Comprehensive Survey on Support Policies and Optimal Market Participation of Renewable Energy

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Abstract: Energy demand in the world is mostly met by conventional sources that cause carbon emissions. Considering environmental problems and the depletion of these sources in the near future, there is a trend towards renewable energy sources (RESs). Also, countries are implementing policies such as investment support, production support, quantity target, and limiting carbon emissions to increase the number of RESs. When these policies are compared, one of them can be superior to another in different countries. Also, superficial supports can cause an excessive financial burden on the governments. RESs have inherently intermittent power generation and in this respect, it is important to correctly estimate the RESs whose production changes with environmental conditions and to offer to the electricity markets optimally. For this reason, it is also important to know the structures of the electricity markets in bidding. Besides, RESs can come together to take an effective position in the market in terms of price and manage their imbalances. These structures can take names such as aggregator, virtual power plant (VPP), and portfolio. Considering the above-mentioned issues, this study aims to investigate in detail the methods applied to increase the number of RESs and the ways these resources participate in the electricity markets. In this context, subjects of policies promoting RESs, electricity market structures, development of the electricity market, optimum bidding strategy and ways of collective participation of RESs in the electricity markets are comprehensively examined under different sections.

Keywords: Electricity market; optimal bidding; renewable energy policies.

1. Introduction

Electricity consumption and electricity production related to this consumption have continuously increased for many years [1]. Most of this produced energy is met by fossil sources that cause environmental problems, and this situation pushes the world in search of new alternative sources [2]. In this respect, the share of renewable energies in total electricity generation increases every year due to the rapid development of wind and solar energy technologies, the serious decreases in investment costs of these technologies, global climate change and the desire of the developed countries to go towards green technologies [3].

Besides, various policies such as feed-in tariff (FIT), feed-in premium (FIP), and green energy certificates (GECs) are implemented by the states to increase the prevalence of renewable energy sources (RESs) [4]. Using renewable portfolio standard (RPS) known as quota obligation (QO) ensures that a certain part of the production is met from RESs [5]. Apart from these policies, carbon pricing, one of the carbon policies (CPs), can make it easier to invest in RESs [6].

As a result of the increasing share of renewable energies, the electrical system has become more flexible and independent of fossil sources but has become dependent on wind and solar energy, which must be monitored instantly and backed up by storage or fossil-powered power plants. This situation reveals the necessity of making the production estimates of wind and solar power plants more consistent and the importance of these power plants to bid optimally for electricity markets. RESs can join the electricity market individually or collectively. With the addition of more than one RES to an aggregator, the aggregator can be placed in the price-maker position and production imbalances can be eliminated through resources balancing each other. Furthermore, the aggregator structure provides easy management of bidding processes for participants regarding participation in electricity markets, and considering the issue of facilitating the imbalance, it offers the opportunity to earn more income. When we look at the studies in the literature and also the real-life applications, it can be seen that RESs are included in different structures for different purposes, such as portfolio, aggregator, microgrid, etc. It should also be noted that there are structures that are evaluated together with energy storage systems (ESSs) and/or conventional energy resources in order to support the stochastic structure of RESs.

Looking at the development of electricity markets, they have undergone a significant liberalization phase by evolving from vertical integration as a result of the transition experience since the 1980s [7]. The liberalization efforts especially in developed countries have made significant progress in the wholesale markets and started to be implemented until the retail markets. Electricity spot markets are operated for the purpose of preparing a balanced market structure by matching the suppliers and consumers with energy buying and selling offers before the deadlines set by Market Operator (MO). Deadline time differs from each other in different countries. For example, the participants present their day-ahead market (DAM) offers for the next day until 12:30 every day at the Turkish Electricity Spot Market EPİAŞ. Amounts exchanged and the market clearing price (MCP) are announced at 13:30. The Intra-Day Market (IDM) in EPİAŞ is a continuous market and offers can be submitted to the market up to 1 hour before physical delivery. In Spain's electricity spot market OMIE, DAM offers can be submitted until 12:00, one day before. The IDM consists of the auction market and the continuous market. The auction market is divided into 6 sub-sessions. For example, Session 1 opens at 14:00 and closes at 15:00. The results are announced at 15:07 for this session. In the continuous market, transactions can be made up to 1 hour before energy delivery. In the event that there is no production or consumption in accordance with the bids submitted, a penalty is imposed by MO by introducing obligations such as buying energy at higher prices or selling energy at lower prices.

Renewable energy support policies, electricity markets, optimum bidding strategy and market participation of RESs have recently attracted the attention of researchers. There are review publications on these topics in the literature. Elavarasan et al [8] examined global policies used to promote renewable energy. Besides, important issues that prevent the development of renewable energy in India were also addressed.

Aparicio et al [9] examined European countries, the US and Australia's experience in wind energy support policies. Zamfir et al. [10] reviewed the policies used to support renewable energy in Romania over the past decade. Atalay et al. [11] conducted a literature review on FIT and tendering mechanisms in developed and developing countries, and analyzed the feasibility of adopting these mechanisms in the Gulf Cooperation Council (GCC). Haas et al. [12] investigated in detail the incentive strategies historically implemented for RESs and their status in the European Union (EU) countries. Lia et al. [13] presented a comprehensive literature analysis on the state-of-the-art research of bidding strategy modeling methods. They discussed recent publications that analyzed the bidding strategy in the liberalized electricity wholesale market.

Steeger et al. [14] investigated publications on the bidding strategy in the literature. They examined which approaches and methods were used to model the bidding problem of hydro-electric producers. They evaluated approaches used could be applied or not applied to other variants in each variant of the bidding problem and examined the applicability of the approaches used in each variant of the bidding problem to other variants. Abhinav and Pindoriya [15] examined renewable energy studies in major electricity markets around the world and explained the key features of the energy market of India. Besides, the authors provided a brief overview of the operating problems caused by the high penetration of wind energy in electricity markets.

In the light of the above information, this study aims to examine in detail the methods applied to increase the number of RESs and the participation ways of these resources in the electricity markets. In this context, support policies promoting RESs, electricity market structures which is one of the most important issues to consider when bidding due to its different structures, development of the electricity market, optimum bidding strategy providing the most profitable situation for the bidder in line with the targeted purpose and ways of collective participation of RESs in the electricity markets are examined comprehensively. It should be noted that a considerable part of the literature on the optimal bidding strategy are examined. Besides, the authors have not come across any study in the literature that the ways of collective participation of RESs are classified in detail.

The organization of the paper is prepared as follows: articles containing renewable energy policies in the literature are examined in Section 2. In Section 3, the history of the electricity markets and the development of the deregulated markets are mentioned and then different types of electricity markets in the world are reviewed. Later in Section 4, articles regarding the optimal bidding of RESs in the literature are reviewed with under different categories. The ways in which

RESs participate collectively in the electricity market are discussed in Section 5. Lastly, Section 6 contains the results of the work and suggestions for future works.

2. Renewable energy support policies

According to the World Energy Outlook of International Energy Agency (IEA) [16], energy production from RESs increased by 7% in 2018 compared to the previous year, accounting for more than a quarter of the total electricity production. The photovoltaic and wind energy make up 90% of this growth. These developments have been achieved with cost reductions as a result of the advancement of technology as well as the application of different incentive mechanisms. The incentive mechanisms can be generally categorized under four titles as investment supports, generation supports, quantity targets, and CPs [17]. An overview of support policies is given in Figure 1.

Figure 1. Support policies for renewable energy sources.

2.1. Investment supports

The development of renewable energy technology is more expensive than conventional energy technologies and therefore requires a large amount of financial investment [18]. Investment support covers financial supports such as subsidies, grants, and tax incentives. The subsidy is usually a cash payment from the government. This support mechanism plays an important role in the development of RES technology. Because before any energy technology matures, a large amount of money support is needed. Besides, as the high amount of support causes high costs, it is generally recommended to be evaluated in areas that need urgent support [19]. More detailed information on subsidies is available in [20], [21], [22] and [23]. Besides, the grants are provided to support renewable energy developers. In this structure, grant money is paid to RES investors who apply for programs opened by the state and deemed appropriate, taking into account the unit investment cost to support the RESs added to their properties. For example, the Texas State

Department of Rural Affairs grants agricultural producers and small businesses a minimum of $2.500 and a maximum of $500.000, if they add biomass, geothermal, hydropower, hydrogen, wind, photovoltaic and tidal power plants [24]. These supports can be given for public institutions as well as private corporations and private individual. Tax incentives include supports such as low-interest and long-term credit, environmental tax exemption, value-added tax exemption. Tax incentives have a function that other economic instruments cannot replace them [19]. Reference [19] and [25] can be examined for detailed tax incentives.

2.2. Generation supports

Generation supports cover generally FIT, FIP, net-metering, and tendering schemes. Historically, FIT mechanisms are the main mechanism used in the US and Europe. The price of FIT is the price paid per kWh for electricity produced from renewable energy producers and delivered to the grid. In other words, the FIT mechanism is the obligation to purchase by the public with a predetermined fixed price and for a specified time [26]. This structure encourages investors unwilling to face insufficient income risks. FITs have been used in many European countries such as Austria, Denmark, Finland, Germany, and the Netherlands [27]. FIT application was first used in the world in 1978 with a different name in the US and then it became common all over the world. Germany was the first country to apply this practice in Europe in 1990. Besides, in the US, wind power developers receive production tax credits (PTCs) as generation support [28]. FIP is an additional support payment above the electricity market price. Unlike FIT, FIP electricity price changes over time depending on the electricity market price [29].

While the FIT mechanism does not provide any incentive to match electricity production to demand, the FIP mechanism can reduce intermittent power generation balancing costs [30] and can be fixed or sliding. In fixed FIP structure, RES participates in the electricity market and receives a fixed premium payment directly on the electricity market price. Although it looks like a simple structure, it also includes risks. While a good income can be obtained when the market price is high, if the market price is too low, the desired income may not be obtained even if a premium is received above the market price. In this respect, minimum and maximum levels in fixed FIP are usually determined for RESs by taking into account also the government institutions that do not want to pay high. In sliding FIP mechanism, average electricity prices, usually taken as 1 month, and reference electricity prices are determined. If the electricity market price is above the reference price, no payment is made. Besides, as in the fixed structure, a minimum price may be determined here to increase the attractiveness of RESs. High payment can promote RESs to produce energy more. The producers who have storage system or is biomass or geothermal producer can handle an advantage. The FIP mechanism has been implemented by EU countries as an alternative to the widely used FIT programs. Spain is the first country in the world to implement this mechanism. Some European countries that use this application are Czech Republic, Denmark, Germany, Netherlands, Finland, and Slovenia. Besides, the net-metering mechanism as the electricity billing structure that consumers deliver the energy produced from RESs to the grid is used to promote small-scale RESs. This structure is generally used for residential wind and photovoltaic energy systems. Tendering schemes are competitive mechanisms to allocate financial support to renewable energy projects where the states make a series of tenders for renewable energy and then the government supports the winning offers, such as FIT, FIP, capacity payments [18].

2.3. Quantity targets

The commonly applied QO system is a minimum limit-based structure to support energy production from RESs [31]. The QO usually consists of a specific renewable energy target defined by the government, and consumers and electricity suppliers must comply with these obligations. Furthermore, GEC markets have been created for renewable producers to compete with each other as energy buyers aim to purchase renewable energy as cheaply as possible [18]. In other words, in this mechanism, electricity supply companies are obliged to produce a certain part of their electricity from RESs. Certified renewable energy producers obtain green certificate for the energy they produce and can trade in the relevant markets. Generation Companies (GENCOs) who buys green certificates, send their certificates to regulatory authorities to prove that they have fulfilled their responsibilities. This mechanism has been adopted in Great Britain, Italy, Belgium, Australia, Chile and large part of the United States. It is stated that the QO is more in line with the requirements of market compliance and competition policies, especially when combined with GECs. Thus, the quantities produced from RESs can be provided in a more controlled manner [31]. GEC is also known as a renewable energy certificate, renewable energy credit, or tradable green certificate. Quota targets are called as RPS in the United States (US). RPS reduces the pressure on government aids and promotes renewable energy [32], [33]. The United Kingdom, United States and Australia are currently countries where RPS is well implemented [32]. In case of failure to fulfill the obligations, penalties are imposed, and this price is usually the highest price in the certificate market. This structure is generally not very suitable for the implementation of technological developments, as it does not encourage expensive RES investments.

2.4. Carbon policies

Governments have issued various regulations to reduce industrial enterprises' carbon emissions. These are carbon cap policy, carbon tax policy, carbon cap-and-trade policy, and carbon offset policy. Carbon cap is a policy in which total carbon emission is limited [34]. The carbon tax is a tax for the amount of CO_2 produced. This application has a relatively low cost and it is applied to slow down global warming by controlling CO_2 emissions. Denmark is the first country to apply the carbon tax in 1991 followed by Finland, the Netherlands, Norway, and Sweden [35]. The appropriate carbon tax can promote renewable energy and reduce carbon emissions. However, high tax rates can affect business performance and industry development [36].

Carbon cap-and-trade is a market-based mechanism which has been applied in Europe, North America, Australia, China, and other parts of the world [37]. In the carbon cap-and-trade policy, producers have to make a payment if they emit more carbon than the predetermined limit. In case they emit less carbon than this limit, they can sell their carbon emission amount to other producers. The carbon offset enables companies to invest in renewable energy projects around the world to balance their carbon footprint [34].

2.5. Literature review of support policies

There are studies in the literature that include the above-mentioned policies and used to promote RESs. Some of them contain a model, while some only address the topic, and no model is included. Besides, when the literature is examined, it is seen that some of these studies deal with a single supporting mechanism, while others consider more than one mechanism in a hybrid way. Here, it can be stated that the combination of mechanisms that are generally complementary and more economical is more successful in promoting RESs than when a single mechanism is applied. While the best incentive mechanism cannot be mentioned according to the results of the research, the mechanisms implemented and their success rates vary from country to country. These studies can be discussed as follows. Hildmann et al. [38] examined empirically the effects of wind and solar power plants on the DAM in the EPEX Germany-Austria region under the FIT mechanism. In the results obtained from the study, they stated that if the costs of RESs were used correctly in the merit-order curve and the total market demand was increased, the functionality of the energy markets could be maintained. Campoccia et al. [26] examined the FIT application that has led to the increase of renewable energy in Europe recently. However, in the study, it was stated that while the FIT mechanism is not suitable for the installation of PV systems in France and Germany, it is suitable in Spain. Simao et al. [39] discussed the situation from a technical and economic perspective when a wind producer struggles to compete in the future electricity market. Besides, they carried out case studies with the FIT application, which is valid in MIBEL. Genoese et al. [40] identified and analyzed the parameters that determine the profit of wind power operators in the Germany FIT model. According to the results obtained from the empirical analysis in the study, it was stated that the premium of 3.5 €/MWh is sufficient to cover the cost of an inaccurate estimate. Javadi et al. [41] proposed a dynamic optimization structure for the composite generation expansion planning and transmission expansion planning problem, taking into account the time-of-use program and FIT incentives. Georgitsioti et al. [42] studied the costs of residential photovoltaic systems in the UK, taking into account changes in the FIT. Doulamis et al. [43] declared that FIT was widely used in the integration of RESs. However, it was stated that aggregators started to be adopted as the prices did not change in the FIT application. Because the aggregator could act as the mediator between the market and the RESs. Helm and Mier [44] examined the market distribution resulting from low capacity costs of RESs under peak pricing applications. In the study, they stated FIT application was used to promote renewable energy and this application provided protection against low prices, many countries planned to reduce renewable energy supports and increase the share of renewable energy, and ESSs could be a solution to the price problem in electrical systems. Nieta et al. [45] presented research on wind energy producers' participation in the DAM with or without incentive payments. According to the results obtained from the study, wind generator reduced the electricity prices, and the imbalance penalties helped the independent system operator (ISO) to eliminate the imbalances.

Wong et al. [27] examined FIT, carbon tax, and cap-and-trade policies that could be used to promote distributed generation investment and incorporated them into a mathematical model. It was stated that the FIT mechanism is necessary to increase the PV investments. However, it had been declared that FIT is extremely costly in the case where it is only aimed to reduce emissions, and cap-and-trade mechanism reduce both emissions and energy costs. Djorup et al. [46] reported that electricity prices declined with an increase in the number of RESs. The authors examined the effect of this situation on financial sustainability. They stated that renewable energy was mostly provided with a FIT and it was wrong to consider FIT as a temporary method that could be removed as the number of renewable energy increased. Dong and Shimada [47] analyzed Japan's electricity companies' response to RPS and FIT implementation. They stated that FIT implementation caused additional costs to consumers and that the Japanese government should take measures to increase its share of renewable energy in the most appropriate way. Vlachos and Biskas [48] stated that FIT and quota implementation were carried out to increase the prevalence of RESs and this situation created political stress with increasing costs. The authors solved this problem with a new market model, including MCPs, reserve prices, and renewable energy supports. The effectiveness of the proposed model was tested with a FIT application and GEC mechanism. Yu-zhuo et al. [49] tackled the system dynamics to establish the long-term development model of the renewable energy industry in the case of FIT and RPS. In the results obtained from the study, they stated that these mechanisms could encourage the long-term and rapid development of the Chinese wind energy industry. Yu-zhuo et al. [50] presented the long-term development model of China's biomass energy industry under FIT and RPS. In the study, it was concluded that RPS could promote the development of the Chinese biomass energy industry according to FIT. The authors aimed to make this study a reference for the government and other countries. Besides, Xin-gang et al. [51] examined the development of the Chinese waste incineration industry under FIT and RPS. Hao et al. [52] evaluated FIT and RPS implementations together and separately. They stated that RPS was reasonable when renewable energy costs were cheaper than conventional production, and FIT was appropriate if renewable and conventional resource costs were approximately the same. Yi et al. [53] proposed an evolutionary game model and system dynamic model to examine the strategies of renewable energy producers under FIT and RPS. In the study, it was stated that in order to support the development of the certificate market and the implementation of the RPS plan, policy makers should avoid setting the quota requirement too low. Choi et al. [54] investigated in South Korea under FIT and RPS mechanisms, and stated that the FIT application was implemented from 2002 to 2011, and RPS was used since 2012. Besides, they specified that the

RPS was more appropriate for photovoltaic systems, and FIT was more suitable for wind energy, biomass, and fuel cells in terms of the government. For the producers, they explain that the opposite of these two situations was valid. Baldick [55] examined in detail the interaction between increased wind, transmission restrictions, GEC, wind and demand correlation, cuts, carbon tax and electricity market prices using the specific example of the Electric Reliability Council of Texas. Lee and Huh [56] stated that oil price was an important factor affecting the spread of RESs. According to the results obtained from the study, they stated that RPS in South Korea increased the spread of renewable energy more than the FIT. Ciarreta et al. [57] stated that the FIT helped to increase the number of RESs, and this situation brought high costs to consumers due to the increasing number of RESs. Besides, they compared FIT application and GEC trade and tested the proposed structure with data from the Spanish electrical system of 2008-2013. Zhang et al. [58] examined the impacts of Chinese energy sector reforms on renewable energy integration. They stated that a deep-rooted electricity market could overcome the difficulties which might arise in this regard. Besides, they explained that policies such as transmission and distribution tariff reform, direct trade reform, FIT, and GEC were implemented in China.

Anatolitis and Klobasa [29] analyzed the revenue of a wind turbine in Germany, taking FIP into account. In References [59] and [60], a review was conducted on the FIP subsidy for wind energy. Schmidt et al. [30] evaluated the effects of FIT and FIP mechanisms on the selection of wind turbine locations. They also demonstrated it on an analytical model for it. Gawel and Purkus [61] investigated the German renewable energy FIP application adopted in 2012. In the results obtained from the analyzes, they stated that FIP application increased the participation of RESs in the market, but FIP would not be sufficient to improve market and system integration. Newbery [62] declared that it was recommended to integrate RESs into the market in the 2015 EU Energy Package. The author stated that premium payments were made on the market price instead of FIT in England and that England which had tried almost all the support mechanisms, had provided good evidence for examination in this regard. Ciarreta et al. [63] discussed empirically the cost of supporting RES through price-based incentive schemes. It was announced that the applied mechanism was generally effective in Spain. It was also stated that this situation caused the share of green resources in the pool to increase from 29% to 57% and the 2012 market price decreased from 45 €/MWh to 25 €/MWh. Chaves-Avila et al.[64] discussed the design of support programs, the priority shipping rule, and the production of RESs of market rules such as negative prices. In the results, authors stated that with FIT and priority dispatch, the number of RESs increased and lower emissions were obtained. Kitzing and Ravn [65] conducted a stochastic analysis for the Nordic electricity system with exemplary offshore wind park. They stated in their results that FIT and FIP have different risk-return relationships.

Upton Jr. and Synder [66] stated that 30 states in the US had adopted RPS, which made it mandatory to meet some of their electricity production from RESs. As an important result, the authors stated that electricity prices increased and electricity demand decreased in states adopting RPS. Young and Bistline [67] investigated the cost of implementing RPS to reduce carbon emissions in the US. The authors stated that this method was not the best policy. Furthermore, they explained that the effectiveness of RPS in carbon reduction depended on natural gas prices. Hou et al. [68] developed a decision-making tool under RPS for retailers at the lower level of their proposed strategy. Palmintier and Webster [69] presented a new and efficient method for production planning using an integer-based clustering method. They also proposed 2035 planning examples for ERCOT under carbon price and RPS. Ning et al. [33] analyzed the reasons for the lack of motivation of RES participation in the market based on Ningxia, China. The study examined the effect of RPS and GEC applications on RESs in Ningxia, China. Ding et al. [70] discussed the integration of wind turbines into the grid and proposed a method in the study to determine the role of wind energy and to guarantee long-term RPS. Bhattacharya et al. [71] examined the social benefits and the effects on the market of RPS, taking into account voluntary GEC practice, differences in consumer preferences, and incomplete market competition. It was stated that the RPS increased the prices in the electricity market, although RPS aimed to increase the use of renewable energy. Rudik [72] suggested a GEC trading model within the RPS framework and explained that the more stringent application of RPS under a competitive certificate trading practice led to a reduction in the share of renewable energy. Wang et al. [73] stated that the GEC program was implemented to reduce the cost of achieving RPS targets but, in this case, there might be inequality in renewable energy distribution. The study included examinations on renewable energy certificate tax and quota applications. In the results of the study, they concluded that RPS was more appropriate as FIT had caused a heavy financial burden for the Chinese government. Zhang et al. [74] stated that FIT implementation caused a huge financial burden for governments, while RPS and GEC could reduce this burden. The authors conducted a case study with China data to examine the effectiveness of RPS and GEC. Besides, they stated that FIT should be applied as a complementary policy when RPS and GEC were not sufficient. Tanaka and Chen [75] analyzed the behavior of RESs in the GEC market and their impact on the electricity market. Besides, they proposed a model for determining market power.

Pineda and Bock [76] proposed a model that included both electricity and the GEC market to assess the amount of renewable energy generation capacity growth. It was stated that the main result obtained from the study, apart from the value of the quota obligation, the correct determination of the noncompliance penalty significantly affected the incentives. Binder et al. [77] obtained data-based results testing the relationships between prices in the electricity sector using the Massachusetts and Connecticut GEC markets. Munoz et al. [78] evaluated the costs of Chile reaching the 70% renewable energy target by 2050. Sun [79] investigated a competitive electricity market operating as the common GEC market of the two countries. The scenarios such as a common green trade market, conventional producers, and carbon emission standards application were discussed in the study. Besides, it was stated that a common GEC market had the potential to increase social benefit. Chuang et al. [80] proposed a method to demonstrate the advantage of implementing a suitable mechanism for the implementation of the GEC system and the inclusion of RESs. They stated that the application of GEC would provide incentives for companies to invest in renewable energy and helped to reduce carbon emissions. Furthermore, it was stated that FIT implementation was a suitable mechanism for Taiwan's long-term goals, but it has prevented the growth of GEC. Lin et al. [32] summarized the experience of countries that have successfully implemented RPS and propose a future in renewable energy, and they explained the reasons why India failed RPS implementation.

In References [34] and [37], efforts were made to reduce the total cost of production, taking into account the carbon trading costs. Hasan et al. [81] explored the preferences of the RESs in entering Australian National Electricity Market. They also discussed carbon taxes and incentives in this research. Hirth and Ueckerdt [82] analyzed support programs and CO_2 pricing policies. It was stated that CP was not generally the best policy, but a policy that included a mixture of support programs and CP should be adopted. Chang and Li [83] analyzed the impact of CP, energy market integration, RPS, and FIT on increasing the number of RESs for the ASEAN region. In the results obtained from the study, they stated that energy market integration was important in increasing the number of RESs, and FIT for the ASEAN region was more cost-effective than RPS. Behboodi et al. [6] conducted a search for optimum installed capacity allocation of RES in the presence of a demand response. The authors reported that the optimal RES capacity level is as sensitive to carbon tax as to initial cost. Qi et al. [35] made a review to find the best prices in centralized and decentralized systems and examined the effects of carbon tax on carbon emissions and earnings. Wang [36] studied how governments choose the most appropriate carbon taxes and emission limits to encourage investment in the implementation of carbon reduction technologies. Vithayasrichareon et al. [84] examined 2030 optimum production portfolios for a scenario created with the carbon price derived from the Monte Carlo generation portfolio model. Nazari and Ardehali [85] presented an optimum bidding strategy, including carbon pricing for a GENCO, taking into account carbon emissions and wind energy uncertainty. Levin et al. [17] presented an optimization model to provide the lowest cost expansion, agreement, and production plan to meet the hourly electricity demand and ancillary services. In the study, the data obtained from the ERCOT electricity market was used to analyze the effects of incentive mechanisms. Besides, they stated that electricity prices were significantly affected by different incentive mechanisms, the carbon tax was a more cost-effective way to reduce emissions, and generation and investment supports were more suitable options to increase renewable energy investments. Mauch et al. [86] investigated the economic feasibility of joining a wind farm and compressed air energy storage hybrid system into the DAM where wind farms are freely competitive in the market. In their results, they explained that it is unlikely to be profitable in the DAM without tax incentives or RPS.

Keyuraphan et al. [20] compared renewable subsidy policies in many countries in the US and Europe. In the results of the study, it was stated that in order to promote renewable resources in Thailand, an obligation and voluntary plan should be adopted. Nicolini and Tavoni [22] investigated the impact of policies for renewable energy in the five largest countries in Europe between 2000 and 2010. It was stated that the policies applied for the countries mentioned in the study were effective in promoting renewable energy in both short and long terms. Yang et al. [23] presented a model to study the impact of government subsidies on renewable energy investments and also explained the types of subsidies and the differences between them. Cansino and Pablo-romero [25] took a comprehensive look at the main tax incentives used to promote green energy in the 27 member states of the EU. They noted that sixteen member states used tax incentives along with quota obligations and price regulation. Liao and Zhao [87] compared the subsidy and tax incentive policies applied with economic analysis.

The studies examined in this section include the participation of RESs in the electricity markets and support policies. The classification of studies involving support mechanisms of RESs, including also non-mentioned above, are given in Table 1. The classification includes studies with and without an optimization model. It is also divided into the types as journal article and conference paper. The superscript $^{\Omega}$, $^{\Delta}$ and ^{6} on the references represent cost minimization, social welfare maximization/profit maximization, and research of RES support, which state the objective of the study, respectively. Furthermore, Table 2 contains information about which support policies are used in some selected countries.

2.6. Evaluation of support policies in terms of renewable energy volatility

RESs are spreading rapidly with political pressures. However, RESs have different structures from traditional generation sources. This situation causes differences in terms of operation of the power system. Energy generated from RESs is generally affected by weather conditions, and it has a high unpredictability and volatility.

Table 1. The categorization of the literature studies by support policies

Support Schemes	Contain an Optimization Model		No Optimization Model Contain	
	Journal Article	Conference Paper	Journal Article	Conference Paper
Carbon tax	[6]$^{\Omega}$, [84]$^{\Omega}$, [85]$^{\Delta}$	[35]$^{\Delta}$, [36]^{6}	–	–
Cap-and-trade	–	[34]$^{\Omega}$, [37]$^{\Omega}$	–	–
Carbon tax, Tax incentive	[81]$^{\Omega}$	–	–	–
FIP	[59]$^{\Omega}$	–	–	[29]^{6}, [60]^{6}
FIT	[40]$^{\Delta}$, [41]$^{\Omega}$, [42]$^{\Omega}$, [43]$^{\Delta}$, [44]$^{\Delta}$, [45]$^{\Delta}$, [88]$^{\Delta}$, [89]^{6}, [90]$^{\Omega}$, [91]$^{\Omega}$, [92]^{6}	–	[38]^{6}, [39]^{6}, [46]^{6}, [93]^{6}, [94]^{6}, [95]^{6}, [96]^{6}	[26]^{6}
FIT, Carbon tax, Cap-and-trade	[27]$^{\Delta}$	–	–	–
FIT, FIP	[97]$^{\Omega}$, [98]$^{\Delta}$	[30]$^{\Delta}$, [65]$^{\Delta,\Omega}$, [99]$^{\Delta}$,	[61]^{6}, [62]^{6}, [63]^{6}, [64]^{6}	–

		[100]Δ		
FIT, FIP, QO	–	–	[101]б, [102]б	–
FIT, GEC	[48]б, [57]Ω	–	[58]б	[103]б
FIT, RPS	[47]б, [49]б, [50]б, [51]б, [52]Δ, [56]б	–	[20]б, [104]б	–
FIT, RPS, GEC, Subsidies	[53]б	–	–	–
FIT, RPS, Carbon tax	[83]Ω	–	–	–
FIT, RPS, Carbon tax, Cap-and-trade	[82]Ω	–	–	–
FIT, RPS, Carbon tax, GEC	[55]б	–	[54]б	–
FIT, RPS, Carbon policies, GEC	[74]Ω	–	–	–
GEC	[76]Δ, [79]Δ, [105]б, [106]Δ	–	[80]б	[107]б, [108]б
RPS	[68]Ω, [109]Δ, [110]Ω	–	[66]б, [67]б	[32]б, [111]б
RPS, Carbon policies	[69]Ω	–	–	–
RPS, Cap-and-trade	[112]б	–	–	–
RPS, GEC	[70]Ω, [71]б, [72]Δ, [73]Δ, [75]б, [77]б, [78]Δ, [113]Δ	[33]б	[114]б, [115]б	–
RPS, Carbon tax, Tax incentive	[17]Ω, [86]Δ	–	–	–
Subsidies	–	[116]б	[9]б, [18]б, [20]б, [21]б, [22]б, [23]б	–
Tax incentive	–	–	[25]б	–
Subsidies, tax incentives	–	–	[87]б	–

(Ω =Cost minimization, Δ =Social welfare maximization/Profit maximization, б =Research of RES support policy),

Table 2. Comparison of support policies in various countries

Country	FIT	FIP	QO/RPS	GEC	Tax Incentives	Subsidies	Tenders	Net metering
Argentina	✓				✓	✓	✓	
Austria	✓			✓		✓		
Australia	✓		✓	✓		✓	✓	
Belgium		✓	✓	✓	✓	✓		✓
Brazil	✓				✓	✓	✓	✓
Canada	✓		✓		✓	✓	✓	✓
Chile							✓	
China	✓		✓	✓	✓	✓	✓	
Colombia					✓	✓		✓

Czech Republic	✓	✓		✓	✓	✓		
Denmark		✓		✓	✓	✓	✓	✓
Finland	✓	✓		✓		✓		
France	✓	✓			✓	✓	✓	
Germany	✓	✓			✓	✓	✓	
Greece	✓	✓			✓	✓	✓	✓
Hungary	✓	✓				✓	✓	✓
India	✓		✓	✓	✓	✓	✓	✓
Italy	✓	✓		✓	✓	✓	✓	✓
Luxembourg	✓	✓				✓	✓	
Mexico			✓	✓	✓		✓	✓
Netherlands		✓			✓	✓	✓	✓
Norway			✓	✓		✓	✓	
Portugal	✓		✓		✓	✓	✓	✓
Slovakia	✓	✓		✓	✓	✓	✓	
South Africa	✓				✓	✓	✓	
Spain	✓	✓		✓	✓	✓	✓	✓
Sweden			✓	✓	✓	✓		
Switzerland	✓					✓		
Turkey	✓					✓	✓	✓
United Kingdom	✓		✓	✓	✓		✓	
United States	✓		✓	✓	✓	✓		✓
Uruguay	✓				✓	✓	✓	✓

Moreover, there may be medium-term (daily, weekly) and long-term (seasonal) fluctuations other than short-term fluctuations in RES output [117]. In this context, when RESs cannot provide the energy they commit to the grid, a reserve must be kept in order to prevent interruption of the energy transmitted [118].

Considering that each RES has a different structure, and their production varies, it is clear that the support policies applied will be beneficial in different rates in terms of supporting RESs. As can be seen from the renewable energy production data for 01/10/2020 - 04/10/2020 obtained from the Turkish Electricity Market Operator as given in Figure 2, there are large changes in the amount of renewable energy produced hourly. In line with this information, it is important to determine the generation incentives provided by the states according to the type of RES resource. It should also be underlined that incentive selection is important for producers.

It can be said that the FIT application is suitable for RESs that do not have energy storage systems, or wind and PV which do not have storage properties unlike biomass, due to their nature. FIP application is more suitable for hydroelectric with dam, geothermal, biomass and RES with ESS. Because in the FIP application, more income can be obtained by selling in the high-priced period through changing prices. Besides, while it is more appropriate for RESs with no storage capacity and with very variable power generation to sell through FIT, PV plants that are partially more evident in production have a chance to earn higher income through FIP. The certainty in power generation will prevent falling into imbalance in the electricity market and will also enable more profitable trade.

It is also important issue for countries to provide incentives to equip RESs with ESSs in terms of a safer system operation, or to support resources with storage properties such as biomass, geothermal and dam hydroelectric with appropriate incentives. Besides, appropriate market rules should be determined in order to protect each market participant of energy trade in GEC markets and carbon cap-and-trade markets, which are generally used in conjunction with the QO application and are established to enable producers to compete with each other. Because, in the oligopoly market situation, other participants may also experience losses.

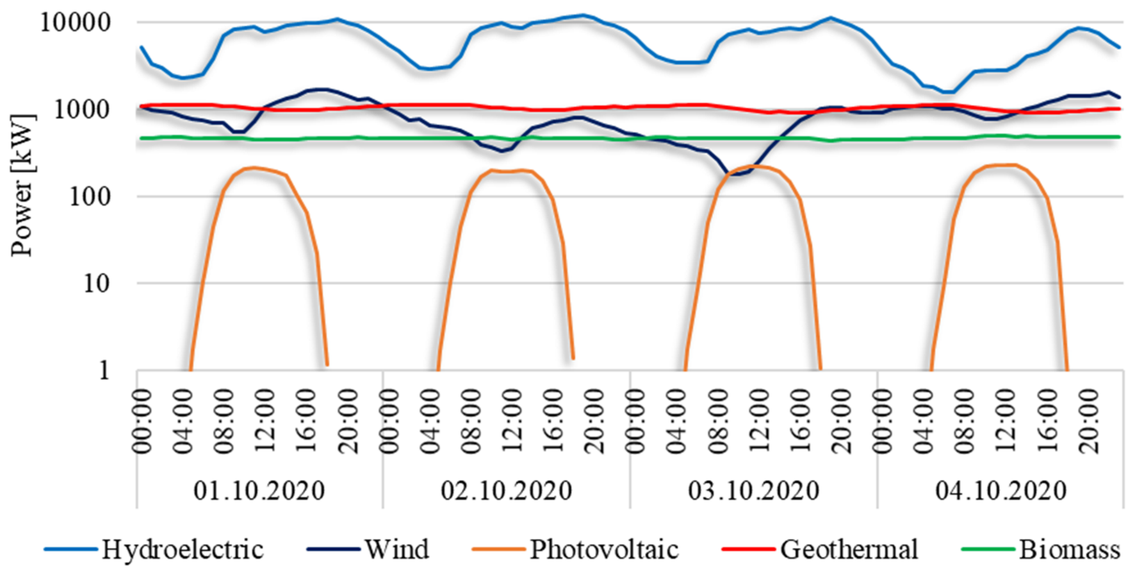

Figure 2. Renewable energy generation example (Turkish market).

3. Information about electricity markets and new trends

Until the 1980s, production, transmission, and distribution services were operated in a monopoly manner by a single company. First in the world, in 1982, liberalization steps were taken in Chile and subsequently, similar transition changes were observed in England, Wales, Norway, Australia [119]. Energy market mechanisms are evaluated in four main categories: vertical integration, a single buyer market, wholesale market, and retail competition [7]. In vertically integrated monopoly markets, production, transmission, distribution, and retail sales functions to electricity companies are provided through a single corporation. This corporation can be either a private company or public.

The single-buyer market model, which is seen as the first step towards the liberal market, allows to the competition. In this model, independent power producers (IPPs) compete to sell the electricity produced to the competent authority. Electricity produced by IPPs is sold to a vertically integrated company at a predetermined price. In the wholesale markets, buyers and sellers operate through a centralized commercial platform. The distribution companies continue to maintain their dominance over the customers in the wholesale markets [3]. The final stage of liberalization is the integration of retail energy markets into wholesale energy markets. In this model, retail companies also compete with each other. Since electricity end users with relatively small energy capacities cannot directly participate in the electricity markets, they join retailers who act as aggregator for themselves and trade in the electricity markets. As a result of the increase in competition among retailers through participation in wholesale electricity markets, electricity end users, who are also given the opportunity to choose their retailers, have the opportunity to access energy cheaper. New Zealand, Australia, Argentina, Norway, Sweden, Spain, and various states of the United States have the retail market [3]. An example of a deregulated electricity market structure is given in Figure 3.

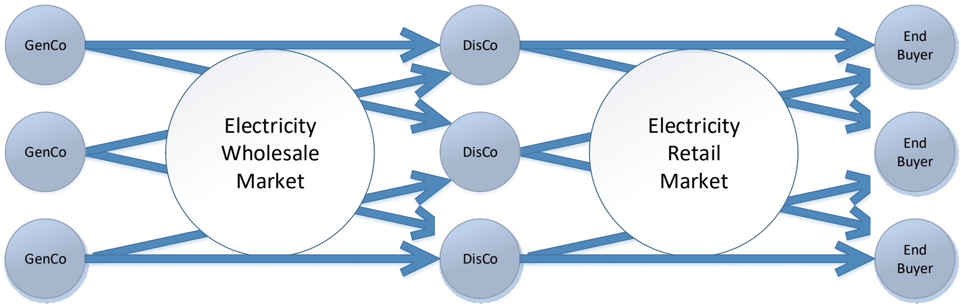

Figure 3. Deregulated electricity market structure.

Regarding the participation of RESs in electricity markets, this issue has become mandatory in many countries as in conventional resources, so the electricity market structures and rules described in this section also include RESs. The realization of the integration of RESs into the power grid through a supporting policy is explained in Section 2.

Conventional energy sources can adjust their production by changing the output power, while RESs can generally provide this situation if they are integrated with a structure such as an energy storage system or flexible load, since they have a stochastic structure. In this respect, while the participation of conventional resources in energy markets is less due to the instability in terms of production beyond their own desires, especially RESs that do not have a storage system need more balancing market structures. Considering that IDMs are mostly established to support RESs and the current structure of these sources, the issue of participation in IDMs and RTMs for renewable resources is more important than other sources.

Generally, the reserve is seen as a potential product for RESs. For example, photovoltaic systems have no moment of inertia and can adjust their output in a very short time like milliseconds. Wind turbines also have the potential to deliver the reserve faster than necessary. However, participation in RTMs may not be allowed in some countries due to technical feasibility reasons. In Great Britain, curtailment has been implemented for wind farms, and in return, 40% more money is paid than producing. However, it is stated that this situation is not an efficient way. Short-term market participation such as the RTM creates difficulties for producers as it involves the preparation and submission of offers without deviations for one hour period. Considering that different market structures exist in different countries, it can be said that the bidding strategies of RES are different in different market environments [120].

Considering that mechanisms such as FIT and FIP will not be implemented in the future due to the increase in the share of RES and economic burden on states, these resources will participate in the market without incentives, like all other resources. In the first implementations of the incentive mechanisms, no matter how much the resource produces, they are directly purchased by the state, while the increase in the number of these resources, the supply and demand balancing problems in the power system operation and unwanted changes occurred in the market price, RESs have started to be responsible for their own imbalance in many countries. In this respect, an intermediate transition period takes place before the issue of direct participation of the RES. In other words, while RESs are supported with a fixed price, they are also responsible to participate in the market.

RESs, like other sources, want to maximize their profits with market operations. Since the decisions made by each market participant in the market will affect the decisions of other participants, there will be changes in the structure of markets with higher share of RESs [121]. In existing countries where support mechanisms are implemented through premium, it can be said that with the increase in the share of RESs in the spot market, the price of electricity generally decreases, and even negative prices may be encountered in cases where production is excessive. This situation is generally due to the fact that the producer gets a premium on the market price. The renewable producer, who has variable power generation and receives economic support, makes the market structure more dynamic.

Generally, electricity markets are called the energy market which have mainly 2 different operators as ISO and MO. The ISO ensures system reliability, stability, and security, and the MO is responsible for the economic dispatch of the energy market [122]. Detailed information on European and US electricity markets and comparison results are comprehensively included in Ref [122] and [123].

There are different types of energy markets depending on their purpose and market-clearing time. The DAM is used to plan every hour of the operation of the following day. For the time DAM is insufficient, the IDM or the hour-ahead market can be used voluntarily. If there is an imbalance between production of RESs and consumption of loads, real-time markets (RTM) also called balancing markets (BM), or regulating markets is activated for system balance during the operational hour [7]. Real-time balancing consists of ancillary services and BM. The BM provides the ISO with redundant capacity for up to 15 minutes of real-time balancing. Frequency control and demand control services are provided through ancillary services. Frequency control is a service performed by commissioning the reserves in terms of protecting the system frequency, while demand control is an application carried out within the scope of emergency measures, that is, in order to prevent the system frequency from falling to a critical level in case of insufficient production capacity, by automatically reducing the demand through instantaneous demand control relays. A structure related to the electricity market is given in Figure 4.

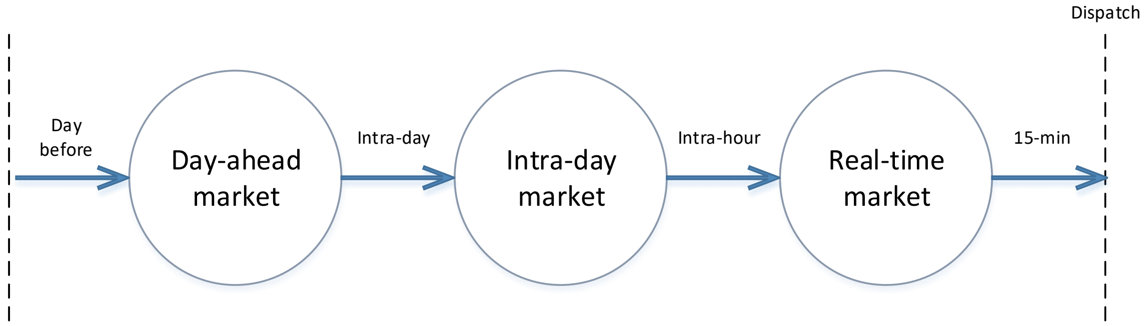

Figure 4. Market types of a spot market.

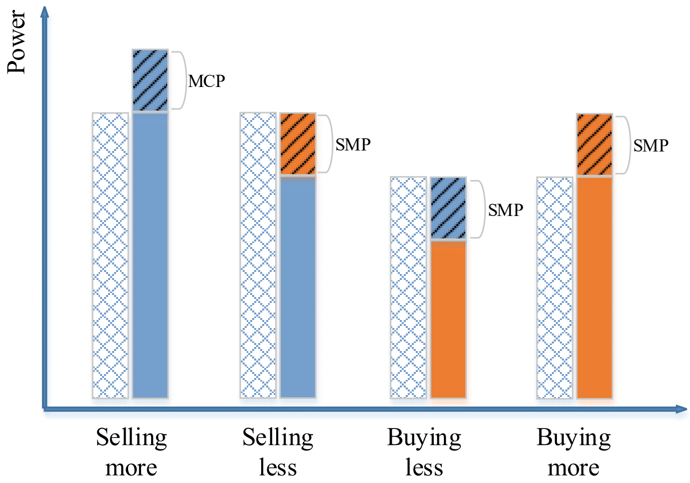

Figure 5. RTM settlements for buying and selling energy.

There are two different market prices as MCP and system marginal price (SMP). The MCP is the spot price determined in DAM, and the SMP is determined in RTM. RTM settlements for production and consumption sides are shown in Figure 5. We assume that SMP is higher than MCP for this example. If a producer generates less than the day ahead contract, it has to purchase energy from real time market by SMP. If a producer generates more than the day ahead contract, it can sell excess energy to the spot market by MCP. If a consumer uses less than the day ahead contract, it can sell the less consumption to spot market by MCP. If a consumer uses more than the day contract, it needs to purchase energy from spot market by SMP.

4. Classification of existing studies regarding optimal bidding in the market participation

Both researchers and GENCOs pay close attention to the studies on making optimal bidding to the electricity markets for wind and solar power plants, which have an intermittent source and have to predict their production constantly before the real production time.

Li et al. [13] presented a study about the optimal bidding of a power plant in the deregulated electricity markets. In the study, firstly information about electricity markets in the world was given. Then the studies conducted in the literature were categorized as focusing on a single GENCO, based on the game theory and the agent system and general information of the articles about this categorization was given. In the study related to the optimal bidding of hydroelectric power plants [14], the review study of the effect of being price-maker and price-taker for both thermal and hydroelectric power producers for optimal bidding were examined. It is stated in the study that it is generally accepted that the offers of the producers do not affect the MCP in terms of simplicity, but the increase in the share of the producer in the total supply may have an effect on the MCP. Besides, it is stated that if a producer changes from price-taking position to price-making position, the model of bidding problems changes, and it can affect the MCP, aggregate supply, market clearing dispatch, and price taker's offer while the producer is in the price-maker position. Abhinav and Pindori [15] introduced the general information about the electricity markets and then a literature review about the Indian markets and the optimal bidding for wind power producers. Detailed information about deterministic, meta-heuristic, and hybrid methods was given by Yamin in [124]. Besides, a review study was made with articles using these methods in the literature.

The optimal bidding-oriented literature is reviewed herein where all articles in this section are categorized into three different topics: These are the market structure, modeling techniques, and related software/solver. Some uncategorized information is indicated as Not specified.

4.1. ***Market structure***

There are several types of market structure combinations for different energy markets. In Table 3, energy markets are classified from both market type and auction rules type points of view. Some of the articles have no indication of market or auction rules type. Only 108 of 194 reviewed articles have clearly stated the market and auction rules type and DAM is the most used market type of all studies. The auction rules are classified into three types as Uniform marginal pricing, Locational marginal pricing (LMP), and pay-as-bid (PAB) pricing. Other studies are indicated as "Not specified".

Ferruzzi et al. [125] proposed an Analog Ensemble method to estimate the uncertainty of the photovoltaic plant of the grid-connected residential MG (microgrid) managed by a prosumer. The prosumer participated in DAM and made decisions for optimal bidding strategy. Nojavan and Zare [126] developed the optimal bidding strategy of a price taker GENCO in DAM by using information gap decision theory. Boonchuay and Ongsakul [127] proposed an optimal risky bidding strategy for a GENCO by self-organizing hierarchical particle swarm optimization (PSO) with time-varying acceleration coefficients. Sahraei-Ardakani and Rahimi-Kian [128] used the dynamic replicator model in an oligopolistic electricity market for both fixed and variable demand cases. The model was based on supply function equilibrium (SFE) and a state-space model was developed to decide the generators' supply functions dynamically. Bosco et al. [129] made an application of a bidding model in a vertically integrated markets especially for Italian wholesale electricity market. They used supply bids and demand elasticity to estimate generation costs. Kian and Cruz [130] modeled the bidding strategies for dynamic oligopolistic electricity markets and used discrete-time Nash bidding strategies. They used a

Cournot model for game theory and demand quantities were decided by the load serving entities. The market price was calculated from the marginal cost of producing electricity. IEEE 14-bus power system was used to test the developed algorithm. Gao and Sheble [131] proposed an SFE model that could be applied in a multiple-period and multiple-market situation with using resource constraint and transmission congestion. The proposed model suggested a set of Nash Equilibrium conditions based on discrete-time optimal control, taking into account the decisions of GENCOs in both the fuel and electricity markets. Kang et al. [132] presented a bidding strategy using the concept of Nash equilibrium. Each GENCO had complete information both its own and other companies' payoffs. Effectiveness of the proposed method was tested with numerical example. Dotoli et al. [133] presented a Nash equilibrium model for auction-based DAM by employing empirical data distributions of the MCP. The model was tested with the Italian electricity market's real data set. Bosco et al. [134] showed that the profit function of a firm could be non-concave and unbounded. The study also proved that monopoly market power can be significantly reduced by vertical integration policy and VPPs. Wen and David [135] proposed a stochastic optimization model for describing two different bidding schemes such as maximum hourly-benefit and minimum stable output bidding strategies in DAM. Besides, a genetic algorithm-based method was presented for overall bidding strategy of California type DAM with a six-supplier numerical example. Nguyen and Le [136] proposed an optimization framework to make a balance between maximizing benefit and minimizing the operation cost of the MG. The optimization problem was projected as a two-stage stochastic problem in which for various uncertainties, the Monte Carlo method was used. Guerrero-Mestre et al. [137] presented different optimal bidding strategies for wind power producers in the DAM. They offered three different strategies for wind power producers, and the strategies were modeled in stochastic mixed-integer linear programming (MILP) context. Lu et al. [138] developed optimal bidding strategies for a pumped-storage unit. In this study, a multistage-looping optimization algorithm was proposed to meet the constraints of the bidding strategy. Pinson et al. [139] proposed a methodology for optimal bidding strategies based on probabilistic forecasts of wind generation. The proposed methodology was demonstrated in the Dutch electricity market. Bajpai et al. [140] presented an optimal bidding strategy of a thermal generator under the uniform price in DAM. The optimal bidding problem was solved by the fuzzy adaptive PSO method. Andrianesis et al. [141] analyzed several recovery mechanisms that result in recovery payments after the DAM was cleared. They proposed a methodology for evaluating the bidding strategy behavior of the participating units for each mechanism. A DAM bidding strategy for retailers with flexible demands was developed by Song and Amelin [142] to maximize the retailers' short-term profit. They applied stochastic programming and made a study with the data from Sweden. Rashedi et al. [143] presented an SFE model for DAM. The multi-agent reinforcement learning model was used to determine the optimal bidding strategy of the suppliers in a non-cooperative game. Markov decision process (MDP) was used to formulate a joint bidding and pricing problem by Xu et al. [144]. The deep deterministic policy gradient algorithm was applied to solve the MDP for optimal bidding.

Kardakos et al. [145] presented an optimal bidding strategy for a strategic producer in a transmission constrained DAM with an LMP mechanism. They converted the bi-level problem to a mathematical program with equilibrium constraints for optimal bidding strategy. Agent-based approach and numerical sensitivity analysis were used for the optimal bidding strategy of GENCO by Mahvi and Ardehali [146]. In this model, the agent-based approach was evaluated at the decision-making stage, while the numerical sensitivity analysis had identified critical control points in terms of the correctness of the decisions taken by GENCOs. Vahidinasab and Jadid [147] proposed a methodology for determining the impacts of suppliers' emission of pollutants on their bidding strategy with the SFE model. For the market clearing process, the LMP mechanism was used. The stochastic bi-level model for wind power producers in the DAM with LMP was developed by Lei et al. [148]. In the upper-level problem, profit maximization of the strategic wind power generator was achieved, while in the lower-level, the market clearing structure was explained. In addition, Karush-Kuhn-Tucker optimality conditions were taken into account in order for the lower-level problem to be included in the upper-level problem. Li and Shahidehpour [149] proposed SFE model for modeling a GENCO's bidding strategy and the competition was modeled as a bi-level problem, and the proposed method was supported by a case study of the eight-bus system. Botterud et al. [150] presented a new model for optimal bidding of wind power producers with LMP, and the model was tested with a real data set of a large-scale wind farm from the US. In the study, uncertainties in electricity market prices were assumed to be Gaussian and kernel density estimation was used to obtain a probabilistic wind energy forecast. Bacteria foraging optimization algorithm was used for the solution of proposed bi-level optimization of bidding strategy under transmission congestion by Jain et al. [151]. Results which were tested on five-bus system and modified IEEE-30 bus system were compared with genetic algorithm-based approach. Fan et al. [152] proposed a minimax regret approach and reformulated the model as MILP by solving with Benders decomposition algorithm. They showed how to create production offer curves with their proposed framework.

Afshar et al. [153] presented a method for wind power producers in a DAM with the PAB method. They formulated an optimal bidding strategy as a bi-level optimization problem and PSO is used for solving the problem. The aim of the upper-level problem was to maximize the wind power generator's earnings, while the aim of the lower-level problem was to clear the DAM price. Besides, a PSO algorithm was applied to solve the problem at both levels. The optimal bidding strategy for a price-taker GENCO was developed by Wang et al. [154]. They presented the effects of different numbers of bidding segments on the bidding strategies of a GENCO. Azadeh et al. [155] proposed a new genetic algorithm approach for optimal bidding strategy in the DAM of profit maximization of a GENCO. In the study, profit maximization of GENCO without considering the profit function of competitors and profit maximization of GENCO by considering both the offer and profit functions of the competitors were discussed from two perspectives. Swider and Weber [156] presented a methodology for profit maximization under-price uncertainty in a day-ahead pay-as-bid market type. A new theorem of bidding strategies for pay-as-bid auction type market from a supplier's side was presented by Rahimiyan and Mashhadi [157]. In the study, perspective was taken from the supplier point of view using risk analysis.

Moreno et al. [158] developed a strategy for wind power producers in DAM and IDMs. A case study was done for the Spanish market to see the benefit of the developed strategy. Qiao et al. [159] developed Point estimate method for wind power generation companies to make maximum profit under various market and wind speed uncertainties. The point estimation method was developed in this study to facilitate the stochastic modeling of the total power output of the wind turbine. Herranz et al. [160] proposed a methodology about optimal demand-side bidding in DAM and IDM. The proposed method provided an optimum bidding strategy for retailers that supply electricity to end users in the short-term electricity market. The aim of the study was to minimize the energy trading cost in DAM and IDM. Rolling stochastic optimization was presented for wind farm and ESS by Ding et al. [161]. Besides, various wind farm and pumped storage plant alternatives were used for case studies and sensitivity analysis.

Iria et al. [162] proposed two different methods for supporting the aggregator of small prosumers and setting the operation of flexible loads. A case study was carried out with Iberian DAM and RTM data to show the effectiveness of the methods.

A stochastic optimization model was used for the optimal bidding strategy in DAM and BM of electric vehicle aggregators by Vagropoulos and Bakirtzis [163]. They proposed a new battery model for a better approximation of the battery charging characteristic. Haghighat et al. [164] compared PAB and marginal pricing mechanism for DAM and RTM. An optimal bidding study of battery systems was done by Mohsenian-Rad et al. [165]. They used real data from California ISO and LMP prices for solving nonlinear problem. Dai and Qiao [166] proposed a bi-level stochastic optimization model for wind power producers to participate in DAM and RTM. They transformed the bi-level model to MILP by using duality theory and Karush-Kuhn-Tucker conditions. Optimal bidding strategy of a MG aggregator for RTM was developed by Pei et al. [167]. The problem was formulated as two stage stochastic price-based unit commitment problem and sample average approximation approach was applied to solve the problem. Dai and Qiao [168] proposed a stochastic programming model using game theory to develop optimal bidding strategies for wind and conventional power producers. The problem with the aim of maximizing the profits of wind generators was handled as stochastic programming. Furthermore, game theory approach was applied in order to eliminate the uncertainty of the participants' behaviors.

Table 3. The categorization of the literature studies by market type and auction rules

Market type	Auction Rules	References
Day-Ahead Market	Uniform Pricing	[125], [126], [127], [128], [129], [130], [131], [132], [133], [134], [135], [136], [137], [138], [139], [140], [141], [142], [143], [144], [169]
	Locational Marginal Pricing	[145], [146], [147], [148], [149], [150], [151], [152], [170]
	Pay-as-bid	[153], [154], [155], [156], [157]
	Not specified	[171], [172], [173], [174], [175], [176], [177], [178], [179], [180], [181], [182], [183], [184], [185], [186], [187], [188], [189], [190], [191], [192], [193], [194], [195], [196], [197], [198], [199], [200], [201], [202], [203], [204], [205], [206], [207], [208]
Day-Ahead and Intra-day Market	Not specified	[158], [159], [160], [161], [209]
Day-Ahead and Real-Time Market	UP	[162], [163]
	PAB	[164]
	LMP	[165], [166], [167], [168], [210]
	Not specified	[211], [212], [213], [214], [215], [216], [217], [218], [219], [220], [221], [222], [223], [224], [225], [226], [227], [228], [229], [230], [231], [232], [233], [234], [235], [236], [237], [238], [239], [240]
Day-Ahead and Ancillary Services Market	UP	[241], [242]
	LMP	[243], [244]
	PAB	[245]
	Not specified	[246], [247], [248], [249], [250], [251], [252]
Day-Ahead, Intra-day and Real-Time Market	UP	[253]
	Not specified	[15], [254]
Day-Ahead, Real-Time and Ancillary Services Market	UP	[255], [256], [257]
	Not specified	[258], [259]
Real-Time Market	LMP	[260], [261], [262]
	Not specified	[263], [264], [265]
Hour Ahead Market	LMP	[266]
	PAB	[267]
Ancillary Services Market	UP	[268]
	PAB	[269]
Regulation Market	UP	[270], [271]
Power Pool	UP	[272], [273], [274], [275], [276], [277]
	LMP	[278]
	Not specified	[279], [280], [281], [282], [283], [284], [285], [286], [287], [288], [289], [290], [291], [292], [293], [294]
Contract Market	Not specified	[295], [296]

Kanakasabapathy and Swarup [241] used a multistage looping algorithm for a pumped-storage plant in DAM and ASM. Different operating scenarios of pumped-storage plant were considered and compared with each other. Li et al. [242] presented price-based unit commitment problem and the problem modeled as stochastic MILP for a GENCO. The study used the expected downside risk for uncertainty about the market price. Wu et al. [243] proposed a stochastic opmitization model for electric vehicle aggregators with variable wind energy to participate in DAM and ASM. A hybrid stochastic/robust optimization approach was developed for the integration of various distributed energy resources (DER) including wind, photovoltaic, micro-turbine, and ESSs by Wang et al. [244]. Nezamabadi and Nazar [245] proposed a model considering supply demand balancing, transmission network topology and security constraints issues for an arbitrage strategy of VPP.

Diaz et al. [253] provided a methodology for wind power producers and a combination of wind and ESS. They used Spanish DAM, IDM, and RTM. Different scenarios regarding wind energy, forecast improvements, price levels and ESS usage were considered. A simple multiple linear regression method was evaluated for the analysis of these conditions.

Moghaddam and Akbari [255] presented a stochastic/robust game-theoretic approach for plug-in electric vehicle aggregator participate in DAM, ASM, and RTM. Stochastic programming based a new method was proposed for a GENCO owning a compressed air energy storage, wind and thermal units by Akbari et al. [256]. The authors stated in their results that the use of compressed air energy storage lowers costs and increases profits. Ottesen et al. [257] proposed a methodology for a flexibility aggregator participating in DAM, ASM, and RTM. They formulated the model as a multi-stage stochastic program and applied it to four industrial companies and one aggregator. A different study was done about DAM, RTM, and ASM together in [258]. Here, the optimal bidding strategy for battery energy storage systems participate in energy markets was investigated. It was stated that batteries can increase its profit with the fast regulation market service.

Gao et al. [260] proposed an optimal bidding strategy of a GENCO under LMP in RTM. Using piecewise staircase energy offer curves, it had been shown that the proposed method effectively solves GENCO's profit maximization problem. A hybrid model consisting of Lagrangian relaxation and genetic algorithm for unit commitment problem was presented by Yamin and Shahidehpour [261]. In addition, the IEEE 118-bus test system was used to prove the effectiveness of the proposed hybrid model for profit-based unit commitment. Taheri et al. [266] used an analytical approach of a transmission-constrained GENCO to participate in an hour-ahead market. The problem was modeled as an SFE and the market price was chosen as LMP. Rahimiyan and Mashhadi [267] presented an optimal bidding strategy with the PAB auction of a supplier participating in the hour-ahead electricity market. An algebraic equation was developed for the proposed optimal bidding model and it was proved that an additional term appeared in this equation.

Soleymani et al. [268] presented a new approach using Nash equilibrium for the optimal bidding strategy of GENCOs in the ASM. GENCOs share total capacity in reserve and energy markets to maximize their profits. A bilevel optimization technique and a mathematical program with equilibrium constraints approach were developed for optimal bidding strategy of a supplier in spinning reserve market by Haghighat et al. [269].

Sadeghi-Mobarakeh and Mohsenian-Rad [270] proposed a mathematical program with equilibrium constraints for California ISO. They focused on optimal bidding in performance-based regulation markets for a large price-maker regulation resource. Xu et al. [271] presented an optimal control and bidding policy for performance-based frequency regulation markets and considered the cost of battery aging to maximize profit. The proposed bidding policy set an optimum control policy in order to maximize market profits while meeting the market performance requirement.

A new approach was developed for a pool-based single-buyer electricity market to make optimal bidding regarding risks by Ma et al. [272]. Zaman et al. [273] proposed two solution approaches based on computational evolution algorithms for a competitive electricity market. The market was designed as SFE and the algorithm was tested with four different IEEE cases. Kumar et al. [274] presented a stochastic optimization approach for strategic bidding using a fuzzy adaptive gravitational search algorithm in a pool-based electricity market with UMP. Kumar et al. [275] proposed a bidding strategy using Shuffled Frog Leaping Algorithm for a pool-based electricity market. Wen and David [276] developed a stochastic optimization formulation and they proposed two methods including Monte Carlo and optimization based methods for solving the optimization problem in a power pool market. A stochastic optimization problem was developed for both power supplies and large consumers in a deregulated power market by Wen and David [277] and it was solved by the Monte-Carlo approach. Shivaie and Ameli [278] proposed a self-adaptive global-based harmony search algorithm for optimal bidding strategies of GENCOs and distribution companies in security-constrained electricity markets with LMP.

*4.2. **Modeling techniques***

There are several modeling techniques in the literature, and three modeling main categories and lots of subcategories are defined in this manner. These three categories are mathematical optimization, game theory-based optimization, and agent-based optimization. Classification of modeling category and modeling techniques in the studies are given in Table 4. Most use method for modeling technique as seen in Table 4 are MILP for mathematical optimization, SFE for game theory-based optimization, and genetic algorithm for agent-based optimization categories. 37 articles have not mentioned any type or model of optimization and they are categorized in the “Not Specified” section. Most of the articles are referred to before in Section 4.1, and the same articles are not referred in this section and only the rest of the articles are mentioned.

Li and Park [211] present an analytical model for wind power producers in day ahead and real time energy markets with LMP. Al-Agtash and Yamin [175] described a new approach for optimal supply curve bidding using benders decomposition in competitive electricity markets and used the IEEE 24-bus system to show the effectiveness of the approach. Optimal bidding using fuzzy linear programming for the vehicle-to-grid option of electric vehicles in the ancillary services market was improved by Ansari et al. [252]. Fuzzy set theory was used to model the uncertainties of data estimation for the electricity market. An online learning algorithm for the multiple-choice knapsack problem was proposed for virtual trading in DAM and RTM by Baltaoglu et al. [225]. Also, the proposed algorithm has been generalized for trading strategies, a measure of risk. The optimal bidding problem of a GENCO was formulated by Gajjar et al. [187] with MDP. In the proposed problem, MDP expressed as a discrete stochastic optimization method was used.

The most used method for mathematical optimization is MILP. Vespucci et al. [182] introduced a model for optimal bidding strategies of a large dimensional producer in a zonal electricity market. Fleten and Kristoffersen [183] presented a model for optimal bidding of a price-taking hydropower procedure in the DAM of Nordic. A robust optimisation for a hybrid concentrating solar power-fossil power plant was described for profit-maximisation by Pousinho et al. [185]. Vaya and Anderson [189] suggested an optimal bidding strategy of a plug-in electric vehicle aggregator in DAM. Xu et al. [192] presented a risk-averse optimal bidding strategy for a demand side aggregator in a DAM. Also in the study, firstly the generic model was introduced to characterize electric vehicles and distributed generation as flexible demand side source. Ntomaris and Bakirtzis [193] developed an optimal bidding model for wind farm and pumped-hydro storage systems in insular power systems. An optimal bidding strategy for a DER aggregator in the DAM was developed by Di Somma et al. [194]. Vatandoust et al. [195] proposed risk-averse optimal bidding of electric vehicles and energy storage aggregator in the day-ahead frequency regulation market. Flach et al. [198] presented a new methodology for optimal bidding of a price-maker hydropower producer in a competitive market. Kardakos et al. [200] presented an optimal offering strategy of a VPP in the DAM which comprises DERs, battery storage systems, and electricity consumers. Ghamkhari et al. [202] proposed a strategic bidding problem for producers in nodal electricity markets. Mehdizadeh and Taghizadegan [203] proposed a robust optimization approach for optimal bidding of a grid-connected MG.

Li et al. [205] proposed a scenario-based stochastic decision-making model for the optimal bidding of integrated natural gas generating units and power-to-gas conversion facilities in energy and regulation markets. Wang et al. [210] presented an optimal bidding strategy for wind power producers in the deregulated electricity markets. An optimal bidding strategy for an energy hub in DAM and RTM was modeled by Davatgaran et al. [213]. The proposed model enabled the energy hub to gain from DAM and RTM. In addition, stochastic optimization was used to eliminate various uncertainties in the study. A new optimal bidding methodology for VPPs including combined heat and power and RESs is presented by Riveros et al. [215]. Plazas et al. [217] introduced an optimal bidding model for a price-taker thermal producer in DAM and BM.

An et al. [220] presented the Sto2Auc framework for MGs and a demonstration of presented framework was done with IEEE 33-buses system. A novel approach to energy exchange between electric vehicle load and wind generation in the DAM, BM, and regulation market was developed by Tavakoli et al. [223]. Liu et al. [224] proposed an optimal bidding model for a MG consisting of intermittent distributed generation (DG), storage system, dispatchable DG, and price responsive loads in DAM and RTM. A new mathematical model was proposed by using hybrid robust-stochastic approach taking into account of uncertainties of load demand, power market prices, solar radiation, temperature and wind speed by Abedinia et al. [280]. Laia et al. [283] presented an optimal bidding of self-scheduling problem for a price-taker thermal power producer in a pool-based electricity market. Stochastic mixed-integer linear programming approach was used to solve the self-scheduling problem. Uncertainty regarding electricity prices has been handled with a series of scenarios. Conejo et al. [286] proposed an optimal bidding strategy of a price-taker producer under-price uncertainty.

In Ref [214] and [251], both MILP and MINLP methods are used together for different cases. Gazafroudi et al. [214] proposed an optimal bidding strategy for autonomous residential energy management systems to manage its domestic energy production and consumption autonomously in day-ahead and real-time stages. Jia et al [251] suggested a framework for a flexible load aggregator which is consisting of distributed storage energy systems, electric vehicles and temperature control loads in the DAM and reserve markets. Nojavan et al. [172] presented an optimal bidding strategy of a price-taker thermal unit producer in a DAM. Alipour et al. [177] introduced an optimal bidding strategy for industrial consumers with cogeneration facilities in DAM. Mehdizadeh et al [178] proposed an optimal bidding strategy of a MG which consists of upstream grid, micro-turbines, PV systems, wind-turbines and ESS.

Ghasemi et al. [184] focused on nodal hourly electricity pricing mechanisms for local and smart distribution companies in DAM. Peik-Herfeh et al. [186] employed price-based unit commitment to model uncertainty of market price and generation sources for a VPP. Khajeh et al. [207] presented an optimal bidding model for a price-maker micro-grid aggregator. An optimal bidding strategy for renewable micro-grids in DAM and RTM was developed by Fazlalipour et al. [216]. Nezamabadi and Nazar [245] presented an arbitrage strategy for VPPs in energy and ASMs. Schäfer et al. [246] developed an optimal bidding strategy for energy-intense processes in ancillary and spot markets. A new multi objective risk-constrained optimal bidding strategy for smart MGs was developed by Rezaei et al. [250].

Contreras et al. [196] presented a new bidding strategy based on an economic principle known as the cobweb theorem which was a balance of price and quantity by using the GENCO's demand curve. Tseng and Zhu [221] proposed an optimal bidding strategy for a thermal generating unit subject to ramp constraints and price uncertainty in the RTM. A new method was presented for the joint and uncoordinated operation of wind farms and pump-storage units in energy and ASMs by Parastegari et al. [248]. Heredia et al. [188] developed an optimal bidding strategy for a price-taking GENCO in the DAM of the Iberian Electricity Market. Li et al. [206] proposed an optimal bidding strategy for demand side resource aggregators taking into account wind power generation in energy and ancillary service markets.

Table 4. The categorization of the literature studies by modeling category and modeling techniques

Modeling category	Modeling techniques	References
Mathematical Optimization	Analytic	[211]
	Benders decomposition	[175]
	Dynamic programming	[253]
	Fuzzy linear programming	[252]
	Generalized reduced	[150]
	Golden section search	[272]
	Linear programming	[163], [232], [233], [236], [262], [293], [294], [295]
	Multiple-choice knapsack	[225]
	Monte Carlo method	[276], [277]
	Model predictive control	[162]
	Markov decision process	[187]
	Mixed-integer linear programming	[136], [137], [141], [142], [145], [148], [152], [154], [165], [166], [182], [183], [185], [189], [192], [193], [194], [195], [198], [200], [202], [203], [205], [210], [213], [215], [217], [220], [223], [224], [234], [235], [237], [238], [242], [243], [244], [256], [270], [280], [281], [283], [284], [286]
	MILP&MINLP	[214], [251]
	MINLP	[126], [169], [172], [177], [178], [184], [186], [207], [216], [245], [246], [250], [254], [259], [289]
	Mixed-integer	[161], [171], [179], [196], [221], [248], [257]
	MIQP	[188]
	MISOCP	[206]
	Multistage looping	[138], [241]
	New method	[176]
	PDIPM	[279]
	Point estimate method	[159]
	Particle Gibbs sample	[204]
	Parametric linear	[260]
	Semidefinite program	[219]
	Stochastic optimization	[158], [218], [227], [247], [290], [296]
	Sequential quadratic	[167]
	Not specified	[134], [139], [170]
Game Theory-based	Cournot	[130], [199], [297]
	Nash equilibrium	[132], [133], [181], [229], [231], [255], [263], [268], [282], [285], [316]
	Supply function	[128], [131], [143], [147], [149], [164], [264], [266], [269], [287], [298], [299], [300]
	Not specified	[168], [222], [226], [230], [239], [240], [301], [302], [303], [304], [305], [306], [307], [308], [309]
Agent-based	ANN&GA	[146]
	Evolutionary algorithm	[249], [273]
	Fuzzy adaptive	[274]
	Genetic algorithm	[125], [135], [155], [160], [261], [310]
	GA&PSO	[275]
	Improved Prey-Predator	[190]
	Lagrange relaxation&	[311]
	Multi-objective differential evolution algorithm	[174]
	Neural networks	[288], [312]
	Particle swarm	[127], [140], [153], [173], [313]

	Q learning method	[180], [267]
	A self-adaptive global-based harmony search algorithm	[278]
	Not specified	[144], [151], [197], [201], [314], [315], [316]

Hajati et al. [176] developed a new method for optimal bidding of a retailer in DAM and regulation markets. Badri et al. [279] introduced an optimal bidding strategy of a GENCO in oligopoly markets considering bilateral contracts and transmission constraints. Mitridati and Pinson [204] presented a Bayesian inference approach to determine the total supply curve in a DAM. Nojavan et al. [281], and Zare et al. [284] focused on a robust optimization approach for the optimal bidding strategy of a retailer with and without demand response programs in the pool market.

Nojavan et al. [171] presented optimal bidding and offering strategies of a compressed air energy storage in deregulated markets. Nojavan et al. [179] suggested optimal bidding strategies of an electricity retailer with multi-tariff pricing options. An optimal bidding model of controllable loads was proposed in DAM and RTM by Yang et al. [219]. Yang et al. [218] proposed an optimization model for an electric vehicle aggregator in DAM and RTM under market uncertainties. Du et al. [227] introduced the opportunities for a wind power producer to purchase or schedule some reserves to balance their deviation in the RTM. Parastegari et al. [247] presented the effect of joint operation of wind farms, pumped energy storage units, photo-voltaic resources and energy storage devices for optimal bidding in energy and reserve markets.

Game theory-based methods consist of Cournot, Nash equilibrium, and SFE. Kebriaei et al. [199] presented two decision making methods like model-based and learning-based bidding strategies for Cournot competition of the Gencos in DAM. Qiu et al. [297] proposed a Cournot competition in the dynamic duopoly electricity markets for the GENCOs. In Ref. [181] by Soleymani et al., a Nash equilibrium strategy for optimal bidding of GENCOs was proposed and hourly forecasted MCP was used as a reference to the model. In [263] and [282], Motalleb and Ghorbani focused on demand response aggregators for selling their stored energy to other aggregators in a market with Nash equilibrium. Park et al. [285] presented a noncooperative game with complete information for analyzing power transactions in a competitive electricity market with Nash equilibrium.

Niu et al. [264] proposed an SFE model with transmission constraints for optimal bidding of forward contracts. Liu et al. [287] introduced the impacts of the learning behavior of GENCOs on the market equilibrium under repeated linear supply-function bidding. Haghighat et al. [298] focused on the effects of the market pricing mechanism under imperfect competition on supplier profit.

Vahidinasab and Jadid [299] proposed a method for optimal bidding strategy of a supplier's emission of pollutants with supply function equilibrium model. A new enhanced bat-inspired algorithm was developed by Niknam et al. [300] to find out the linear SFE of GENCOs in a network-constrained electricity market.

Agent-based theories have different sub-sections. The genetic algorithm and PSO are the most used ones. Bigdeli et al. [312] proposed a new bidding strategy for PAB market suppliers by artificial neural networks. A new bidding strategy for DAM was developed for GENCOs and evolutionary programming was used by Attaviriyanupap et al. [249]. Gountis and Bakirtzis [310] presented a methodology for the optimal bidding strategies of electricity producers in a competitive electricity market with a genetic algorithm. A novel prey-predator optimization algorithm was proposed by Bahmani-Firouzi et al. [190] for scenario-based optimal bidding strategies of GENCOs in the incomplete information electricity market. Sudhakar et al. [311] developed a hybrid Lagrange Relaxation–Differential Evolution algorithm for solving the profit based unit commitment problem. Nojavan et al. [173] proposed a hybrid approach based on information gap decision theory and modified PSO for the optimal bidding strategy of a price-taker GENCO in DAM. Peng et al. [174] presented a hybrid multi-objective differential evolution optimization algorithm for generating and bidding in the market. Lim and Kim [180] proposed an optimal bidding strategy using a Q-learning algorithm for load shedding in MGs.

Cipriano et al. [288] developed a neural network model for short-term forecasting of electricity prices in the Colombian electricity market. Soleymani [313] proposed a new method combination of PSO and simulated annealing for an optimal bidding strategy of GENCOs in an electricity market.

4.3. ***Related software and solvers***

In the literature, most of the articles do not mention the software or solver of the optimization problem. We classify the articles which are mentioned the software/solver type in different but limited categories. GAMS is the most used software for optimal bidding problems. There are 45 articles using GAMS with different solvers in the relevant literature search. Most of these articles did not mention their solver type but Ref. [191], [163], [247], [256], and [280] used CPLEX for solving the optimal bidding problems on GAMS. Only Ref. [148] by Lei et al. used CONOPT solver on GAMS for the stochastic bi-level model of wind power producers in the DAM. MATLAB was one of the most used software with 27 articles for optimal bidding problems. In Ref. [159] and Ref. [224], the authors used CPLEX solver with MATLAB. In the Ref. [137], [212], [258] and [270], MATLAB and GAMS used together for the parts of optimization problems. AMPL with CPLEX solver was used for developing an optimal bidding strategy for a price-taking GENCO in DAM by Heredia et al. [188]. Mitridati and Pinson [71] used Python with Gurobi solver for a game-theoretic approach in a DAM. Iria et al. [162] used Python with CPLEX solver for the aggregator of small prosumers of optimal bidding. The relevant classification of software and solver in the studies are given in Table 5.

Table 5. The categorization of the literature studies by software and solver

Software	Solver	References
AMPL	CPLEX	[188]
	Not specified	[205]
C++	Not specified	[261]
FORTRAN	Not specified	[221]
FICO	Not specified	[295]
GAMS	AlphaECP and LindoGloabal	[254]
	CONOPT	[148]
	CPLEX	[163], [191], [235], [237], [247], [256], [280]
	Not specified	[126], [136], [142], [145], [168], [169], [171], [172], [177], [178], [179], [181], [182], [184], [185], [186], [193], [195], [200], [203], [208], [213], [214], [215], [216], [217], [223], [243], [245], [246], [248], [250], [255], [281], [283], [284], [286], [299], [303], [313]
MATLAB	CPLEX	[159], [224], [229], [234]
	Gurobi	[209]
	Not specified	[125], [127], [133], [151], [156], [158], [166], [167], [174], [187], [189], [190], [201], [220], [233], [244], [251], [252], [259], [264], [273], [274], [275], [278], [311], [314], [317]
MATLAB&GAMS	BARON	[289]
	Not specified	[137], [212], [258], [270]
MATPOWER	Not specified	[128], [263], [293]
Python	CPLEX	[162]
	Gurobi	[204], [238]
R	Not specified	[211]

5. Classification of ways of collective participation of renewable energy sources in the electricity market

The number of RESs has increased with various supports, however, practices such as FIT bring governments a financial burden. In this regard, these sources are planned to be added directly to the electricity markets in the future. When a RES offers to the electricity market, it may not be able to fulfill this obligation in real-time due to its stochastic nature and it may fall into imbalance. As a result of this, the imbalance can lead to a decrease in the profits of the power plant. In this respect, it seems reasonable that RESs participate in the market collectively. These producers are generally gathered under the structure of the so-called aggregator that RESs can be combined regardless of their location. In this case, total imbalance may decrease if one renewable source experiences a negative imbalance, and another renewable source experience a positive imbalance.

The imbalance cost of each producer can be determined by agreement with the aggregator. Besides, an aggregator may be in a position that determines the price in the market. The structure showing that the aggregator including RESs is bidding in the electricity market is given in Figure 6. This is generally profitable for all parties that join the aggregator. In the literature, RESs participate collectively in the electricity market by taking place under the aggregator, wind energy aggregator, portfolio, a group of wind producers, MG, and VPP. These combined structures can only contain RESs or combined heat and power, thermal power plant, microturbine, etc. sources together with RESs. The classification of structures in which RESs join the market collectively in the literature is given in Table 6. In the table, references are grouped according to their objective which is cost minimization and profit maximization. Besides, the electricity market participated for each study is expressed with a superscript (^{d}=DAM, ^{i}=IDM, ^{rt}=RTM, ^{frp}= flexible ramping product market, ^{em}=electricity market, ^{cm}=contract market, ^{bc}=bilateral contract, ^{fm}=forwards markets, ^{sgm}=smart grid market, ^{dr}=demand response market, ^{as}=ancillary service market).

Table 6. Classification of ways of RESs to participate in the electricity market collectively

Participation way	Objective of study	
	Cost Minimization	Profit Maximization
A group of wind producers		[137]^{d,rt}, [228]^{d,rt}, [229]^{d,i,rt}
Aggregator	[162]^{d,rt}, [262]^{rt}	[230]^{d,rt}
Renewable energy system		[170]^{d}
DER Aggregator		[194]^{d}
Microgrid	[178]^{d}, [203]^{d}	[216]^{d,rt}, [224]^{d,rt}, [244]^{d,as,frp}, [254]^{d,as}, [289]^{em}
Portfolio	[231]^{d,i,rt} , [290]^{em}	[232]^{d,rt}, [291]^{d,rt,bc,fm,sgm}, [295]^{cm}, [296]^{cm}
VPP	[97]^{em,as,dr,cm}, [209]^{d,i}, [233]^{d,rt}, [234]^{d,rt}, [259]^{d,rt,as}, [292]^{em}, [293]^{em,as}	[43]^{sm}, [89]^{d,i}, [186]^{d}, [200]^{d,rt}, [208]^{d}, [235]^{d,rt,as}, [236]^{d,rt}, [237]^{d,rt}, [238]^{d,rt}, [294]^{em}
Wind power aggregator		[239]^{d,rt}, [240]^{d,rt}

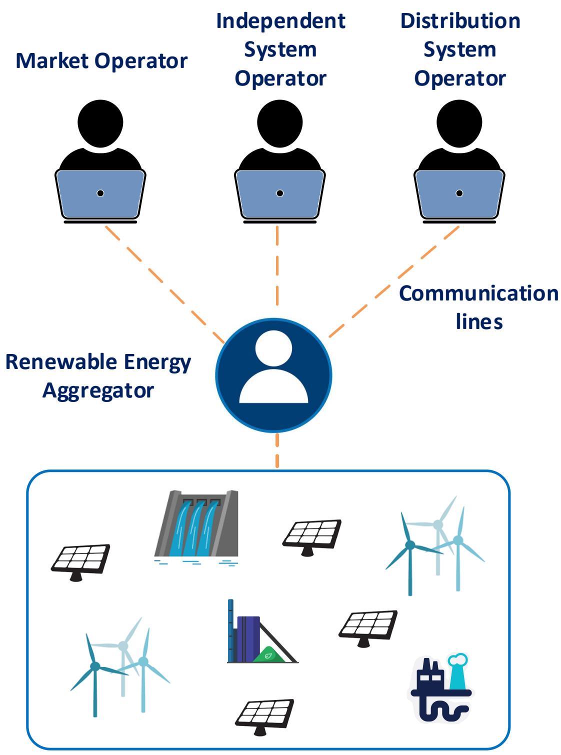

Figure 6. Structure in which the aggregator joins the electricity market.

Chakraborty et al. [228] implemented a new method for allocating production deviation costs of a group of renewable energy producers. Thus, they aimed to promote the integration of RESs. Nguyen and Le [229] proposed a model for sharing the profit from a joint bid of a group of wind energy producers given as a cooperative game theory approach. Ryu et al. [230] suggested a collaborative structure in which aggregated RESs participate in the DAM and RTM. Herein, a bidding model expressed as a Gaussian residual bidding is presented to maximize coalition earnings under different price penalty rates. Ruhi et al. [262] evaluated the profits that can be made through a strategic production curtailment in an electricity market, as it makes it difficult for renewable energy aggregator to monitor and regulate market interactions. Pandey et al. [170] presented a model in which the RES aggregator bid to ISO taking into account the uncertainty in the energy produced and the associated financial risk.

Chen and Trifkovic [289] presented an optimum planning strategy for the participation of a microgrid comprising PV, wind turbine, load and battery ESS in the electricity market. Fazlalipour et al. [254] explored the optimum bidding strategy for low voltage renewable MG. Fanzeres et al. [295] created a methodology for determining the optimum renewable energy portfolio of a firm to trade in the forward market. Maier et al. [296] presented a portfolio-based approach for selecting long-term investments in small-scale renewable energy projects and selecting suitable contracts for electricity selling.

Hellmers et al. [232] examined the portfolio effect of a system consisting of a combined heat and power, and wind farm. The authors determined the aim of the study as reducing imbalances and increasing total profit. Pinto et al. [291] proposed a portfolio optimization method to provide the best investment profile for market players. Neto et al. [290] proposed a structure for risk analysis and portfolio optimization of hydroelectric power plant, wind and PV facilities. Bashi et al. [231] analyzed the electricity market trade for companies that have wind power plants and thermal power plants in their portfolios. Mohammadi et al. [208] developed a model that combines wind farm and demand response. In their results, the authors stated that the combination of these two sources could provide promising results. Zhao et al. [233] proposed a model for a VPP containing renewable DERs and flexible loads to participates in the DAM and RTM. Dabbagh and Sheikh-El-Eslami [235] proposed a two-level risk-averse bidding strategy for a VPP to participates in the energy and reserve market.

Rahimiyan and Baringo [236] offered a two-stage optimum bidding approach for a VPP consisting of loads, a wind farm and an ESS to participates in the DAM and RTM. In the first stage, the bidding strategy was decided in the DAM, and in the second stage, the RTM bidding decisions were made for every hour of the day. Zhang et al. [292] presented a comprehensive VPP model that integrates different types of distributed RESs. Moreover, the study proposed a scenario-based analysis model to calculate the risk cost of VPP. Nguyen et al. [237] put forward a mathematical model for a VPP to participates in the electricity market and the intra-day demand response exchange market. Koraki and Strunz

[209] proposed a structure that enables the market participation of DERs of a VPP and cooperates with the distribution system operator, as well as presented a set of diagrams.

Mazzi et al. [238] proposed an innovative market model that allows participants in the BM to act as an active agent and a passive agent. To prove the effectiveness of the proposed model, they considered a VPP structure trading in the DAM and dual-price BM. Banshwar et al. [293] suggested a structure for VPP of RESs and pumped-storage to participates in the energy and ancillary services market. In the study, potential uncertainties caused by RESs and demand response were addressed with robust optimization. Besides, VPPs joined the electricity market in order to gain maximum profit. Tang and Yang [234] explained a model in which a VPP aims to obtain maximum revenue from electricity markets by planning ESSs, demand response and RES. Mohy-ud-din et al. [259] presented a structure for a VPP consisting of ESS, wind power plants and non-RESs to participate in the DAM and RTM. Alahyari et al. [294] presented a structure for the participation of a VPP, which includes wind power plants and electric vehicle parking lots, in the energy and reserve market. Tang and Jain [239] studied the problem of how the aggregator chooses wind farms, then discussed ISO's problem of pricing wind power for random economic distribution. Zhao et al. [240] proposed a risky power contract in which aggregated wind energy producers could trade electricity. The marginal contribution and diversity contribution of each resources to the group of all wind resources was fairly reflected in the profit earned in competitive equilibrium.

6. Trend evolution of the literature studies related to RES supports and market participation

In this section, the references discussed in this study on the incentive mechanisms used by governments to promote RESs and the optimal participation of RESs in the electricity markets are analyzed. The evaluated studies consist of journal articles, conference papers, and book in different years since 2001. An analysis of the trend evolution of these literature studies focused on RES support policies and optimal market participation in the last two decades, which has been examined in detail, is given in Figure 7. As can be seen from the figure, it is seen that the number of journal articles, conference papers, and books carried out has increased significantly in recent years in terms of increasing the need for RESs in power systems and easy management to participate in the electricity market of resources increasing incessant through support policies. Besides, it can be said that the number of publications increase significantly since 2015. The percentage distribution of total annual publications for each year is given in Figure 7.b.

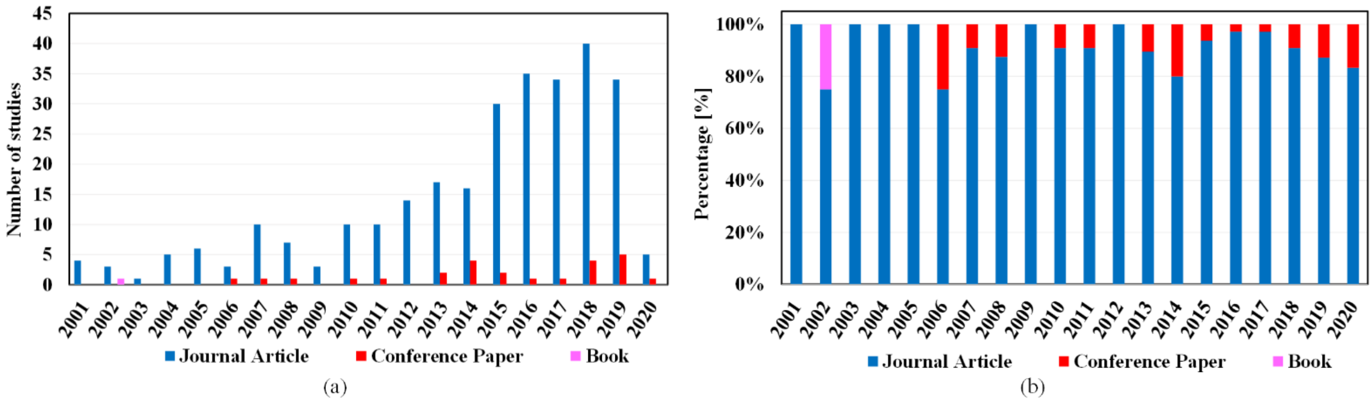

Figure 7. The representation of the trend evolution regarding literature studies evaluated in this study: (a) Variation of the total number of "journal article", "conference paper" and “book”, (b) The percentage of "journal article", "conference paper" and “book” in the relevant periods.

On the other hand, Figure 8 looks at the subject from the perspective of each sub-title. In other words, in terms of the topics expressing here in sub-titles, the distribution is given according to the years, taking into account the papers whose technical characteristics are specified. These topics are given in a, b, c, d, and e in the figure, respectively, as RES support policies, market type and auction rules, modeling category and modeling techniques, software and solver, and electricity market participation collectively. It can be said that the number of publications for all sub-figures has increased significantly since 2015. It should be underlined that studies whose technical specifications are not specified are not considered herein. The number of conference papers among publications related to RES incentive policies is high. Many of these conference papers are just papers that aim to explain the topic and do not include an optimization model. The total number of publications in the subfigures are 99 in Figure 8.a, 173 in Figure 8.b, 180 in Figure 8.c, 98 in Figure 8.d, and 40 in Figure 8.e, respectively.

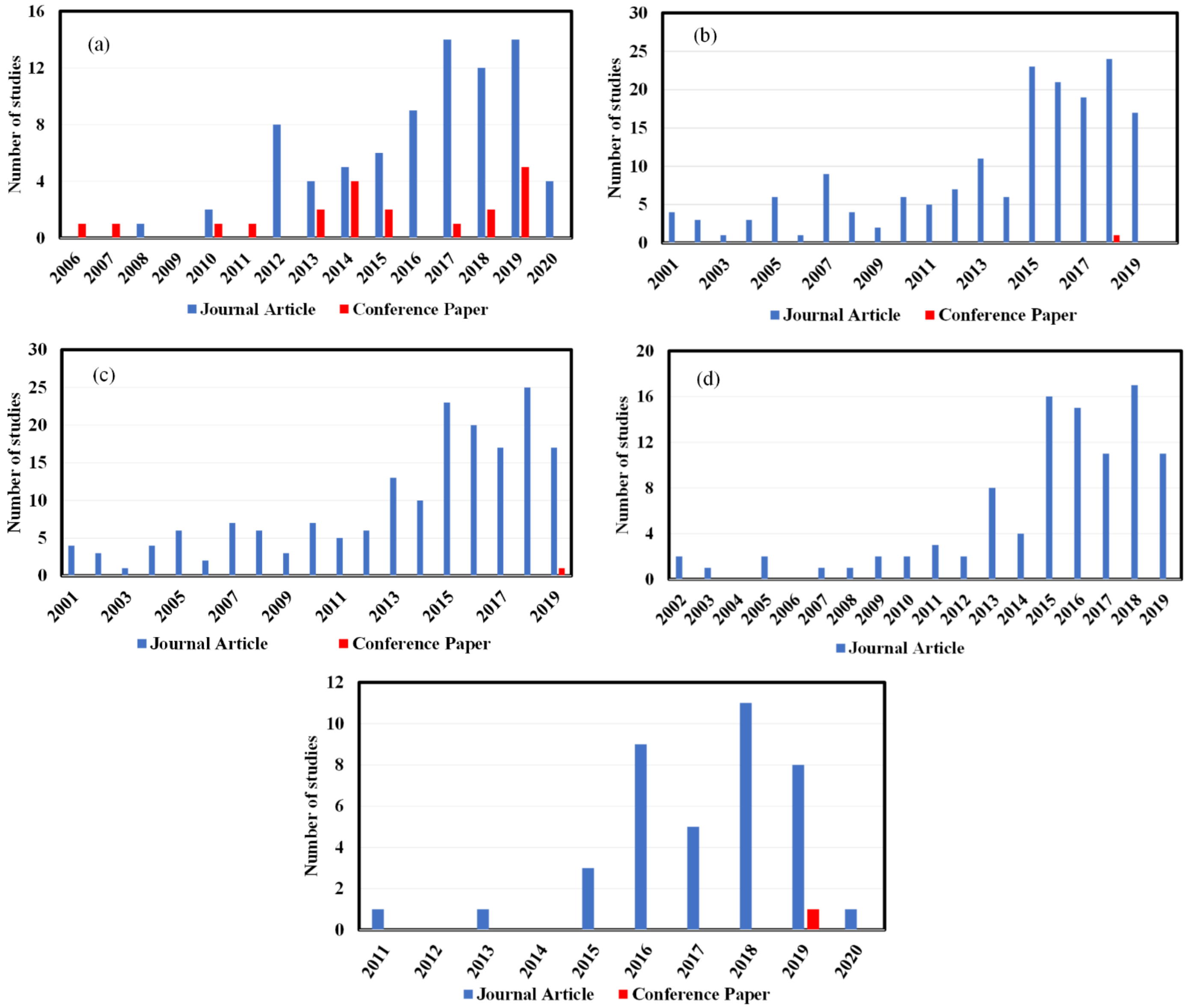

Figure 8. The representation of the trend evolution regarding literature studies evaluated in this study: Variation of the total number of studies related to (a) the RES support policies (Table 1), (b) the market type and auction rules (Table 3), (c) the modeling category and modeling techniques (Table 4), (d) the software and solver (Table 5), (e) the electricity market participation collectively (Table 6).

7. Concluding Remarks

There is a trend towards RESs in the world especially due to environmental problems. In this context, governments have implemented various policies to promote RESs. These policies can generally be expressed as investment support, production support, quantity targets, and CPs. Investment support includes various tax incentives, grants, and installation subsidies by governments. Tax incentives, grants, and subsidies are widely applied in many countries to promote RESs. Generation support generally means payment per unit of electricity produced, and this structure includes FIT, FIP, net-metering, and tender. FIT is the oldest commonly used mechanism, and FIP refers to the premium paid above the market price. The first country to implement FIP in the world is Spain, and the first country to implement FIT in Europe is Germany. The US applied a fixed price mechanism, with a different name, in 1978. In the FIT mechanism, the amount paid may be heavy for governments in some cases. In this situation, RPS/QO and GEC applications can reduce this load. However, according to FIT, RPS/QO and GEC reduce participants' profits. In this respect, FIT can continue to be implemented as a complementary policy. In the FIP application, it is generally more suitable for sources such as biomass and geothermal or sources with an ESS since a payment above the market price can be obtained. It can be advantageous in the optimal management situation for the producer since it can generate income above the market price. In general, as the production uncertainty increases, it is more appropriate to get incentives with the FIT mechanism. Besides, it can be stated that PV facilities, whose production is more specific than other RESs such as wind power plants, can gain more profit with FIP. Net-metering is an application that encourages small-scale prosumers and is intended to be included more in the future. The tender is a competitive mechanism that provides financial support. The quota implementation includes RPS or QO. It means the necessity of producing a certain amount of renewable energy. It is generally integrated with a GEC market. Generally, one certificate per 1 MWh renewable energy produced is earned and it can be traded in the market. CPs generally aim to reduce carbon emissions. Generally, CPs are not the best way to increase the number of RESs, and in this regard, financial support should be provided with this policy. Besides, the high level of the carbon tax may affect manufacturers' business performance and industry development.

It is planned to add RESs directly to the electricity market in many countries. In this respect, the importance of the optimum bidding strategy increases. With this purpose, a detailed review of optimal bidding including all articles in the literature was provided in this study, and the publications were categorized into 3 types. Many factors affected the optimal bidding of a GENCO for the price offers given to the energy market. First of all and the most important one was the structure of the electricity market. This required different strategies for each of the DAM, IDM, BM, and reserve markets. The pricing mechanisms applied in the energy markets were another factor affecting the bidding strategy. Different offers made for each of the LMP, PAB, or UP price mechanisms. The prices that occurred for different times in the DAM and BM were also one of the important factors in the optimal bidding strategies. Besides, which energy source the power plant uses was also one of the most important factors affecting optimal bidding. The management style of the generation power plant was also effective in optimal bidding mechanisms. RESs could join the electricity market individually or collectively. Besides, a producer might be in a price-maker position indirectly if it took place in an aggregator while one producer was in a price taker position in the market. Considering these situations as well as RESs have been in charge of their own imbalances in the electricity markets, it would be appropriate to collect RESs under a combiner. In the literature, RESs were collected under structures such as aggregator, portfolio, a group of producers, VPP, and MG. It should be stated that the calculation method or algorithm chosen was important for optimal bidding. The decision depending on many different situations included and not included here has an important effect on optimal bidding and it can change the quality of the offer.

It should be stated that increasing the number and capacity of renewable energy sources is very important for the sustainability of electrical energy and environmentally friendly power system. However, these sources by their very nature have stochastic power generation and as a result their generation can vary greatly. In this respect, while obtaining a clean and economical energy, the structure resulting from uncertainty can cause major problems in terms of the operation of the power system, mainly operating cost. For this reason, it cannot be said that increasing the number and capacity of renewable energy sources will always bring full benefits to the power system. In this respect, it will be appropriate to determine the location and capacity of renewable energy sources with optimum problem solution according to the power system to be applied.

It can be said that the number of studies in terms of RES support policies and optimum electricity market participation of these sources increase of late years, as can be seen in Section 6, where the trend evolution of the papers discussed (article, conference paper, book) in this study is evaluated. Looking at the studies in detail, in recent years, systems such as demand management, smart grids, storage in the form of vehicle-to-grid (V2G), and combining the production of power plants regardless of location such as aggregator, portfolio, VPP, and studies in these areas have come to the fore. In this respect, it will not be surprising to see in more countries that both developing the flexibility of the markets and containing prosumers. In future studies, research can be carried out to increase the prevalence of prosumers within the smart grid and under demand management, and to integrate electric vehicles, which can also operate in V2G mode, with RESs. Considering that the power system will be entirely composed of RESs in the future, it will be useful to conduct research on flexible load selections to be added to the aggregator structure consisting of RES in order to reduce imbalances of RES and ensure reliable system operation. Furthermore, although the increased capacity of RESs bring many benefits in terms of environmental pollution and sustainability of the electrical energy, there is a capacity for the RESs to be included in the power system due to constraints. In this respect, studies to be carried out taking into account the dynamic line ratings especially for transmission lines will make a great contribution to the field. Besides, when it is assumed that determining the appropriate capacity has a significant role in reducing the operation cost of the power system, determining the optimum capacity and number issue according to the system to be applied is indispensable for future power systems.

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