agents on one side of the market communicate messages. This market institution is more common in settings where one side of the market is a single agent. In procurement auctions, for example, a single buyer solicits offers from suppliers.

The single auctions used in the reviewed papers (15 percent) generally involve consumers submitting bids which are then cleared by a market operator. The market operator can also play the role of aggregator, local energy operator and even DSO. Possible examples include consumers in a community bidding to acquire units of excess renewable energy available at a given time (an ascending, one-side auction, with varying supply) (e.g., [82]), to demand response units bidding to offer flexibility or energy reduction services at a particular time (which is a reverse auction, up to the limit required by the system operator) (e.g., [121]). Figure 9a shows a flowchart for a typical single auction price formation mechanism.

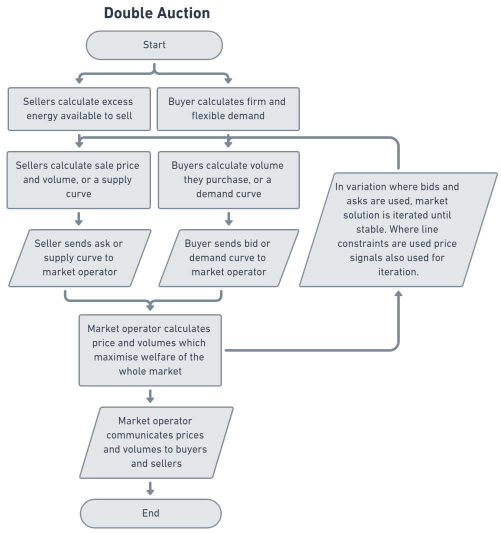
Double auction: The double auction is a common market institution in transactive and P2P energy systems. It has been used and tested both theoretically and empirically since the original GridWise Olympic Peninsula transactive energy project [169]. The double auction is the largest and probably the most well understood category of price formation mechanisms in the reviewed papers, being widely used in both wholesale energy markets and financial markets. While the double auction has many forms, its defining feature is the ability of both buyers and sellers to send messages – buyer bids communicating willingness to pay that reflect underlying utility and preferences, and seller asks communicating willingness to accept that reflect underlying costs. When the double auction is repeated (as is usually the case in electricity market applications), the double auction yields highly efficient outcomes through an information-rich environment that enables considerable learning among market agents [170]. Figure 9b shows a flowchart for a typical double auction price formation mechanism.

Smith [171] drew attention to the efficiency properties of the double auction by subjecting the double auction institution to the first controlled laboratory experiments in economics, and later theorized that these efficiency properties arise from the double auction's ability to satisfy what he called the Hayek Hypothesis: "Strict privacy together with the trading rules of a market institution [a repeated double auction] suffice to produce competitive outcomes at or near 100% efficiency" [172]. By communicating bid and ask information widely to agents participating in the market, the double auction creates an information-rich environment that facilitates learning as the market is repeated, and enables adaptability and flexibility in the face of unknown and changing conditions. These features are well-suited to the physical constraints of electric systems.

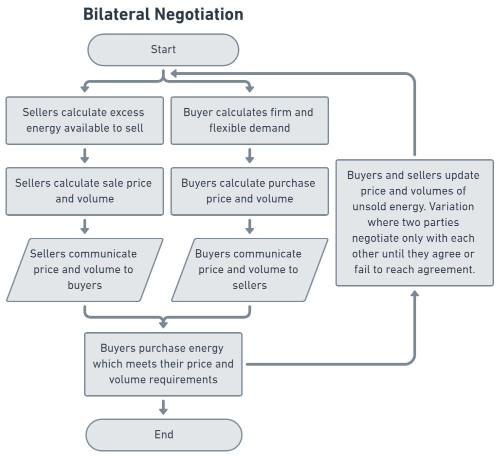
25 percent of the 139 papers reviewed used some form of a double auction, with demand bids from consumers and supply asks or offers from generators/other prosumers. The institutions used in the literature include several subcategories, with the two most common being a double clock auction and a continuous double auction. A double clock auction is cleared at specific time points or regular intervals, usually in real time but also for day-ahead forward markets (e.g., [89], [157]). In a continuous double auction the market is cleared continuously, such as in stock markets that use



(a) Single auction



(b) Double auction



(c) Bilateral trading

Figure 9: Price formation mechanism flowcharts.

order books to keep track of standing bids and offers (e.g., [135], [42]).

System-determined mechanisms: Market institutions and price formation vary by industry and context. The requirement for real-time physical coordination and balance in electric systems has led to price formation in some projects that relies on system-determined mechanisms (23 percent of papers reviewed). This category encompasses all mechanisms that do not rely on market bids and offers, and are instead set by a platform operator, based on a pre-agreed or pre-set mechanism or formula. The "system operator" setting the prices is broadly defined and varies from paper to paper - it could potentially be the community energy aggregator, local retailer, or DSO. Common types of mechanisms mentioned include:

- Uniform or fixed prices, up to a limit or per unit
- Pricing such as fixed FiTs on the generation side, or TOU (time-of-use) prices on the demand side
- Mechanisms where the price set for local renewable energy is set at some fixed ratio (e.g. mid-point or average between peak import and export prices)

- Mechanisms that use a function of demand or some other signal (e.g. quadratic on demand)
- Mechanism where the community aggregator uses an established technique from cooperative game theory (e.g. Shapley value) to redistribute benefits in the local transactive energy scheme participants

Negotiation-based mechanisms: The auction institutions described above typically involve a centralized market platform in which buyers and sellers participate. A more decentralized approach that resembles bilateral search uses negotiation-based mechanisms. Negotiation in automating P2P micro-energy transactions is often automated with specialized, AI-enabled software, such as negotiating autonomous agents. Unlike auctions (single and double), which are a more structured method of price formation, negotiation prices depend on the local one-one (or sometimes one-many) offers being made and accepted. However, they have the potential to allow truly decentralized P2P energy transactions. 11 percent of the papers reviewed used a form of negotiation-based price formation. Figure 9c shows a flow chart for a typical bilateral negotiation price formation mechanism.

Equilibrium-based mechanisms: Equilibrium-based mechanisms include those mechanisms where price is formed based on bids/offers from the agents (usually prosumers, but could also be suppliers, flexibility providers etc.), but price is formed as a derived equilibrium of the interaction, using a game-theoretic solution concept to construct the equilibrium. Several papers explore how an iterated exchange of bids results in convergence to a price equilibrium. The game-theoretic equilibrium concepts employed include Nash equilibrium (most frequent), but also Cournot, Stackelberg, or other competitive market equilibria. 8 percent of the papers reviewed used a form of equilibrium-based price formation.

Not specified or not explicitly mentioned: A sizeable number of the reviewed papers (18 percent) do not include a description of how the price is formed, mostly because price is probably not a key element of the paper. Several papers are completely unrelated to prices (are about forecasting, low-level control etc.) Another insightful reason is that several P2P and transactive energy exchange mechanisms (especially in the context of a local communities) are "relationship based", not price based. For example, in some local community energy projects, exchanging excess energy is done on a reciprocal basis, not on price, or the excess is redistributed by a local aggregator or operator based on some fairness criteria, not monetary payment.

3.5.3. Data sharing and user preferences

In order to persuade end-users to actively engage and participate in distributed market models, the markets should treat participants fairly and provide them with means for informed decision-making. Therefore, one crucial aspect of the markets is the data/information shared amongst participants.

In cases when the trade is between one or two large buyers (e.g., grid operators [88], aggregators [77]) and many smaller sellers (e.g., prosumers, consumers), the buyers usually share the information about the volume of commodity they are after and potentially price information. Based on this information, the sellers then can form their bids and participate in the market. The sellers' bids usually contain at least information about the volume of commodity available for the announced price [72, 74], the price for which the requested commodity can be provided [49] or both [67, 68, 89, 109, 111]. This is the usual data flow in TE markets, where aggregators sit between prosumers and the central market operator, whose role in many cases is played by the DSOs themselves [77, 88].

As the end-users are considered to be the main market participant in these market models, it is worth focusing on the data/information shared by them. The main data items shared by prosumers are listed in Table 10 and the main observations are summarised below.

For each of the market model types electricity price and volume information for a specific trading period are the main data items that are shared by prosumers either with the other prosumers [46, 59, 98, 101, 144, 156, 157] if the market is fully decentralised or with a central market operators [9, 35, 52, 68, 78, 89, 111, 132, 161] that clears the market. Therefore, the vast majority of market models use only these two data items to determine the market output. Demand/supply curves are the main data items shared by prosumers in market models where the bidding takes place for several trading periods [28, 38, 71, 76, 106, 153], for example in day-ahead market models.

Table 10: Data shared by prosumers.

Data type	Recipient	Market model type & References			
		P2P	TE	CSC	Combined
Price	Prosmer	[148]	[54]	-	-
	Central market operator	[36]	[49]	-	-
Volume	Prosumer	[33, 45, 57, 86, 94, 119, 125]	-	-	-
	Consumer	[69, 142, 158]	-	-	-
	Retailer	-	[72, 74]	-	-
Price & Volume	Prosumer	[31, 37, 40, 42, 43, 46, 59, 60, 70, 83, 92, 126, 129, 131, 135, 138, 139, 143, 144, 156, 157]	[64, 97, 98, 101, 115, 147, 152]	[26]	-
	Central market operator	[9, 32, 35, 37, 58, 78, 85, 102, 132, 137, 138, 155, 157, 160]	[52, 63, 65, 67, 68, 75, 79, 82, 89, 104, 109, 111, 112, 136, 161]	-	[29, 30, 117]
Demand & Supply curve	Prosumer	[38, 48, 91, 130]	-	-	-
	Central market operator	[34, 44, 47, 55, 90, 93, 102, 106, 121, 140, 150, 154]	[50, 62, 71, 73, 76, 77, 80, 81, 87, 88, 95, 99, 100, 103, 107, 113, 114, 134, 146, 153]	[24]	[28]
Controlable loads	Prosumer	[149]	[96]	-	-
Flexibility available	Central market operator	[106, 140, 150]	[76, 88, 100]	-	-
Battery SoC	Central market operator	[47, 93, 150]	-	-	-
Distribution line distance	Central market operator	[34]	[111]	-	-
Discomfort level	Central market operator	-	[73]	-	-
Eagerness factor	Central market operator	[37, 121]	-	-	-
Willingness to pay/accept	Prosumer	[41]	-	-	-

In few market models, prosumers share either only electricity price [36, 49, 54, 148] or volume [33, 69, 74, 86, 119, 125] information. This is due to the fact that the market models have buyers (e.g. grid operator in TE models or prosumers in P2P models) who announce only price or volume information, hence the prosumers who sell only need to submit volume or price information. These types of market models offer limited flexibility as prosumers could express their trading preferences only in one parameter – price or volume.

The vast majority of the models use only users' price information as a main factor when clearing the market. Only few market models support more detailed/concrete user preferences to be included in user bids/offers [34, 37, 41, 73, 111, 121]. Very few market models allow users to express their trading preferences in their bids using parameters such as comfort level [73], eagerness factor [37, 121] or willingness to pay [41]. These market models are mainly from the P2P type, which strengthens the argument that as P2P market models focus more on individual transactions between peers, they support more options for individuals to express their trading needs and preferences. Apart from price/volume and supply/demand curve information, TE and CSC market models do not support options for more personalised information sharing. This further supports the argument that the TE and CSC market models focus more on providing services to the grid and community respectively, rather than favouring individual transactions between peers. A few market models also allow users to include parameters that indicate a level of flexibility being available at the user-end. These parameters include the presence of controllable loads [96, 149], available flexibility [76, 88, 100, 106, 140, 150] and the state-of-charge of batteries/storage devices [47, 93, 150] owned by prosumers. Very few market models use any type of grid information when clearing the market. For example, only a couple of market models consider the physical distance (e.g., in terms of length of distribution lines [34, 111]) between the trading prosumers. Most of the market models focus on collecting information/data that would satisfy the needs of the market, hence neglecting the more personalised trading preferences users might have.

In order to support more personalised trading amongst prosumers, market models would need to support means by which users can select their preferred trading peers. Current market models support only the price information as an indicator when prosumers choose their trading peer. Hence, they assume that financial benefits (increased revenues and reduces costs) would be the main driving force for participating in these markets.

Unfortunately, none of the market models support information/data share that would allow prosumers to indicate their preferred prosumers to be matched with. For example, some prosumers might prefer to trade with specific prosumers (relatives/friends/colleagues), or might prefer to buy electricity produced by specific type of resource (e.g. only green energy or only energy produced by PVs). The analysed markets models do not differentiate between prosumers who sell only green energy and the ones who sell electricity from energy storage devices (which might have been recharged with electricity from the main grid, e.g., electricity generated at fossil-based thermal stations).

3.5.4. Settlement period & gate closure

The settlement period of an electricity market is the period of time over which a market participant must balance their supply and demand of energy. Gate closure is the length of time before the settlement period when the wholesale market closes. Together, the settlement period and gate closure length determine how far in advance a market participant must predict their supply and demand for energy, and over what period they must make that prediction. In traditional electricity markets settlement periods are typically around 30 minutes [167], but can be as short as 5 minutes [173]. Gate closure is around one hour prior to the start of the settlement period [167].

The papers included in the review had settlement periods ranging from 15 seconds to 1 day. Gate closure ranged from zero, i.e. a real time market, to one day. For very short settlement periods there is a strong correlation between the settlement period length and gate closure. Only one paper [44] had a settlement period of less than one minute (15 seconds) and that was also the only paper to model a gate closure of less than one minute (20 seconds).

As the settlement period increases there is less correlation between settlement period and gate closure. The two papers which model three minute settlement periods both use one hour gate closures [132, 152]. The gate closure of papers modelling a five minute settlement period ranges from five minutes [51, 130] to one day, e.g. [26, 106, 108, 142, 149]. As the settlement period grows longer, there is less use of short gate closures. At a settlement period of 15 minutes, the smallest gate closure is 15 minutes [70, 144], and they go up to one day [73, 127, 135, 140]. This trend continues with 30 minute [61] and one hour [43, 97] settlement periods, where the shortest gate closure is the same as the length of the settlement period, and the longest is one day [93, 106, 131, 147].

3.5.5. Risk in the market

While dealing with various forms of risks will be one of the biggest challenges of distributed energy markets in the future, only very few papers have considered it in their market designs. Risk this context mainly can be broadly defined as internal or external impact factors that can negatively influence the overall performance of a market.

Papers that identified or considered different types of risks in their market models were only associated with P2P and TE markets. Some market models have considered the risk of arbitrage by keeping the information shared to a minimum [56] or proposing a two-sided settlement mechanism using the least favourable price as the market clearing price [62]. Liu et al. [147] has simulated data manipulation and malicious behaviour by withholding energy trading quantities to manipulate market prices.

Another risk category considered was the impact of sudden price fluctuations [38] or making use of price caps to avoid negative or unexpected outcomes to to price [125]. Risks of the physical component of markets have also been considered in the form of disconnecting a market place from the main grid and operating in island mode in the case of system failures [30]. Another commonly considered risk is the uncertainty of load and generation and their implications for the market performance [115, 136]. Security of the IT systems transactions are performed on have only been considered in a few cases [143].

Risks identified in the reviewed literature are mainly of financial and operational nature. As most of the market models proposed make use of modelling and simulation to test their designs, they are limited in their ability to consider differed types of risks. However, with the uptake of such markets in real-world environments, the identification and consideration of these risks will be inescapable. Early recognition and the developed of appropriate market tools to respond to such risks will be a decisive factor on the success and adoption of LEM models. Although not all risks can be assessed in a simulated environment, more research is required to address those that can and raise awareness to those that cannot be simulated.

4. Research gaps and future research directions

The results in the previous sections have highlighted the key differences and similarities between P2P, TE and CSC markets, showing how the concepts are currently addressed and described in the literature. The analysis has also shown that there are substantial gaps in the current academic literature that need to be addressed for P2P, TE and CSC markets to operate at scale. The following section highlights five key research gaps that require further analysis in the future.

4.1. Physical constraints

Unfortunately, only few of the analysed market models incorporate a comprehensive market mechanisms that take into account grid constraints [62, 108, 112, 134]. Most market models focus either simply on the virtual market layer where transactions among market participants are agreed or rely on a single type of grid constraint such as congestion [80]. Further research is needed to design market mechanisms that can incorporate various grid constraints. This could be achieved by grid operators feeding the market with various parameters which would indicate the grid status on various critical points. The market model then would have to have mechanisms in place to translate these parameters to concrete desired actions with regards to the physical grid (e.g. reduce/increase supply at specific grid access point). Once this is in place, the market clearance phase then could take this into account when performing the matching between market participants. Transactions that would further violate the grid constraints could be vetoed while the ones that would have positive effect on the grid could be prioritised. Bundling the grid constraints with pricing mechanisms and user preferences would potentially result in more complete market models that apart from the virtual market layer take into account also the physical infrastructure as well as user preferences.

4.2. Lack of holistic approach for the market operation

Although there is rich literature on different P2P, CSC, TE or combined market models, existing solutions focus mainly on one phase of these models – the market clearance phase, including bid/offer submission, market price determination and market participants matching/transaction selection. Other crucial phases, such as bid/offer creation incorporating user preferences, strategic bidding, billing/settlements and dispute resolution [174], have been largely neglected.

The bid/offer creation phase should be able to capture (i) the diverse available resources of the users (e.g., PVs, storage, EVs, HVAC), (ii) the predicted user demand/supply, (iii) users' preferences in terms of level of comfort and available flexibility (e.g. deviations in battery levels, room temperature), and (iv) users' preferences in terms of market participation (e.g. favour community instead of profit, trade with preferred peers). Existing approaches either take into account only user resources and completely ignore user preferences or consider only the user preferences in terms of their comfort level within their household [25, 121]. What most solutions fail to consider is the diverse preferences of users with regards the market participation. The overwhelming assumption is that users will be profit driven, hence their market participation will seek profit maximisation or cost reduction. However, not all users are profit driven. Some of them value community welfare or environmental benefits more than simply financial benefits [175, 176]. Most of the current market models fail to capture such user preferences. More research is needed in the bid/offer creation phases such that the bids are able to capture various user preferences and those preferences are taken into account when the market is cleared. Note that relevant work on user preferences was not included in our literature review as these were published at other that our selected venues e.g. conferences [175, 177] or social science-oriented venues [178]. Nevertheless, what is still not addressed is how the findings of such related work could be integrated into the technical market design models.

Strategic bidding is another phase that has seen little attention. User bids/offers can be devised based on the available resources and user preferences, however determining when would be the best time, what would be the best volume to be offered and for what price would need external information about the market and possibly information about the other users intentions. As shown in Table 10, only limited information is shared between market participants, mainly focusing on the price and volume of electricity requested/offered. In other words, the bidding strategies would also need to incorporate various market/grid/user prediction models which would help users to devise strategies maximising the chances of their preferences to be fulfilled.

Billing and settlements is the phase proceeding market clearance. Once the transaction details such as trading prices, volumes and trading users have been set, the next phase would be to sort out the payments amongst the market participants. In contrast to the retail market, where users simply have contractual obligations with only one entity – their supplier, in P2P/CSC/TE market models, users could potentially trade with every other market participant. In theory, every single user could be trading with a different user at every trading period. If one assumes half-hourly trading periods, this leads to over 1400 monthly trading periods, hence potentially each user completing transactions with 1400+ users per billing cycle – a month. It is yet to be investigated how dealing with so many transactions per user would be best resolved. Would users be left to deal with such high number of transactions, would these transactions be handled by a third-party for them, and if yes, which market participant would take this role? It is likely that the following two options would be predominant: (1) a central market operator (e.g. trading platform) handles all user transactions automatically (as in [179]) or (2) users handle them themselves with the help of distributed ledger technologies (as in [143]). Both options of course come with additional costs that would need to be born by the users. It is yet to be seen how these additional costs will be integrated within the market models (monthly fees or charges per service) and what effect they would have on the market participants.

In addition, most market models have the market clearing phase before the actual trading period. In other words, volumes to be traded, prices and transaction parties are determined in advance. Market models assume that the volumes agreed in advance will be delivered during the trading period. However, in practice, this might not be possible. Bids/offers are devised based on predictions, and those predictions are not always accurate. The question "What happens when a user could not deliver the volume agreed" arise. Would unfulfilled commitments be settled on the retail and FIT prices or would be there any punishment/reward mechanism in place? Such mechanisms would have to be linked to the billing and settlement phase as well as use data from the market clearance phase (volumes agreed) and smart meters (volumes delivered). It would be interesting to investigate these options and devise billing and settlement algorithms that fit best the proposed P2P/CSC/TE market models.

Another important phase which has been largely ignored by the literature is dispute resolution. In any market model that involves transactions between market participants there must be mechanisms in place to deal with any disagreements between the market participants. As mentioned above, delivering the promised volume of electricity at the agreed trading period might not always be possible. This might result in disputes among the participants about who unfulfilled their commitments by how much and who should cover the difference. Therefore, proposed market models should be accompanied with dispute resolution mechanisms that are user-friendly.

4.3. Scalability and replicability

Most market designs evaluated as part of this analysis are subject to predefined market conditions with regards to the type and number of participants. Few studies have tested their market proposal on increasing numbers of participation [42, 86, 88, 95, 98, 102, 140, 143]. The majority of market designs proposed operate within fixed environments and set boundary conditions such as the type of stakeholders involved or the governance models applied. However, to enable successful uptake of P2P, TE and CSC in the future, market designs need to be able to respond to the dynamic nature of real-life applications. Both, changing parameters from within the market as well as changing environmental conditions will impact the performance of a market.

To meet the challenges and requirements of real-life LEMs, market designs need to satisfy two key criteria, namely market scalability and replicabiltiy. As our analysis has shown, we have to differentiate between two types of scalability. Firstly, markets need to be able to react to increasing numbers of participants. Section 3.5.1 has shown that most market designs and settlement mechanisms have been tested using low numbers of participation to provide an initial proof of concept.

More research is required into the performance of markets with high number of participation as well as changing market participation over time. Section 3.4 highlighted the scale at which markets can operate. Given the constantly changing energy market requirements, further analysis into the different operation scales is needed to understand the full extend and impact of LEMs. It is crucial to comprehend how markets will behave when growing building scale to community scale. While scalability has been identified as a reoccurring theme in the papers analysed, it is mostly referring to the computational complexity of a market [28, 73, 97, 145, 156]. Specifically this means that by either increasing the number of participants or number of transactions the optimisation problem's solving time and computational resources needed lie within an acceptable range. Multiple papers have recognised scalability as a key area that still needs to be addressed in future research [91, 100].

On the other side, the concept of replicability has been barely touched upon in the papers analysed. Replicability too, can be assessed from two perspectives. Firstly, a particular market design could be replicated in a different contexts and locations, being exposed to changed internal and external parameters, such as the type of participants, assets or requirement and typology of a different electricity grid. Secondly, replicability does also refer to different regulatory context a market design needs to be able to operate in. This is especially the case when replicating a pilot project in a different region or country with divergent policy and regulatory landscapes or or norms and values.

While market scalability can be tested in a simulated environment (still subject to some limitations) replicability of market designs will require a mixture of quantitative and qualitative assessment methods. Integrating the concept of LEM models in energy regulation can contribute to better replicability assessments by defining clear boundary conditions in which the market can operate. Both scalability and replicability of market designs play a defining role in the future success of local energy markets. Those markets designs with the greatest replicability and scalability potential will dominate the LEM landscape.

4.4. Information security

The P2P/TE/CSC market models rely on vast volumes of data to meet their goals. These data are either exchanged directly among the market participants in fully decentralised models or indirectly via central market operators in centralised models. Furthermore, the sources of these data could range from small sensors on distribution lines and prosumer side (e.g. remote terminal units, smart meters, HEMSs) to large equipment (e.g. substations) and other market participants (e.g. suppliers, DSOs, aggregators, etc.). As the market outcome heavily depends on these data, the reliability, authenticity and thrust-worthiness of these data are of paramount importance [180].

Unfortunately, despite being 'disconnected' from the public networks, critical energy sector assets have already been successfully hacked by criminals, the cyber-attacks on the Ukrainian power grid causing blackout to millions of people in 2015 [181]. Considering that P2P/TE/CSC market models would make prosumers active participants in the energy sector, this would increase considerably the attack surface exploitable by criminals. Hence, it is likely that these models, if implemented in practice, would be seen as attractive targets of cyber-attacks. Since some of these market models base their decisions on (real-time) data about the current grid status, aiming to avoid any grid instability, such data could easily be targeted by malicious players (such as terrorists or hostile foreign states) as a way to cause blackouts and disrupt the critical infrastructure of a nation.

Moreover, as highlighted in Section 3.5.5, the outcome of the market operation has direct implication on the (financial) value distribution among market players, hence, there is also a high motivation for market participants to attempt to manipulate the market output for their own benefits [182]. For example, malicious prosumers might try to manipulate other prosumers' bids/offers in order to maximise the chances of their own bids being selected.

In order to protect against these types of attacks, the following security requirements, among others, must be satisfied: entity authentication, data authenticity and non-repudiation (accountability) [182]. Unfortunately, the analysed market models seem to ignore or neglect the importance of ensuring the secure operation of these markets. As some of the data used by the market could come from sensors with limited storage and processing capabilities, off-the-shelf authentication and integrity protection mechanisms might not be directly applicable [180]. A further research is needed to investigate the applicability of light-weight authentication mechanisms to P2P/TE/CSC market models.

4.5. Prosumer privacy

As mentioned above, P2P/TE/CSC models process vast amounts of data collected by various market participants. As discussed in Section 3.5.3, one of these participants, and probably most crucial in terms of data provision, are the prosumers. They send their bids/offers either directly to other prosumers in a peer-to-peer fashion or to central market operators. These bids can contain various types of data, including but not limited to: prosumer identity, volume of electricity, price information, user preferences, etc. (see Table 10). As consumers usually bid for volumes that are needed to meet their demand, the volumes information in their bids are closely correlated with their household's load profile. Such fine-grained load profiles are already known to be reveal a lot of sensitive information about the activities in the household, hence they are classed as personal data [183]. Therefore, as volumes in the consumers' bids can leak information about their load profiles, this information is also considered personal information. Moreover, price information could also leak information about the well-being and financial situation of prosumers. High asking price for a large volume of electricity could indicate that the household is not in a rush to sell the electricity, revealing the presence of large (expensive) batteries or devices that consume a lot – an indication for the financial status of the household's occupants. Furthermore, user preferences such as preferred trading peers and source of electricity could reveal information about the social contacts of prosumers and their environmental beliefs respectively. In summary, user bids (specifically the information they contain) are personal data and need special protection as the General Data Protection Regulation (GDPR) [184] requires data processors (entities that collect and process data – prosumers and central market operator in this case) to follow the data minimsation approach, which is to collect and process as little personal data as possible.

Unfortunately, most of the proposed market models do not take prosumer privacy into account. One should fully trust the market operators to not misuse their data. For example, central market operators usually have full access to prosumers bids in order to clear the market and compute the market output. To eliminate the need to trust them, the question which arises here is "Can the market operators perform the market operations without learning prosumers' bids?". Fortunately, advanced cryptographic primitives could help in this regard as some of them can support operations (including addition, multiplication, sorting, comparison, etc.) on encrypted data. For example, market operators could clear the market without even seeing individual prosumers' information. Such techniques have already been applied to P2P markets that use relatively simple operations such as double auction [185, 186] and aggregation [187–189]. However, as the computational requirements for the application of these techniques increase exponentially with the increase of the complexity of the market's optimisation model as well as with the increase of the number of market participants, they are not yet fully deployable in real P2P/TE/CSC market models that could use complex clearing mechanisms and serve thousands of prosumers. Further research is needed to bring these powerful cryptographic techniques in practice.

5. Conclusion

LEMs have seen increased interest in the academic literature as they are regarded an appropriate tool to respond to some of the challenges energy markets are currently facing. They can incentivise the integration and uptake of renewable energy which is urgently needed to meet global carbon reduction targets. Some of the most commonly referred to concepts that fall within the category of LEMs are P2P, TE and CSC markets. This structured literature review aimed to provide insights into the current state-of-the-art of these models from a markets and transactions perspective highlighting some of the differences and similarities between these models to respond to the lack of consensus amongst the academic community and provide insights into current research gaps.

To analyse the current academic literature in a structured manner we adapted the TEAM framework which is used to assess businesses from an ecosystem architecture perspective. A total of 139 peer-reviewed papers have been assessed considering the strategy, technology and value of each proposed market model. The framework was further extended to also gather data with regards to the assumptions made in the market models proposed and the participants involved.

Our analysis focused on highlighting the key defining characteristics of P2P, TE and CSC models. The results show that P2P and CSC market mainly focus on providing a financial incentive to market participants while TE markets have a stronger focus on providing grid-related services. Compared to the first two models, CSC markets are poorly represented in the literature, which could be attributed to its definition in the EU REDII. CSC markets focus on the community and locality aspect of energy markets and follow a rather centralised governance structure (Section 3.1). These different focus areas have been supported by the main market value and participants' needs identified (Section 3.2.1 and 3.2.2). We further evaluated the type of market participants involved and provided an overview of the assets considered in the markets (Section 3.3.1 and 3.3.2). While P2P markets mainly focus on small-scale individual energy users, TE markets have a more diverse involvement of different market participants of different scale. The assessment of the number of market participants involved showed that most market mechanisms modeled are tested with only a small number of participants limiting its replicability for real-life implementation (Section 3.4.1). While both P2P and CSC markets mainly focus on small scale energy users, TE markets have a more diverse scale of operation supporting the main findings that TE markets operate across various scale of the energy system (Section 3.4.2). An assessment of the types of grid models and constraints highlighted that only P2P and TE markets focus on the operation of the grid and the typology of the infrastructure (Section 3.4.3). Finally we have provided an overview of the different modes of market operation. We have identified six archetypal market mechanisms used across all models (Section 3.5.1). The assessment of the price formation mechanisms showed that they are three key archetypal mechanisms used commonly across the literature (Section 3.5.2). Finally we assessed the data shared amongst participants and the user preferences (Section 3.5.3). We provided an overview of the settlement periods and gate closures (Section 3.5.4) used and addressed the main market risks (Section 3.5.5).

We concluded the paper providing an overview of the key research gaps identified which require further analysis in the future. The key areas identified relate to the physical constraints considered and the replicability and scalability of the markets models for the uptake in real-world environments. We further identified a lack of a holistic approach to operate the market, which includes market features such as bid/offer creation, strategic bidding, billing and settlement and dispute resolution. Finally there remain open areas with regards to information security and prosumer privacy of P2P, TE and CSC.

6. Data Availability

The completed data extraction table which formed the basis of the analysis presented in this paper is available at https://doi.org/10.48420/16930768.

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Appendix A. Data Extraction Table Code Book

This study developed a data extraction table which was used to consistently extract data from each paper in the review. The data extraction table is based on *The Business Ecosystem Architecture Modelling* (TEAM) framework [22]. For more details on the data extraction process see section 2.3. Details about how to access the full data extraction table are available in section 6. Table A.11 contains the code book for the data extraction table. The code book contains a list of all data extraction fields, the type of data required and a description of the data required.

	Data Extraction Field	**Data Type**	**Description**
	Research question	Free text	Why was this paper written (i.e. what question is this paper addressing)?
	Future work	Free text	What is noted as still to be researched/addressed as continuation/building on this work?
	Category of definition: P2P or TE or CSC	Choice of: P2P, TE, CSC	Please choose the category which best fits the paper given the definitions.
	Definitions	Free text	How does the paper define the repsective P2P / CSC / TE market? (Please copy/paste the definition verbatim from the text)
Assumptions	Forecast uncertainty	Boolean: yes/no	Does the agent know what his/her supply and demand will be for the trading period (where agent can be household, or a market if trade is between markets, or microgrids, etc.).
	Rationality	Boolean: yes/no	Are the agents expected to be rational (e.g., act in accordance with a utility function, know/calculate precisely what their benefits are, etc.)? Note, models which are based on empirical data may not require agent rationality.
	Perfect information	Boolean: yes/no	Do the agents know and share with each other all information about the market? (e.g, how much energy is generated, traded, who the agents are, etc.)
	Transaction charges	Boolean: yes/no	The financial charges to be paid by the agents to undertake each transactions.
	Supplier of last resort	Boolean: yes/no	Is the market grid-connected and so can the agents fall back to the grid if the supply from peers is short/used up?
	Type of tariffs	Choice: static, dynamic, time of use	Which kind of tariff does the supplier (of last resort) apply to the market? E.g. static, dynamic, time of use, or something else?
	Grid constraints	Boolean: yes/no	Does the model account for grid constraints?
	Power losses	Boolean: yes/no	Does the model account for power losses?
	Type of grid model	Free text	Does the model use a specific model of grid, e.g. IEEE-33 bus grid?
	Origin of data	Free text	Where does load and generation data come from?
Market Participants	Pure generators	Boolean: yes/no	Does the modelled market include entities which only generate energy?

	Pure consumers	Boolean: yes/no	Does the modelled market include entities which only consume energy?
	Prosumers	Boolean: yes/no	Does the modelled market include entities which consume and generate energy?
	Aggregator	Boolean: yes/no	Does the modelled market include an entity which acts on behalf of a group of smaller market participants?
	Retailer	Boolean: yes/no	Does the modelled market include an entity which connects to another large market?
	Central market operator	Boolean: yes/no	Does the modelled market include a single agent which runs either the market or the platform, e.g. this could be an entity which is only a market operator, it could be a function carried out by an aggregator or DSO, or it could be a transaction server. However it does not include many entities sharing this task in a decentralised manner.
	Grid operator	Boolean: yes/no	Does the modelled market include a grid operator that interacts with the market?
Strategic Layer	Customers	Free text	Agents being supplied with one of the commodities through the market.
	Internal competitors	Free text	Agents who participate in the market for one of the commodities being traded and engage in competitive behaviour.
	External competitors	Free text	Agents outside the market competing with the market for one of the commodities being traded in the market.
	Enablers	Free text	Entities who do not directly participate in the market but supply essential products or services to make the market work, e.g. blockchain miner, or ICT provider.
	Rule makers, associations	Free text	Entities who do not directly participate in the market but set market rules or constraints (e.g. thermal constraints).
	Core needs	Free text	Need in terms of main trade purpose.
	Secondary needs	Free text	Need in terms of (optional) secondary trade purpose.
	Commodity / attribute being traded	Free text	Commodity or attribute traded in the market (e.g. electricity, flexibility, reactive power, active power, renewable energy, battery capacity, etc.)
	Price formation mechanism	Free text	The system by which market prices are determined, e.g. single auction, double auction, merit ordering.
	Time scale	Free text	The time between the market being cleared and the product being delivered, e.g. 1 day, 1 hour, 15 minute.
	Settlement period	Free text	The duration of time over which the energy can be delivered.
	Test duration	Free text	The length of the experiment or simulation.
	Market size	Free text	The number nodes in the market.
	Controllable assets	Free text	Any equipment, generation, demand or storage, which can be controlled. e.g. batteries, appliances which can participate in demand response, CHP plants.
	Non-controllable assets	Free text	Any equipment, generation or demand, which cannot be controlled. e.g. solar panels, non-controllable loads.

	Coordination paradigms	Choice: individual optimisation, central optimisation, multiple optimisation	If there is a market optimisation taking place, does it take place on the individual agent level or is the market optimised centrally for the whole community?
	Strategic behaviour	Boolean: yes/no	Do agents adjust their strategy based on speculation or the expected behaviour of other agents?
	Switching costs	Boolean: not specified/specified	What costs are incurred by agents who want to switch into or out of the market?
	Value transfers	Free text	Movement of the commodity that has been purchased in the market.
Value Layer	Commercial transactions	Free text	All financial flows, including payments to e.g. blockchain miners, network operators, aggregators. Describe the flow of money between parties.
	Transaction dependencies	Free text	Which financial / commercial factors affect contract creation and which factors might prevent a contract being fulfilled. To whom do they apply and how?
	Settlement	Free text	How are different energy contracts settled.
	Fraud	Boolean: yes/no	Do market participants act against the market rules?
	Other market risks	Boolean: yes/no	Are there any other factors which might adversely affect the market, e.g. data loss, hardware failure, etc?
	Specific the other market risk	Free text	Describe the other market risk.
	Distribution of benefits, costs or risks	Free text	Any information in the paper about how benefits, costs or risks arising from the respective market participation/operation are distributed between participants.
Technology Layer	Semantics	Free text	What information is shared?
	Ontologies	Free text	Who is that information shared with?
	Privacy	Free text	Do agents specify any privacy preferences with regard to data sharing?
	Choreography	Free text	The order in which market functions occur.
	Physical dependencies	Free text	Are there any physical market constraints, e.g. thermal line limits, state of charge of batteries? To whom do they apply and how?
	Rating	Choice: 1, 2, 3	A subjective opinion on how important the paper is. 1 = very relevant, 2 = not too relevant, 3 = not relevant at all.
	Country link	Free text	Is the paper about a specific country?
	Notes	Free text	Is there any additional information about the market which has not been recorded so far?

Table A.11: Data extraction table code book