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

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Abstract

Peer-to-peer, community or collective self-consumption, and transactive energy markets offer new models for trading energy locally. Over the past five years, there has been significant growth in the amount of academic literature examining how these local energy markets might function. This systematic literature review of 139 peer-reviewed journal articles examines the market designs used in these energy trading models. A modified version of the Business Ecosystem Architecture Modelling framework is used to extract market model information from the literature, and to identify differences and similarities between the models. This paper examines how peer-to-peer, community self-consumption and transactive energy markets are described in current literature. It explores the similarities and differences between these markets in terms of participation, governance structure, topology, and design. This paper systematises peer-to-peer, community self-consumption and transactive energy market designs, identifying six archetypes. Finally, it identifies five evidence gaps which require future research before these markets could be widely adopted. These evidence gaps are the lack of: consideration of physical constraints; a holistic approach to market design and operation; consideration about how these market designs will scale; consideration of information security; and, consideration of market participant privacy.

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Nomenclature

CSC	Community or collective self-consumption
DER	Distributed energy resource
DSO	Distribution system operator
EV	Electric vehicle
LEM	Local energy market
P2P	Peer-to-peer
PV	Photovoltaic
TE	Transactive energy
TEAM	The Business Ecosystem Architecture Modelling framework

1. Introduction

Fundamental changes are transforming energy markets globally. Distributed energy resources (DERs), such as photovoltaic (PV) and wind generators, and storage devices are being installed at ever increasing rates [1]. DERs can help to reduce emissions and meet the carbon reduction targets many countries have committed to under the Paris Agreement [2]. However, the intermittent nature of most renewable energy sources creates challenges for network and system operators. Keeping energy supply and demand in balance poses a greater challenge with lower proportions of dispatchable generation. Simultaneously, demand is likely to increase due to the electrification of heating and transportation [3]. Existing energy markets are limited in their ability to respond to these new challenges [4]. To avoid high grid reinforcement costs, and to respond to the changes in load behaviour and volume, new market and balancing mechanisms are needed.

Local energy markets (LEMs) have emerged as a leading approach to foster the integration of more DERs into the electricity system [4]. The purpose of LEMs is to incentivise small energy consumers, producers and prosumers to exchange energy with one another in a competitive market, and to balance energy supply and demand locally [5]. In this literature review, we provide a systematisation of knowledge of the market design and transaction aspects of LEMs. We aim to help researchers in this area understand the types of LEMs being researched and the nuances of the different market types.

Three distinct types of LEM have emerged. Firstly, peer-to-peer (P2P) markets allow direct trading of energy without an intermediary. They aim to provide energy users with an incentive to actively engage in energy markets [6]. Secondly, community or collective self-consumption (CSC) is when co-located energy prosumers trade their surplus energy in a market arrangement [7–9]. The term CSC originates from a regulatory context that focuses on the empowerment of energy users [7]. Its definition is a collection of the participants' activities, rather than the organisational market structure [8]. Finally, transactive energy (TE) markets balance supply and demand in electricity systems via decentralised coordination [10]. The aim of TE markets is to manage decentralised resources in an autonomous way using price signals to provide system stability [11]. While the three market types share common features, they have distinct characteristics in terms of size, operational scale and the main trading purpose. In the current literature, these LEM types are used interchangeably, with a lack of consensus on their meaning and the differences between the market types.

Several recent review articles analyse LEMs. Khorasany et al. [12] review market designs for local energy trading, focusing on scalability, overheads, and how they address grid constraints. Tushar et al. [13] review P2P electricity trading techniques, providing an overview of their key features and the benefits they bring to the grid and prosumers. Their focus is on market clearing mechanisms. Similarly, Jin et al. [14] classify and organise the literature on market designs and clearing methods, with a focus on local flexibility markets. Tsaousoglou et al. [15] review LEMs focusing on four key attributes of the market: scope, modelling assumptions, objectives, and mechanisms. Sousa et al. [16] review consumer-centric electricity markets, integrating the behaviour of all market participants, not only prosumers. Zhou et al. [17] review P2P market designs, as well as trading platforms, physical and ICT infrastructure, social science perspectives and policy implications. Soto et al. [18] analyse trading platforms, blockchain, game theory, simulations, optimisation methods and algorithms used in P2P markets. Aggarwal et al. [19] focus on optimisation models used in P2P markets, providing a comprehensive taxonomy. Andoni et al. [20] provide a systematic review of how blockchain technology is used in the energy sector. Similarly, Siano et al. [21] explore the application of distributed ledger technology in TE markets, experimenting with different consensus mechanisms. Kirli et al. [22] review the application of smart contracts in energy systems.

These review articles make a valuable contribution to the current state-of-the-art. However, the systematisation of knowledge of the market design and transaction aspects of LEMs presented in this paper gives an insight into the different applications of these markets. It outlines the underlying operating conditions needed for these markets to function successfully. By identifying the key evidence gaps in the field of LEMs, we help researchers direct their efforts to provide the evidence policy makers, regulators and companies will need to design and adopt these markets. The terms P2P, CSC and TE are ill-defined. The results in this paper are broken down by each of the three market types to reveal overlaps and differences between them. This systematic literature review makes four important contributions:

(1) It examines the types of markets described as either P2P, CSC or TE in the academic literature. This review analyses the similarities, differences and overlaps between these three types of market.

(2) It develops six archetypal market designs based on the market types found in the literature, which are presented alongside the main price formation mechanisms used.

(3) It presents detailed information about the value proposition, the size of participants, scale and operating conditions of the markets, broken down by the market type.

(4) It details five significant evidence gaps found in the literature. These are the lack of: consideration of physical constraints; a holistic approach to market design and operation; consideration about how these market designs will scale; consideration of information security; and, consideration of participant privacy.

The remainder of this paper is structured as follows. Section 2 presents the methodology used for the systematic literature review, including the literature search, decision on paper inclusion/exclusion, data extraction and analysis. Section 3 presents the results of the analysis and a discussion of the results. Section 4 details the research gaps found during the review. Finally, Section 5 provides concluding remarks. Appendix A contains additional supporting results data. Appendix B contains the code book for the data extraction table used in this analysis.

2. Methodology

This literature review followed a systematic process for paper selection and data extraction. This section details the process used to search for relevant literature, make decisions on which literature to include in, or exclude from the review, and to 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 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 paper 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 the removal of 454 duplicate search results.

The choice of search term was based on the fact that P2P, CSC and TE are ill-defined terms. By minimising the search terms to variations of P2P, CSC and TE, plus 'electricity', we aimed to find the widest possible range of literature which the authors define as concerning one of these markets. Search terms in Scopus and Web of Science must appear in the results for it to be included. Therefore, adding additional terms would exclude results, rather than widen the search.

The only filter applied to the search results was to limit them to peer-reviewed journal articles. No limits were placed on the year of publication, country of study or other factors.

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 in the full text review.

Inclusion criteria:

- The paper is written in English.
- The paper concerns electricity markets.
- The author defines the subject of the paper as P2P, CSC or TE uses of electricity – there are no universally agreed upon definitions for P2P, CSC or TE; therefore papers were included based on whether the author defined their paper as concerning one of these topics.
- The paper analyses one or more entities which transact, or a market.
- 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 were 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 for data extraction. During the data extraction process a further six papers were removed, leaving a total of 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 [23]. The TEAM framework is designed to analyse a group of businesses that do not have a central coordinator controlling them, but rely on common ICT infrastructure. The businesses in the ecosystem must cooperate on things such as communication protocols, but compete with each other on price. This mixture of cooperation and competition is described as a coopetition game.

This leaderless coopetition game is very analogous to LEMs. There is not necessarily a central coordinator directing the market, 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 that the contracted energy has been supplied and demanded. The market participants also compete with each other in the purchase and sale of energy or other market commodities. The TEAM framework therefore provides a good basis for analysing P2P markets and other LEMs.

The TEAM framework examines three broad aspects of a market: the needs of the customers and participants of the market; the distribution of costs, risks and benefits within the market; and the data sharing requirements within the market. The holistic analysis of the market provided by the TEAM framework looks not just at the main businesses, but also at the rule makers and complimenting businesses in the market. This makes it appropriate for examining energy markets where regulators, wire operators and system operators must be considered alongside the energy traders.

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 author defines the market in the paper as a P2P, CSC or TE market, and how the author defines those terms.
- Additional data about modelling assumptions used in the paper, including 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 ICT and technology requirements.

A complete list of the data extracted for each paper can be found in Appendix B. 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.

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 the 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 identify six archetypal P2P, CSC and TE market designs (Section 3.2). These archetypal market designs are backed up by a more detailed analysis of specific aspects of the markets, including the price formation mechanism (Section 3.3), the market value proposition (Section 3.4), and the market participants and the resources available to them (Section 3.5). This section begins with a summary of the types of papers discovered in the literature search, and a discussion of the defining characteristics of P2P, CSC and TE markets (Section 3.1).

Of the 139 papers included in this analysis, 77 modelled a P2P market, 61 modelled a TE market, but only 6 modelled a CSC market. The very small sample size of CSC markets in the results limits the extent to which conclusions about CSC markets can be drawn. Results for CSC markets are still presented, but caution is required when generalising these. Note that five papers present multiple markets. Therefore, the number of markets modelled is more than the number of papers included in the review.

Only two of the 139 papers in the review are case studies of pilot projects [24, 25]. Of the remaining 137 papers, 135 were mathematical models of markets and 2 were surveys. Although some of the mathematical models used real data, such as from loads, generations (e.g. [26–29]) or grid models (see Section 3.6.3), the mathematical models tend to focus on particular aspects of a market, rather than creating a model which could be directly implemented. This means that not all papers present information on all market elements covered in this analysis. Therefore, some sections of analysis do not include all 139 papers, where some of the papers did not include the information for that particular analysis.

3.1. Defining characteristics of P2P, CSC and TE markets

The terms P2P, CSC and TE are ill-defined and are used to describe a diverse range of markets. This section examines how the terms P2P, CSC and TE are used by categorising the markets in the reviewed literature. This analysis only includes papers that provide a definition of P2P, CSC or TE, or give a statement on the purpose of the market. Of the 139 papers in the review, 70 were included in this analysis. Table 1 presents references for each characteristic of the respective market type.

Only papers in the review concerning P2P markets explicitly discuss the size of the market participants. These range from small participants, e.g. residential energy consumers and prosumers [25, 28, 30, 31], to larger ones such as buildings and microgrids [32, 33]. Market participant size is discussed further in Section 3.6.2.

P2P markets tend to be more decentralised than CSC markets. In CSC markets, participants are typically closely geographically located [34]. Participants in P2P markets can trade energy with each other directly [6, 26, 32, 35–42], or through centralised third parties [26, 27, 43]. CSC markets are generally operated in a more collaborative manner, for example using a non-profit centralised manager [44]. None of the papers considering TE markets gives information on the market governance.

P2P and CSC markets tend to operate at small scales, e.g. within distribution networks, whereas TE markets operate at all scales. Whilst there are examples of small TE markets [45–48], there are also examples of TE markets which trade over entire electricity networks [49–51]. P2P and CSC markets often aim to incentivise the use of local generation [25, 26, 31, 34, 52–54] or other local resources [26, 38, 55, 56, 56].

TE markets focus more on providing grid services than P2P and CSC markets. Papers presenting TE markets frequently aim to create a secure and efficient energy supply [57, 58]. They do this by focusing on the balance of energy supply and demand [45, 46, 49–51, 59–63], and the integration of flexible loads or storage devices [58, 63–69].

TE markets more frequently consider technical complications and operating conditions [76, 79], or reliability and demand constraints [47, 78]. They also provide demand-side response [47, 68, 69, 76]. There are some examples of P2P markets providing flexibility [24, 56, 75] and stability services to the network [33, 80]. There are fewer examples of CSC markets providing grid services. One example which was found involved a community manager coordinating prosumers to provide peak shaving services by minimising the maximum imported energy [44].

Papers considering P2P and TE markets tend to put more emphasis on specifying the market structure and design than papers focusing on CSC markets. The concept of P2P energy trading is based on a competitive market structure [52] where users engage in bilateral negotiation [40, 42, 82–84], making use of contracts for the settlements [31, 85]. In TE markets, engagement is generally through bidding [45, 79], price negotiations [68, 94] or auction based market clearing mechanisms [46, 48, 94]. TE markets can be operated as an extension of [81, 86] or replacement to [65] wholesale markets. TE markets can also operate as a sub-system of existing markets [67]. TE systems are set up in a market-based environment [48, 59, 62, 64, 69, 78, 81] aligning participants' interests with those of the wider energy system [50] by using economic incentives [48, 49, 57, 59, 63, 78, 81, 86]. The use of locational marginal pricing [61, 67, 87] and the response to price signals [46, 66, 87, 88] can optimise load behaviour. More details on markets structure and price formation can be found in Sections 3.2 and 3.3, respectively.

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

Category	**Characteristics**	**P2P**	**TE**	**CSC**
Participation	Small-scale participants	[25, 28, 30, 31]	-	-
	Participants from various scales	[32, 33]	-	-
	Participants located in one community	-	-	[34]
Governance	Energy trading without intermediary	[6, 26, 32, 35–42]	-	-
	Energy trading with intermediary	[26, 27, 43]	-	[44]
Locality & typology	Local energy generation	[25, 26, 31, 52–54]	[58, 63–67]	[34]
	Local energy consumption	[38, 55, 56]	-	[26]
	Close geographical proximity	[26, 55, 70–74]	[45–48]	-
	Virtual trading of energy and different layers of the grid	[40, 70]	-	-
	Operating across various grid layers	-	[49–51]	-
Market services	Demand-side response	[24, 56, 75]	[47, 68, 69, 76]	-
	Supply/demand balancing	-	[45, 46, 49–51, 59–63]	[44, 77]
	Response to grid constraints	-	[47, 76, 78, 79]	-
	Grid stability and system efficiency	[33, 80]	[57, 58]	-
Market design	Competitive market structure	[52]	[48, 59, 62, 64, 69, 78, 81]	-
	Bilateral market transactions	[40, 42, 82–84]	-	-
	Contracts	[31, 85]	-	-
	Price signals and economic incentives		[46, 48, 49, 57, 59, 63, 66, 78, 81, 86–88]	-
Market transactions	Maximise total welfare	[71, 89]	-	-
	Set own trading preferences	[85, 89, 90]	[50]	-
	Trading of surplus energy	[26, 74, 75, 80, 89, 91–93]	-	[26, 44]

While all three market types share characteristics, the analysis of the definitions shows that they each have a particular focus. P2P markets incentivise individuals to participate in energy markets. CSC markets create energy communities which act for the benefit of the group. TE markets optimise resources, providing services to the electricity system.

3.2. Market design

Six archetypal market designs have been identified in the papers: futures market, real time market, mixed decentralised/centralised market, mixed futures/real time market, multi-layer market, and settlement after the fact. The market design is the manner in which the price formation mechanisms are strung together to form a complete market (see Section 3.3 for more detail on individual price formation mechanisms). Figure 1 shows flowcharts for each of the archetypal market designs. In some cases, such as a futures market (Figure 1a), a single price formation mechanism is used. Whereas in other market designs, such as a mixed decentralised/centralised market (Figure 1c), several different price formation mechanisms are used in succession over different time periods. In this section, each of the market designs found in the reviewed literature is described, along with an analysis of how each is typically used. Figure 2 shows the number of papers that use each type of market design and price formation mechanism. Table A.5 in Appendix A shows the price formation mechanism and market design used in each paper. Of the 139 papers included in the review, 55 provided sufficient information to be included in the market design analysis.

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. Single auction, double auction and bilateral negotiation price formation mechanisms are all found paired with futures markets. Futures markets are 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 [95]. Figure 1a 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 assume the markets are linked to larger traditional electricity systems 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 1b shows an 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 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 clarify the P2P/CSC/TE market. Both single and double auctions are used for the centralised part of the market in the reviewed literature. Figure 1c shows an archetypal flowchart for a mixed decentralised/centralised market.

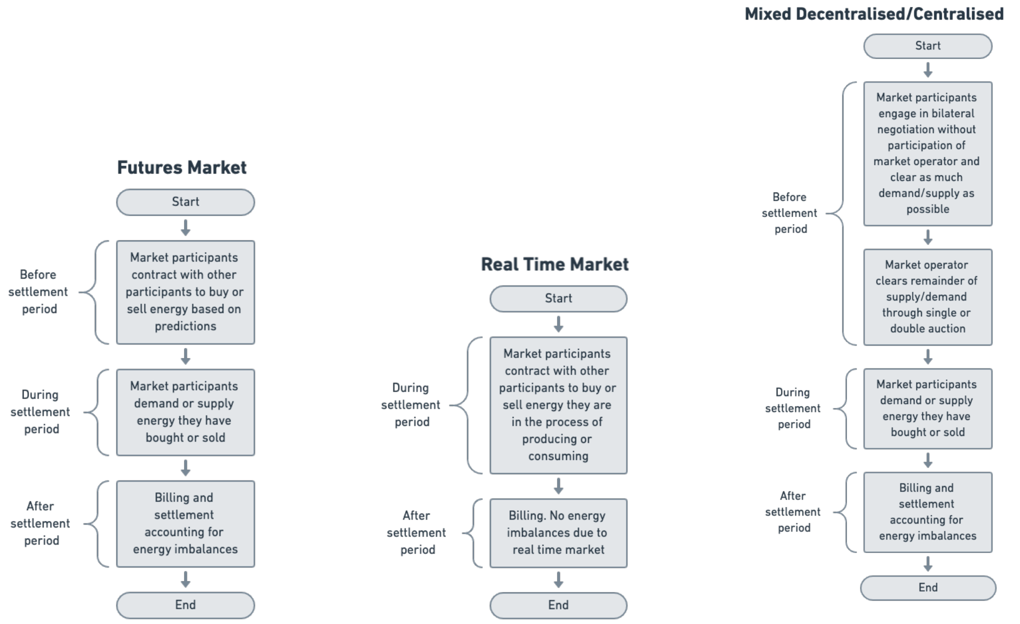
Mixed futures/real time market: In a mixed futures/real time market, there is some trading ahead of the settlement period based on predicted supply and demand for energy. There is then further trading during the settlement period, at which time market participants can correct their position in the market due to any forecasting errors. Mixed futures/real time markets are found with both single and double auctions in the papers reviewed. Figure 1d shows an archetypal flowchart for a mixed futures/real time market.

Multi-layer market: Multi-layer markets are settled at multiple levels. For example, there may be multiple markets at the bottom level which are cleared internally. An aggregator within each of these markets then participates in a higher level market to clear 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 1e shows an 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 markets, participants are paid or charged for energy they supplied or demanded after the settlement period. These markets use a system-determined price formation mechanism, energy is bought or sold at a fixed price. Market participants can purchase or sell as much energy as they require at these fixed prices. Therefore, no trading to determine an equilibrium price and volume is done ahead of the settlement period. Figure 1f shows an archetypal flowchart for a market settled after the fact.

3.3. Price formation mechanism

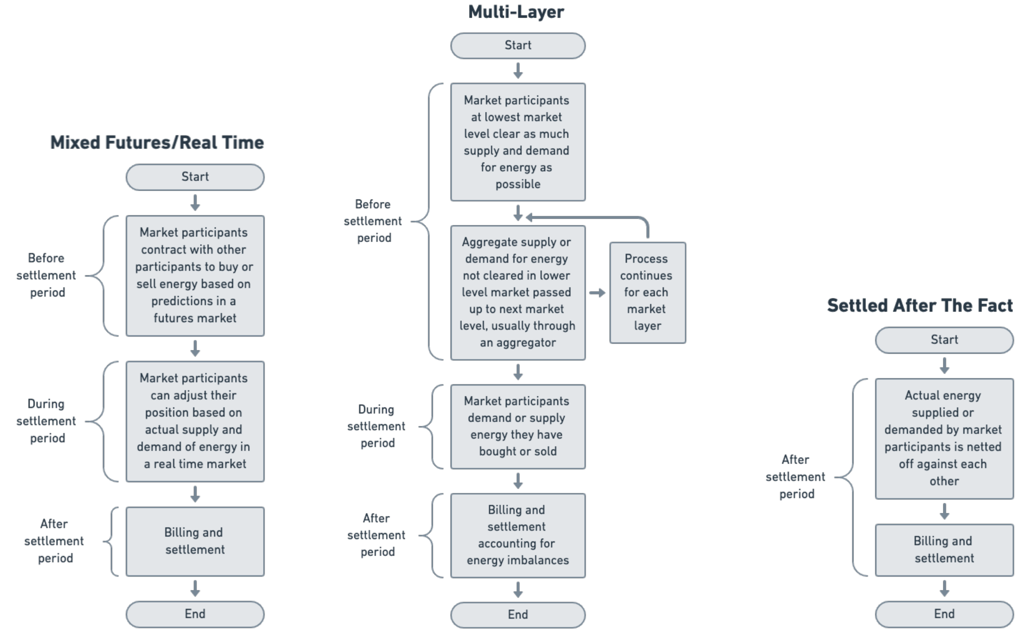
Price formation is the mechanism by which market prices are discovered. Exchange takes place within the context of a market institution, the rules that specify which messages (e.g. buyer bids,



(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 1: Market design flowcharts

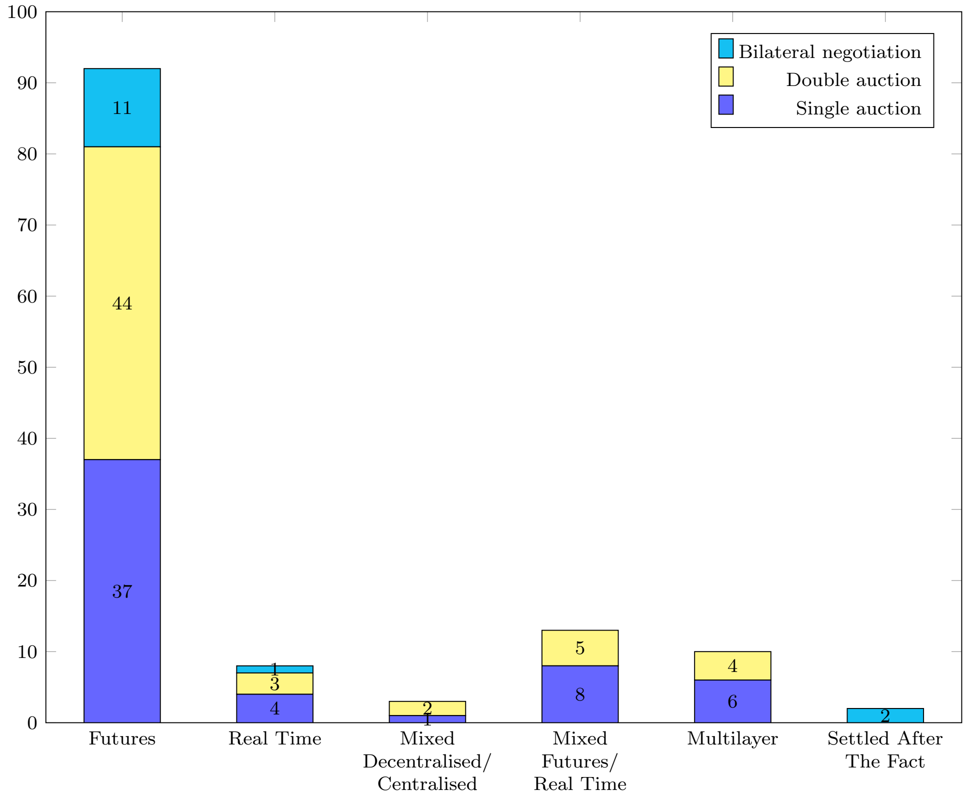


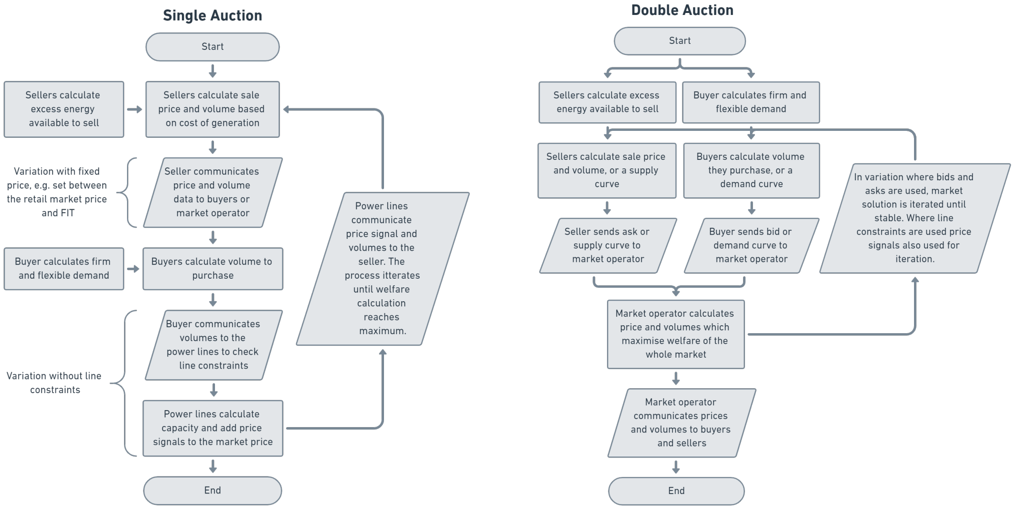
Figure 2: Number of markets using each market design and price formation mechanism

seller asks) are permitted, which agents are allowed to communicate messages, and how agents transact. Market institutions thus define price formation processes. Of the 139 papers included in the review, 53 provided sufficient information to be included in the price formation mechanism analysis. In the papers reviewed for this survey, five main categories of price formation mechanism 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.

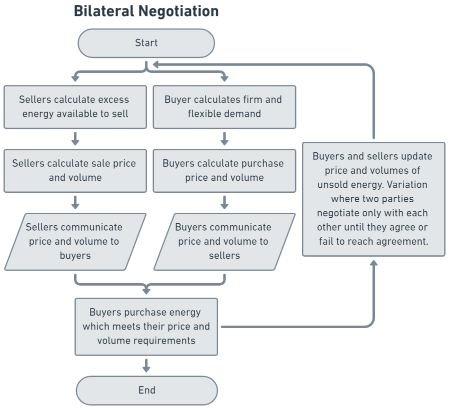
The single auctions used in the reviewed papers (15% of markets reviewed) generally involve consumers submitting bids which are then cleared by a market operator. The market operator role can be performed by an aggregator, local energy operator and even distribution system operator (DSO), amongst others. Examples of single auctions 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) [81], and 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) [96]. Figure 3a shows a flowchart for a typical single auction price formation mechanism.

Double auction: The double auction is a common market institution in P2P, CSC and TE energy systems. Twenty-five percent of the 139 papers reviewed used some form of a double auction. It has been used and tested both theoretically and empirically since the original GridWise Olympic Peninsula TE project [97]. 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



(a) Single auction

(b) Double auction



(c) Bilateral trading

Figure 3: Price formation mechanism flowcharts

is the ability of both buyers and sellers to send messages. Buyer bids communicate willingness to pay that reflect underlying utility and preferences. Seller asks communicate willingness to accept that reflect underlying costs. When the double auction is repeated (as is usually the case in electricity market applications), it yields highly efficient outcomes through an information-rich environment that enables considerable learning among market agents [98]. 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 [88, 99]. In a continuous double auction, the market is cleared continuously, such as in stock markets that use order books to keep track of standing bids and offers [41, 100]. Figure 3b shows a flowchart for a typical double auction price formation mechanism.

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% 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 feed-in tariffs on the generation side, or 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 TE scheme participants.

Negotiation-based mechanisms: The auction institutions described above typically involve a centralised market platform in which buyers and sellers participate. A more decentralised approach that resembles bilateral search uses negotiation-based mechanisms. Negotiation-based P2P transactions are often automated with specialised, AI-enabled software, such as negotiating autonomous agents. Unlike single and double auctions, which are a more structured method of price formation, negotiation prices depend on the local one-to-one (or sometimes one-to-many) offers being made and accepted. However, they have the potential to allow truly decentralised P2P energy transactions. Eleven percent of the papers reviewed used a form of negotiation-based price formation. Figure 3c 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 equilibrium. Eight 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%) do not include a description of how the price is formed, mostly because price is not a key element of the paper. Several papers are completely unrelated to prices (they are about forecasting, low-level control etc.) Another insightful reason is that several P2P and TE exchange mechanisms (especially in the context of 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.

3.4. Market value proposition

The value proposition of the market is the benefit which the market brings to its participants through the trading of a commodity. In this section, we analyse the commodities traded in the markets, and the value brought by these trades to the participants. The benefits of the market are described as the needs of the market participants in the following sections.

3.4.1. Market commodity

Of the 139 papers included in the review, 130 provided information on the commodity traded in the market. Electrical energy was traded in all the markets reviewed which provided that information (130 of 130 papers). In most cases, electrical energy was 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) [56, 62, 63, 90, 101–107], or in a flexibility only market (10 of 130 papers) [47, 49, 69, 76, 77, 79, 108–111]. Finally, some markets traded ancillary services such as reactive power, either alongside energy (five of 130 papers) [50, 51, 112–114], or as a standalone ancillary services market (two of 130 papers) [61, 115].

Although electrical energy was always traded in the markets reviewed, it was sometimes combined with other forms of energy. Combined heat and power markets are found in five of 130 papers [91, 116–119]. One presented a combined power and gas market [120], and one paper presented a combined power, heat and gas market [121]. It should be noted that the search term used in this study contained 'electricity', so pure heat or gas markets are excluded.

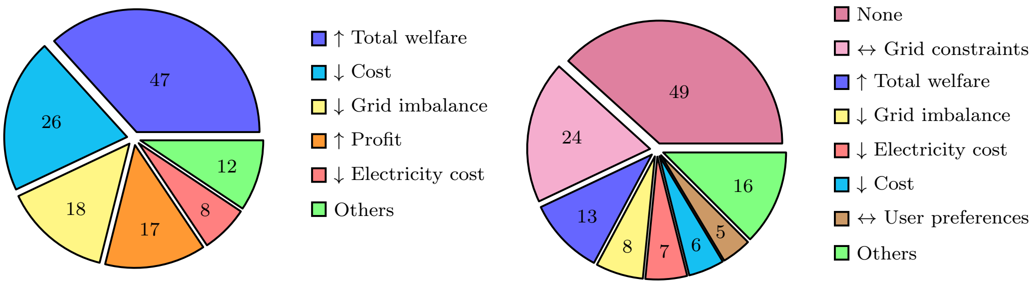
Almost all P2P markets only trade electrical energy. This could be due to the fact that P2P markets typically focus on providing services to prosumers, who demand or supply electrical energy. The majority of TE markets trade flexibility alongside electrical energy. This could be due to the fact that TE markets provide services to the electricity system, which needs flexibility to keep supply and demand for energy in balance. Three of the five CSC markets only traded electrical energy, while two also traded flexibility.

3.4.2. Benefits to market participants

Of the 139 papers reviewed, 128 provided information on the benefits of participating in the market. These benefits are primarily financial, e.g. profits from the sale of energy [40, 74, 120, 122, 123] or minimising the price paid for energy [84, 86, 93, 124]. Many markets also had secondary objectives, e.g. ensuring power line thermal limits are not exceeded [39, 41, 43, 62, 84, 104, 115, 125, 126]. Figure 4 breaks down the primary and secondary market benefits by number of papers. Table A.6 in Appendix A provides references for the primary and secondary benefits (needs) of the market participants, broken down by commodity (see Section 3.4.1 for more details on market commodities). Figure 4 and Table A.6 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 provides the end users, e.g. prosumers, with higher profits or lower costs, depending on their role in the market (seller or buyer). If a market only provides one financial benefit to the market participants then we use the specific term instead of total welfare. We use the term electricity cost if the market aims to reduce the electricity cost, which is beneficial to all grid users, not only the market participants.

Energy buyers and sellers both benefit in P2P, CSC and TE markets. Buyers benefit by purchasing energy at below the retail market rate. Sellers benefit by selling energy at above the feed-in tariff rate, if one exists, or by selling energy at all if not [28, 59]. The distribution of the benefits between the buyer and seller depends on the market price (see Section 3.3 for more detail on market prices). Many papers do not explicitly compare the P2P/CSC/TE market price to retail market and feed-in tariff prices. Therefore, it is often not possible to quantify the benefit of the P2P/CSC/TE market over the traditional market.

For some sellers in P2P, CSC and TE markets, there may be no other means of selling their excess energy. P2P, CSC and TE markets are also less rigid than traditional markets about the types of generation which are permissible. Feed-in tariff schemes have limitations on the type and



(a) Core need

(b) Secondary need

Figure 4: Needs of market participants (↑ Increase; ↓ Reduce; ↔ Respect)

size of generation which is allowed [127]. Typically, storage is not compensated under feed-in tariff schemes.

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 [26, 35, 52, 128]. These include balancing costs [2] and network costs [3]. It is likely that P2P, CSC and TE markets will be subject to some level of balancing and network costs [129, 130]. However, they 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 when compared to the models presented in the current literature.

Some markets also provided a service to the grid, such as energy balancing [4]. These services are normally compensated through time-of-use pricing. For example, a flexible load can be compensated for shifting in time by the fact that they buy energy at a lower price. Or, a storage device can be 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.

Unlike in P2P, CSC and TE markets, traditional energy systems procure these balancing services 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). It is therefore possible that by only paying balancing services at arbitrage rates in P2P/CSC/TE markets, they are being under-compensated when compared to their value added to the system. Their compensation will be lower than the market price for energy in P2P/CSC/TE markets, compared to above the market price for energy in traditional markets.

In traditional electricity markets, there are normally minimum bid sizes for balancing markets. The types of resources which can participate in balancing in P2P/CSC/TE markets are often too small to provide those services in traditional markets. The fact they can be compensated for balancing services at all in P2P, CSC and TE markets is additional value to those participants.

One reason these flexible resources are not fully compensated for their true service is that most P2P, CSC and TE markets 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 in the futures market, or the papers do not consider cash out at all. If the papers considered imbalance charges, flexible resources may be valued more highly because their price would be compared to the cash out price, rather than the energy price.

The majority of the articles reviewed either only provide information about the benefits of participating in P2P, CSC or TE markets, or provide limited information about the costs of participating. In addition, a predominant assumption in the papers reviewed is that the market participants already possess the necessary assets (e.g. storage, PV, etc.) to generate and trade electricity. The value proposition of these markets then takes as a benchmark the benefits one can obtain from using these assets in the traditional market and derives the benefits obtained by participating in the P2P/CSC/TE market.

What then becomes even more interesting is to find out the value proposition vis-à-vis cost involved in participating in P2P/CSC/TE electricity markets considering the capital investments in assets. Although important, this analysis is out of the scope of this paper as the TEAM framework does not facilitate the collection of sufficient data to perform this analysis.

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[2] 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 market participants' energy imbalances.

[3] 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.

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

3.5. *Market participants*

In the following section, we take a detailed look at the participants involved in the markets. We look at the types of participants, taking a frequentist approach, and analyse the assets participants contribute to the market.

3.5.1. *Types of market participants*

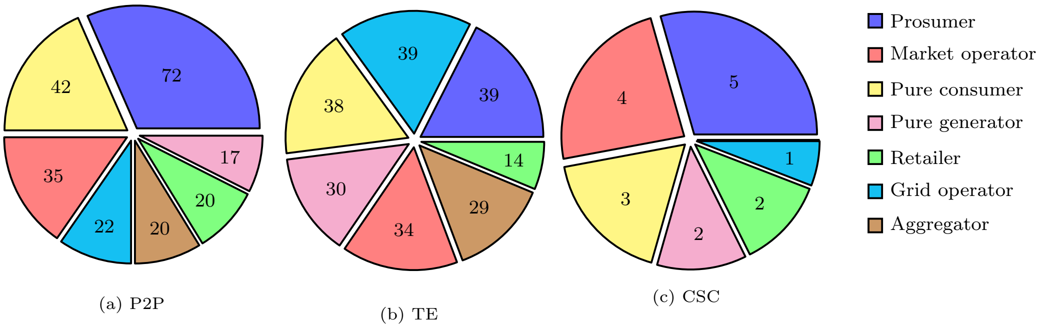
Market designs and operating conditions can be distinguished based on the participants involved in the market. We differentiate between seven different types of market participants: pure generators, pure consumers, prosumers, aggregators, retailers, central market operators and grid operators. Figure 5 shows the types of market participants, split by type of market. Some papers are represented multiple times if more than one market was discussed. Of the 139 papers included in this review, 136 papers contained the correct information to be included in this analysis. Detailed references for the types of market participants considered by each paper can be found in Table A.7 in Appendix A. A description of each participant can be found in the code book in Appendix B.

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 being the least frequently represented. 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. However, the inclusion of other participants such as retailers, grid operators and aggregators shows the diversity P2P markets and the different ways they integrate into existing energy markets.

In TE markets, grid operators and prosumers play the most significant role. Both are represented in 64% of papers. They are closely followed by pure consumers, in 62% of markets. Fifty-five percent of papers include a central market operator. Around half of all papers include pure generators and aggregators. Retailers were the least frequent market participant, appearing in 23% of markets. TE markets have a more even distribution of market participant types than P2P markets. This supports the defining characteristic of TE markets (Section 3.1) that they can operate at various levels of the grid with a diverse range of participants.

Over 83% of CSC markets are centred around energy prosumers. A central market operator existed in 67% of cases. Half of the papers considered pure consumers. Retailers, pure generators and grid operators were the least prominent market players in CSC markets. None included an aggregator. This highlights the centralised nature of CSC markets. It should be stressed that only a small sample size of CSC markets have been analysed.

The dominant participants in all three types of market are prosumers, pure consumers and market operators. TE markets put a stronger focus on grid operators, pure generators and aggregators than P2P markets. This supports the findings in Section 3.1 that TE markets are more 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 equal distribution of different market participants. This is supported by the characteristics identified in Section 3.1 where



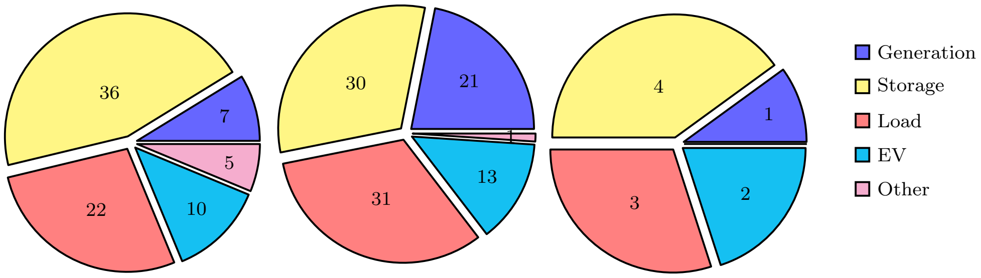
(a) P2P (b) TE (c) CSC

Figure 5: Types of market participants

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 to create diversity of load and generation profiles. However, that diversity might also increase complexity when operating the market, as a wider range of market behaviours have to be taken into account.

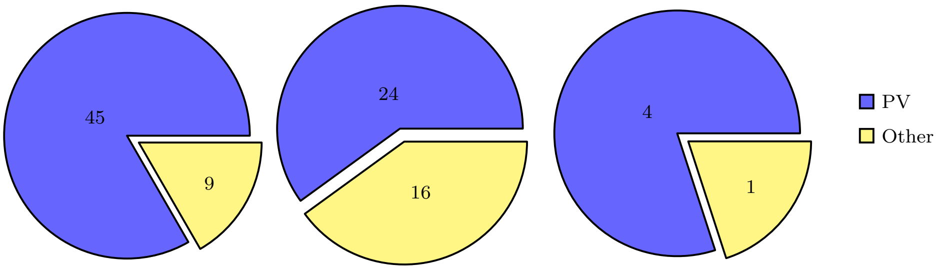
3.5.2. Assets of market participants

Assets participating in the market were classified as either controllable or non-controllable. Controllable assets are energy generators or loads that can be dispatched on demand. Controllable loads can either be shifted, curtailed or completely disconnected depending on their specific properties. These assets can provide 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 that are not shiftable or shapeable. Of the 139 papers included in the review, 123 contained the correct data to be included in the analysis of market participants' assets.



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

Figure 6: Types of controllable market assets



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

Figure 7: Types of non-controllable market assets

Assets participating in markets directly and indirectly (e.g. through a home energy manager) were considered in this analysis. Figure 6 shows the frequency of controllable asset types, split by market type. Nearly 80% of all markets include controllable assets. Storage devices and dispatchable loads played a major role in all types of market. 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 [53, 128] or thermal storage units [67, 117, 118] were considered.

All three market types integrated controllable load in their designs. In P2P and CSC markets, controllable loads were usually shiftable appliances [33, 101, 102, 124, 131], air conditioners [90, 111, 124] or heat pumps [33]. In TE markets, shiftable appliances were also a key source of flexibility [59, 68, 103, 109, 119]. Heat pumps were frequently used as the main source of load control [49, 59, 68, 88, 99, 116, 117]. TE markets put a stronger focus on dispatchable generation, including combined heat and power [67, 116–118] or traditional fuel-based generators [49, 57, 119]. In a few cases, P2P markets made use of diesel generators [42, 132, 133]. All three models considered electric vehicles (EV) in their markets, although not as frequently as other controllable assets. An overview of the references that used controllable assets can be found in Table A.8 in Appendix A.

There is a clear difference between the non-controllable assets found in P2P and CSC markets when compared to TE markets. Figure 7 shows the types of non-controllable generation units found in the literature, grouped as either PV generators or other distributed generators. P2P markets mainly include PV generators. When size is explicitly mentioned, most markets refer to small-scale rooftop PV systems. In a few cases, multiple generation units have been considered, mostly PV paired with wind generation [56, 114, 121, 134]. By contrast, TE markets more frequently include other types of distributed generation. In these cases, wind energy is dominant [61, 105, 113, 114, 120]. In CSC markets, most non-controllable generation units were PV installations, with one exception [77].

3.6. Market scale

The scale of a market is key to understanding its operating conditions. This section first looks at the size of the markets in terms of the number of nodes or participants involved. Secondly, it investigates the scale of the participants in each market.

3.6.1. Participation in markets

This section focuses on analysing the size and scale of the markets in terms of the number of participants involved. Where multiple markets have been tested, the one with the highest number of participants was included in this analysis. An overview of the number of papers and size of the markets is given in Figure 8. Instead of specifying the number and type of participants, some papers referred to nodes which is usually the number of agents or buses a market is optimised for, e.g. [81, 113, 134]. Where the number of participants was not given, the number of nodes was used in the analysis instead. Of the 139 papers in this review, 117 provided information about the number of market participants and are included in this analysis.

Most papers present 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. Sixteen papers present markets with 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 found in Table 2.

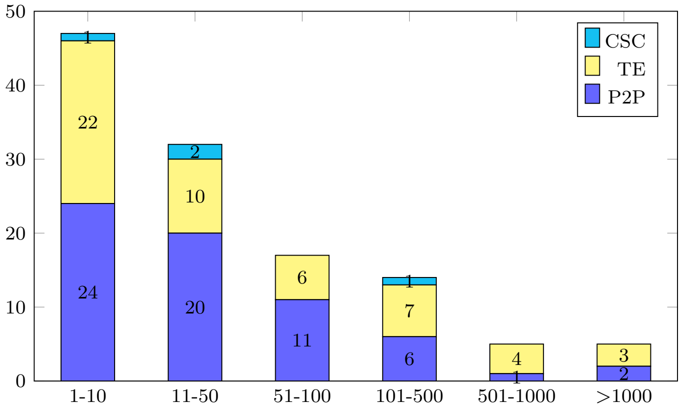


Figure 8: Number of nodes/participants in the market

Most authors built their markets using small participation numbers to demonstrate the functionality of their market mechanisms. While this can help to evaluate the performance of a market, it only provides limited insights into the 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 [60, 79, 109, 123], rather than individual households optimising load profiles.

For all papers with more than 500 participants, the test duration varied between a few hours and a maximum of one day, with one exception where the test duration was two months [135]. Although the models look at larger scale adoption, they are not tested for resiliency or diversity of load. However, where fewer participants have been included in the market, longer simulation durations have been tested [35, 81, 136]. More research is required into markets operating at larger scales, with a couple of hundred participants or more.

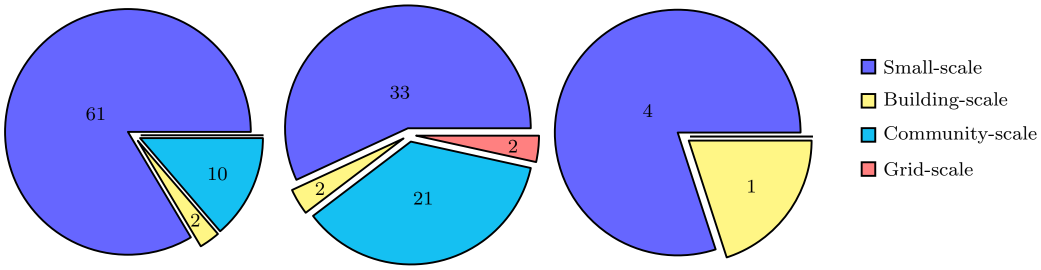
Table 2: Number of market participants

Participation	**P2P**	**TE**	**CSC**
1-10 participants	[6, 25–29, 36, 39, 52, 53, 56, 71, 72, 74, 91, 124, 128, 134, 137–142]	[45, 46, 57, 64, 65, 68, 81, 86, 99, 103, 104, 108, 112, 115, 117, 143–149]	[26]
11-50 participants	[24, 30–32, 35, 37, 40–42, 54, 84, 102, 106, 122, 131, 132, 150–153]	[37, 51, 59, 87, 94, 107, 110, 118, 120, 125]	[44, 102]
51-100 participants	[55, 73, 85, 93, 96, 100, 121, 126, 154–156]	[47, 62, 113, 136, 157, 158]	-
101-500 participants	[70, 75, 90, 92, 101, 159]	[63, 76, 105, 119, 160–162]	[34]
501-1000 participants	[111]	[50, 60, 69, 88]	-
>1000 participants	[123, 135]	[78, 79, 109]	-

3.6.2. Size of market participants

A second important characteristic is the scale of participants in the market. The scale here refers to the size of the market participants. We divide participants into small-scale, building-scale, microgrid/community-scale or grid-scale. In cases where multiple scales of participants were present, the scale was selected according to the key targeted group of the market. Small-scale market participants are predominantly residential/individual energy users. In markets with building-scale participants, multiple buildings trade with each other. They can be either larger residential or commercial/industrial buildings. Community or microgrid-scale markets do not focus on the individual energy users in the market, but rather operate as a community. Grid-scale market participants are directly linked and provide benefits to the distribution or transmission network. Identifying the scale of market participants helps us to understand the main trading purpose of a market, by means of who the market was designed for, and its ability to scale in the future. Of the 139 papers included in the review, 131 provided information on the size of the market participants and have been included in this analysis. An overview of the scale of market participants can be seen in Figure 9. Table 3 provides the associated references.

Most papers focus on developing markets for small-scale participants. In the case of P2P markets,



(a) P2P

(b) TE

(c) CSC

Figure 9: Scale of market participants

Table 3: Scale of market participants

Participant-scale	**P2P**	**TE**	**CSC**
Small-scale	[6, 24, 25, 27–31, 33, 35–37, 43, 52, 54–56, 70–75, 80, 82–85, 91–93, 96, 100–102, 106, 111, 121–123, 126, 131, 133–135, 137, 139–142, 150–156, 159, 163, 164]	[37, 45, 47, 48, 50, 51, 59, 60, 62, 63, 68, 69, 78, 79, 81, 87, 88, 99, 103, 108, 109, 113, 115, 116, 119, 120, 128, 136, 147, 148, 157, 158, 161]	[34, 44, 77, 102]
Building-scale	[26, 124]	[67, 149]	[26]
Microgrid/ Community-scale	[32, 39–42, 53, 90, 114, 132, 138]	[46, 49, 57, 64, 76, 86, 94, 105, 107, 110, 112, 114, 117, 118, 125, 143–146, 160, 162]	-
Grid-scale	-	[61, 104]	-

nearly all papers focus on small-scale residential energy users, or in some cases EVs [54, 73, 151]. A few papers have considered trading at community-scale. These markets usually include transactions between microgrids [32, 39, 132], within virtual power plants [40] or with industrial energy users [42, 90, 138]. Examples of building-scale trading includes trading between campus-buildings [26] or buildings in clusters [124]. Similarly, papers proposing CSC markets mainly consider small-scale energy users in their analysis [34, 44, 77, 102]. The scale of users in TE markets is more diverse, although the key target group are still small-scale users. Building-scale TE models consider commercial buildings, such as schools and offices, or manufacturing plants [67, 149]. Most microgrid/community-scale papers with TE markets focus on trading between microgrids [57, 118, 143, 145]. However, two papers focus on trading between aggregators [76, 125], and one conducts trading through a virtual power plant [110]. The grid-scale markets operate at higher grid levels and are targeted specifically at the transmission or distribution grids [61, 145]. Although small-scale participants are dominant in TE markets, those papers included proportionally more grid-scale markets than papers examining P2P or CSC markets. This shows that TE markets operate across various scales, from small scale to grid scale applications.

An analysis comparing the number of market participants and the market scale to the price formation mechanism and market design was conducted to examine the relationship between market size and complexity. No correlation was found between the market design or price formation mechanism and the market scale or number of participants. Only a small number of papers model markets with a large number of participants (five models contained more than 1000 participants), and most papers modelled small scale markets. Therefore, it is possible that the reviewed literature would not identify issues relating to scaling complexity of the market designs and price formation mechanisms. Section 4.3 provides further discussion of the scalability research gap.

3.6.3. Types of grid model

Due to the link between LEMs and low/medium voltage networks, many papers have been devoted to analysing grid integration constraints. Forty-eight of the 139 papers reviewed used a grid model to test the effect of their market on the power network. Along with voltage range operation limits [126], other constraints have been highlighted, including but not limited to, phase imbalance, power peaks, upstream generation, transmission capacity, and line congestion [33, 52, 56, 128, 134]. It is worth noting that besides grid constraint, power losses have an essential impact on the physical implementation of the commercial transaction too [84, 140]. A detailed analysis of the technical aspect of power losses and network constraints integration to the transaction design has been assessed by Dudjak et al. [165].

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 test feeders. Table A.9 in Appendix A provides references for each paper that considers grid models, including the grid model used and the type of analysis performed. The relatively small number of papers using each grid model and performing each type of analysis limits the bench-marking which can be done between the different analyses.

3.7. Market operation

In the following section, we discuss the type of data shared between participants and the user preferences considered (Section 3.7.1). We then provide insights into the settlement period and gate closure times used in the markets (Section 3.7.2).

3.7.1. Data sharing and user preferences

In order to persuade end-users to actively engage and participate in LEMs, markets should treat participants fairly and provide them with means of informed decision-making. Therefore, one crucial aspect of the markets is the data/information shared amongst participants. Of the 139 papers in the review, 113 provided information about data sharing and user preferences.

In cases when the trade is between one or two large buyers (e.g. grid operators [87] or aggregators [76]) and many smaller sellers (e.g. prosumers or consumers), the buyers usually share information about the volume of the commodity they wish to purchase and potentially price information. Based on this information, the sellers can then 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 [60, 69], the price for which the requested commodity can be provided [64] or both [50, 51, 88, 110, 112]. 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 grid operators themselves [76, 87]. Table 4 provides a summary of the types of information shared in different markets.

In all market types, electricity price and volume information for a specific trading period are the main types of data shared by prosumers, either with the other prosumers if the market is fully decentralised [52, 72, 94, 99, 132, 141, 161], or with a central market operator that clears the market [6, 32, 51, 66, 80, 88, 112, 155, 157]. Therefore, the vast majority of markets use only these two data items to determine the market output. Supply and demand curves are the main data items shared by participants in markets where the bidding takes place for several trading periods [36, 37, 62, 68, 106, 149], for example in day-ahead markets. In a few markets, prosumers only share electricity price [33, 64, 67, 133] or volume [24, 28, 60, 85, 121, 139]. This is due to the fact that the markets 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 markets offer limited flexibility as prosumers can only express their trading preferences via one parameter – price or volume.

3.7.2. 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. Of the 139 papers in the review, 110 provided information about the settlement period and gate closure in the market. 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 [95], but can be as short as 5 minutes [166]. Gate closure is around one hour prior to the start of the settlement period [95].

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 [27] 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 [147, 155]. The gate closure of papers modelling a five minute settlement period ranges from five minutes [65, 154] to one day, e.g. [77, 106, 109, 124, 138]. 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 [75, 141], and they go up to one day [59, 100, 123, 153]. This trend continues

Table 4: Data shared in markets

Data type	Recipient	Market type & references			
		P2P	TE	CSC	Combined
Price	Prosmer	[133]	[67]	-	-
	Central market operator	[33]	[64]	-	-
Volume	Prosumer	[28, 43, 70, 85, 93, 121, 139]	-	-	-
	Consumer	[24, 138, 163]	-	-	-
	Retailer	-	[60, 69]	-	-
Price & volume	Prosumer	[25, 35, 39, 41, 42, 52, 72, 73, 75, 82, 91, 99, 100, 122, 132, 134, 135, 137, 141, 151, 159]	[47, 94, 117, 143, 144, 147, 161]	[77]	-
	Central market operator	[6, 29, 30, 32, 35, 71, 80, 84, 99, 101, 137, 150, 152, 155]	[46, 48, 50, 51, 61, 66, 78, 81, 88, 104, 110, 112, 113, 145, 157]	-	[102, 114, 119]
Demand & supply curve	Prosumer	[36, 54, 90, 154]	-	-	-
	Central market operator	[27, 31, 53, 55, 89, 92, 96, 101, 106, 123, 131, 142]	[45, 57, 59, 62, 63, 68, 76, 79, 86, 87, 103, 107, 108, 115, 116, 125, 148, 149, 158, 160]	[34]	[37]
Controllable loads	Prosumer	[124]	[162]	-	-
Flexibility available	Central market operator	[106, 123, 142]	[62, 87, 108]	-	-
Battery SoC	Central market operator	[53, 92, 142]	-	-	-
Distribution line distance	Central market operator	[31]	[112]	-	-
Discomfort level	Central market operator	-	[59]	-	-
Eagerness factor	Central market operator	[35, 96]	-	-	-
Willingness to pay/accept	Prosumer	[40]	-	-	-

with 30 minutes [74] and one hour [42, 144] settlement periods, where the shortest gate closure is the same as the length of the settlement period, and the longest is one day [92, 106, 134, 143].

4. Research gaps and future research directions

The results in the previous sections have highlighted the key differences and similarities of P2P, CSC and TE markets and also LEMs as a whole, 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, CSC and TE markets to operate at scale. This section highlights five key research gaps that require further analysis.

4.1. Consideration of physical constraints

LEMs incentivise energy transactions between participants connected to the medium/low voltage distribution networks. This creates bidirectional power flows in systems designed for unidirectional power flows. It is therefore important to consider physical grid constraints when clearing LEMs. Only about one-fifth of the analysed markets incorporate a comprehensive market mechanism that takes into account physical grid constraints [45, 109, 113, 125] (see Table A.6). The rest of the analysed markets either focus on the virtual market layer where transactions among market participants are agreed, or only examine a single type of grid constraint such as congestion [79]. Further research is needed to design market mechanisms that can incorporate the full range of grid constraints. This could be achieved by grid operators feeding the market with various parameters which would indicate the grid status. The market 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 a specific grid access point). Once this is in place, the market clearance phase could take this into account when matching market participants. Transactions that would further violate the grid constraints could be vetoed while the ones that would have a positive effect on the grid could be prioritised. Bundling the grid constraints with pricing mechanisms and user preferences would potentially result in more complete markets that take into account the physical infrastructure as well as user preferences.

In addition, a key aspect of successfully managing the physical constraints of the grid infrastructure is a close integration of LEMs with the current power system, as well as their integration and coordination with the traditional energy markets such as wholesale, retail and balancing markets. Some work has already been done in this direction (see for example [15, 167, 168]). Furthermore, apart from their integration, quantifying the effect of these local energy markets on the traditional markets is something that needs in-depth investigation.

4.2. Lack of holistic approach to market operation

Although there is a rich literature on different P2P, CSC and TE markets, existing solutions focus mainly on the market clearance phase, including bid/offer submission, market price determination and market participant matching/transaction selection. Other crucial phases, such as bid/offer creation incorporating user preferences, strategic bidding, billing/settlements and dispute resolution [169], have been largely neglected.

The bid/offer creation phase should be able to capture (i) the diverse available resources of the users, (ii) the predicted user supply and demand, (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. favouring community over profit, trading 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 [44, 96].

Strategic bidding is another phase that has seen little attention. User bids and offers can be devised based on the available resources and user preferences. However, determining the best time, volume and price needs external information about the market and possibly information about the other users' intentions. As shown in Table 4, only limited information is shared between market participants in the current models, mainly focusing on the price and volume of electricity requested/offered.

Billing and settlements is the phase proceeding market clearance [170]. Once the transaction details such as prices and volumes have been set, the next phase is to sort out the payments amongst the market participants. In contrast to the retail market, where users have contractual obligations with only one entity, their supplier, in P2P, CSC and TE markets, users can potentially trade with every other market participant. Most markets have the market clearing phase before the settlement period. Volumes to be traded, prices and transaction parties are determined in advance. Markets assume that the volumes agreed in advance will be delivered during the trading period. In practice, this might not be the case due to errors in the predictions.

Another important phase that has been largely ignored by the literature is dispute resolution [171]. In any market that involves transactions between participants, there must be mechanisms in place to deal with any disagreements.

4.3. Scalability and replicability

Few studies have tested their market proposal on large numbers of participants [41, 85, 87, 101, 123, 159–161]. The majority of markets 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, CSC and TE markets in the future, market designs need to be able to respond to the dynamic nature of real-life applications. Dynamic parameters from within the market, as well as dynamic environmental conditions will impact the performance of a market.

To enable the uptake of LEMs, market designs need to satisfy two key criteria, namely market scalability and replicability. 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. Our analysis has not found any correlation between market size and complexity. However, Section 3.2 has shown that most market designs and settlement mechanisms have been tested using low numbers of participants to provide an initial proof of concept. Secondly, markets need to be able to react to changing market conditions over time, such as the type of assets in the market. More research on the performance of markets with a high number of participants and changing market participation over time is required.

The concept of replicability has barely been touched upon in the papers analysed. Replicability can also be assessed from two perspectives. Firstly, a particular market design could be replicated in different contexts and locations. This could include being exposed to various internal and external parameters. These might include different types of participants, assets, requirements and electricity grid typologies. Secondly, replicability also refers to the different regulatory contexts in which markets must operate. This is especially the case when replicating a pilot project in a different region or country with divergent policy and regulatory landscapes or norms and values.

4.4. Information security

P2P, CSC and TE markets rely on vast volumes of data. These data are either exchanged directly among the market participants in fully decentralised models, or indirectly via central market operators in centralised models. The source of these data could range from small sensors on distribution lines and prosumers' assets (e.g. remote terminal units, smart meters, home energy management systems) to large equipment (e.g. substations) and other market participants (e.g. suppliers, network operators, aggregators, etc.). As the market outcome heavily depends on these data, the reliability, authenticity and trustworthiness of these data are of paramount importance [172].

4.5. Prosumer privacy

The bids and offers submitted by market participants contain data about their energy use which may be classed as personal data [173]. The reviewed papers do not consider the risks of loss of this personal data either during transfer or from a market operator.

5. Conclusion

LEMs have seen increased interest in the academic literature as they are regarded as 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. P2P, CSC and TE markets are some of the most common LEM concepts. However, these terms are currently used interchangeably and lack a clear definition, which can lead to misconceptions amongst the scientific community and result in slower development. Through the systematisation of knowledge of recent studies, we create an overview of the current state-of-art research with regards to the market design and transaction aspects of LEMs. We contribute to a transparent and clear representation of the underlying concepts and assumptions of LEMs. The results of this review highlight the main differences and similarities between P2P, CSC and TE markets and disclose key evidence gaps that require further research for LEMs to be successfully implemented in the future.

To analyse the current academic literature in a structured manner, we adapted the TEAM framework [23], which is used to analyse businesses that must both compete and cooperate in order to make a market function (Section 2.3). A total of 139 peer-reviewed papers have been assessed considering the strategy, technology and value of each proposed market. The framework was further extended to gather data about the assumptions made in the markets, and the participants involved.

Our analysis of the defining characteristics of P2P, CSC and TE markets shows that P2P and CSC markets mainly focus on providing a financial incentive to market participants. TE markets have a stronger focus on providing grid-related services. Compared to the P2P and TE markets, CSC markets are poorly represented in the literature. CSC markets focus on the community and locality aspects of energy markets and follow a rather centralised governance structure (Section 3.1).

We have identified six archetypal designs used in P2P, CSC and TE markets. They mainly vary with regards to their degree of centralisation and the number and types of price formation mechanisms needed to settle the market (Section 3.2). The assessment of the price formation mechanisms showed that there are three key archetypal mechanisms predominately used across the literature; single and double auctions and bilateral negotiations (Section 3.3).

We assessed the value proposition of the markets. The most common commodity traded in P2P energy markets is electrical energy. TE markets more frequently trade flexibility. This can be referred back to the fact that P2P markets are more focused on providing services to the market participants, while TE markets have a stronger focus on providing services to the grid (Section 3.4.1). Most markets provide benefits to the participants, compensating them for their services by increasing the total welfare in the market or reducing the costs of the participants. However, most papers do not consider installation costs, which limits their applicability in real contexts (Section 3.4.2).

We evaluated the types of market participants involved and provided an overview of the assets in the markets (Sections 3.5.1 and 3.5.2). While P2P markets mainly focus on small-scale individual energy users, TE markets have a more diverse range of market participants across different scales. All market types showed strong dependence on energy storage capacity. The assessment of the number of market participants showed that most market mechanisms modelled are tested with only a small number of participants. They are mainly case studies as a proof-of-concept of the proposed market mechanism. This limits their replicability for real-life implementation, especially for markets with a couple of hundred participants or more (Section 3.6.1).

While both P2P and CSC markets mainly focus on small scale energy users, TE markets have a more diverse scale of operation. This supports the finding that TE markets operate across various scales of the energy system. 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 3.6.3).

We concluded the paper by providing an overview of the key research gaps identified during the review. These research gaps are the lack of: consideration of physical constraints; a holistic approach to market design and operation; consideration about how these market designs will scale; consideration of information security; and, consideration of market participant privacy.

The vast majority of papers in this review (137 of 139) were simulations or surveys and typically focused on a specific aspect of the market. Pilot projects, by contrast, must take a holistic approach to market design because they are actually implemented, albeit often with deviations from regulations. Well studied pilot projects with thorough and publicly available results are an essential next step in testing the feasibility of LEMs.

6. Data Availability

The completed data extraction table [174] 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. Additional Data

This appendix contains tables of supporting data and references. Each table is referenced in the relevant part of the results section, and is briefly introduced here as well.

Table A.5 provides references for the market design and price formation mechanisms. The papers are grouped based on market design, price formation mechanism and market type (P2P, CSC or TE). Discussion about market design is provided in Section 3.2 and discussion about price formation mechanism is provided in Section 3.3.

Table A.6 provides references based on the different market participant needs and the market commodity, broken down by market types (P2P, CSC or TE). The market commodity is discussed further in Section 3.4.1 and the needs of the market participants are discussed in Section 3.4.2.

Table A.7 provides references for the types of market participants, split by market type (P2P, CSC or TE). Further discussion of market participants can be found in Section 3.5.1.

Table A.8 provides references for the different types of assets of market participants split by market type (P2P, CSC or TE). Further discussion about the assets of market participants can be found in Section 3.5.2.

Table A.9 provides references for each type of grid model used, split by market type (P2P or TE) and what the grid was used to model (constraints, power loss or other). Further information about the grid models used in the reviewed literature is available in Section 3.6.3.

Table A.5: 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	[6, 27, 29, 31, 43, 52, 56, 84, 89, 92, 96, 106, 111, 121, 134, 135, 138, 142, 163, 164]	[133]	[53]	[123, 175]	[159]	-	P2P
	[49, 50, 57, 62, 65, 66, 79, 81, 86, 87, 105, 112, 149, 158, 162]	[60, 61, 119]	-	[45, 51, 59, 63, 67, 120]	[47, 104, 145, 148, 160]	-	TE
	[26, 34]	-	-	-		-	CSC
Double auction	[21, 25, 28, 30, 32, 33, 36, 37, 40, 41, 55, 72, 74, 75, 90, 100, 101, 126, 128, 131, 150–155]	[54, 73]	[35, 124]	[132]	[114]	-	P2P
	[46, 64, 69, 76, 94, 103, 108–110, 115, 116, 118, 125, 143, 146, 147, 157]	[88]	-	[48, 68, 99, 107]	[78, 117]	-	TE
	[44]	-	-	-	[102]	-	CSC
Bilateral negotiation	[42, 82, 85, 122, 137, 156, 161]	[71]	-	-	-	[24, 139]	P2P
	[39, 94, 144]		-	-	-		TE
	[77]		-	-	-		CSC

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

Table A.6: Needs of participants addressed by P2P, CSC and TE markets

Core need	**Secondary need**	**Commodity**	**P2P**	**TE**	**CSC**
↑ Total welfare	None	Electricity	[6, 27, 28, 52, 56, 70, 89, 135, 139, 151, 153, 154, 175]	[60, 118]	-
↑ Total welfare	None	Flexibility	-	[108]	-
↑ Total welfare	↔ Grid constraints	Electricity	[37, 39, 134, 155]	[37, 69, 125, 146, 161]	-
↑ Total welfare	↔ Grid constraints	Flexibility	-	[50, 59, 112, 113]	-
↑ Total welfare	↓ Electricity cost	Electricity	[24, 72, 82]	-	-
↑ Total welfare	↓ Electricity cost	Flexibility	[102]	-	[102]
↑ Total welfare	↓ Grid imbalance	Electricity	[36, 54, 100]	[117, 145]	-
↑ Total welfare	↔ User preferences	Electricity	[42]	-	-
↑ Total welfare	↔ User preferences	Flexibility	[85]	-	-
↑ Total welfare	↓ Consumption	Electricity	[150]	-	-
↑ Total welfare	↓ Electricity loss	Electricity	[31]	-	-
↑ Total welfare	↓ CO2 emissions	Electricity	[137]	-	-
↑ Total welfare	↑ RES use	Electricity	[32]	-	-
↑ Total welfare	Fair cost distribution	Electricity	[106]	-	-
↑ Total welfare	↑ Self-consumption	Electricity	[55]	-	-
↑ Profit	None	Electricity	[26, 35, 80, 122]	[48, 66, 94, 120]	[26]
↑ Profit	None	Flexibility	[123]	[65]	-
↑ Profit	↔ Grid constraints	Electricity	[40, 126]	-	-
↑ Profit	↔ Grid constraints	Flexibility	-	[62]	-
↑ Profit	↑ RES use	Electricity	[74]	[116]	-
↑ Profit	↓ Grid imbalance	Electricity	-	[110]	-
↓ Cost	None	Electricity	[71, 83, 91, 92, 138, 141, 156, 159]	[67, 148, 158, 162]	-
↓ Cost	None	Flexibility	-	[78, 109]	-
↓ Cost	↔ Grid constraints	Electricity	[43]	[64, 104]	-
↓ Cost	↔ User preferences	Electricity	[96]	-	-
↓ Cost	↔ User preferences	Flexibility	-	[63, 68]	-
↓ Cost	↓ Grid imbalance	Flexibility	[90]	[103]	-
↓ Cost	↑ Total welfare	Electricity	[30]	-	-
↓ Cost	↓ Electricity cost	Electricity	-	[143]	-
↓ Cost	↑ Self-consumption	Electricity	-	-	[34]
↓ Cost	↑ Return on investment	Electricity	[133]	-	-
↓ Electricity cost	None	Electricity	[124]	[144]	-
↓ Electricity cost	↑ Total welfare	Electricity	[93]	-	-
↓ Electricity cost	↑ Total welfare	Flexibility	[128]	[86]	-
↓ Electricity cost	↔ Grid constraints	Electricity	[84]	-	-
↓ Electricity cost	↓ Cost	Flexibility	[53]	-	-
↓ Electricity cost	Fair cost distribution	Flexibility	[142]	-	-
↓ Grid imbalance	None	Electricity	[164]	[147]	-
↓ Grid imbalance	None	Flexibility	-	[46, 149]	-
↓ Grid imbalance	↑ Total welfare	Electricity	[73, 121]	[45]	-
↓ Grid imbalance	↑ Total welfare	Flexibility	-	[47, 49]	-
↓ Grid imbalance	↓ Electricity cost	Electricity	-	[160]	-
↓ Grid imbalance	↓ Cost	Electricity	[131]	-	-
↓ Grid imbalance	↓ Cost	Flexibility	[29]	[88]	-
↓ Grid imbalance	↔ Grid constraints	Flexibility	[41]	[79]	-
↓ Grid imbalance	↑ Profit	Electricity	[75]	-	-
↓ Grid imbalance	↑ Profit	Flexibility	-	[105]	-
↓ Grid imbalance	↓ Grid dependence	Flexibility	-	[107]	-
↔ Grid constraints	↑ Total welfare	Electricity	[132]	[61]	-
↔ Grid constraints	↓ Cost	Flexibility	-	[87]	-
↑ Flexible demand use	↑ Total welfare	Flexibility	[33, 101]	-	-
↑ Self-consumption	None	Flexibility	-	-	[77]
↑ Self-consumption	↓ Cost	Flexibility	-	[99]	-
↓ Grid dependence	↑ Self-consumption	Electricity	[163]	-	-
↓ Peak load	↔ Grid constraints	Flexibility	-	[76]	-
↑ Ancillary services	↔ Grid constraints	Electricity	-	[115]	-
↔ User preferences	None	Electricity	-	-	[44]
↑ DER use	↑ Profit	Electricity	-	[57]	-

Legend: ↑ Increase; ↓ Reduce; ↔ Respect

Table A.7: Market participants

Participant type	**P2P**	**TE**	**CSC**
Pure generators			
Entities which only generate energy	[32, 41–43, 74, 83, 89, 101, 114, 121–123, 132, 133, 137, 138, 141]	[45, 46, 50, 51, 57, 61, 64, 66, 67, 86, 88, 94, 103–105, 107, 108, 110, 113, 114, 116–120, 125, 136, 145–147]	[44, 77]
Pure consumers			
Entities which only consume energy	[21, 24, 25, 29, 31–33, 35, 36, 41–43, 53, 56, 70, 71, 74, 75, 80, 82, 83, 89, 92, 93, 101, 102, 111, 114, 121, 122, 124, 126, 131, 133, 134, 137–139, 150, 152, 163, 164]	[21, 45, 46, 48, 49, 59–63, 66, 69, 86–88, 94, 103–105, 107–109, 113, 114, 116, 117, 119, 120, 125, 136, 144–148, 157, 160, 162]	[44, 77, 102]
Prosumers			
Entities which consume and generate energy	[6, 21, 24–33, 35–37, 39–43, 52–56, 70–75, 80, 82–85, 90–93, 96, 100, 102, 106, 111, 114, 121–124, 126, 128, 132–135, 137, 139–142, 150–156, 159, 163, 164, 175]	[21, 37, 45, 47, 48, 50, 51, 57, 59, 62, 65, 67, 68, 78, 81, 86–88, 99, 104, 105, 107, 112, 114, 115, 117, 120, 125, 136, 144, 145, 147–149, 157, 158, 160–162]	[26, 34, 44, 77, 102]
Aggregator			
Entity that act on behalf of a group of smaller market participants	[21, 33, 36, 39–42, 73, 74, 85, 89, 93, 111, 114, 123, 124, 128, 132, 139, 151]	[21, 47, 49–51, 62, 63, 68, 76, 78, 79, 87, 94, 104, 105, 107, 108, 114, 116, 119, 120, 144–149, 160, 162]	-
Retailer			
Entity that connects to other large markets	[24, 26, 35, 36, 42, 52, 53, 55, 72, 80, 85, 101, 114, 124, 128, 131, 139, 152, 153, 159]	[48–51, 57, 60, 94, 104, 105, 112, 114, 146, 160, 162]	[26, 44]
Central market operator			
Single agent which runs the market or the platform	[26, 27, 30–33, 35, 37, 41, 43, 53, 55, 56, 72, 73, 80, 83, 92, 96, 101, 102, 106, 111, 114, 123, 138, 140, 142, 150–152, 155, 159, 163, 175]	[37, 45, 46, 48, 50, 51, 57, 59, 61, 65–68, 76, 78, 81, 86, 88, 99, 105, 107, 113, 114, 116, 119, 125, 145, 146, 148, 149, 157, 158, 160, 162]	[26, 34, 44, 102]
Grid operator			
Entity that operates the electricity network and interacts with the market	[21, 32, 37, 41, 71, 72, 83–85, 93, 100–102, 111, 114, 123, 131, 133, 141, 151, 152, 175]	[21, 37, 45, 47, 49–51, 58, 59, 61, 62, 64, 65, 67, 69, 76, 78, 79, 81, 86, 87, 94, 99, 103, 104, 110, 112–115, 118, 119, 136, 145–147, 158, 160, 162]	[102]

Table A.8: Controllable and non-controllable assets of P2P, CSC and TE markets

Type of control	**Type of assets**	**P2P**	**TE**	**CSC**
Controllable assets	Generation Storage Load	-	[45, 49, 57, 117, 118, 145]	-
	Storage Load EV	[91, 102]	[50, 59, 68, 79, 107]	[102]
	Generation Storage	[114, 133]	[67, 110, 114, 125, 143]	-
	Storage Load	[21, 29, 33, 39, 43, 90, 106, 121, 128, 131]	[21, 87, 99, 104, 105, 108, 113, 120, 148, 158]	[77]
	Load EV	[101, 152]	[103, 109]	-
	Generation Load	[132]	[78, 88, 116, 119]	[44]
	Storage EV	[54, 135]	[47]	[34]
	Generation	[42, 141, 153]	[61, 64, 66, 86, 94, 112]	-
	Storage	[26–28, 53, 55, 72, 74, 82, 85, 92, 93, 96, 126, 134, 150, 155, 159, 163]	[115, 144, 147]	[26]
	Load	[6, 36, 52, 111, 124, 138, 142]	[46, 51, 69, 160]	-
	EV	[73, 151]	[60, 62, 63, 76, 149]	-
	Other	[40, 41, 83, 137, 175]	[136]	-
Non-controllable assets	PV Other	[29, 56, 114, 121, 134, 159]	[57, 61, 64, 81, 104, 113, 114, 117]	[77]
	PV	[6, 21, 24–28, 30, 31, 33, 35, 36, 53, 55, 71, 72, 80, 82, 85, 90–92, 96, 100–102, 106, 123, 126, 128, 132, 133, 135, 139, 150, 152–154, 163]	[21, 47, 50, 59, 67, 68, 88, 108, 115, 118, 144, 147, 148, 157, 158, 161]	[26, 44, 102]
	Other	[43, 52, 74]	[45, 60, 94, 105, 120, 125, 143, 149]	-

Table A.9: Types of grid model

Grid model	**P2P**			**TE**		
	Grid Constraints	**Power Loss**	**Other**	**Grid Constraints**	**Power Loss**	**Other**
IEEE 13 bus	[52, 75, 111]	-	-	[50, 76, 92, 125]	[50, 76, 125]	-
IEEE 14 bus	[56]	-	[35]	-	-	-
IEEE 24 bus	-	-	-	[105]	[105]	-
IEEE 30 bus	[33]	-	-	[61]	[61]	-
IEEE 33 bus	[128]	-	-	[112, 160]	[112, 160]	-
IEEE 37 bus	-	-	-	[104, 107, 109, 161]	[109, 161]	-
IEEE 39 bus	[84]	[84]	-	-	-	-
IEEE 55 bus*	[96, 132, 154]	[96, 154]	-	[47]	[47]	-
IEEE 69 bus	-	-	-	[87, 113]	[87, 113]	-
IEEE 118 bus	-	-	-	[105]	[105]	-
IEEE 123 bus	[28, 33, 128]	-	-	[64, 76, 160, 161]	[64, 76, 160, 161]	-
ISO 5-bus**	-	-	-	[51]	[51]	-
CIGRE 6 bus***	[6]	-	-	-	-	-
CIGRE 15 bus*	[41]	-	-	-	-	-
SCE 56 bus**	[175]	-	-	-	-	-
WECC 240 node***	-	-	-	[78]	[78]	-
PJM 5 bus	-	-	-	[103, 104]	[103]	-
Real Network	[126, 140]	[126, 140]	[31]	[62]	-	[162]
Simulation Case	[42, 134]	[42, 134]	-	[81, 86, 104, 115, 120]	[115, 120]	[104, 110, 119, 144]

*: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

Appendix B. 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 [23]. 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 B.10 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?
	Country link	Free text	Is the paper about a specific country?

Table B.10: Data extraction table code book