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Transactive energy in microgrid communities: A systematic review

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ABSTRACT

This study aims to perform a systematic review with research indicators on microgrids (MGs) and transactive energy (TE) to identify the evolution of scientific productions in this field and analyze the interactions involving the utility and prosumers in MGs. The research indicators proved that the interest in MGs is growing in numerous countries whose concern is to seek alternative energy generation with renewable energy sources (RES) to supply an increasing demand for energy production and reduce the impacts of atmospheric pollutants. Moreover, the insertion of blockchain technology in the energy market can provide significant advances in the commercialization of electric energy, enabling virtual transactions to be conducted in a decentralized and secure way, managing numerous smart contracts, and contributing reasonably to introducing prosumers in energy transactions in MGs. This systematic review enabled us to shed more light and direct the study methodology to answer the questions surrounding this research. The aspects found explore concepts similar to the characteristics of TE and MGs exposed in the review of indicators. It was possible to perceive that the research strategy was successfully employed and has considerable academic significance, especially in this theme. Additionally, a new approach to the topic was presented by analyzing the interactions of prosumers and utility. The sustainable aspect related to MGs communities is highlighted because of the self-supply of smart homes and the use of RES.

1. Introduction

The microgrids (MGs) emerged with the idea of self-supplying their sites; however, this scenario changed rapidly with the realization that transactional techniques can be employed strategically to gain economic advantages [1]. In this context, demand response (DR) and transactive energy (TE) programs have become widely discussed in research seeking to balance consumption and production in the energy grid [2]. TE involves characteristics that enable the distribution system to function considering the flexible behavior of both consumers and prosumers in the balance between supply and demand. DR programs generally impose stricter and more restrictive limits on flexibility actions, making it difficult to employ holistic solutions in favor of the necessary balance between supply and demand [3].

To balance supply and demand in the electric power system, TE uses economic and control tools for power exchange management in the electric infrastructure [4,5]. The power sector has been driven by including distributed energy resources (DERs) [6] and advances in disruptive technologies [7]. Applying methods such as TE coupled with MGs has created new paradigms to be studied in this sector. For this reason, theoretical research on the subject is highly relevant, especially regarding the interest of the energy market focused on systems that integrate renewable energy sources (RES) and present solutions to environmental problems; hence, MGs have become an even more attractive alternative [8].

The MGs are conceptualized as a local distribution system with distributed generators; they incorporate clean sources, energy storage systems (ESSs) and loads [9]. When the power distribution system faces a failure or when it does not meet power quality requirements, MGs may overcome these limitations by operating autonomously [10]. Thus, the network can increase its efficiency and transmit more security and credibility to consumers, as it can act in a connected way to the network or independently [11].

Some review articles have analyzed aspects such as the protection of MGs [12], the modernization of the grid in uncertain environments [13], the relevance of the transactive power system of decentralized MGs considering a functional layer structure [14], bidding strategies in transactive power systems [15], and concepts of transactional energy market structure for MG management [16]. Nonetheless, there are no known reviews in the literature analyzing research indicators focusing on MGs and transactive power that incorporates the study of the relationship of consumers, prosumers, and producers and how these actors integrate with MG concepts. Given this scenario, a systematic review is

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Abbreviations

AMI	Advanced Metering Infrastructure
ANN	Artificial Neural Network
BESS	Battery Energy Storage System
DERs	Distributed Energy Resources
DLT	Distributed Ledger Technology
DR	Demand Response
DSM	Demand-Side Management
DSO	Distribution System Operator
ESMS	Economical Storage Management System
ESSs	Energy Storage Systems
H-MG	Home Microgrid
HEMS	Home Energy Management Systems
IBR	Inclining Block Rate
LEM	Local Energy Markets
LPBA	Load Profile-Benefit Assessment
LSEs	Load Serving Entities
MASCEM	Multi-Agent Simulator of Competitive Electricity Markets
MASGriP	Multi-Agent Smart Grid Simulation Platform
MDL	Maximum Demand Limit
MGs	Microgrids
MILP	Mixed Integer Linear Programming
NILM	Non-Intrusive Load Monitoring
P2G	Peer-to-Grid
P2P	Peer-to-Peer
RES	Renewable Energy Sources
RTP	Real-Time Pricing
SPT	Stepwise Power Tariff
TE	Transactive energy
TOU	Time-of-Use

proposed that addresses indicators in order to examine citation data in a given research area and draw conclusions about scientific publications, verify influences in the chosen research field, and detect emerging trends.

This study aimed to conduct a systematic review with research indicators on MGs and TE to identify the evolution of scientific productions in this field and analyze the interactions involving the utility and prosumers in a MG. First, publications between 2012 and 2022 were studied and evaluated quantitatively, leading to research trends from the past ten years to be found and analyzed. The countries, affiliations of the scientific productions, authors, coauthors, and keywords addressing this theme were discovered. Subsequently, the issues related to the moment of energy consumption of the user, the moments of exporting energy to the grid by the prosumer, feeding the consumer or storage, and managing the stored energy considering the best price and how these concepts can be introduced into a MG were presented.

The main contributions of this work are presented below:

- Identification of the review characteristics of articles related to the topic of TE and MGs using the research indicators;
- Exposure of data on the scientific production of the countries that produce the most on the subject and the affiliations that produce the most and presentation of research trends by analyzing the Keywords Plus and scientific productions;
- Evaluation of the number of citations and the most cited publications to verify the most covered subjects that are related to the theme and the contributions to the scientific field;
- Analysis of the interactions of prosumers and utilities addressing the main interactions related to the moments of energy consumption of the user, exporting energy to the grid by the prosumer, feeding the consumer or storage, and managing the stored energy considering the best price;
- Integration of the concepts presented in the analysis of prosumer and utility interactions to identify the main aspects part of MGs.

The review methodology adopted is developed and explained in Section 2. The results and discussions are provided in Section 3, which addresses the characteristics of the scientific productions, analysis of the scientific productions of the countries and affiliations, evaluation of the Keywords Plus, analysis of the most cited scientific productions, and interpretation of the results. Section 4 analyzes the interactions between prosumers and utilities. Lastly, the paper is concluded in Section 5.

2. Methodology

This study conducted a systematic review of studies on TE related to MGs in August 2022 using Scopus and Web of Science. These databases were chosen because they have a vast collection of articles and feature the world's leading publishers, including Elsevier, IEEE, and Springer [17,18]. The keywords used in this study were considered to encompass a broad range of contributions related to the focus: 'microgrid,' 'transactive energy,' 'transacting energy,' 'smart contracts,' 'blockchain,' and 'reliability.' Table 1 lists the steps of the article identification process in the chosen databases and the type of search, the search field, the search string, the period, and the document type. The databases have different terminology for paper conference publication in the type of document. Papers may be indexed by Scopus as the conference paper and indexed by Web of Science as proceedings paper. Language restrictions were not used.

Investigations involving research indicators address the analysis of research trends through the results of scientific publications from distinct countries [19], affiliations or institutions [20], research fields [21,22], journals [23], evaluation of citations [24], and keywords or Keywords Plus [25]. A concept map of the main analyses of this study and research stages are illustrated in Fig. 1.

The data package analysis tool Bibliometrix was used to improve the study of the databases [26]; it has an extension called 'biblioshiny' that allows users to find the indicators deemed necessary. Hence, the next section presents the results and discussions found.

3. Results and discussion

The search returned 557 documents from the Scopus database and 475 from the Web of Science database. After applying a restriction to the document type, the search resulted in 501 documents in Scopus and 472 in the Web of Science. The databases were joined using the R 3.6.3 software and RStudio to analyze the databases and remove duplicates; 348 duplicates were removed, and the final file totaled 625 documents. Of these documents, 58% were articles, 33% were conference papers, 6% were review papers, and 3% were proceedings papers. The following sections present the results and discussions of this database.

3.1. Characteristics of the scientific productions

The results were analyzed according to the titles, abstracts, and keywords. The evolution of publications is presented in Fig.2, in which one can note that publications on the theme began in 2012, and significant growth only began after 2016.

Initial research addressed strategies and opportunities for MGs in the use of TE techniques [1], application of transactive operations in MGs [27], and management methods for transactive power systems in smart grids [28]. Fig. 2 shows a growing trend of research related to the

Table 1
Steps in the process of identifying articles on TE in MGs.

Investigation Process		
Database	Scopus	Web of Science
Type of survey	Advanced search	Advanced search
Search fields	TITLE-ABS-KEY (title, abstract, and keywords)	ALL
Search string	((“microgrid*" AND (“smart contracts *" OR “blockchain*" OR “transactive energy*" OR “transacting energy*" OR (“transacting energy*" AND “reliability*"))))	((“microgrid*" AND (“smart contracts *" OR “blockchain*" OR “transactive energy*" OR “transacting energy*" OR (“transacting energy*" AND “reliability*"))))
Search period	Every year until 2022	Every year until 2022
Type of document	Article, conference paper, and review	Article, proceedings paper, and review

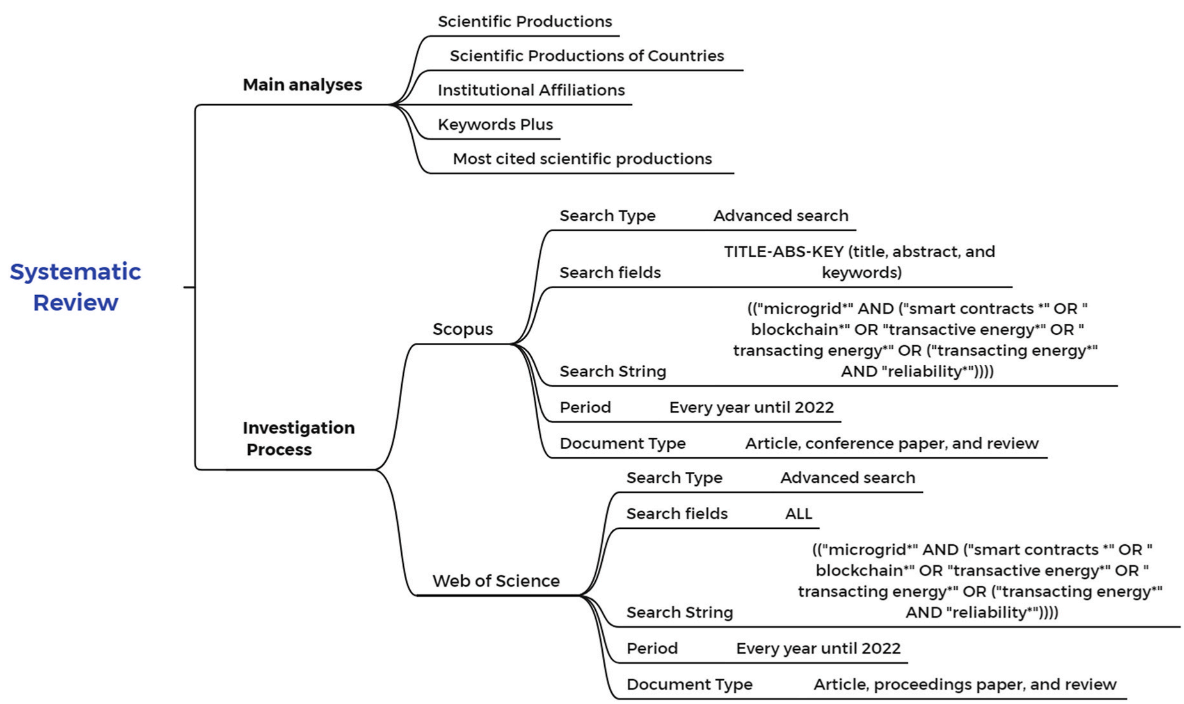

Fig. 1. Concept map of the main analyses and research process carried out.

subject, and one explanation for this is that there are barriers to be overcome concerning DERs, including peaks in overall operator demand. In search of better management of these resources, there is a demand for a decentralized control system that can exchange energy locally and store and decrease demand fluctuations [29]. Another factor that may have encouraged the increased interest in the topic of this study is the growth in the use of renewable sources worldwide and the advancement in storage technology [30]. The decrease in the curve in 2022 is due to the incomplete count of months in this year.

The authors who have a more significant contribution to the research field are evaluated according to the number of publications, their citations, the average number of citations per article, and the H-index, which is a research indicator that suggests the measurement between scientific productivity and the number of citations, making it possible to verify the scientific impact of a researcher or an organization [31]. The authors’ information is listed in Table 2.

We also verified the collaborative works between the authors in Table 2. The analysis of co-authorship can provide information on a network of authors; in this aspect, one can observe if the authors collaborated to influence the knowledge, the exchange of ideas, and methods of their research [32]. In the evaluation of co-authorship in Table 2, we noted that the author Marzband M., with the highest number of published documents (11 articles, 3 proceedings papers, and 1 conference paper), has 13 papers as a co-author and 2 as the lead author. These last two are the articles entitled “Smart transactive energy framework in grid-connected multiple home microgrids under independent and coalition operations” [33] and “Framework for smart transactive energy in home-microgrids considering coalition formation and demand side management” [34]. The first article is co-authored by Pouresmaeil E., Guerrero J., and Lightbody G, whereas the second one is co-authored by Pouresmaeil E. and Lightbody G.

The second author with the most publications (Zhang Y.) has 13 publications as co-author (11 articles and 2 conference papers) and 2 documents as the lead author (1 article and 1 conference paper). The third author with the most publications (Li Z) has 9 articles as a co-author and 4 publications as the lead author: 3 articles and 1 conference paper. Of these publications, Zhang Y. participated in 1 article as a co-author, and author Wang Y. participated in 1 article as the lead author. The next author with the most publications (Wang Y.) has 8 publications as co-author (7 articles and 1 conference paper) and 5 papers as the lead author. Of these publications, Li Y. participated in 1 article as co-author as well as Li J; Li Y. published 9 articles and 2 conference papers, being the lead author of 3 articles. The sixth author with the most publications (Daneshvar M.) has 11 publications, being the lead author of 7 articles and 3 conference papers. Of these publications, Mohammadi-Ivatloo B. participated as co-author in 7 articles, 2

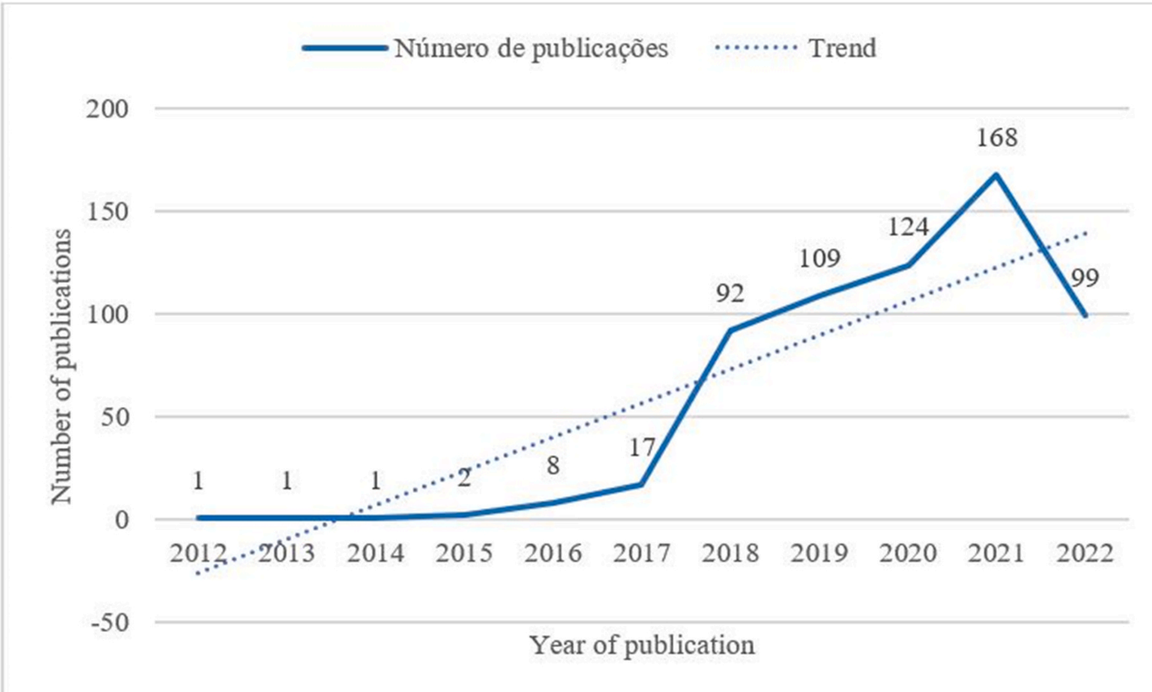

Fig. 2. The number of papers per year of publication addressing TE related to MGs.

Table 2
Information about the authors who have published the most on the research topic.

No.	Authors	Documents	Number of citations	Average number of citations per article	H-Index
1	Marzband M.	15	429	29	9
2	Zhang Y.	15	650	43	5
3	Li Z.	13	811	62	7
4	Wang Y.	13	94	7	5
5	Liu Y.	11	82	7	3
6	Daneshvar M.	11	214	19	8
7	Mohammadi-Ivatloo B.	11	214	19	8
8	Guerrero J.	10	378	38	6
9	Li J.	10	267	27	4
10	Mahmud M.	10	174	17	8
11	Wu Y.	9	116	13	5
12	Zare K.	9	127	14	6
13	Zhang X.	9	137	15	4
14	Akter M.	8	154	19	7
15	Asadi S.	8	213	27	8

conference papers, and 1 review. In these studies, Asadi S. co-authored 8 publications (7 articles and 1 conference paper) and Zare K. co-authored 6 publications (4 articles and 2 conference papers). The author Guerrero J. has 10 publications as a co-author (5 articles, 3 reviews, and 2 conference papers) with the collaboration of Marzband M. (1 article) and Wu Y. (2 articles and 1 review). The next author with the most publications (Mahmud M.) has 10 publications as a co-author: 6 conference papers, 3 articles, and 1 reviews. Of these publications, Akter M. participated in 5 conference papers and 3 articles, being the lead author of 7. Notably, Li J., with 9 publications (8 articles and 1 review), is the lead author of 3 articles, and the authors' Wu Y. and Zhang X. participated as the co-authors of 1 article each.

3.2. Analysis of scientific production per country and institutional affiliations

This review study identified publications by authors from 64 countries; the scientific production data from 10 countries producing the most on the topic and the total number of citations from each country are shown in Fig. 3.

The countries with the most publications in the target area of the study are China, (35.04%), the United States (20.32%), India (10.40%), and Iran (9.12%). The scientific production of the countries with the most citations include China (1340 citations), the United Kingdom (1228 citations), the United States (777 citations), and Iran (395 citations). Table 3 shows the affiliations that produce the most on the subject and their respective countries and number of publications.

As shown above, the affiliations that produced the most are located in China and Singapore: North China Electric Power University and Nanyang Technological University. The third affiliation that produces the most is Iran, which has many affiliations, including the Islamic Azad University, the University of Tabriz, Amirkabir University of Technology, and the Sharif University of Technology. Next are Denmark, Finland, Australia, and Kazakhstan, with Aalborg University, Aalto University, Deakin University, and Nazarbayev University, respectively.

The previous analysis revealed that China is leading the rank of countries in the research area considered, being the one with the greatest number of scientific productions, citations, and the affiliation related to the subject. The United States comes next when considering the number of scientific productions and citations. A highlight goes to Iran when affiliations are assumed (Table 3).

3.3. Evaluation of the Keywords Plus

The Keywords Plus were analyzed, which are terms that frequently occur in the titles of the authors' references; these terms are provided using an algorithm that identifies words or phrases in the reference list [35,36]. The classification of the 15 Keywords Plus most used, their respective frequencies, and the intervals analyzed are listed in Table 4.

The total number of Keywords Plus found in the study was 2,686, and

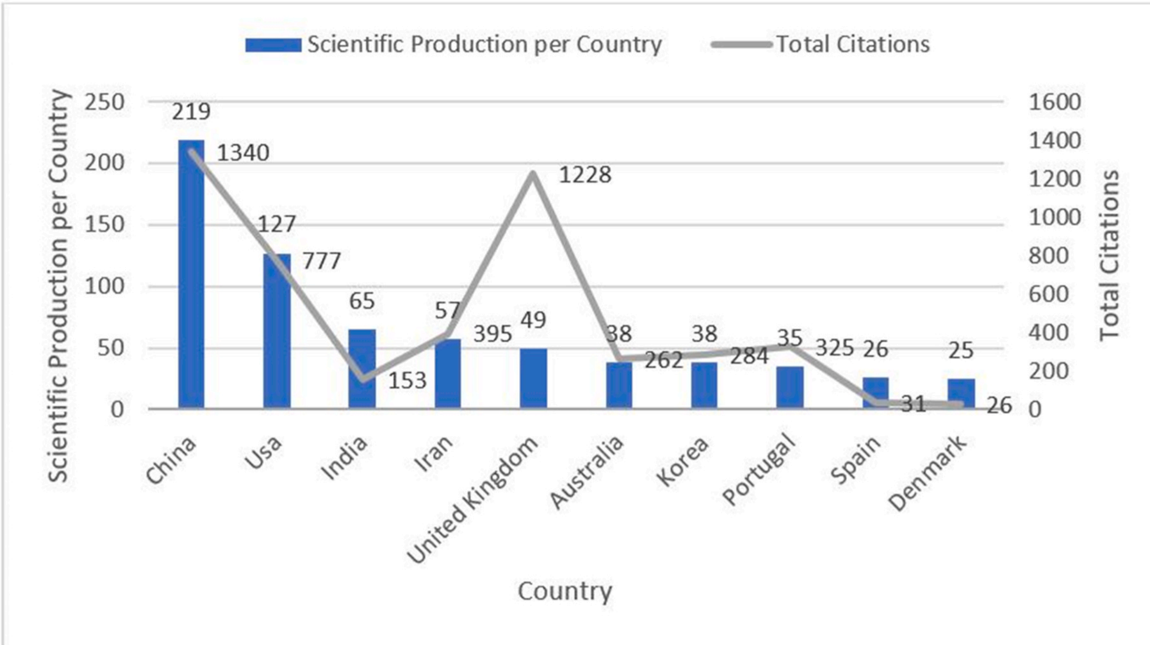

Fig. 3. The most relevant scientific production per country and total citations for TE related to MGs.

Table 3
Most productive affiliations.

Affiliations	Country	Articles
North China Electric Power University	China	20
Nanyang Technological University	Singapore	19
Islamic Azad University	Iran	16
University of Tabriz	Iran	16
Aalborg University	Denmark	14
Aalto University	Finland	9
Amirkabir University of Technology	Iran	9
Deakin University	Australia	9
Nazarbayev University	Kazakhstan	9
Sharif University of Technology	Iran	9

the evolution of the topic over the periods and the summary of research trends are listed in Table 4. The words with the 5 highest total frequencies are: “microgrids,” “blockchain,” “power markets,” “peer to peer,” and “electric power transmission networks.” In the first period (2012–2014), the initial studies mainly covered topics on “peer to peer,” “smart power grids,” “smart grid,” “transactive energy,” “commerce,” and “energy resources.” In the second period (2015–2017), the most addressed subjects were “microgrids,” “transactive energy,” “smart grid,” “blockchain,” “commerce,” and “energy resources.” Research related to MG and TE is present in this interval, although only slightly. The following period (2018–2020) revealed the highest frequencies, and the most addressed subjects were “microgrids,” “blockchain,” “power markets,” “commerce,” “transactive energy,” and “peer to peer.” It is understood that the interest in MGs and TE soared in this period and introduced these topics more intensively to energy trading, blockchain technology, and peer-to-peer (P2P) architecture. In the last period (2021–2022), the topics in this period included “blockchain,” “microgrids,” “power markets,” “peer to peer,” “renewable energy resources,” and “electric power transmission networks.” We observed that in the last interval, blockchain technology has the highest frequency and the second highest is MGs; thus, it is understood that research involving the topic has increased with the insertion of blockchain technology in the energy market. By analyzing the most frequent words in the literature, the citations of the documents evaluated are closely related to the theme of our study. One of the reasons to check Keywords Plus is to detect research trends in a given scientific area [37]. Therefore, it is possible to justify the trend in Fig. 2 and the terms encompassing it in this field of study.

Table 4
The most frequently cited words in the documents’ references.

Rank	Keywords Plus	Total occurrences	2012–2014	2015–2017	2018–2020	2021–2022
1	microgrids	458	0 (0%)	14 (3%)	226 (49%)	218 (48%)
2	blockchain	381	0 (0%)	8 (2%)	145 (38%)	228 (60%)
3	power or energy markets	240	0 (0%)	5 (2%)	127 (53%)	108 (45%)
4	peer to peer	143	2 (1%)	1 (1%)	66 (46%)	76 (53%)
5	electric power transmission networks	141	0 (0%)	8 (6%)	62 (44%)	71 (50%)
6	renewable energy resources	138	0 (0%)	8 (6%)	58 (42%)	72 (52%)
7	transactive energy	134	1 (1%)	9 (7%)	86 (64%)	38 (28%)
8	commerce	132	1 (1%)	8 (6%)	102 (77%)	21 (16%)
9	smart power grids	109	2 (2%)	6 (6%)	49 (45%)	52 (48%)
10	energy resources	92	1 (1%)	8 (9%)	48 (52%)	35 (38%)
11	energy trading	76	0 (0%)	0 (0%)	35 (46%)	41 (54%)
12	distributed energy resources	72	0 (0%)	2 (3%)	38 (53%)	32 (44%)
13	smart grid	68	2 (3%)	9 (13%)	29 (43%)	28 (41%)
14	energy	65	0 (0%)	0 (0%)	11 (17%)	54 (83%)
15	energy management	59	0 (0%)	8 (14%)	22 (37%)	29 (49%)

3.4. Analysis of the most cited scientific productions

Research indicators examine the quality of a study, its impact, and references. The evaluation of the number of citations a paper receives is considered a pivotal indicator to evaluate and one of the most used in this type of analysis [38]. The 10 most cited scientific productions among the 625 documents analyzed in this review are presented in Table 5, followed by the corresponding objectives and contributions' description.

The article with the most citations is entitled "Designing microgrid energy markets: A case study: The Brooklyn Microgrid" [39], with 774 citations. The authors present an approach applied in a MG community (i.e., Brooklyn MGs project). The case study proposed in the article sought to verify the reliability of the balance between energy generation and consumption in a local market by applying blockchain technology in a local market. As contributions, the study showed that blockchain technology could be a suitable tool in MGs communities; in addition, the authors analyzed 7 operational components (MG configurations, network connection, information system, market mechanism, price mechanism, commercialization, and regulation) that contribute to the efficiency of decentralized local markets that use blockchain.

The second most cited article is "Blockchain technology in the energy sector: A systematic review of challenges and opportunities" [40], with 624 citations. The authors' research conducts a systematic review analysis covering the main advantages, disadvantages, and challenges associated with utilizing blockchain technology in industrial and research projects. The authors' goal was to classify and present the primary aspects that involve blockchain implementation, emphasizing the technical challenges and market barriers. The article's contributions refer to the overview provided by the systematic review, classification of types of technologies addressing the advantages and disadvantages, innovations, and opportunities for the energy sector, and evaluate 140 blockchain projects developed by companies and researchers.

The third most cited article, "Consortium Blockchain for Secure Energy Trading in Industrial Internet of Things" [41], had 596 citations. The authors evaluated the use of blockchain technology, considering different P2P power-sharing scenarios for the industrial internet of things. The study sought to increase reliability in energy transactions with a secure and private system. The article presents as contributions the elaboration of a unified system with reasonable price that uses blockchain for energy for the industrial internet of things, develops optimal pricing tactics with the Stackelberg methodology, and suggests payments through credits to minimize delays in transactions.

The fourth article with the most citations is entitled "Blockchain Based Decentralized Management of Demand Response Programs in Smart Energy Grids" [42], with 270 citations. The authors developed a model that uses DR for blockchain-based distributed energy management. The purpose of the study was to present blockchain technology as a tool capable of securely storing customer consumption data and applying it to DR and energy transactions. The study's contributions include elaborating the model from the blockchain for distributed management, the automatic implementation of smart contracts, and the analysis that uses consensus to validate the DR.

In fifth place, the article entitled "Bilateral Contract Networks for Peer-to-Peer Energy Trading" [43], with 240 citations. The authors proposed a new market design for bilateral contract network trading in real-time and future markets with different types of agents (e.g., generators with traditional fuel sources, suppliers acting in a mediating manner, and prosumers). The study explained that power systems can benefit from using small-scale distributed networks for overall demand control, and the contribution can be significant in decreasing investments in transmission infrastructure and upstream production and improving network efficiency and energy security.

The sixth most cited publication is entitled "Blockchains for decentralized optimization of energy resources in microgrid networks" [44], with 224 citations. The authors approached an energy market structure that uses P2P and blockchain in an associated way to ensure operational conditions, concessionaire autonomy for payments, and greater security and trust. The aim was to improve decentralized management through blockchain and smart contracts. The study contributions take place in the demonstration of distributed energy management, application of blockchain to increase reliability, and smart contracts for self-deployment of payments.

The seventh paper is entitled "Local electricity market designs for peer-to-peer trading: The role of battery flexibility" [45], with 189 citations. The authors carried out a study of battery flexibility strategies in energy market projects and aimed to verify different configurations for decentralized or centralized batteries in local energy markets and prosumers. Thus, a P2P commerce structure based on linear programming was developed where the advantages of end consumers were

Table 5
Scientific productions most cited by authors.

No.	Paper and journal	Document type	Title	Total citations
1	[39], APPLIED ENERGY	Article	Designing microgrid energy markets: A case study: The Brooklyn Microgrid	774
2	[40], RENEWABLE AND SUSTAINABLE ENERGY REVIEWS	Article	Blockchain technology in the energy sector: A systematic review of challenges and opportunities	624
3	[41], IEEE TRANSACTIONS ON INDUSTRIAL INFORMATICS	Article	Consortium Blockchain for Secure Energy Trading in Industrial Internet of Things	596
4	[42], SENSORS	Article	Blockchain Based Decentralized Management of Demand Response Programs in Smart Energy Grids	270
5	[43], IEEE TRANSACTIONS ON SMART GRID	Article	Bilateral Contract Networks for Peer-to-Peer Energy Trading	240
6	[44], 2017 IEEE CONFERENCE ON CONTROL TECHNOLOGY AND APPLICATIONS	Conference paper	Blockchains for decentralized optimization of energy resources in microgrid networks	224
7	[45], APPLIED ENERGY	Article	Local electricity market designs for peer-to-peer trading: The role of battery flexibility	189
8	[46], RENEWABLE ENERGY	Article	Smart transactive energy framework in grid-connected multiple home microgrids under independent and coalition operations	171
9	[47], IEEE TRANSACTIONS ON SYSTEMS, MAN, AND CYBERNETICS: SYSTEMS	Conference paper	Energy Crowdsourcing and Peer-to-Peer Energy Trading in Blockchain-Enabled Smart Grids	169
10	[48], IEEE SYSTEMS JOURNAL	Article	A Survey and Evaluation of the Potentials of Distributed Ledger Technology for Peer-to-Peer Transactive Energy Exchanges in Local Energy Markets	161

investigated. The research contributions are related to reducing end-consumer costs through the combination of negotiations and storage flexibility.

The next most cited article is "Smart transactive energy framework in grid-connected multiple home microgrids under independent and coalition operations" [46], with 171 citations. The authors presented a system that enables cooperation among operators in multiple H-MG based on a smart TE framework. The article develops a coalition-building strategy combined with responsive load demand, and the goal was to provide a maximum profit distribution among all participants considering factors such as uncertainty of variables and demand fluctuations. The proposed model also provides an increase in market competitiveness.

The next most cited publication is titled "Energy Crowdsourcing and Peer-to-Peer Energy Trading in Blockchain-Enabled Smart Grids" [47], with 169 citations. The authors covered a new optimization model focusing on the operations and use of blockchain technology. The aim is to introduce a crowdsourced energy system to the energy market on a collaborative scale managed by the proposed optimal model and blockchain framework. The article demonstrates the electricity market that can be applied in an islanded or grid-connected way, the development of an optimization model, approaches to P2P negotiation techniques, and the crowdsourced energy system.

Lastly, the tenth most cited article is titled "A Survey and Evaluation of the Potentials of Distributed Ledger Technology for Peer-to-Peer Transactive Energy Exchanges in Local Energy Markets" [48], with 161 citations, aimed to conduct a theoretical survey to study and discuss concepts on TE systems, distributed ledger technology (DLT) from blockchain, P2P energy, and local energy markets (LEM). The paper's contributions cover the investigations and evaluations of DLT and installation of decentralized TE systems, a new project based on blockchain, in addition to the analysis of LEM to increase their efficiency in a modern system.

3.5. Interpretation of the research indicators

The analyses carried out show the general characteristics of the scientific productions published and indexed in the Scopus and Web of Science databases. The types of studied documents were articles, conference papers, proceedings papers, and reviews. Table 6 presents the analyses that led to this review, the main implications, and the preliminary conclusions.

Table 6
Characteristics of the scientific productions addressing TE related to MGs.

Analysis	Main implications	Preliminary conclusions
Number of scientific productions per document type	58% are articles, 33% are conference papers, 6% are reviews, and 3% are proceedings papers	The number of research and conference papers is more expressive than review articles
Number of documents by year of publication	The topic started to be studied in the literature after 2012 and peaked in 2018	The topic has a trend line that suggests that there is an increase in research related to the subject
Number of articles per language	100% of the documents were published in English	English is the main language of the publications studied
Number of articles per country	China, the United States, India, and Iran are the countries with the highest productivity	Different countries show similar productivity on the theme
Number of articles per affiliations	Institutions from China have led the ranking with the most publications on TE and MGs, although Iran has a great representation of affiliations, and when added to the productions of these affiliations, we have a greater number of publications that surpasses China	China and Iran have the most productive affiliations on the theme
The most commonly used Keywords Plus to represent the scientific productions	Keywords Plus shows the links between MGs, blockchain, power markets, P2P, electric power transmission networks, renewable energy resources, and transactive energy	Research in transative energy, MGs, and the inclusion of the topic in the energy market and commercialization was noted
Number of citations per publication	The most cited scientific production presented 774 citations	The authors with the highest productivity are not necessarily the most cited ones
Characterization of the most cited scientific production	The most cited publications are articles that are mostly published in energy journals	The approaches presented more competitive models for the market, day-ahead energy resource management, interaction with prosumers, blockchain, P2P energy, and more efficient and secure systems

Scientific production is crucial in developing research, as shown in Table 6, given the characteristics involving the field of TE and MGs. One can also observe that research papers (58%) and conference papers (33%) represent a considerable number of publications in the studied approaches, whereas reviews (6%) and proceedings papers (3%) are less significant. Although conference papers do not have a rigid publication process as peer-reviewed research papers, they are relevant in academia because they present a holistic and detailed view of current research by providing new ideas that support scientific knowledge [49]. The indicators analyzed in this study were the following: the language of publication, number of publications over time, most relevant information about the authors and their coauthors, scientific production of the countries, affiliations, Keywords Plus, and the articles with the most citations.

Research on TE and MGs is not yet consolidated; the topic has been studied for the last 10 years (2012–2022), and more recently, researchers' interest in the subject has been growing, primarily in developed countries such as China and the United States. The use of MGs is related to the global demand for energy supply, and this search also includes a need for generation systems that employ renewable energy [50,51]. China, for instance, produces over 40% of the world's increased renewable capacity; this is due to its concern over air pollutants and capacity guidelines structured by the Chinese government [52].

Notably, Iran has a significant share in the number of publications and institutions involved in the subject addressed. Although Iran is not a developed country and has an energy production based on fossil fuels [53,54], the results show that it has been seeking new energy sources. According to Sadat et al. [55], the interest in renewable sources is growing in Iran, and research that presents the combination of these energies through hybrid MGs is found in the literature [56,57].

The analysis of the Keywords Plus over the years reveals that, in recent years, MGs and TE are developing subjects that are more and more present in the energy market and commercialization every day. Interest in terms such as "blockchain", "P2P" and "renewable energy resources" related to the researched subjects has increased. Blockchain technology is a tool used to perform energy transactions securely [58], and it is important because smart grids create privacy and security risks [59]. The search for RESs linked to this research topic corroborates the interest of countries aiming to develop research addressing new forms of energy production and that use renewable energy.

What is more, the analysis of the most cited articles demonstrates that most studies present new structures for the market that provide improvements in efficiency, security, profit, competitiveness, and management. The issues addressed by the articles converge to investigations of uncertainty, DR, P2P, losses, interaction with prosumers, and new strategies. Hence, it is highly relevant to mention that the application of blockchain in studies, including [30,44,47,48,60–126] , thereby confirming the previously established relationship between the subject matter and the use of blockchain technology in MGs.

4. Analysis of prosumers and utility interactions

A MG can operate in an isolated manner [127] or be connected to the electric power grid [128]; its architecture consists of numerous devices and elements, such as controllers, communication structures, storage and management systems, and distributed generators [129,130]. In addition, MGs can act in communities with consumers and prosumers through transactive power. The role of the utility within this system is critical as MGs operate connected to the electrical grid; RESs also stand out, including photovoltaics and wind power, making MGs very attractive and providing a sustainable aspect to this system.

This section proposes to analyze this system through the interactions between the electricity service provider or utility and the prosumers based on decisions that must be made considering these interactions. These decisions address the moment of energy consumption of the user, the moment of energy export to the grid by the prosumer, the moment of feeding the consumer or storage, the moment of managing the stored energy considering the best price, and finally, how these previous problems can be incorporated into MG concepts. An overview of each decision studied in the analysis of the interactions involving prosumers and utility and its main aspects found in the literature is provided in Fig. 4.

In the following subsections, the interactions between prosumer and utility described in Fig. 4 are analyzed and discussed.

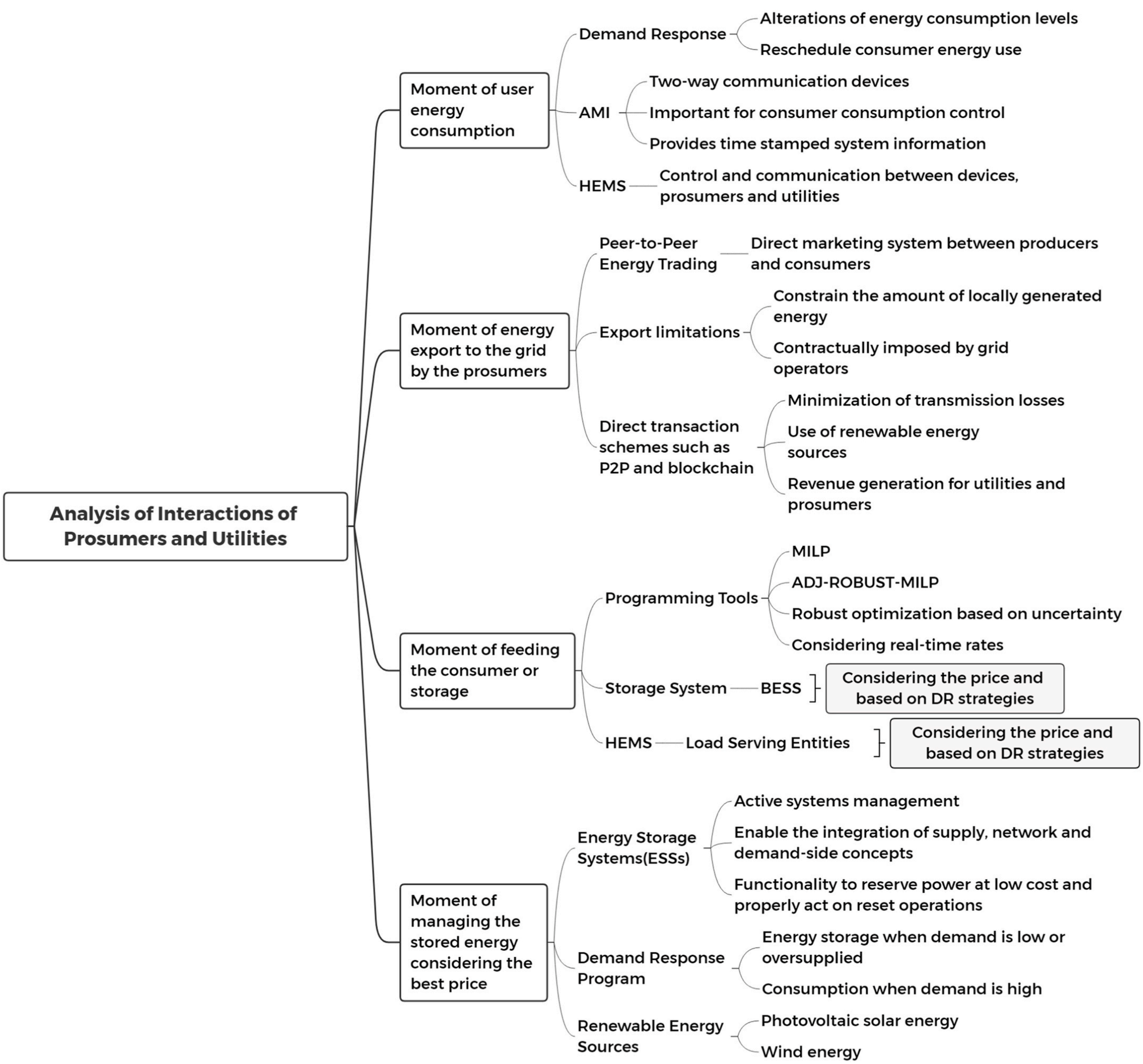

Fig. 4. Concept map of the analysis of prosumer and utility interactions with the decisions studied.

4.1. Moment of user energy consumption

According to Pawar and Vittal K. [131], an insufficient power supply can lead to a plethora of problems for consumers, especially in developing countries that face unscheduled power interruptions at peak times. In this context, smart grids can act to change this reality of the sector for the consumer and the utility. Furthermore, the demand-side management (DSM) system makes it possible to achieve fast responses during outages, fault management, and peak load changes.

The main aspect of DR is the possibility to reschedule consumers' energy use; thus, the operating expenses of high-priced generators may be decreased, which can also be an efficient solution for the user and utilities for managing the power grid [132]. In addition, there are Advanced Metering Infrastructure (AMI) devices that work alongside the user in MGs, provides time stamped system information and are two-way communication devices [133]. The data provided by these meters is important for the consumer's consumption control (i.e., energy consumption patterns are registered and used for automatic control of household appliances). Hence, home Energy management systems (HEMS) stand out [134,135].

El-Baz, Tzscheutschler, and Wagner [136] explained that HEMS can maintain control and communication between devices, prosumers, and utilities. This system acts in real-time by sending price signals by the utility to the prosumers. Thus, prosumers can modify their energy consumption from peak to off-peak times. According to Gust et al. [137], the user's consumption on the grid can be divided into the peak time (the higher price) and the off-peak time (the lower price). Using the battery charging and discharging intelligently allows the MG operator to change the load from peak to off-peak hours, consequently reducing overall costs.

In order to obtain an improved demand-side energy management result during the peak consumption period, scheduling is subject to many constraints. It can be understood that each device in the system is subject or not subject to scheduling [138]. Therefore, it is possible to characterize an appliance so that it has a schedule that can be interrupted and uninterrupted. This means that an ordinary household appliance (e.g., a washing machine) can be programmed not to be interrupted and another device (e.g., a swimming pool pump) to be interrupted [139,140].

It is understood from the concept map in Fig. 4 that the energy system is flexible for the consumer and increased customer interaction with the utility in real-time when it comes to the existing interactions at the time of user energy consumption. The changes in energy consumption levels and the rescheduling of consumer energy use provided by DR contribute to creating new user energy patterns and providing energy demand with greater flexibility and lower costs. According to Eid et al. [141], DRs can optimize the system coordination process and are characterized by adjusting economic signals, responsiveness, and demand-side flexibility mechanisms. The change in the role of the traditional passive consumer to an active member in the grid is a consequence of introducing smart meters and information and communication technology in the operation of electrical systems [142].

4.2. Time of exporting energy to the grid by the prosumers

The active presence of prosumers in the distributed electricity market is due to the implementation of the P2P energy trading model. This model performs negotiations that allow energy trading in a local market and uses advanced energy management tools for a smart grid [143]. This method allows the system to integrate many prosumers into the distribution grid, and other users can use the surplus electricity [144]. At the moment that the prosumer has this excess electrical energy in the system, it is necessary to decide what to do with it, so it must be decided if this energy will be stored in some storage device, downsized, exported back to the grid, or sold to other energy users [145].

Buying and selling electricity in the P2P energy trading market establishes a direct trading system between producers and consumers without the need for an energy agency [145]. Wang et al. [146] explained that using direct transaction schemes such as P2P and blockchain for end users saves money, minimizes transmission losses, increases RES utilization, and produces revenue for utilities and prosumers. Nonetheless, there is a need for a robust and low-cost trading model that can adapt to changes in data and prices [147]. This is because energy trading in a distribution system deals with real-time price fluctuations, frequent payment of energy tariffs, and dynamically adjusted energy consumption planning [148].

Real-time operations in MGs are subject to frequent changes in their operating conditions, and such constraints encompass contractual adjustments of energy and demand charges as well as export limitations [137]. Export limitations are barriers to reducing the amount of energy produced at a given location and exporting it to the main grid. These limitations are established contractually by the grid operators, and this is necessary to avoid an uncontrolled situation that may threaten the stability of the main grid due to large amounts fed [149]. The concept map in Fig. 4 shows that P2P energy trading is closely related to the moment of energy export to the grid by the prosumer; P2P trading allows surplus energy to be shared with other grid users or the utility, consequently optimizing the system and reducing loesses. In a MG community, this method can stimulate competitiveness among prosumers, maximizing profit and lowering costs.

4.3. The time of consumer feeding or storage

One way to ensure uninterrupted power supply in MG operations, especially in islanded mode, is by using storage devices (e.g., ultracapacitors and batteries) [150,151], albeit the storage capacity of these devices is restricted because of their physical limitations [152]. Energy storage allows a device such as a battery to store the energy generated at some point, usually when demand is low or in periods of oversupply. The consumption of this energy can be done later, which is generally when demand is high [153].

According to Akter et al. [154], MGs have different types of structures, and this is because the variations of households depend on the type of RES, in particular the photovoltaic energy source, and on ESSs. The latter has much relevance in the active management of power supply systems, and its important role is intensified by including intermittent RES in the power supply. What is more, ESS technologies are used to assist in balancing energy supply and demand, as they store energy and convert it when necessary [155]. These storage systems have numerous technical and economic advantages and enable the integration of supply-, grid-, and demand-side concepts [153]. During periods of power supply to the grid, ESSs have the functionality to reserve energy at a low cost and perform adequately in system restart operations after blackouts [156]. The concept map in Fig. 4 shows that the timing of consumer feed-in is tied to ESSs and DR; this is because using both of them together reduces system imbalance.

4.4. The moment for managing the stored energy considering the best price

Many studies have presented programming tools for managing household energy problems in demand-side smart systems [135,157–166]; Paterakis et al. [167] presented household appliance management with emphasis on scheduling and control of appliances by implementing mixed integer linear programming (MILP). The authors stated that this makes it possible to obtain economic benefits for residential energy management; in addition, the inclusion of ESSs in batteries tied to DR strategies makes the system more efficient and decreases electricity costs. The study of a management problem of a home storage system that includes distributed generation was proposed by De Azevedo et al. [168]. In this paper, the authors applied MILP with robust adjustable programming (ADJ-ROBUST-MILP) to solve uncertainties in load, price, PV generation, and energy tariffs in real-time.

The model that these authors developed admits to having a daily reserve for battery energy storage system (BESS) considering the price, and such a model can be used in smart contracts or DR programs. Alipour et al. [169] applied robust uncertainty-based optimization to protect grid users from price risks when considering real-time tariffs. Safdarian et al. [170] reported that the operation of smart devices in an optimal manner for end-users at the household level is done by the HEMS, and the coordination of the system can be performed by load serving entities (LSEs) based on DR strategies. It encompasses the understanding that DR programs contribute to price dynamics, and the strategies adopted by DR make energy management (in terms of the price) more efficient. The concept map in Fig. 4 shows that controlling the moment of stored energy management considering the best price mainly depends on programming tools since they can solve a problem and consider many variables that interfere with storage systems' price and management.

4.5. Microgrids

The MGs provide end consumers with a significant return, such as low-cost electricity for users, decreased power grid dependency, reduced service charges, and revenue when injecting surplus electricity into the grid [171]. The commercialization of this power can be done by the peer-to-grid (P2G) structures, in which prosumers purchase electricity from the utility when there is no excess power and sell the surplus to the power supplier. Local purchasing and selling of electricity in a neighborhood or a MG community can be accomplished by P2P power-sharing; the various users can share with each other and with the main grid. According to Zhou et al. [172] the P2P energy market is categorized into three types: (i) centralized, (ii) decentralized, and (iii) distributed market. The centralized market (i) requires a coordinator to communicate and collected data among with each peer, in order to determine if it is importing from or exporting power to the MG. In the decentralized market (ii), transactions are carried out bilaterally between peers, thus not requiring a main coordination. The last, distributed market (iii), encompass both centralized and decentralized attributes and normally request price signals to peers.

These energy schemes contribute to the self-consumption of the consumer's energy production and energy transactions on the grid. In addition, user participation involves various interactions and decisions that affect the system, and those that have been analyzed in this study are as follows: the moment of user energy consumption, the moment of energy export to the grid by the prosumer, the moment of consumer feeding or storage, and the moment of management of stored energy considering the best price. Given the difficulty in understanding how such concepts can be incorporated into MGs, Fig. 5 was elaborated to illustrate how the concepts can be related to MGs and the analysis of prosumer and utility interactions.

To understand how the interactions of prosumers and utilities are incorporated into MGs, please see Fig. 5; we sought to analyze the articles of the systematic review in the database in Scopus and Web of Science and relate the relevant papers with each decision studied to seek the main aspects and similarities of the concepts in the literature. Regarding the **user's moment of energy consumption**, M. Marzband et al. [33] employed collisions to cause impacts that alter the consumption in multiple systems of domestic MGs; as a result, this enables maximum profit. Amanbek et al. [173] addressed contribution metric concepts to make distribution systems with prosumer MGs competitive. Management is done by TE scheduling, and prosumers can acquire points for selling or consuming energy. The contribution metric identifies which prosumer contributes the most in the grid; those who get the most advantages are the ones who contribute the most and consume the least. Ortiz et al. [174] proposed using a method called load profile-benefit assessment (LPBA) to manage energy consumption through guidelines provided to users, and LPBA application maximized welfare benefits. In a smart city context, Chui et al. [175] focused on analyzing ways to improve energy consumption; they investigated smart meters and how non-intrusive load monitoring (NILM) can contribute to identifying the consumption profile of electrical devices. Some authors, such as [176,177], and [178], used DR programs for flexible load control because implementing DR programs allows consumption to be adjusted in relation to price changes in the energy market and helps in the decision-making process. In Ref. [176], the TOU for DR was used for

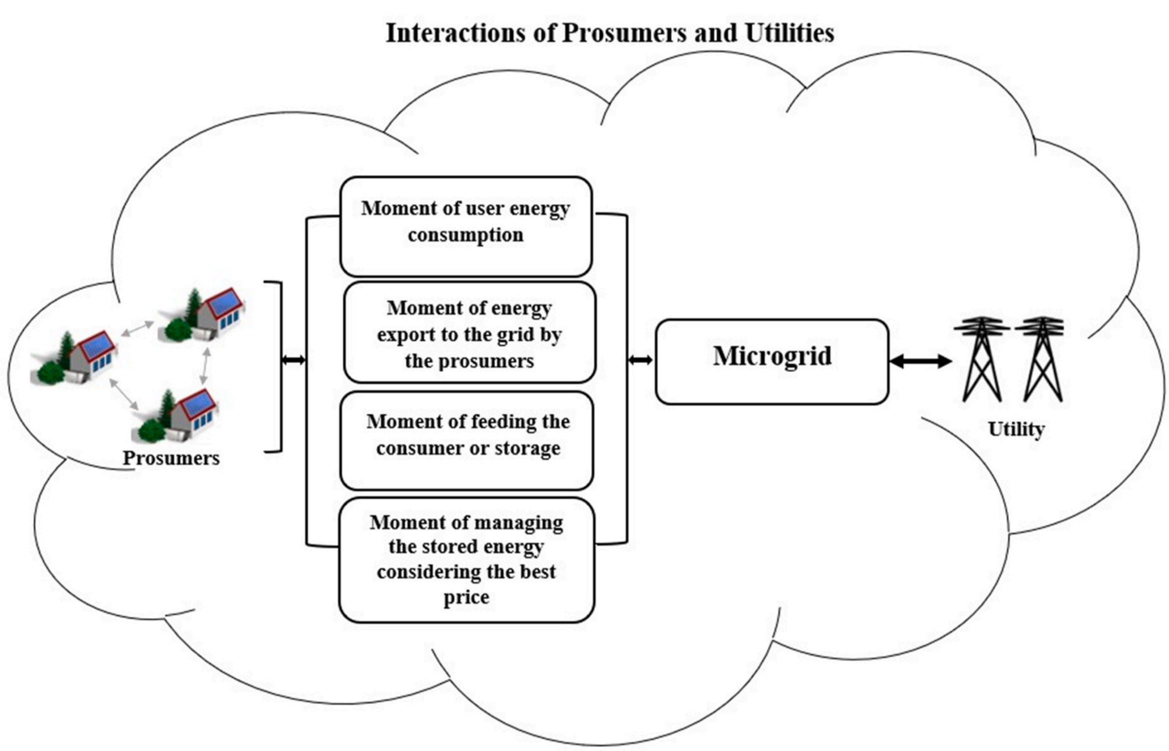

Fig. 5. The role of the MG in the scenario regarding the analyses of prosumer and utility interactions.

large energy consumers, while Talwariya et al. [177] applied the game theory model to different types of consumers in a retail regulation market. The authors analyzed grid users by categories and considered stepwise power tariff conditions (SPT) based on DR to reduce energy consumption. Sypatayev et al. [178] addressed DR, DSM, and auctions among customers, in which consumers can bid on demand reductions. Moreover, Singh et al. [179] examined the utility's price signals to determine the consumption pattern of users. The problem considers as constraints: the maximum demand limit (MDL) signals, time-of-use (ToU) price, and dynamic priority of a load. The problem focuses on flattening the daily energy consumption curve by distributing the operation of the smart home devices; for this purpose, low price periods are verified and that meet the MDL constraint. The work of Javadi et al. [180] sought to find an optimal consumption strategy for a residence by applying HEMS and energy consumption scheduling. To formulate the problem at hand, the authors considered a stochastic optimization problem with a single objective in a MILP framework, so it is possible to efficiently determine the global optimal solution. The paper showed that the real-time pricing (RTP) method is a highly efficient tool to represent the real scenario of the electricity market and one way to solve the overconsumption is by using the inclining block rate (IBR) and ToU tariff methods together. Gomes et al. [181] used predicting methods to determine the consumption of the MG user, while Malik et al. [182] utilized the knapsack method and prioritized plug and play (PPnP) to determine the optimal consumption for a three-tier structure that included many layers of autonomous agents. Daneshvar et al. [183] analyzed the consumption patterns of users through pricing schemes and load response, making demand-side energy management possible.

Wang et al. [184] assume the Monte Carlo simulation to deal with the lack of predictability of DERs and the unforeseen load consumption in energy trading with Multidimensional Willingness of Microgrids. Danzi et al. [185] developed a framework based on a blockchain scheme, which increases the reliability of distributed consumption information and allows DERs to operate at low capacity. The authors apply proportionality tactics between DERs and energy production to minimize the power surplus while maintaining voltage patterns, thanks to a blockchain structure that encompass smart contracts and allows the proportional tactic control. Pop et al. [42] apply distributed ledger based on decentralized blockchain technology to control prosumer consumption. The user consumption data is obtained from smart meters based on the internet of things and the financial settlement of energy consumption automatically applied by smart contracts. DR programs have also been used to balance demand and power generation. Meena et al. [186] argue that the MGs' performance may be optimized through intelligent management based on DR programs that maintain the community consumption under certain pre-established limits. Afzal et al. [187] apply a framework based on game theory to minimize the total energy consumption cost in the community, involving distributed blockchain to reliable energy transition between users, to control smart meters, and also to settle consumption by smart contracts. O'regan et al. [188] discuss device types that may by used in the energy production and in the energy consumption, such as smart meters, actuators, sensors, transactive controllers, and HEMS controllers. In addition, the authors propose the use of blockchain technology to ensure transparency of the information obtained.

Onumanyi et al. [189] address control strategies used by distribution system operators (DSO) to provide price signals while managing electricity consumption rates. Jamil et al. [190] propose a P2P energy trading market using blockchain technology, with two well-defined modules: the former is charged of ensuring safety while controlling real-time energy negotiations and energy consumption, through the use of blockchain technology; the latter employ smart contracts to predict energy consumption based on historical consumption data. Riki et al. [191] develop a voluntary interruption management method to neighborhood energy trading. Niaei et al. [192] support that uncertainties related to energy consumption and to RES must be considered, due to the obvious interference in the stability of transactions. Guo et al. [193] propose a platform called OpenADR to energy consumption control, involving a DR program and blockchain technology to implement safe and effective energy management. Mezquita et al. [194] present in their review how DSM can be used to control electricity consumption considering three main concepts: energy conservation; peak displacement; and the use of distributed generators. Peak displacement may shift the period of peak consumption to an off-peak one, while maintaining energy conservation and increasing reliability and eventually reducing transmission losses thanks to the use of distributed generators. Laayati et al. [195] develop a smart meter project based on blockchain technology to optimize the management of electricity consumption. Lin et al. [196] propose the optimal electricity scheduling together with blockchain technology to improve user's energy consumption in MGs. Yahaya et al. [197] develop an HEM system to perform the energy consumption displacement. Dzobo et al. [198] apply smart contracts to system stability when monitoring prosumers' energy consumption.

As for the **timing of power export to the grid by the prosumer**, the MG can dispatch and control local generation and demand resources [199]. The study by Akter et al. [200] demonstrated a three-level hierarchical structure that contributes to transitive power management in neighboring MGs. This structure contributes to the sharing of excess energy among prosumers, which means energy savings may sometimes occur. In addition, the study considered the cost and benefit of different tariffs to determine the financial advantages for users of a sharing system. Through this, the authors realized that even customers who do not have storage systems and a RES had reduced feed-in tariffs. Janko and Johnson [201] created a method to manage the sharing trade between grid-connected MGs through scalable multi-agent tools in a TE market and, similarly to the previous study, they concluded that energy trade between consumers reduces costs individually and for the entire network. Akter et al. [202] analyzed two approaches for energy trading among the users of a residential MGs; the first is a pre-defined strategy and the second uses game theory with multiplayer. The comparison between the two showed that there is not much difference in terms of savings, although the second approach provides users with more flexibility. Qiu et al. [203] studied the optimal scheduling for prosumers and considered two scenarios in the algorithm. The first scenario involves daily prosumer scheduling in a superior model and mixed integer nonlinear programming is used, and the second one deals with real-time prosumer scheduling. In the latter, adapting the DERs in real-time to maintain balanced systems is necessary because of energy shifts considering a lower model and a nonlinear programming problem with continuous variables. To optimize the energy exchange, Kalysh et al. [204] suggested using P2P trading to maximize the prosumers' profit, and the surplus energy is sold for an optimal price. The elaboration of the problem is performed by the 0/1 knapsack method, and dynamic programming was used to solve the problem. The amount of energy that the prosumer will sell must be disclosed, in return the consumers respond with the desired amount to purchase and the corresponding price. Gayo et al. [205] explained that when energy consumption is higher than production in MG, the strategy adopted by the prosumer with stored energy must be to sell, considering that the price of the network is more expensive than the supply, this because in that moment the price of electric energy rises. Kang et al. [92] present a trading platform that uses blockchain and smart contracts, supporting that energy exchange constraints are only due to consumer and/or prosumer. Ding et al. [206] propose an approach to sharing the energy surplus from the MG in the P2P commerce to meet the neighborhood energy demand, using industrial Internet of Things. Alsunaidi and Khan [207] develop an implementation of Ethereum smart contracts and the consensus algorithm to allow the energy surplus sale, in the prosumer perspective.

In papers that have concepts of **consumer feed-in or storage timing**, Amin et al. [208] stand out; the authors analyzed costs and benefits based on real-time energy tariffs involving a BESS and a photovoltaic system on MGs. This study created an algorithm to analyze the battery charge and discharge cycle and found significant savings in solar purchases by installing BESSs for proactive consumers with the right batteries. Nunna et al. [209] presented a TE trading platform in MGs considering agents and, by using this platform, they developed a framework that suggests two types of the energy storage markets: one at a local scale using ESSs in MGs and another global or community included in the intra- and inter-MG TE market. The study by Harish et al. [210] addressed the concepts of battery charging and discharging to utilize these strategies, and the authors used optimal scheduling tactics that include a centralized P2P station. Still regarding battery charging and discharging strategies, Worku et al. [211] presented a battery controller that works connected to the islanded network; it operates based on $d-q$ decoupled current control, thus the battery can be charged and discharged to achieve its purpose. Ganjehlou et al. [212] studied H-MG in order to verify a new techno-economic approach that includes coalition systems and multi-level optimization. The paper developed a new framework that makes it possible to intelligently charge and discharge energy storage and electric vehicles. Different scenarios with and without coalition for different loads were examined, and it was concluded that the algorithm performs better regarding energy loss, costs, and reliability of the main grid in scenarios with coalition. In their study, Gayo et al. [205] explained that the best strategy for excess energy is to load from the storage system or interruptible loads that are connected because prices are lower. Furthermore, these authors suggested a local market structure that consists of exchanging energy in many time periods in a day and before the payment. Thus, each prosumer will have detailed information on production and consumption forecast for subsequent periods, price of energy exchange with the grid, loading conditions of the storage system, and consumption adapts with interruptible loads.

As for research addressing concepts applicable to the **moment of stored energy management considering the best price**, one can refer to William Cox and Considine [213], who reported switching techniques for operations management in administering autonomous MGs and in communities; this approach is called structured energy. Smart grid systems must deal with the energy dispatch problem when managing the stored energy considering the best price. The authors Shawn A. Chandler et al. [28] used control techniques for dispatch optimization for transactive power systems, and the techniques are a MILP-MG dispatch system and an artificial neural network (ANN) dispatch system. To improve end-resource management and cope with power suppliers' price fluctuations in smart grids, Pinto et al. [214] integrated two multi-agent simulation platforms. The first platform is the multi-agent simulator of competitive electricity markets (MASCEM), which is intended to study the power market, and the second is the multi-agent smart grid simulation platform (MASGriP) to simulate the smart grid operation and production scenario. To optimize power exchanges and improve system decision-making regarding factors such as power price, injected power, and ESS power costs, Nayak et al. [215] developed and applied an economical storage management system (ESMS) that enables MG optimization. P. Siano et al. [216] studied prosumers' adoption of a new transactive controller, and this mechanism can manage electric storage systems. The controller acts by considering price signals at the user, can access smart contracts, and can also control controllable electric loads. Lüth et al. [45] study the relevance of ESS and P2P in local markets, thus proposing both decentralized and centralized storage configurations in energy management to provide flexibility and the consequent cost reduction to consumers. Table A1 (Appendix A) summarizes the main characteristics found in the Scopus and Web of Science databases, considering each decision analyzed in the interactions.

5. Discussion and conclusion

Our findings showed that the insertion of blockchain technology in the energy market provides a major advance in the commercialization of electricity. It allows decentralized and secure virtual transactions, the licensing of numerous smart contracts, and contributes significantly to introducing prosumers to energy transactions in MG communities. The research indicators proved that the interest in MGs is growing in numerous countries whose concern is to seek alternative energy generation that has RES both to supply an increasing demand for energy production and decrease the impacts of atmospheric pollutants. We also observed that TE techniques make market models more competitive and encompass many concepts, such as P2P power-sharing, collision strategies combined the responsive load demand, energy management systems, DR programs, ESSs, the creation of new competitive market structures with TE techniques, TE management, economic control, interaction with prosumers, real-time analysis, and uncertainty assessments. The analysis of the interactions of prosumers and utilities during energy consumption by users, the moment of export of energy to the grid by the prosumer, the moment of feeding the consumer or storage, and the moment of management of stored energy considering the best price provided a better understanding of the definitions and characteristics found in the literature. In order to shed more light on how each moment would be inserted into the MG system, a systematic review was performed, unveiling key aspects involving the studied moments.

The moment of energy consumption of the user has as one of the main aspects the DR programs. This makes it possible to control the user's consumption, establish new consumption patterns, optimize the system coordination process, make consumption adjustments, and reduce energy costs. To increase efficiency and optimize consumption reduction, DR is coupled with other concepts, including SPT, DSM, MDL signals, and TOU. In addition, research has presented consumption improvement methods such as HEMS, which changes energy consumption from peak to off-peak hours, the RTP method for real scenario analysis, and when used in conjunction with IBR methods and TOU tariff, can solve the problem of excessive consumption, prediction methods to determine MG user consumption, smart meters to determine consumer profile, contribution metrics to stimulate distribution systems with competitive prosumer MGs, and the use of collisions in systems to change consumption in multiple H-MG systems.

The moment of energy export to the grid by the prosumer has energy sharing as the main aspect. Energy trading allows energy export among consumers of MG communities and the utility. Moreover, power-sharing can be done by transactive power, which is a way to interfere in the energy supply system through power exchange, and P2P power trading, which is a mechanism that allows each peer (user) to decide which peer to trade (buy or sell). It is interesting to consider energy tariffs, dispatch, and control of local production and demand resources, cost analysis, optimal energy scheduling, optimal pricing, and energy sales strategies considering storage and best pricing.

Concerning the timing of powering the consumer, the main aspect is charging and discharging strategies in ESSs. Among the methods discussed that contribute to charging and discharging tactics are the analysis of the battery charge and discharge cycle using an algorithm, as the right battery can lead to significant energy savings, optimal scheduling strategies that include a centralized P2P station, use of battery controllers, and techno-economic approach that include coalition systems and multi-level optimization for developing frameworks to intelligently charge and discharge energy storage and electric vehicles. Excess energy charging is carried out from the storage system or from connected interruptible loads because the prices are lower.

The moment of stored energy management considering the best price has as main aspect programming tools such as MILP-MG dispatch system and ANN dispatch system to deal with the energy dispatch problem. Multi-agent simulation platforms such as MASCEM and MASGriP are also addressed, as these are used to improve end-resource management and deal with price fluctuations of power suppliers in smart grids. The use of transactive controller by prosumers is used for managing electric storage systems and because it can consider the best price, as well as having access to smart contracts and control controllable electric loads.

This systematic review allowed us to shed more light on this theme and direct the study methodology to answer the questions surrounding this paper. The aspects found explore concepts similar to the characteristics of TE and MGs exposed in the review of indicators, enabling us to perceive that the research strategy was successfully employed and has much academic significance and for the topic. Furthermore, a new approach to the topic is presented by analyzing the interactions of the prosumer and the utility. It emphasizes the sustainable aspect of MG communities because of the self-supply of smart homes and the use of RES.

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

No data was used for the research described in the article.

Acknowledgments

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Appendix A

Table A1
The main aspects found in the systematic review performed in the Scopus and Web of Science databases.

Analysis of prosumer and utility interactions	Main aspects	Authors
The moment of users' energy consumption	a. Collisions in multiple H-MG systems;	a [33].
	b. Metric for stimulating distribution systems;	b [173].
	c. LPBA method;	c [174].
	d. Smart meters and NILM;	d [175].
	e. DR programs, TOU, SPT, DSM, and auctions among customers;	e [176–178].
	f. MDL signals, TOU, and the dynamic priority of a load;	f [179].
	g. HEMS, RTP, MILP, IBR, and TOU;	g [180].
	h. Predicting methods;	h [181].
	i. The knapsack method and PPnP;	i [182].
	j. Pricing schemes, load response, demand-side energy;	j [183].
	k. Monte Carlo simulations, DREs, and Multidimensional Willingness;	k [184].
	l. Blockchain, DREs, smart contracts, proportional tactic control;	l [185].
	m. Distributed ledger, blockchain, smart meters, smart contracts, and DR;	m [42].
	n. DR programs;	n [186].
	o. Game theory, blockchain, smart meters, and smart contracts;	o [187].
	p. Smart meters, actuators, sensors, transactive controllers, HEMS controllers, and blockchain;	p [188].
	q. DSO;	q [189].
	r. P2P, blockchain, and smart contracts;	r [190].
	s. Voluntary interruption management method;	s [191].
	t. Uncertainties and RES;	t [192].
	u. DR program and blockchain;	u [193].
	v. DSM and distributed generators;	v [194].
	w. Smart meter and blockchain;	w [195].
	x. Blockchain and optimal electricity scheduling;	x [196].
	y. HEM;	y [197].
	z. Smart contracts.	z [198].
The moment of energy export to the grid by the prosumer	a. Dispatch and control local production and demand resources;	a [199].
	b. System for sharing surplus energy, considered the cost and benefit of different tariffs;	b [200].
	c. Scalable multi-agent tools;	c [201].
	d. Pre-defined strategy and game theory with multiplayer;	d [201].
	e. Optimal scheduling and real-time;	e [203].
	f. P2P trading, optimal price, knapsack method and dynamic programming;	f [204].
	g. Strategies for prosumers in MGs, considering the price.	g [205].
	h. Blockchain and smart contracts;	h [92].
	i. Industrial Internet of Things and P2P;	i [206].
	j. Blockchain, P2P, smart contracts, and consensus algorithm.	j [207].
The moment of consumer feeding or storage	a. Real-time energy tariffs, BESS, the battery charge and discharge cycle;	a [208].
	b. Energy storage market;	b [209].
	c. Battery charging and discharging, optimal scheduling, and P2P;	c [210].
	d. Battery controller for charging and discharging;	d [211].
	e. Coalition systems, multi-level optimization, charge and discharge energy storage;	e [212].
	f. Energy exchange price with the grid, storage system loading conditions, and consumption adapting with interruptible loads.	f [205].
The moment for managing the stored energy considering the best price	a. Switching techniques for operations management;	a [213].
	b. Control techniques for dispatch, optimization for transactive power systems, MILP, and ANN;	b [28].
	c. Price fluctuations, simulation platforms (MASCEM and MASGriP), power price, injected power, and ESS power costs;	c [214].
	d. ESMS algorithm;	d [215].
	e. Transactive controller, price signals, smart contracts, and control controllable electric loads;	e [216].
	f. Decentralized and centralized storage.	f [45].

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