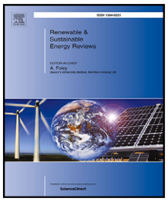
Renewable and Sustainable Energy Reviews 162 (2022) 112403

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser



Peer-to-peer, community self-consumption, and transactive energy: A systematic literature review of local energy market models

Timothy Capper [a,*,1], Anna Gorbatcheva [b,1], Mustafa A. Mustafa [c,d], Mohamed Bahloul [e], Jan Marc Schwidtal [f], Ruzanna Chitchyan [g], Merlinda Andoni [h,i], Valentin Robu [j,k], Mehdi Montakhabi [l], Ian J. Scott [m], Christina Francis [n], Tanaka Mbavarira [o], Juan Manuel Espana [p], Lynne Kiesling [q]

[a] *Tyndall Centre for Climate Change Research, School of Engineering, The University of Manchester, Oxford Road, Manchester, M13 9PL, United Kingdom*
[b] *Energy Institute, University College London, 14 Upper Woburn Place, London, WC1H 0NN, United Kingdom*
[c] *Department of Computer Science, The University of Manchester, Oxford Road, Manchester, M13 9PL, United Kingdom*
[d] *imec-COSIC, KU Leuven, Kasteelpark Arenberg 10, bus 2452, Leuven-Heverlee, B-3001, Belgium*
[e] *International Energy Research Centre, Tyndall National Institute, Cork, Ireland*
[f] *Department of Industrial Engineering, University of Padua, Via Giovanni Gradengio 6/a, Padova (PD), 35131, Italy*
[g] *Department of Computer Science, University of Bristol, Bristol, BS8 1TH, United Kingdom*
[h] *Smart Systems Group, School of Engineering and Physical Sciences, Heriot-Watt University, Edinburgh, EH14 4AS, United Kingdom*
[i] *James Watt School of Engineering, University of Glasgow, Glasgow, United Kingdom*
[j] *CWI, National Research Institute for Mathematics and Computer Science, Amsterdam, 1098XG, Netherlands*
[k] *Algorithmics Group, EEMCS, Delft University of Technology (TU Delft), 2628 XE Delft, Netherlands*
[l] *imec-SMIT, Vrije Universiteit Brussel, Pleinlaan 9, Brussels, 1050, Belgium*
[m] *NOVA Information Management School (NOVA IMS), Universidade Nova de Lisboa, Campus de Campolide, Lisbon, 1070-312, Portugal*
[n] *School of Engineering, University of Edinburgh, Edinburgh, EH9 3DW, United Kingdom*
[o] *Institute for Innovation and Technology Management, Lucerne University of Applied Sciences & Arts, Horw, 6048, Switzerland*
[p] *Universidad EIA, Vda. El Penasco, Envigado, Antioquia, Colombia*
[q] *University of Colorado-Denver, Denver, United States*

ARTICLE INFO

Keywords:
Peer-to-peer
Community self-consumption
Transactive energy
Market model
Electricity trading
Energy trading
Smart grid
Local energy market
Prosumer

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.

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

---

* Corresponding author.
E-mail address: timothy.capper@manchester.ac.uk (T. Capper).

[1] TC and AG have contributed equally to this work.

https://doi.org/10.1016/j.rser.2022.112403
Received 19 November 2021; Received in revised form 17 March 2022; Accepted 24 March 2022

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

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. [12] review market designs for local energy trading, focusing on scalability, overheads, and how they address grid constraints. [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, [14] classify and organise the literature on market designs and clearing methods, with a focus on local flexibility markets. [15] review LEMs focusing on four key attributes of the market: scope, modelling assumptions, objectives, and mechanisms. [16] review consumer-centric electricity markets, integrating the behaviour of all market participants, not only prosumers. [17] review P2P market designs, as well as trading platforms, physical and ICT infrastructure, social science perspectives and policy implications. [18] analyse trading platforms, blockchain, game theory, simulations, optimisation methods and algorithms used in P2P markets. [19] focus on optimisation models used in P2P markets, providing a comprehensive taxonomy. [20] provide a systematic review of how blockchain technology is used in the energy sector. Similarly, [21] explore the application of distributed ledger technology in TE markets, experimenting with different consensus mechanisms. [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 ‘Data Availability’.

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.

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). Fig. 1 shows flowcharts for each of the archetypal market designs. In some cases, such as a futures market (Fig. 1(a)), a single price formation mechanism is used. Whereas in other market designs, such as a mixed decentralised/centralised market (Fig. 1(c)), 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. Fig. 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]. Fig. 1(a) 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. Fig. 1(b) 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

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]

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. Fig. 1(c) 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. Fig. 1(d) 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. Fig. 1(e) 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. Fig. 1(f) shows an archetypal flowchart for a market settled after the fact.

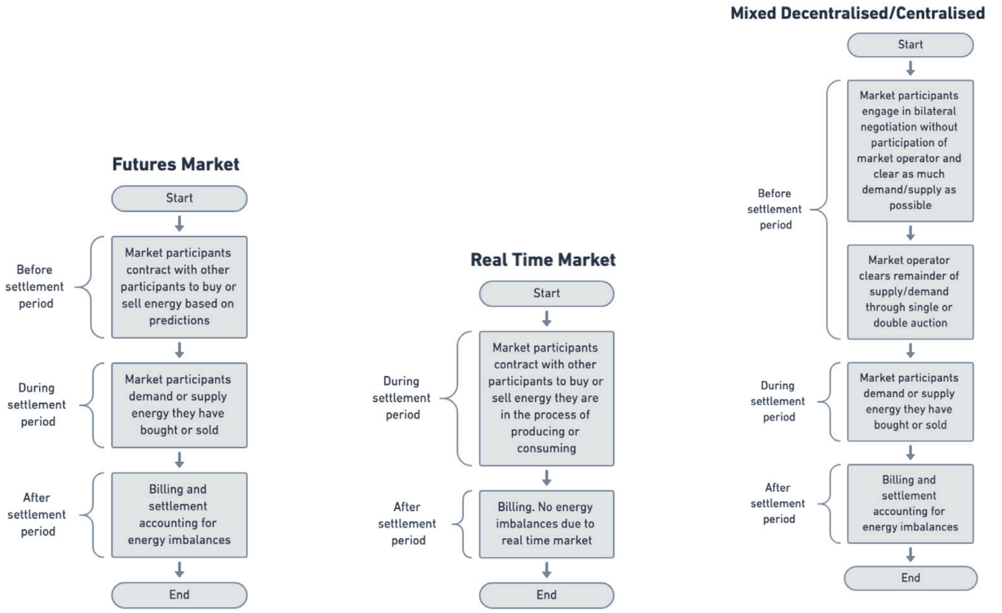
3.3. *Price formation mechanism*

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, 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]. Fig. 3(a) shows a flowchart for a typical single auction price formation mechanism.

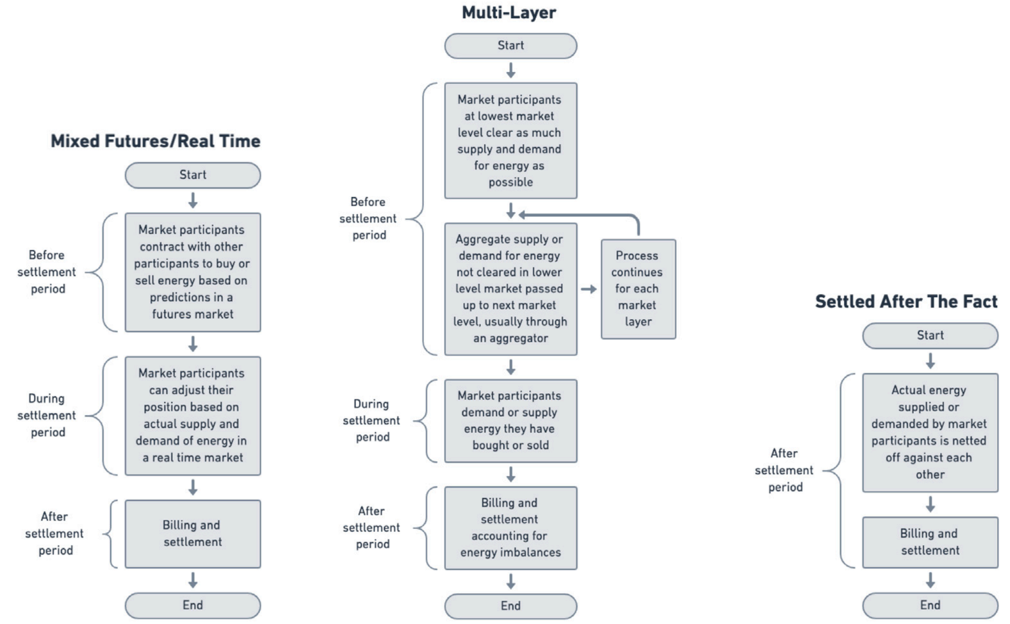
Double auction: The double auction is a common market institution in P2P, CSC and TE energy systems. Twenty-five percent of the 139



(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

Fig. 1. Market design flowcharts.

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 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]. Fig. 3(b) 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

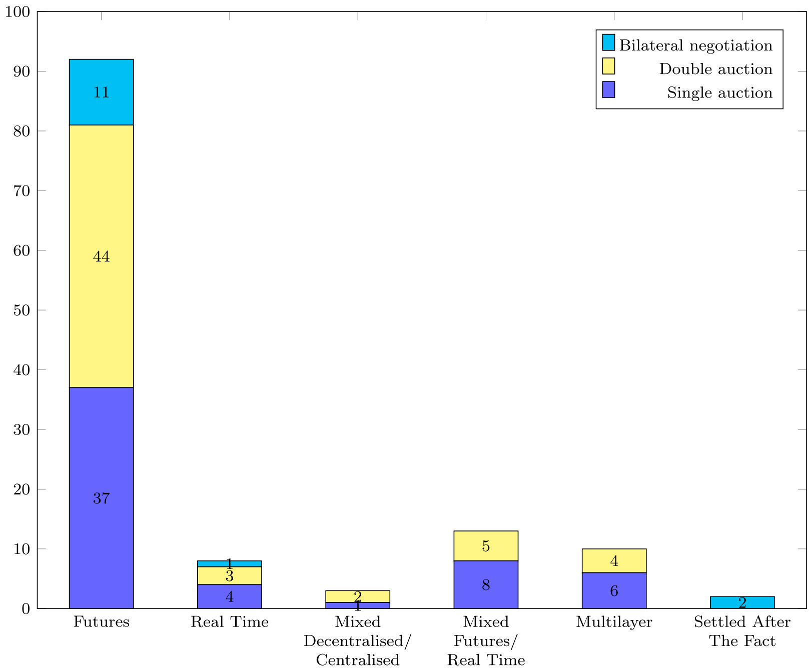
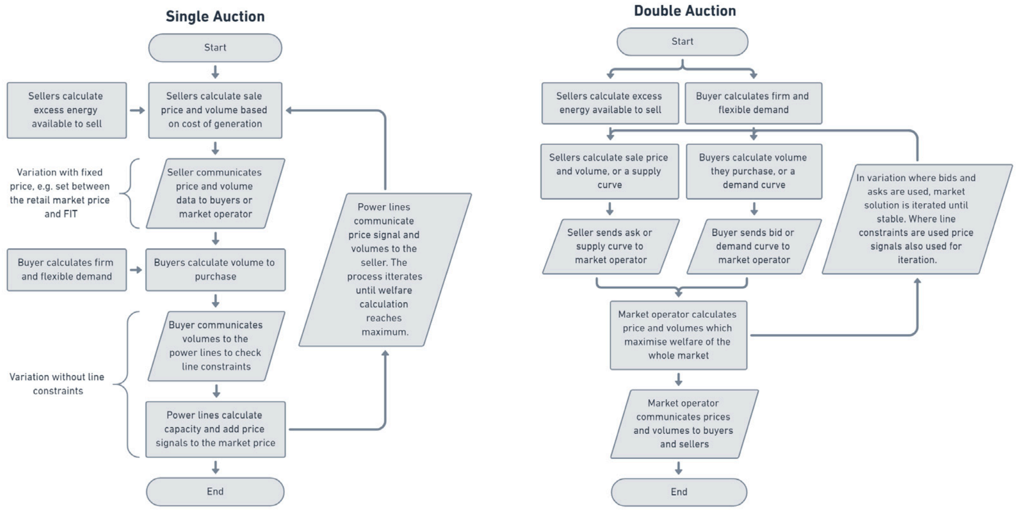
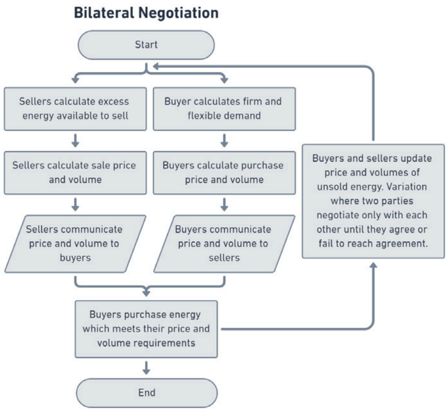


Fig. 2. Number of markets using each market design and price formation mechanism.



(a) Single auction

(b) Double auction



(c) Bilateral trading

Fig. 3. Price formation mechanism flowcharts.

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. Fig. 3(c) 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.

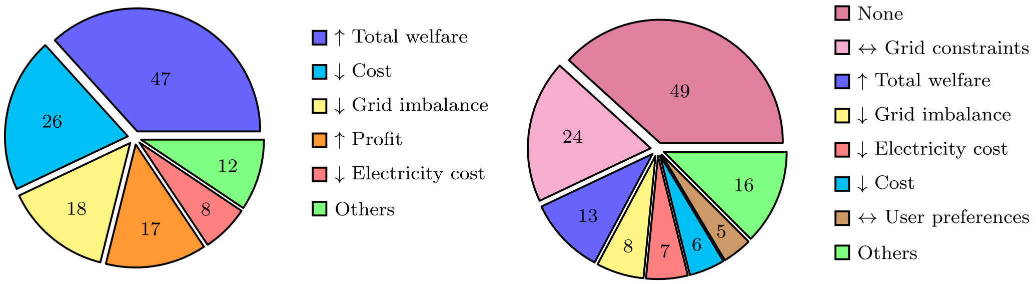
3.4.2. Benefits to market participants

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]. Fig. 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). Fig. 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 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



(a) Core need

(b) Secondary need

Fig. 4. Needs of market participants (↑ Increase; ↓ Reduce; ↔ Respect).

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.

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. Fig. 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.

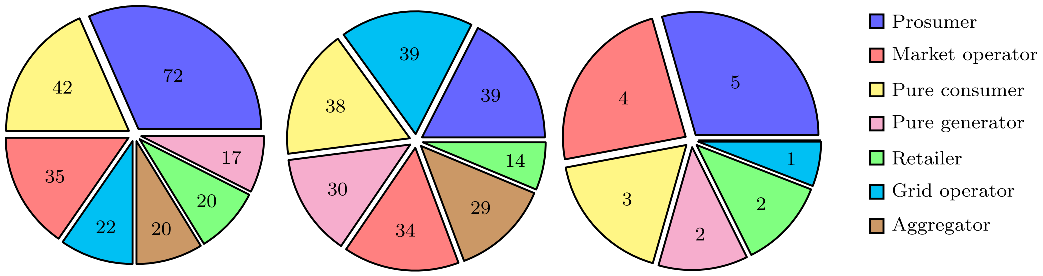
In TE markets, grid operators and prosumers play the most significant role. Both are represented in 64% of papers. They are closely followed by pure consumers, in 62% of markets. Fifty-five percent of

---

[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.



(a) P2P

(b) TE

(c) CSC

Fig. 5. Types of market participants.

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 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.

Assets participating in markets directly and indirectly (e.g. through a home energy manager) were considered in this analysis. Fig. 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. Fig. 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].

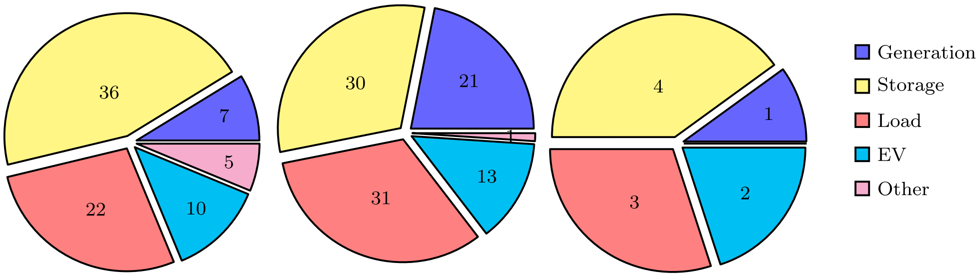
3.6. Market scale

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

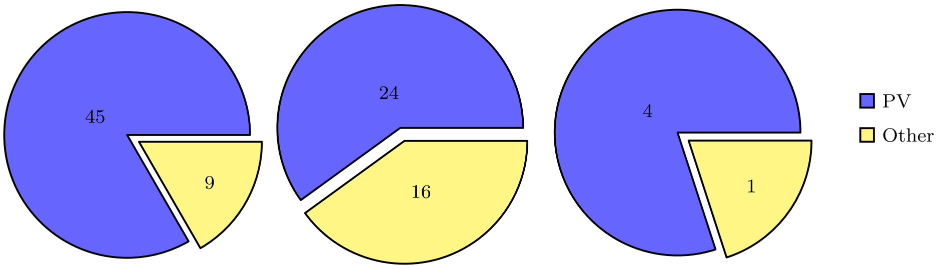
This section focuses on analysing the size and scale of the markets in terms of the number of participants involved. Where multiple markets have been tested, the one with the highest number of participants was included in this analysis. An overview of the number of papers and size of the markets is given in Fig. 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.



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

Fig. 6. Types of controllable market assets.



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

Fig. 7. Types of non-controllable market assets.

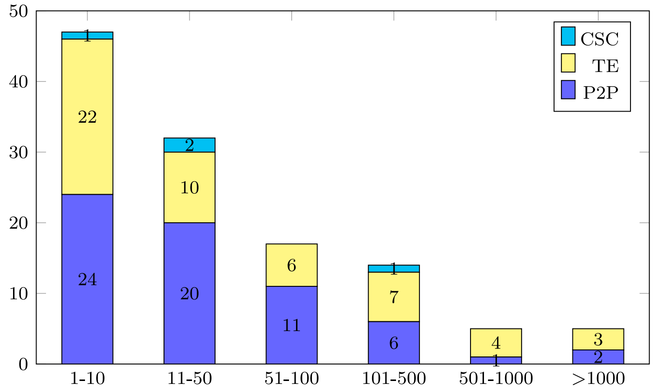


Fig. 8. Number of nodes/participants in the market.

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.

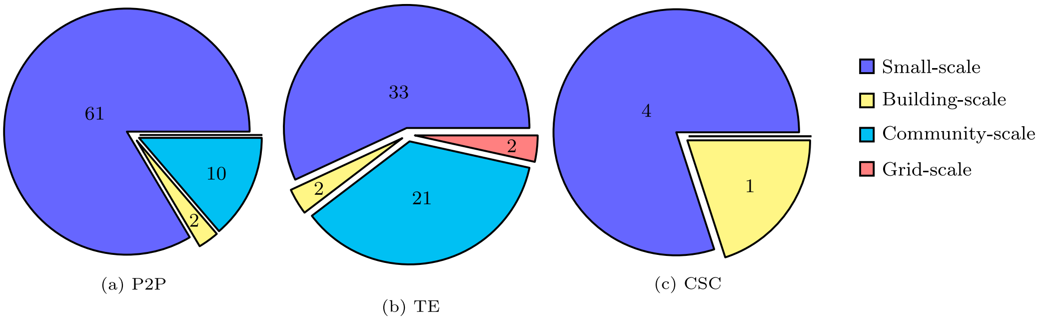
3.6.2. Size of market participants

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 Fig. 9. Table 3 provides the associated references.

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

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]	–



(a) P2P

(b) TE

(c) CSC

Fig. 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]	–

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 [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

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]	–	–	–

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 s 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 s) and that was also the only paper to model a gate closure of less than one minute (20 s).

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 min, the smallest gate closure is 15 minutes [75,141], and they go up to one day [59,100,123,153]. This trend continues 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.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The completed data extraction table [175] which formed the basis of the analysis presented in this paper is available at https://doi.org/10.48420/16930768.

Acknowledgements

This publication is part of the work of the Global Observatory on Peer-to-Peer, Community Self-Consumption and Transactive Energy Models (GO-P2P), a task of the User-Centred Energy Systems Technology Collaboration Programme (UsersTCP), run under the auspices of the International Energy Agency (IEA). GO-P2P benefits from the support of Australia, Belgium, Ireland, Italy, the Netherlands, Switzerland, the United Kingdom and the United States.

The author TC received financial support from the EPSRC (grant number EP/L016141/1) through the Power Networks Centre for Doctoral Training.

The author AG received funding from the EPSRC Centre for Doctoral Training in Energy Demand (LoLo), grant numbers EP/L01517X/1 and EP/H009612/1.

The author MAM received funding from the EPSRC through the project EnnCore EP/T026995/1, Flemish Government through the FWO SBO project SNIPPET S007619, and The University of Manchester through DKO Fellowship.

The author MB would like to acknowledge the support of the Department of the Environment, Climate and Communications (DECC) and the Sustainable Energy Authority of Ireland for the GO-P2P project.

The author RC received funding from the EPSRC and InnovateUK co-funded EnergyREV project (grant number EP/S031863/1).

The author MA recieved funding from the EPSRC through the National Centre for Energy Systems Integration (CESI) (grant number EP/P001173/1) and the DecarbonISation PAThways for Cooling and Heating (DISPATCH) project (grant number EP/V042955/1).

The author VR received funding from the European Union's Horizon 2020 programme under the Marie Sklodowska-Curie TESTBED2 project (grant number 872172).

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]	[123,174]	[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	[6,27,28,52,56,70,89,135,139,151,153,154,174]	[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]	–	–

(*continued on next page*)

The author MM recieved funding from the Flemish Government through the FWO SBO SNIPPET project (grant number S007619).

The author IJS recieved funding from the European Regional Development Fund through the Operational Programme for Competitiveness and Internationalization (COMPETE 2020), the Lisbon Portugal Regional Operational Program (LISBOA 2020), and the PRO-FCT under the CMU Portugal programme through the BEE2WasteCrypto project (grant number IDT-COP 45933).

The author JME recieved funding from the Royal Academy of Engineering through the Transforming Systems Through Partnerships programme (grant number TSP2021_100067).

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

Table A.6 (*continued*).

Core need	Secondary need	Commodity	P2P	TE	CSC
↓ 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	[6,21,24–33,35–37,39–43,52–56,70–75,80,82–85,90–93,96,100,102,106,111,114,121–124,126,128,132–135,137,139–142,150–156,159,163,164,174]	[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	[26,27,30–33,35,37,41,43,53,55,56,72,73,80,83,92,96,101,102,106,111,114,123,138,140,142,150–152,155,159,163,174]	[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	[21,32,37,41,71,72,83–85,93,100–102,111,114,123,131,133,141,151,152,174]	[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	[40,41,83,137,174]	[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[a]	[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[b]	–	–	–	[51]	[51]	–
CIGRE 6 bus[c]	[6]	–	–	–	–	–
CIGRE 15 bus[d]	[41]	–	–	–	–	–
SCE 56 bus[e]	[174]	–	–	–	–	–
WECC 240 node[f]	–	–	–	[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]

[a] European Low Voltage Test Feeder.
[b] ISO 5-bus transmission test system.
[c] CIGRE Benchmark LV Microgrid network.
[d] CIGRE 15bus European benchmark.
[e] Southern California Edison (SCE) 56-bus test feeder.
[f] CAISO-240 node WECC.

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

Table B.10
Data extraction table code book.

	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 respective 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 h, 15 min.
	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.

(*continued on next page*)

Table B.10 (*continued*).

	Data extraction field	Data type	Description
	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?

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.

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 'Data Availability'. 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.

References

[1] International Renewable Energy Agency. Global energy transformation: A roadmap to 2050 (2019 edition). 2019, URL https://www.irena.org/publications/2019/Apr/Global-energy-transformation-A-roadmap-to-2050-2019Edition.

[2] United Nations Framework Convention on Climate Change. Paris agreement. Paris; 2015, URL https://unfccc.int/sites/default/files/english_paris_agreement.pdf.

[3] International Energy Agency. Net zero by 2050: A roadmap for the global energy sector. Paris; 2021, URL https://www.iea.org/reports/net-zero-by-2050.

[4] Hvelplund F. Renewable energy and the need for local energy markets. Energy 2006;31:2293–302. http://dx.doi.org/10.1016/j.energy.2006.01.016.

[5] Mengelkamp E, Notheisen B, Beer C, Dauer D, Weinhardt C. A blockchain-based smart grid: towards sustainable local energy markets. Comput Sci - Res Develop 2017;33:207–14. http://dx.doi.org/10.1007/s00450-017-0360-9.

[6] Zhang C, Wu J, Zhou Y, Cheng M, Long C. Peer-to-peer energy trading in a microgrid. Appl Energy 2018;220. http://dx.doi.org/10.1016/j.apenergy.2018.03.010.

[7] European Parliament. Directive (EU) 2018/2001 of the European parliament and of the council of 11 december 2018 on the promotion of the use of energy from renewable sources (recast). 2018, URL https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2018.328.01.0082.01.ENG.

[8] Dorian F, Andreas T, Josh R, Stanislas d, Gubina A. Collective self-consumption and energy communities: Overview of emerging regulatory approaches in europe. 2019, URL https://www.compile-project.eu/.

[9] Frieden D, Tuerk A, Neumann C, D'herbemont JRS, Roberts J, Eu R, Furlan M, Herenčić L, Pavlin B, Marouço R, Primo N, Antunes AR, Rónai B. Collective self-consumption and energy communities: Trends and challenges in the transposition of the EU framework. 2020, URL https://www.rescoop.eu/uploads/rescoop/downloads/Collective-self-consumption-and-energy-communities.-Trends-and-challenges-in-the-transposition-of-the-EU-framework.pdf.

[10] Chen S, Liu CC. From demand response to transactive energy: state of the art. J Mod Power Syst Clean Energy 2017;5:10–9. http://dx.doi.org/10.1007/s40565-016-0256-x.

[11] The GridWise Architecture Council. GridWise Transactive energy framework version 1.0. 2015, URL https://www.gridwiseac.org/pdfs/te_framework_report_pnnl-22946.pdf.

[12] Khorasany M, Mishra Y, Ledwich G. Market framework for local energy trading : A review of potential designs and market clearing approaches. IET Gener, Trans Distrib 2018. http://dx.doi.org/10.1049/iet-gtd.2018.5309.

[13] Tushar W, Saha TK, Yuen C, Smith D, Poor HV. Peer-to-peer trading in electricity networks: An overview. IEEE Trans Smart Grid 2020;11:3185–200. http://dx.doi.org/10.1109/TSG.2020.2969657.

[14] Jin X, Wu Q, Jia H. Local flexibility markets: Literature review on concepts, models and clearing methods. Appl Energy 2020;261. http://dx.doi.org/10.1016/j.apenergy.2019.114387.

[15] Tsaousoglou G, Giraldo JS, Paterakis NG. Market mechanisms for local electricity markets: A review of models, solution concepts and algorithmic techniques. Renew Sustain Energy Rev 2022;156:111890. http://dx.doi.org/10.1016/j.rser.2021.111890.

[16] Sousa T, Soares T, Pinson P, Moret F, Baroche T, Sorin E. Peer-to-peer and community-based markets: A comprehensive review. Renew Sustain Energy Rev 2019;104:367–78. http://dx.doi.org/10.1016/j.rser.2019.01.036.

[17] Zhou Y, Wu J, Long C, Ming W. State-of-the-art analysis and perspectives for peer-to-peer energy trading. Engineering 2020;6:739–53. http://dx.doi.org/10.1016/j.eng.2020.06.002.

[18] Soto EA, Bosman LB, Wollega E, Leon-Salas WD. Peer-to-peer energy trading: A review of the literature. Appl Energy 2021;283. http://dx.doi.org/10.1016/j.apenergy.2020.116268.

[19] Aggarwal S, Kumar N, Tanwar S, Alazab M. A survey on energy trading in the smart grid: Taxonomy, research challenges and solutions. IEEE Access 2021;9. http://dx.doi.org/10.1109/ACCESS.2021.3104354.

[20] Andoni M, Robu V, Flynn D, Abram S, Geach D, Jenkins D, McCallum P, Peacock A. Blockchain technology in the energy sector: A systematic review of challenges and opportunities. Renew Sustain Energy Rev 2019;100. http://dx.doi.org/10.1016/j.rser.2018.10.014.

[21] Siano P, Marco GD, Rolan A, Loia V. A survey and evaluation of the potentials of distributed ledger technology for peer-to-peer transactive energy exchanges in local energy markets. IEEE Syst J 2019;13. http://dx.doi.org/10.1109/JSYST.2019.2903172.

[22] Kirli D, Couraud B, Robu V, Salgado-Bravo M, Norbu S, Andoni M, Antonopoulos I, Negrete-Pincetic M, Flynn D, Kiprakis A. Smart contracts in energy systems: A systematic review of fundamental approaches and implementations. Renew Sustain Energy Rev 2022;158:112013. http://dx.doi.org/10.1016/j.rser.2021.112013.

[23] Wieringa R, Engelsman W, Gordijn J, Ionita D. A business ecosystem architecture modeling framework. In: Proceedings - 21st ieee conference on business informatics, CBI 2019. 1, Institute of Electrical and Electronics Engineers Inc.; 2019, p. 147–56. http://dx.doi.org/10.1109/CBI.2019.00024.

[24] Klein LP, Krivoglazova A, Matos L, Landeck J, de Azevedo M. A novel peer-to-peer energy sharing business model for the portuguese energy market. Energies 2019;13. http://dx.doi.org/10.3390/en13010125.

[25] Mengelkamp E, Gärttner J, Rock K, Kessler S, Orsini L, Weinhardt C. Designing microgrid energy markets. Appl Energy 2018;210. http://dx.doi.org/10.1016/j.apenergy.2017.06.054.

[26] Rodrigues DL, Ye X, Xia X, Zhu B. Battery energy storage sizing optimisation for different ownership structures in a peer-to-peer energy sharing community. Appl Energy 2020;262. http://dx.doi.org/10.1016/j.apenergy.2020.114498.

[27] Yebiyo M, Mercado R, Gillich A, Chaer I, Day A, Paurine A. Novel economic modelling of a peer-to-peer electricity market with the inclusion of distributed energy storage—The possible case of a more robust and better electricity grid. The Electricity J 2020;33. http://dx.doi.org/10.1016/j.tej.2020.106709.

[28] Tushar W, Saha TK, Yuen C, Azim MI, Morstyn T, Poor HV, Niyato D, Bean R. A coalition formation game framework for peer-to-peer energy trading. Appl Energy 2020;261. http://dx.doi.org/10.1016/j.apenergy.2019.114436.

[29] Zepter JM, Lüth A, del Granado PC, Egging R. Prosumer integration in wholesale electricity markets: Synergies of peer-to-peer trade and residential storage. Energy Build 2019;184. http://dx.doi.org/10.1016/j.enbuild.2018.12.003.

[30] Tushar W, Saha TK, Yuen C, Morstyn T, Nahid-Al-Masood, Poor HV, Bean R. Grid influenced peer-to-peer energy trading. IEEE Trans Smart Grid 2020;11. http://dx.doi.org/10.1109/TSG.2019.2937981.

[31] Neagu B-C, Ivanov O, Grigoras G, Gavrilas M. A new vision on the prosumers energy surplus trading considering smart peer-to-peer contracts. Mathematics 2020;8. http://dx.doi.org/10.3390/math8020235.

[32] Wang N, Xu W, Xu Z, Shao W. Peer-to-peer energy trading among microgrids with multidimensional willingness. Energies 2018;11. http://dx.doi.org/10.3390/en11123312.

[33] Liu W, Qi D, Wen F. Intraday residential demand response scheme based on peer-to-peer energy trading. IEEE Trans Ind Inf 2020;16:1823–35. http://dx.doi.org/10.1109/TII.2019.2929498.

[34] Heinisch V, Odenberger M, Göransson L, Johnsson F. Organizing prosumers into electricity trading communities: Costs to attain electricity transfer limitations and self-sufficiency goals. Int J Energy Res 2019;43:7021–39. http://dx.doi.org/10.1002/er.4720.

[35] Amin W, Huang Q, Afzal M, Khan AA, Umer K, Ahmed SA. A converging non-cooperative & cooperative game theory approach for stabilizing peer-to-peer electricity trading. Electr Power Syst Res 2020;183. http://dx.doi.org/10.1016/j.epsr.2020.106278.

[36] Wang Y, Wu X, Li Y, Yan R, Tan Y, Qiao X, Cao Y. Autonomous energy community based on energy contract. IET Gener, Trans Distrib 2020;14. http://dx.doi.org/10.1049/iet-gtd.2019.1223.

[37] Khorasany M, Mishra Y, Ledwich G. Hybrid trading scheme for peer-to-peer energy trading in transactive energy markets. IET Gener, Trans Distrib 2020;14. http://dx.doi.org/10.1049/iet-gtd.2019.1233.

[38] Brown D, Hall S, Davis ME. Prosumers in the post subsidy era: an exploration of new prosumer business models in the UK. Energy Policy 2019;135. http://dx.doi.org/10.1016/j.enpol.2019.110984.

[39] Zhang J, Hu C, Zheng C, Rui T, Shen W, Wang B. Distributed peer-to-peer electricity trading considering network loss in a distribution system. Energies 2019;12. http://dx.doi.org/10.3390/en12224318.

[40] Lyu, Xu, Wang, Fu, Xu. A two-layer interactive mechanism for peer-to-peer energy trading among virtual power plants. Energies 2019;12. http://dx.doi.org/10.3390/en12193628.

[41] Troncia M, Galici M, Mureddu M, Ghiani E, Pilo F. Distributed ledger technologies for peer-to-peer local markets in distribution networks. Energies 2019;12. http://dx.doi.org/10.3390/en12173249.

[42] Sorin E, Bobo L, Pinson P. Consensus-based approach to peer-to-peer electricity markets with product differentiation. IEEE Trans Power Syst 2019;34. http://dx.doi.org/10.1109/TPWRS.2018.2872880.

[43] Hou W, Guo L, Ning Z. Local electricity storage for blockchain-based energy trading in industrial internet of things. IEEE Trans Ind Inf 2019;15. http://dx.doi.org/10.1109/TII.2019.2900401.

[44] Moret F, Pinson P. Energy collectives: A community and fairness based approach to future electricity markets. IEEE Trans Power Syst 2019;34. http://dx.doi.org/10.1109/TPWRS.2018.2808961.

[45] Nezamabadi H, Vahidinasab V. Microgrids bidding strategy in a transactive energy market. Sci Iranica 2019. http://dx.doi.org/10.24200/sci.2019.54148.3616.

[46] Prinsloo G, Mammoli A, Dobson R. Customer domain supply and load coordination: A case for smart villages and transactive control in rural off-grid microgrids. Energy 2017;135. http://dx.doi.org/10.1016/j.energy.2017.06.106.

[47] Morstyn T, Teytelboym A, McCulloch MD. Designing decentralized markets for distribution system flexibility. IEEE Trans Power Syst 2019;34. http://dx.doi.org/10.1109/TPWRS.2018.2886244.

[48] Chen T, Su W. Indirect customer-to-customer energy trading with reinforcement learning. IEEE Trans Smart Grid 2019;10. http://dx.doi.org/10.1109/TSG.2018.2857449.

[49] Good N, Cesena EAM, Heltorp C, Mancarella P. A transactive energy modelling and assessment framework for demand response business cases in smart distributed multi-energy systems. Energy 2019;184. http://dx.doi.org/10.1016/j.energy.2018.02.089.

[50] Palacios JP, Samper ME, Vargas A. Dynamic transactive energy scheme for smart distribution networks in a latin American context. IET Gener, Trans Distrib 2019;13. http://dx.doi.org/10.1049/iet-gtd.2018.5272.

[51] Nguyen HT, Battula S, Takkala RR, Wang Z, Tesfatsion L. An integrated transmission and distribution test system for evaluation of transactive energy designs. Appl Energy 2019;240. http://dx.doi.org/10.1016/j.apenergy.2019.01.178.

[52] Khorasany M, Mishra Y, Ledwich G. A decentralized bilateral energy trading system for peer-to-peer electricity markets. IEEE Trans Ind Electron 2020;67. http://dx.doi.org/10.1109/TIE.2019.2931229.

[53] Lüth A, Zepter JM, del Granado PC, Egging R. Local electricity market designs for peer-to-peer trading: The role of battery flexibility. Appl Energy 2018;229. http://dx.doi.org/10.1016/j.apenergy.2018.08.004.

[54] Yang X, Wang G, He H, Lu J, Zhang Y. Automated demand response framework in ELNs: Decentralized scheduling and smart contract. IEEE Trans Syst, Man, Cybern: Syst 2020;50. http://dx.doi.org/10.1109/TSMC.2019.2903485.

[55] Basnet A, Zhong J. Integrating gas energy storage system in a peer-to-peer community energy market for enhanced operation. Int J Electr Power Energy Syst 2020;118. http://dx.doi.org/10.1016/j.ijepes.2019.105789.

[56] Cadre HL, Jacquot P, Wan C, Alasseur C. Peer-to-peer electricity market analysis: From variational to generalized Nash equilibrium. European J Oper Res 2020;282. http://dx.doi.org/10.1016/j.ejor.2019.09.035.

[57] Marzband M, Fouladfar MH, Akorede MF, Lightbody G, Pouresmaeil E. Framework for smart transactive energy in home-microgrids considering coalition formation and demand side management. Sustainable Cities Soc 2018;40. http://dx.doi.org/10.1016/j.scs.2018.04.010.

[58] Hao H, Corbin CD, Kalsi K, Pratt RG. Transactive control of commercial buildings for demand response. IEEE Trans Power Syst 2017;32. http://dx.doi.org/10.1109/TPWRS.2016.2559485.

[59] Nizami MSH, Hossain MJ, Fernandez E. Multiagent-based transactive energy management systems for residential buildings with distributed energy resources. IEEE Trans Ind Inf 2020;16. http://dx.doi.org/10.1109/TII.2019.2932109.

[60] Tan X, Leon-Garcia A, Wu Y, Tsang DH. Posted-price retailing of transactive energy: An optimal online mechanism without prediction. IEEE J Sel Areas Commun 2020;38:5–16. http://dx.doi.org/10.1109/JSAC.2019.2951930.

[61] Rayati M, Goghari SA, Gheidari ZN, Ranjbar AM. An optimal and decentralized transactive energy system for electrical grids with high penetration of renewable energy sources. Int J Electr Power Energy Syst 2019;113:850–60. http://dx.doi.org/10.1016/j.ijepes.2019.06.017.

[62] Hu J, Yang G, Ziras C, Kok K. Aggregator operation in the balancing market through network-constrained transactive energy. IEEE Trans Power Syst 2019;34:4071–80. http://dx.doi.org/10.1109/TPWRS.2018.2874255.

[63] Liu Z, Wu Q, Ma K, Shahidehpour M, Xue Y, Huang S. Two-stage optimal scheduling of electric vehicle charging based on transactive control. IEEE Trans Smart Grid 2019;10. http://dx.doi.org/10.1109/TSG.2018.2815593.

[64] Liu W, Zhan J, Chung CY. A novel transactive energy control mechanism for collaborative networked microgrids. IEEE Trans Power Syst 2019;34. http://dx.doi.org/10.1109/TPWRS.2018.2881251.

[65] Moazeni S, Defourny B. Optimal control of energy storage under random operation permissions. IISE Trans 2018;50. http://dx.doi.org/10.1080/24725854.2017.1401756.

[66] Ghorani R, Fotuhi-Firuzabad M, Moeini-Aghtaie M. Optimal bidding strategy of transactive agents in local energy markets. IEEE Trans Smart Grid 2019;10. http://dx.doi.org/10.1109/TSG.2018.2878024.

[67] Chen Y, Hu M. Swarm intelligence–based distributed stochastic model predictive control for transactive operation of networked building clusters. Energy Build 2019;198. http://dx.doi.org/10.1016/j.enbuild.2019.06.010.

[68] Nizami M, Hossain M, Amin BR, Fernandez E. A residential energy management system with bi-level optimization-based bidding strategy for day-ahead bi-directional electricity trading. Appl Energy 2020;261. http://dx.doi.org/10.1016/j.apenergy.2019.114322.

[69] Lian J, Ren H, Sun Y, Hammerstrom DJ. Performance evaluation for transactive energy systems using double-auction market. IEEE Trans Power Syst 2019;34:4128–37. http://dx.doi.org/10.1109/TPWRS.2018.2875919.

[70] Hahnel UJ, Herberz M, Pena-Bello A, Parra D, Brosch T. Becoming prosumer: Revealing trading preferences and decision-making strategies in peer-to-peer energy communities. Energy Policy 2020;137. http://dx.doi.org/10.1016/j.enpol.2019.111098.

[71] Kuruseelan S, Vaithilingam C. Peer-to-peer energy trading of a community connected with an AC and DC microgrid. Energies 2019;12. http://dx.doi.org/10.3390/en12193709.

[72] Paudel A, Chaudhari K, Long C, Gooi HB. Peer-to-peer energy trading in a prosumer-based community microgrid: A game-theoretic model. IEEE Trans Ind Electron 2019;66. http://dx.doi.org/10.1109/TIE.2018.2874578.

[73] Kang J, Yu R, Huang X, Maharjan S, Zhang Y, Hossain E. Enabling localized peer-to-peer electricity trading among plug-in hybrid electric vehicles using consortium blockchains. IEEE Trans Ind Inf 2017;13. http://dx.doi.org/10.1109/TII.2017.2709784.

[74] Zhou S, Hu Z, Gu W, Jiang M, Zhang X-P. Artificial intelligence based smart energy community management: A reinforcement learning approach. CSEE J Power Energy Syst 2019. http://dx.doi.org/10.17775/CSEEJPES.2018.00840.

[75] Chen K, Lin J, Song Y. Trading strategy optimization for a prosumer in continuous double auction-based peer-to-peer market: A prediction-integration model. Appl Energy 2019;242. http://dx.doi.org/10.1016/j.apenergy.2019.03.094.

[76] Masood A, Hu J, Xin A, Sayed AR, Yang G. Transactive energy for aggregated electric vehicles to reduce system peak load considering network constraints. IEEE Access 2020;8:31519–29. http://dx.doi.org/10.1109/ACCESS.2020.2973284.

[77] Amato A, Martino BD, Scialdone M, Venticinque S. Distributed architecture for agents-based energy negotiation in solar powered micro-grids. Concurr Comput: Pract Exper 2016;28. http://dx.doi.org/10.1002/cpe.3757.

[78] Mukherjee M, Marinovici L, Hardy T, Hansen J. Framework for large-scale implementation of wholesale-retail transactive control mechanism. Int J Electr Power Energy Syst 2020;115. http://dx.doi.org/10.1016/j.ijepes.2019.105464.

[79] Nazir MS, Hiskens IA. A dynamical systems approach to modeling and analysis of transactive energy coordination. IEEE Trans Power Syst 2019;34. http://dx.doi.org/10.1109/TPWRS.2018.2834913.

[80] An J, Lee M, Yeom S, Hong T. Determining the peer-to-peer electricity trading price and strategy for energy prosumers and consumers within a microgrid. Appl Energy 2020;261. http://dx.doi.org/10.1016/j.apenergy.2019.114335.

[81] Li Z, Shahidehpour M, Alabdulwahab A, Al-Turki Y. Valuation of distributed energy resources in active distribution networks. The Electricity J 2019;32. http://dx.doi.org/10.1016/j.tej.2019.03.001.

[82] Etukudor C, Couraud B, Robu V, Früh WG, Flynn D, Okereke C. Automated negotiation for peer-to-peer electricity trading in local energy markets. Energies 2020;13. http://dx.doi.org/10.3390/en13040920.

[83] Leelasantitham A. A business model guideline of electricity utility systems based on blockchain technology in thailand: A case study of consumers, prosumers and SMEs. Wirel Pers Commun 2020;115. http://dx.doi.org/10.1007/s11277-020-07202-8.

[84] Baroche T, Pinson P, Latimier RLG, Ahmed HB. Exogenous cost allocation in peer-to-peer electricity markets. IEEE Trans Power Syst 2019;34. http://dx.doi.org/10.1109/TPWRS.2019.2896654.

[85] Chakraborty S, Baarslag T, Kaisers M. Automated peer-to-peer negotiation for energy contract settlements in residential cooperatives. Appl Energy 2020;259. http://dx.doi.org/10.1016/j.apenergy.2019.114173.

[86] Renani YK, Ehsan M, Shahidehpour M. Optimal transactive market operations with distribution system operators. IEEE Trans Smart Grid 2018;9. http://dx.doi.org/10.1109/TSG.2017.2718546.

[87] Faqiry MN, Wang L, Wu H. HEMS-Enabled transactive flexibility in real-time operation of three-phase unbalanced distribution systems. J Mod Power Syst Clean Energy 2019;7. http://dx.doi.org/10.1007/s40565-019-0553-2.

[88] Behboodi S, Chassin DP, Djilali N, Crawford C. Transactive control of fast-acting demand response based on thermostatic loads in real-time retail electricity markets. Appl Energy 2018;210. http://dx.doi.org/10.1016/j.apenergy.2017.07.058.

[89] Yu Y, Guo Y, Min W, Zeng F. Trusted transactions in micro-grid based on blockchain. Energies 2019;12. http://dx.doi.org/10.3390/en12101952.

[90] Li Y, Yang W, He P, Chen C, Wang X. Design and management of a distributed hybrid energy system through smart contract and blockchain. Appl Energy 2019;248. http://dx.doi.org/10.1016/j.apenergy.2019.04.132.

[91] Jing R, Xie MN, Wang FX, Chen LX. Fair P2P energy trading between residential and commercial multi-energy systems enabling integrated demand-side management. Appl Energy 2020;262. http://dx.doi.org/10.1016/j.apenergy.2020.114551.

[92] Nguyen S, Peng W, Sokolowski P, Alahakoon D, Yu X. Optimizing rooftop photovoltaic distributed generation with battery storage for peer-to-peer energy trading. Appl Energy 2018;228. http://dx.doi.org/10.1016/j.apenergy.2018.07.042.

[93] Long C, Wu J, Zhou Y, Jenkins N. Peer-to-peer energy sharing through a two-stage aggregated battery control in a community microgrid. Appl Energy 2018;226. http://dx.doi.org/10.1016/j.apenergy.2018.05.097.

[94] Pinto T, Faia R, Ghazvini MAF, Soares J, Corchado JM, Vale Z. Decision support for small players negotiations under a transactive energy framework. IEEE Trans Power Syst 2019;34. http://dx.doi.org/10.1109/TPWRS.2018.2861325.

[95] Elexon. Balancing & settlement code. 2020, URL https://www.elexon.co.uk/bsc-and-codes/balancing-settlement-code/.

[96] Morstyn T, McCulloch MD. Multiclass energy management for peer-to-peer energy trading driven by prosumer preferences. IEEE Trans Power Syst 2019;34. http://dx.doi.org/10.1109/TPWRS.2018.2834472.

[97] Hammerstrom DJ, Ambrosio R, Carlon TA, DeSteese JG, Horst GR, Kajfasz R, Kiesling LL, Michie P, Pratt RG, Yao M, Brous J, Chassin DP, Guttromson RT, Katipamula S, Le NT, Oliver TV, Thompson SE. Pacific northwest GridWise testbed demonstration projects; part I. Olympic peninsula project. Richland, WA: Pacific Northwest National Laboratory (PNNL); 2008, http://dx.doi.org/10.2172/926113.

[98] Easley D, Ledyard J. Theories of price formation and exchange in double oral auction markets. In: Friedman D, Rust J, editors. The Double Auction Market: Institutions, Theory, and Evidence. Reading, MA: Addison-Wesley; 1993, p. 63–98.

[99] El-Baz W, Tzscheutschler P, Wagner U. Integration of energy markets in microgrids: A double-sided auction with device-oriented bidding strategies. Appl Energy 2019;241. http://dx.doi.org/10.1016/j.apenergy.2019.02.049.

[100] Wang Z, Yu X, Mu Y, Jia H. A distributed peer-to-peer energy transaction method for diversified prosumers in urban community microgrid system. Appl Energy 2020;260. http://dx.doi.org/10.1016/j.apenergy.2019.114327.

[101] Zhang Z, Li R, Li F. A novel peer-to-peer local electricity market for joint trading of energy and uncertainty. IEEE Trans Smart Grid 2020;11. http://dx.doi.org/10.1109/TSG.2019.2933574.

[102] Zhou S, Zou F, Wu Z, Gu W, Hong Q, Booth C. A smart community energy management scheme considering user dominated demand side response and P2P trading. Int J Electr Power Energy Syst 2020;114. http://dx.doi.org/10.1016/j.ijepes.2019.105378.

[103] Melendez KA, Subramanian V, Das TK, Kwon C. Empowering end-use consumers of electricity to aggregate for demand-side participation. Appl Energy 2019;248. http://dx.doi.org/10.1016/j.apenergy.2019.04.092.

[104] Liu C, Zhou J, Pan Y, Li Z, Wang Y, Xu D, Ding Q, Luo Z, Shahidehpour M. Multi-period market operation of transmission-distribution systems based on heterogeneous decomposition and coordination. Energies 2019;12. http://dx.doi.org/10.3390/en12163126.

[105] Mohy-ud-din G, Muttaqi KM, Sutanto D. Transactive energy-based planning framework for VPPs in a co-optimised day-ahead and real-time energy market with ancillary services. IET Gener, Trans Distrib 2019;13. http://dx.doi.org/10.1049/iet-gtd.2018.5831.

[106] Alam MR, St-Hilaire M, Kunz T. Peer-to-peer energy trading among smart homes. Appl Energy 2019;238. http://dx.doi.org/10.1016/j.apenergy.2019.01.091.

[107] Nunna HSVSK, Srinivasan D. Multiagent-based transactive energy framework for distribution systems with smart microgrids. IEEE Trans Ind Inf 2017;13. http://dx.doi.org/10.1109/TII.2017.2679808.

[108] Babar M, Grela J, Ożadowicz A, Nguyen P, Hanzelka Z, Kamphuis I. Energy flexometer: Transactive energy-based internet of things technology. Energies 2018;11. http://dx.doi.org/10.3390/en11030568.

[109] Divshali PH, Choi B, Liang H, Söder L. Transactive demand side management programs in smart grids with high penetration of EVs. Energies 2017;10. http://dx.doi.org/10.3390/en10101640.

[110] Qiu J, Meng K, Zheng Y, Dong ZY. Optimal scheduling of distributed energy resources as a virtual power plant in a transactive energy framework. IET Gener, Trans Distrib 2017;11:3417–27. http://dx.doi.org/10.1049/iet-gtd.2017.0268.

[111] Lopez-Rodriguez I, Hernandez-Tejera M. Infrastructure based on supernodes and software agents for the implementation of energy markets in demand-response programs. Appl Energy 2015;158. http://dx.doi.org/10.1016/j.apenergy.2015.08.039.

[112] Wang Y, Huang Z, Shahidehpour M, Lai LL, Wang Z, Zhu Q. Reconfigurable distribution network for managing transactive energy in a multi-microgrid system. IEEE Trans Smart Grid 2020;11. http://dx.doi.org/10.1109/TSG.2019.2935565.

[113] Faqiry MN, Edmonds L, Wu H, Pahwa A. Distribution locational marginal price-based transactive day-ahead market with variable renewable generation. Appl Energy 2020;259. http://dx.doi.org/10.1016/j.apenergy.2019.114103.

[114] Moslehi K, Kumar ABR. Autonomous resilient grids in an IoT landscape vision for a nested transactive grid. IEEE Trans Power Syst 2019;34. http://dx.doi.org/10.1109/TPWRS.2018.2810134.

[115] Silvestre MLD, Gallo P, Ippolito MG, Musca R, Sanseverino ER, Tran QTT, Zizzo G. Ancillary services in the energy blockchain for microgrids. IEEE Trans Ind Appl 2019;55. http://dx.doi.org/10.1109/TIA.2019.2909496.

[116] Wang D, Hu Q, Jia H, Hou K, Du W, Chen N, Wang X, Fan M. Integrated demand response in district electricity-heating network considering double auction retail energy market based on demand-side energy stations. Appl Energy 2019;248. http://dx.doi.org/10.1016/j.apenergy.2019.04.050.

[117] Marzband M, Azarinejadian F, Savaghebi M, Pouresmaeil E, Guerrero JM, Lightbody G. Smart transactive energy framework in grid-connected multiple home microgrids under independent and coalition operations. Renew Energy 2018;126. http://dx.doi.org/10.1016/j.renene.2018.03.021.

[118] Chen Y, Hu M. Balancing collective and individual interests in transactive energy management of interconnected micro-grid clusters. Energy 2016;109. http://dx.doi.org/10.1016/j.energy.2016.05.052.

[119] Siano P, Sarno D, Straccia L, Marrazzo AT. A novel method for evaluating the impact of residential demand response in a real time distribution energy market. J Ambient Intell Humaniz Comput 2016;7. http://dx.doi.org/10.1007/s12652-015-0339-y.

[120] Qiu J, Zhao J, Yang H, Dong ZY. Optimal scheduling for prosumers in coupled transactive power and gas systems. IEEE Trans Power Syst 2018;33. http://dx.doi.org/10.1109/TPWRS.2017.2715983.

[121] Zhang H, Li Y, Gao DW, Zhou J. Distributed optimal energy management for energy internet. IEEE Trans Ind Inf 2017;13. http://dx.doi.org/10.1109/TII.2017.2714199.

[122] Saxena K, Abhyankar AR. Agent based bilateral transactive market for emerging distribution system considering imbalances. Sustain Energy, Grids Networks 2019;18. http://dx.doi.org/10.1016/j.segan.2019.100203.

[123] Wu J, Hu J, Ai X, Zhang Z, Hu H. Multi-time scale energy management of electric vehicle model-based prosumers by using virtual battery model. Appl Energy 2019;251. http://dx.doi.org/10.1016/j.apenergy.2019.113312.

[124] Cui S, Wang Y-W, Xiao J-W. Peer-to-peer energy sharing among smart energy buildings by distributed transaction. IEEE Trans Smart Grid 2019;10. http://dx.doi.org/10.1109/TSG.2019.2906059.

[125] Faqiry M, Edmonds L, Zhang H, Khodaei A, Wu H. Transactive-market-based operation of distributed electrical energy storage with grid constraints. Energies 2017;10. http://dx.doi.org/10.3390/en10111891.

[126] Guerrero J, Chapman AC, Verbic G. Decentralized P2P energy trading under network constraints in a low-voltage network. IEEE Trans Smart Grid 2019;10. http://dx.doi.org/10.1109/TSG.2018.2878445.

[127] Ofgem. Smart export guarantee: Guidance for generators. 2019, URL https://www.ofgem.gov.uk/system/files/docs/2020/02/seg_generator_guidance_-_final_for_publication.pdf.

[128] Feng C, Li Z, Shahidehpour M, Wen F, Li Q. Stackelberg game based transactive pricing for optimal demand response in power distribution systems. Int J Electr Power Energy Syst 2020;118. http://dx.doi.org/10.1016/j.ijepes.2019.105764.

[129] Wen X, Abbes D, Francois B. Modeling of photovoltaic power uncertainties for impact analysis on generation scheduling and cost of an urban micro grid. Math Comput Simulation 2021;183:116–28. http://dx.doi.org/10.1016/j.matcom.2020.02.023.

[130] Zhou B, Meng Y, Huang W, Wang H, Deng L, Huang S, Wei J. Multi-energy net load forecasting for integrated local energy systems with heterogeneous prosumers. Int J Electr Power Energy Syst 2021;126. http://dx.doi.org/10.1016/j.ijepes.2020.106542.

[131] Noor S, Yang W, Guo M, van Dam KH, Wang X. Energy demand side management within micro-grid networks enhanced by blockchain. Appl Energy 2018;228. http://dx.doi.org/10.1016/j.apenergy.2018.07.012.

[132] Morstyn T, Teytelboym A, Mcculloch MD. Bilateral contract networks for peer-to-peer energy trading. IEEE Trans Smart Grid 2019;10. http://dx.doi.org/10.1109/TSG.2017.2786668.

[133] Meena NK, Yang J, Zacharis E. Optimisation framework for the design and operation of open-market urban and remote community microgrids. Appl Energy 2019;252. http://dx.doi.org/10.1016/j.apenergy.2019.113399.

[134] Reihani E, Siano P, Genova M. A new method for peer-to-peer energy exchange in distribution grids. Energies 2020;13. http://dx.doi.org/10.3390/en13040799.

[135] Park L, Lee S, Chang H. A sustainable home energy prosumer-chain methodology with energy tags over the blockchain. Sustainability 2018;10. http://dx.doi.org/10.3390/su10030658.

[136] Cesena EAM, Good N, Syrri AL, Mancarella P. Techno-economic and business case assessment of multi-energy microgrids with co-optimization of energy, reserve and reliability services. Appl Energy 2018;210. http://dx.doi.org/10.1016/j.apenergy.2017.08.131.

[137] Anoh K, Maharjan S, Ikpehai A, Zhang Y, Adebisi B. Energy peer-to-peer trading in virtual microgrids in smart grids: A game-theoretic approach. IEEE Trans Smart Grid 2020;11. http://dx.doi.org/10.1109/TSG.2019.2934830.

[138] Dang C, Zhang J, Kwong C-P, Li L. Demand side load management for big industrial energy users under blockchain-based peer-to-peer electricity market. IEEE Trans Smart Grid 2019;10. http://dx.doi.org/10.1109/TSG.2019.2904629.

[139] Cali U, Cakir O. Energy policy instruments for distributed ledger technology empowered peer-to-peer local energy markets. IEEE Access 2019;7. http://dx.doi.org/10.1109/ACCESS.2019.2923906.

[140] Silvestre MLD, Gallo P, Ippolito MG, Sanseverino ER, Zizzo G. A technical approach to the energy blockchain in microgrids. IEEE Trans Ind Inf 2018;14. http://dx.doi.org/10.1109/TII.2018.2806357.

[141] Tushar W, Saha TK, Yuen C, Liddell P, Bean R, Poor HV. Peer-to-peer energy trading with sustainable user participation: A game theoretic approach. IEEE Access 2018;6. http://dx.doi.org/10.1109/ACCESS.2018.2875405.

[142] Alam MR, St-Hilaire M, Kunz T. An optimal P2P energy trading model for smart homes in the smart grid. Energy Efficiency 2017;10. http://dx.doi.org/10.1007/s12053-017-9532-5.

[143] Liu Y, Gooi HB, Li Y, Xin H, Ye J. A secure distributed transactive energy management scheme for multiple interconnected microgrids considering misbehaviors. IEEE Trans Smart Grid 2019;10. http://dx.doi.org/10.1109/TSG.2019.2895229.

[144] Janko SA, Johnson NG. Scalable multi-agent microgrid negotiations for a transactive energy market. Appl Energy 2018;229. http://dx.doi.org/10.1016/j.apenergy.2018.08.026.

[145] Liu Y, Zuo K, Liu XA, Liu J, Kennedy JM. Dynamic pricing for decentralized energy trading in micro-grids. Appl Energy 2018;228. http://dx.doi.org/10.1016/j.apenergy.2018.06.124.

[146] Pinto T, Ghazvini MF, Soares J, Faia R, Corchado J, Castro R, Vale Z. Decision support for negotiations among microgrids using a multiagent architecture. Energies 2018;11. http://dx.doi.org/10.3390/en11102526.

[147] Prinsloo G, Dobson R, Mammoli A. Synthesis of an intelligent rural village microgrid control strategy based on smartgrid multi-agent modelling and transactive energy management principles. Energy 2018;147. http://dx.doi.org/10.1016/j.energy.2018.01.056.

[148] Akter M, Mahmud M, Oo A. A hierarchical transactive energy management system for energy sharing in residential microgrids. Energies 2017;10. http://dx.doi.org/10.3390/en10122098.

[149] Qi W, Shen B, Zhang H, Shen Z-JM. Sharing demand-side energy resources - A conceptual design. Energy 2017;135. http://dx.doi.org/10.1016/j.energy.2017.06.144.

[150] Huang H, Nie S, Lin J, Wang Y, Dong J. Optimization of peer-to-peer power trading in a microgrid with distributed PV and battery energy storage systems. Sustainability 2020;12. http://dx.doi.org/10.3390/su12030923.

[151] Liu H, Zhang Y, Zheng S, Li Y. Electric vehicle power trading mechanism based on blockchain and smart contract in V2G network. IEEE Access 2019;7. http://dx.doi.org/10.1109/ACCESS.2019.2951057.

[152] Zhou Y, Wu J, Long C. Evaluation of peer-to-peer energy sharing mechanisms based on a multiagent simulation framework. Appl Energy 2018;222. http://dx.doi.org/10.1016/j.apenergy.2018.02.089.

[153] Ghosh A, Aggarwal V, Wan H. Strategic prosumers: How to set the prices in a tiered market? IEEE Trans Ind Inf 2019;15. http://dx.doi.org/10.1109/TII.2018.2889301.

[154] Hayes B, Thakur S, Breslin J. Co-simulation of electricity distribution networks and peer to peer energy trading platforms. Int J Electr Power Energy Syst 2020;115. http://dx.doi.org/10.1016/j.ijepes.2019.105419.

[155] Zhang H, Zhang H, Song L, Li Y, Han Z, Poor HV. Peer-to-peer energy trading in DC packetized power microgrids. IEEE J Sel Areas Commun 2020;38. http://dx.doi.org/10.1109/JSAC.2019.2951991.

[156] Khorasany M, Mishra Y, Babaki B, Ledwich G. Enhancing scalability of peer-to-peer energy markets using adaptive segmentation method. J Mod Power Syst Clean Energy 2019;7. http://dx.doi.org/10.1007/s40565-019-0510-0.

[157] Lin J, Pipattanasomporn M, Rahman S. Comparative analysis of auction mechanisms and bidding strategies for P2P solar transactive energy markets. Appl Energy 2019;255. http://dx.doi.org/10.1016/j.apenergy.2019.113687.

[158] Moghaddam MHY, Leon-Garcia A. A fog-based internet of energy architecture for transactive energy management systems. IEEE Internet Things J 2018;5. http://dx.doi.org/10.1109/JIOT.2018.2805899.

[159] Luo F, Dong ZY, Liang G, Murata J, Xu Z. A distributed electricity trading system in active distribution networks based on multi-agent coalition and blockchain. IEEE Trans Power Syst 2019;34. http://dx.doi.org/10.1109/TPWRS.2018.2876612.

[160] Liu Z, Wang L, Ma L. A transactive energy framework for coordinated energy management of networked microgrids with distributionally robust optimization. IEEE Trans Power Syst 2020;35. http://dx.doi.org/10.1109/TPWRS.2019.2933180.

[161] Li J, Zhang C, Xu Z, Wang J, Zhao J, Zhang Y-JA. Distributed transactive energy trading framework in distribution networks. IEEE Trans Power Syst 2018;33. http://dx.doi.org/10.1109/TPWRS.2018.2854649.

[162] Lezama F, Soares J, Hernandez-Leal P, Kaisers M, Pinto T, Vale Z. Local energy markets: Paving the path toward fully transactive energy systems. IEEE Trans Power Syst 2019;34. http://dx.doi.org/10.1109/TPWRS.2018.2833959.

[163] Samuel O, Almogren A, Javaid A, Zuair M, Ullah I, Javaid N. Leveraging blockchain technology for secure energy trading and least-cost evaluation of decentralized contributions to electrification in sub-saharan Africa. Entropy 2020;22. http://dx.doi.org/10.3390/e22020226.

[164] Inayat K, Hwang SO. Load balancing in decentralized smart grid trade system using blockchain. J Intell Fuzzy Systems 2018;35. http://dx.doi.org/10.3233/JIFS-169832.

[165] Dudjak V, Neves D, Alskaif T, Khadem S, Pena-Bello A, Saggese P, Bowler B, Andoni M, Bertolini M, Zhou Y, Lormeteau B, Mustafa MA, Wang Y, Francis C, Zobiri F, Parra D, Papaemmanouil A. Impact of local energy markets integration in power systems layer: A comprehensive review. Appl Energy 2021;301:117434. http://dx.doi.org/10.1016/j.apenergy.2021.117434.

[166] Australian Energy Market Operator. Five-minute settlement: High level design. 2017, URL https://www.aemc.gov.au/sites/default/files/content/b862be5a-4460-4b72-a90b-8f73117f301c/5MS-HLD-Final-4-Sep.pdf.

[167] Gerard H, Puente EIR, Six D. Coordination between transmission and distribution system operators in the electricity sector: A conceptual framework. Utilities Policy 2018;50:40–8. http://dx.doi.org/10.1016/j.jup.2017.09.011.

[168] Iria J, Scott P, Attarha A. Network-constrained bidding optimization strategy for aggregators of prosumers. Energy 2020;207:118266. http://dx.doi.org/10.1016/j.energy.2020.118266.

[169] Abidin A, Callaerts R, Deconinck G, Shenja VDG, Madhusudan A, Montakhabi M, Mustafa MA, Nikova S, Orlando D, Schroers J, Vanhove S, Zobiri F. Poster: SNIPPET – Secure and privacy-friendly peer-to-peer electricity trading. In: Network and distributed system security symposium (NDSS). San Diego: Internet Society; 2020.

[170] Thandi R, Mustafa MA. Privacy-enhancing settlements protocol in peer-to-peer energy trading markets. In: In 13th international conference on innovative smart grid technologies (ISGT 2022). Washington DC: IEEE; 2021, http://dx.doi.org/10.1109/ISGT.2014.6816376.

[171] Mustafa MA, Cleemput S, Abidin A. A local electricity trading market: Security analysis. In: 2016 ieee pes innovative smart grid technologies conference europe (ISGT-Europe). IEEE; 2016, http://dx.doi.org/10.1109/ISGTEurope.2016.7856269.

[172] Kalogridis G, Sooriyabandara M, Fan Z, Mustafa MA. Toward unified security and privacy protection for smart meter networks. IEEE Syst J 2014;8. http://dx.doi.org/10.1109/JSYST.2013.2260940.

[173] Quinn EL. Privacy and the new energy infrastructure. SSRN Electron J 2009. http://dx.doi.org/10.2139/ssrn.1370731.

[174] Wang S, Taha AF, Wang J, Kvaternik K, Hahn A. Energy crowdsourcing and peer-to-peer energy trading in blockchain-enabled smart grids. IEEE Trans Syst, Man, Cybern: Syst 2019;49:1612–23. http://dx.doi.org/10.1109/TSMC.2019.2916565.

[175] Capper T, Gorbatcheva A, Schwidtal JM, Mustafa MA, Andoni M, Chitchyan R, Robu V, Montakhabi M, Piccini P, Bahloul M, Mbavarira T, Kiesling L, Scott IJ, Francis C, Espana JM, Troncia M. Peer-to-peer, self-consumption and transactive energy literature review data extraction table. 2022, http://dx.doi.org/10.48420/16930768.