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Market design of an energy exchange: The case of Greece

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ABSTRACT

Driven by the liberalization of the energy market that began in the 1990s, the European Union aims to unify its internal market and achieve price convergence among all European economies. The majority of European countries have successfully established power exchanges, aiming to conduct cross-border transactions in a transparent and reliable manner. This paper provides a comprehensive overview of prior literature on the market design of the European Power Exchanges. It also identifies recent developments in the electricity market in Greece and describes the structure of the Hellenic Energy Exchange and the markets that will be formed in the future. These upcoming markets are expected to provide greater flexibility to all market participants. At the same time, the Hellenic Energy Exchange is expected to facilitate the integration of Greece into the rest South East European electricity markets.

1. Introduction

The liberalization of energy markets began in the 1990s as an attempt to unify the internal market and achieve price convergence across all European economies. The movement towards the use of a single energy market in Europe is explicitly directed by the European Union (EU) through various directives (Directive 96/92/EG, Directive 98/30/EG, Directive 2003/54/EC and Directive 2003/55/EC). In particular, this process is clearly specified by the EU through the Third Energy Package.

The majority of EU countries have successfully established power exchanges (PXs[1]) through which cross-border transactions are conducted in a transparent and reliable manner, ensuring greater liquidity in the energy market and at the same time providing a competitive environment for the benefit of the consumers. Additionally, PXs encounter supplementary advantages, such as easier access, lower transaction costs, elimination of counterparty risk, neutrality, price reference, clearing and settlement services.

Power exchanges are considered an important part of the European energy sector, both in terms of physical and financial trading. Based on the most recent available data, the total volume of electricity traded across the European Union amounted to 12,647 TWh for 2017, out of which 42.3% was traded among PXs (European Commission DG, 2018). Given the ongoing coupling among various regions in Europe, in the coming years we are likely to witness a significant integration among energy markets. Currently, electronic auctions are conducted daily, where energy products such as electricity, natural gas, CO_2 emissions and green certificates are traded between PXs all over Europe. The first PX that was established in the EU was OMIE [1997] in Spain, followed by APX [1999] in the Netherlands and the United Kingdom, Nordpool [2001] in the Scandinavian countries, EEX [2002] in Germany and more recently IBEX [2014] in Bulgaria and CROPEX [2016] in Croatia. The main difference among those PXs is liquidity, since the less developed PXs struggle to survive or try to integrate with their neighbours in the region. Their role, design, and function of PXs have received considerable attention over the past decades.

In the case of Greece, the framework of the energy market was reshaped radically in February of 2017, when the Market Operator (LAGIE – Operator of Electricity Market) and Athens Stock Exchange (ATHEX) signed a memorandum of cooperation, aiming to establish the Hellenic Energy Exchange (HEE). The upcoming PX is going to replace the current system of mandatory pooling. However, market design

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[1] Power Exchange: PX, Athens Stock Exchange: ATHEX, Hellenic Energy Exchange: HEE, Transmission System Operator: TSO, Renewable Energy Source: RES, Operator of Electricity Market: LAGIE, Public Power Corporation: PPC, Regulatory Authority for Energy: RAE, Agency for Cooperation of Energy Regulators: ACER, Independent Power Transmission Operator: (IPTO or ADMIE), Hellenic Gas Transmission System Operator: DESFA, RES Administrator and Guarantees of Origin: DAPEEP, Over the Counter: OTC, Market Abuse Regulation: MAR, European Market Infrastructure Regulation: EMIR, Regulation on Wholesale Energy Market Integrity and Transparency: REMIT, Markets in Financial Instruments Directive II: MIFID II, Nominated Electricity Market Operator: NEMO, European Securities and Markets Authority: ESMA.

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fundamentals in the HEE are still unexplored. To the best of our knowledge, there are no previous studies analysing those radical reforms which have occurred in the Greek energy sector.

Prior research has solely focused on issues related to congestion management and capacity allocation (Biskas et al. 2013, 2017; Dourbois and Biskas, 2014). These topics are broadly covered by studies in the field of engineering, which leaves questions about other important elements of PXs' functions still unanswered. Concepts such as market design and market structure, bidding system modelling, auction structure and order types are of extreme importance, since a growing number of researchers and market participants are seeking to better understand the role of PXs and explore ways to take advantage of their services. Besides, by providing evidence from the ongoing market design implementation, our study is relevant from a market design and governance of energy markets point of view. Despite the fact that there are previous studies that examine these concepts for other European power exchanges, such as APX, EEX and Nordpool (Madlener and Kaufmann, 2002; Bichpuriya and Soman, 2010), there is no similar study for the case of Greece. Thus, this research contributes to the literature by presenting the implementation of a power exchange in the case of Greece.

Based on the above, we provide an updated review by explicitly addressing three basic points. First, we review previous studies on the field of PXs, their market design and integration. Second, this study presents the latest developments in the Greek energy sector. Third, we investigate the formation of the Hellenic Energy Exchange and three new markets - day-ahead, intraday and forward - and discuss the new market codes. This research will be useful for policy makers, supervisory authorities, and market participants – such as traders and asset optimizers, since it sheds light on a number of issues regarding PXs' market design and function.

The paper is comprised of five sections. Section 2 presents an extended overview of studies dealing with PXs, their architecture standards and their imminent integration towards a single European energy market. Section 3 describes the case of Greece and explicitly breaks down the structure of the Hellenic Energy Exchange and the markets that are going to be formed during the upcoming period. Section 4 concludes the study and displays its main findings as they apply to energy policy and the managerial implications of the results and some future research directions.

2. Literature review

2.1. Power exchange

A power exchange is broadly defined as a competitive wholesale trading facility designed for energy commodities such as electricity and natural gas. In general, PXs are governed by similar operating mechanisms and rules, regardless of the country in which they operate. A key feature of PXs is that they provide a marketplace where different forms of energy and energy-related financial products are traded based on standardized characteristics, quality and transaction terms. In such a marketplace, vendors interact with buyers and through specific and transparent procedures, the law of supply and demand shapes the price.

More specifically, a PX is a central electronic auction platform that connects buyers and sellers (Bajpai and Singh, 2004). Its basic role is to match the demand and supply, and consequently, to determine a public market-clearing price. Most of the time, electricity is thought of as the core market since other energy products, such as natural gas and environmental products, only enter the platform after the market reaches a certain level of development.

There are four markets in an advanced PX. Firstly, the day-ahead market, which refers to transactions occurring the day before delivery. This procedure permits both market participants[2] and the Transmission System Operator (TSO) to have a balanced timeframe for arranging the physical aspects of delivery (Boisseleau, 2002). Secondly, the intraday market which includes local and complementary intraday auctions. In the intraday market, trading occurs on the same day as delivery. Thirdly, in the forward market, transactions are arranged on a given day, with both physical and financial delivery occurring at a pre-defined future time. A developed forward market commonly includes derivatives, such as forwards, futures and options. Finally, the fourth market is broadly known as the balancing market, where the technical constraints of the network are considered. The balancing market is not taken into consideration in the following analysis, given that its structure and operation are the TSO's purview and not included in the HEE's responsibilities.

A fair-sized body of literature has examined the operation of PXs. The first systematic report on designing markets for electricity was conducted by Stoft (2002), who provided both the theoretical and practical foundations for power market structures. Madlener and Kaufmann (2002) analysed electricity trading in Europe and reviewed the core features regarding the most important PXs in Europe. In particular, the authors scrutinized topics such as the modelling of bidding systems, bidding strategies, types of auctions, and trading systems.

The fundamentals of power system economics are thoroughly discussed by Kirschen and Strbac (2004). In their seminal research, the authors highlighted the essential features for the understanding of electricity markets from the microeconomics and competition perspectives. An early investigation on spot and future markets was conducted by Muermann and Shore (2005). Termini and Cavallo (2007) contributed to existing literature by analysing the role of futures as an explanatory factor on the behaviour of spot market prices.

Morey (2001) and Tesfatsion (2009) reviewed the theoretical and practical perspectives of the auction framework. Concepts such as pricing rules, market efficiency and competitive market clearing were explained in detail, accompanied by a plethora of illustrative examples. Bichpuriya and Soman (2010) provided an overview of European PXs, where features specific to electricity trading were at the core of their analysis. Trading mechanisms, bid types and execution conditions were the main subjects of their study. Recently, Harris (2013) outlined the technical and quantitative arguments on market structure and pricing models. Finally, Mastro (2013) investigated the underlying theory and various technical insights on how financial derivatives are initially structured and subsequently traded in PXs.

2.2. Market design

The design features for transmission networks—such as rail, telecommunications, gas, electricity and other networks affected by congestion—are mostly identical. Aside from congestion management, a plethora of issues need to be addressed to consider the market design of a PX as efficient. Early work on this field is mainly focused on the design of competition auctions (Che, 1993). The first systematic report on the broad concept of PX market design was conducted by Wilson (1997). His study refers to activity rules about the auction process and bid formation. He also investigated issues such as organizational forms and trading agreements that are considered to be major parts of the market design procedure (Wilson, 2002). Furthermore, an efficient market design is mandatory to deal with the monitoring and detection of incidents related to market power abuse (Newbery, 1995). Twomey et al. (2005) conducted a literature review concluding that easily accessible and comprehensive data would be most efficient for market power monitoring, and a parallel structure would facilitate market design evaluation. (Bigerna et al., 2016), analysed the concept of monitoring market power in the context of the development of renewable energy sources. The authors addressed the issue in the Italian Power Exchange (IPEX) from 2004 to 2007 utilizing hourly data provided by the Gestore del Mercato Electrico (GME). They found that for the case of the Italian electricity market various generators exercise market power. Their analysis revealed that competition works when the

[2] Participants include generators, distribution companies, traders and large consumers.

market is unique, but due to structural line congestion, the hours in which segmentation favors market power have increased.

Focusing on specific European PXs' market designs, prior research is available regarding Nordpool in the Scandinavian countries and APX in the Netherlands (Flatabø et al., 2003; Tanrisever et al., 2015). Particular emphasis was placed on the day-ahead and intraday markets by Weber (2010), who traced the development of the European electricity markets by reviewing all major PX market designs. The economics of an effective liberalized electricity market design are documented by Biggar and Hesamzadeh (2014). As far as balancing markets, Müsgens et al. (2014) analysed and illustrated the essentials that direct behaviour of electricity markets and their design in Germany.

A recent review of theoretical auction features is presented by Ocker et al. (2016), who empirically analysed 24 European countries and provided an overview of the existing balancing power markets' designs. Hogan (2016) demonstrated a framework of efficient electricity day-ahead markets, outlining several descriptive cases and valuable discussions of the benefits and pitfalls of virtual bidding. Finally, a recent review conducted by Ringler et al. (2017) showed that diverging national market designs pose a threat to the development of an internal EU electricity market. Taking into consideration the various challenges of electricity market design, their study highlighted how different design aspects affect generation adequacy and welfare in Europe. Their results supported the benefits of market coupling, both in terms of welfare and generation adequacy. Overall, beyond the observed coordinated desire for a common market design, the actual integration of the European PXs is a significant issue that needs to be considered (Hyland, 2016). The following subsection reviews the literature on the European energy markets' integration.

2.3. Integration of european power markets

In line with the Third Energy Package, the EU's short-term objective is homogeneity in the way all individual European PXs operate, thus assisting the long-term establishment of a single pan-European energy market (European Commission DG TREN, 2008). Price coupling is the most efficient method for the integration of individual European wholesale electricity markets. It has two important characteristics. The first feature is that prices from the day-ahead market should be shaped independently in each member state. The second feature is the maximum acceptable load between two countries, meaning that the integration process permits the transfer of energy from a country with a surplus to one with a deficit.

In theory, under the hypothesis of no physical limitation during the transfer of electricity among cross-border connections, a low-cost country would be able to export electricity to countries that had a higher cost of production. Hence, if these tradable amounts are substantial enough, the prices would converge, until eventually a single price would dominate the shared electricity market. This process of electricity market coupling is shaped with implicit auctions on the day-ahead market, and through continuous cross-border trading on the intraday market.

Under the target model's directive (Directive 2009/72/EC), each country needs to organize its wholesale electricity market alongside the establishment of the four markets (forward, day-ahead, intraday and balancing). In that way, the anticipated concepts of the market and price coupling are expected to stimulate cross-border transactions throughout Europe. Hence, an effective allocation of the energy reserves is achieved, while competition among the countries involved is enhanced. At the same time, the liquidity is increasing among the PXs and consequently the overall economic output of the interconnected markets is amplified. In contrast to the trend which is apparent among the Central European and Northern European economies, countries in South-Eastern Europe (SEE) experience limited market liberalization and limited cross-border transactions. Thus, individual PXs such as Southern Pool in Slovenia, CROPEX in Croatia and IBEX in Bulgaria face serious difficulties in their operation and imminent integration, mainly due to the lack of liquidity.

All these concepts related to the subject of European electricity market integration have been widely addressed by empirical studies (Green, 2001; Jamasb and Pollitt, 2005; Karsten Neuhoff, Benjamin F. Hobbs, 2011; Böckers and Heimeshoff, 2014; Sotiriadis et al., 2016). For example, Ringel (2003) studied the market distortions and imperfections related to a fully functional single European market. He argued that by overcoming specific disturbances, the EU would actively foster the transformation towards a single energy market. Meeus et al. (2009) illustrated the market coupling optimization problem and discussed how market coupling promotes the further integration of wholesale trading arrangements across country borders. They also argued that enhanced regulatory actions aiming to reinforce cooperation between PXs are necessary for the organization of cross-border trade. Sakellaris (2011) reviewed the developments towards a regional energy market in SEE. In particular, the author discussed the regional framework in the wholesale market and provided recommendations for the enhancement of the regional day-ahead market. Biskas et al. (2014) reviewed the degree of integration among the European energy markets and concluded that the integration among the European wholesale energy markets has increased mainly in Central European countries, accompanied with poor evidence regarding the rest of Europe. Carvalho et al. (2015) discussed the main determinants on the market splitting behaviour of the Iberian electricity spot markets. They concluded that the European interconnection capacity target of 10% of the peak demand of the smallest inter-connected market might be insufficient to maintain electricity market integration. Carvalho et al. (2016)a,b also highlighted the importance of strong cross-border interconnections and found that the interconnection between Denmark and Germany should be reinforced. The merit order effect and the role of arbitrage dynamics of prices as more renewable energies enter the production mix are documented by Carvalho et al. (2016)a,b and Carvalho and Pereira (2018).

Newbery et al. (2016), aiming to increase spot trading efficiency, estimated the potential benefit of coupling interconnectors accompanied by effective balancing services across borders. The authors claimed that further improvements are feasible by rejecting unscheduled flows and encouraging the penetration of renewables with better market design. A recent paper by Beus et al. (2018) sketched an updated outline of Croatia's electricity market design, identifying crucial obstacles that delay the progress of a functioning electricity market towards its further integration into a single pan-European electricity market. Table 1 presents a brief overview of studies that have examined the concept of PXs.

3. The case of Greece

After carefully analysing the relevant literature, this research goes one step further in illustrating the current reforms of the Greek energy sector. Aiming to enhance competition compared to the previous period, Greece has introduced numerous steps towards the liberalization and deregulation of its wholesale electricity market (Danias et al., 2013; Milonas, 2015). In particular, the electricity fuel mix in Greece has achieved considerable milestones in terms of diversification. For instance, in 2018 the penetration of RES was raised to nearly 22% of the total generation. Prior research related to the topic, highlighted particular issues arising from the increased penetration of renewable energy sources in the system.

In line with Kabouris and Kanellos (2009), from a technical point of view, the Greek energy supply industry faces a variety of technical problems and challenges such as frequency and voltage regulation, available transmission capacities to accommodate RES plants, power quality issues, monitoring and control by the energy management systems, operational practices, ancillary services and connection interfaces. Concerning electricity economics, large RES penetration will

Table 1
Summary of country specific studies on the concept of Power Exchanges.

Authors (Year of Publication)	Overview	Market Sample
Newbery D. (1995)	An investigation of market power effects in the UK following liberalization of the wholesale electricity market. The paper argues that the contract market, which makes entry contestable, will ensure that long-run average prices are kept at a competitive entry level, with increased competition mainly increasing medium-run volatility and short-run economic efficiency.	UK
Madlener R., Kaufmann M. (2002)	A literature review of the exchange-based spot market trading of electricity in Western Europe. The paper analyses issues related to grid constraints, modelling of bidding systems, bidding strategies, types of auctions, pricing, matching rules, types of spot markets, trading systems, the main benefits and the success factors of power exchanges.	Belgium Denmark France Germany Italy Netherlands Norway Spain Sweden UK
Flatabø et al. (2003)	An overview of the Nordpool Power Exchange (company structure, products, services, members) and its role, ownership structure, system size, trading operations and system function.	Denmark Norway Sweden
Twomey et al. (2005)	A literature review of market power monitoring in electricity wholesale markets. Definitions, strategies and methods of mitigating market power are included. The authors conclude that, due to the large amount of data collected by regulators, easily accessible and comprehensive data supports effective market power monitoring and facilitates market design evaluation.	European Countries & USA
Bichpuriya, Y.K., S. A. Soman (2010)	An overview of electric power exchanges. The authors describe the fundamentals of electricity trading (Trading mechanisms, consumers'/producers' surpluses, social welfare). The paper also investigates the design issues of PXs (Bid types, products and execution conditions). Finally, the study provides an overview of PX concepts and their implementation.	Belgium Denmark France Germany India Norway Sweden
Weber, C. (2010)	Market designs of the major European power markets are reviewed, with a focus on liquidity in the spot and intraday markets. Key features are the short-term adjustments required by wind energy. The necessity of sufficient liquidity in intraday markets is highlighted, leading to an evaluation of proposals for improving liquidity in the short-term market, including the use of continuous spot trading or the use of intraday auctions.	Denmark France Germany Norway Spain Sweden UK
Tanrisever et al. (2015)	The paper investigates the organization and function of the Dutch electricity market and reviews the roles of the main market participants. It also discusses the process of financial trading and clearing mechanisms through organized futures exchange and the spot market. Overall, the study analyses the APX day-ahead spot prices and the real-time imbalance prices.	Netherlands
Biskas et al. (2017)	The paper presents the basic design variables and options for the integration of the Greek wholesale electricity market with other European markets. It illustrates the transitional phase for the full integration of the Greek intraday and balancing markets. Finally, a simulation analysis highlights the implications of utilizing European-based order formats in the restructured Greek electricity market on schedules.	Greece
Beus et al. (2018)	The authors provide a comprehensive overview of electricity market design according to laws related to the electricity sector in Croatia. The paper also sheds light on key obstacles that hamper the development of the Croatian Power Exchange. Finally, the authors review the necessary prerequisites for market coupling with the Slovenian Power Exchange and the Hungarian Power Exchange.	Croatia Hungary Slovenia

impact emissions, energy balances and generation mix. Bigerna and Bollino (2016) concluded that in the Italian electricity market the actual hourly market design is inadequate to achieve an efficient solution in the presence of a large and increasing share of renewable energy sources in the system. This is an important aspect that needs to be also considered in the case of Greece. Since 2017, the reference value of RES in Greece is being determined by an auction system that has been launched by the Regulatory Authority for Energy (RAE). The auctions are being carried out electronically and during this two-year period (2017–2019) a total of three auctions have been completed. The reference prices for RES resulting from the first auction were 68,81€/MWh for photovoltaic projects bigger than 1MW and 69,53 for wind projects bigger than 3MW. The next auction is planned to take place in June 2019 for 300 MW of wind and 300 MW of photovoltaic capacity.

As well as the goal of increased percentage of renewable energy sources (RES) in the electricity fuel mix, the transition towards the target model imposes the establishment of a PX accompanied by the formation of the day-ahead, intraday, forward and balancing markets. The Greek electricity system is interconnected with Italy, Turkey, Albania, North Macedonia and Bulgaria, allowing exports and imports of electricity to cover loads with a comparatively low cost and to dispose the generation surplus. This provides a significant potential for enhanced trading and market coupling, mainly between Greece and the interconnected neighbouring countries. For example, the interconnection of Greece with Italy represents 50,43% of the total Greek electricity exports in 2018, meaning that cross border electricity transmission has greatly improved over the last years. To date, Greece remains a net electricity importer. However, the country can also be converted into a net exporter. Once the HEE officially starts to operate, the process of market coupling will definitely improve the usage and efficiency of the interconnections, hence, the effectiveness of the daily-capacities allocation on the borders will increase. According to ENTSO-E (2018), following the establishment of the HEE, market coupling with Italy is expected to take place during the 1st quarter of 2020, while coupling with Bulgaria and North Macedonia is anticipated to occur near the end of 2020.

According to the International Energy Agency (2017), total electricity consumption in Greece is estimated to be 52.4 TWh, while total electricity generation is about 48.9 TWh (2017). In terms of consumption allocation, 38.5% is directed towards commercial use, 33.4% is for residential use, 24.2% is for industrial use and 3.9% is for transportation and other sectors. The electricity generation mix is made up of natural gas (33.96%), coal (33.9%), RES (21.54%) and hydro (10.6%) – (2018).

The vertically integrated state-owned electricity company called the Public Power Corporation (PPC) dominates the electricity value chain in Greece. Consequently, the PPC accounts for 75% of the nation's thermal electricity generation and approximately 79% of the installed thermal generation capacity. In terms of the day-ahead market, which also includes RES, hydro and imports, the PPC's share was 53% in 2016. Moreover, in the retail market the company's share is currently 75.8% (May 2019). Nowadays, even though 25 participants are active in the market, the second-largest alternative supplier reaches only 4.8% of total market's share. However, as part of the economic adjustment program, the PPC's share is going to be decreased to 50% by the end of 2019, meaning that radical changes are about to occur in the country's electrical sector. This long-term process faced significant issues towards the liberalization which is properly documented by Tsoukas and Papoulias (2005). The authors explored the peculiarities of the management of third-order change in the Greek state-owned electricity utility. In previous years, the electricity market in Greece operated through the public company LAGIE that was responsible for undertaking the operation and monitor of the day-ahead market (Regulation 2015/1222/EC). LAGIE's further responsibilities comprised clearing, settlement and reporting of transactions to both the RAE and the Agency for the Cooperation of Energy Regulators (ACER).

3.1. Hellenic Energy Exchange

Aiming to modify the aforementioned structure, the Greek authorities -in co-operation with the European Commission - have formed a framework for the implementation of the target model guidelines. Implementation of the reforms was undertaken by the Joint Research Centre which, in conjunction with LAGIE, appointed an international consultant to deliver a detailed market design and codes. On June 2018, the HEE was established and undertook all the responsibilities that previously belonged to LAGIE.[3]

According to Greek legislation, LAGIE will participate with a share of 22% in the new entity, thus ensuring the participation of the Greek state. The Athens Stock Exchange owns a share of 21% and its role is of central importance, since it is expected to contribute the necessary expertise to the formation of the HEE. Beyond those two major shareholders, the remaining required capital will be covered by the contributions of other entities, such as the electricity and gas TSOs (ADMIE 20% and DESFA 7%, respectively), the European Bank for Reconstruction and Development (20%) and Cyprus Stock Exchange (10%). In terms of ownership structure, each acquisition or transfer of shares for which the shareholding percentage reaches or exceeds 1/5, 1/3, 1/2 or 2/3 of share capital is subject to prior approval from the RAE.

The operation of the energy market is complemented by new provisions that will allow natural gas markets to enter the platform. At the same time, the target is to overcome the regulatory feed-in tariff scheme and assist the further penetration of RES into the forthcoming PX as suppliers. Following the formation of the HEE, a new entity will be established as the market clearing house, named EnEx Clear. Consistent with the proposed market codes, spot markets are concerned with the physically-deployed energy-based financial instruments, with the ability to limit or broaden the scope of the license to non-physical energy financial instruments. This means the Hellenic Capital Market Commission is the authority responsible for granting a license to the HEE, and which also is obliged to supervise the forward market. Therefore, based on the introduced legal framework financial products traded in the HEE, such as derivatives, options and futures, are subject to specific financial legislation (Directive 2014/65 /EU-MiFID II, Regulation (EU) 600 /MiFID II).

One major reform accompanying the establishment of the HEE is the introduction of implicit auctions throughout the continued trading. According to the core assumption of explicit auctions that take place during the forward market, cross-border capacity markets are independent from the energy markets of other countries/zones. Theoretically, when bidding for cross-border capacity, traders are perfectly aware of the supply-demand conditions in the two zones and can predict with full accuracy the effect of cross-border trading on the energy price difference between the zones. However, traders are not able to achieve this effectively in terms of real time conditions, which ultimately leads to less price convergence, more frequent adverse flows and less social welfare.

In contrast, in implicit auctions that take place during the day-ahead and intraday markets, the transmission capacity between bidding areas is available to the spot price mechanism, accompanied by bids/offers per area. Therefore, the subsequent prices per zone replicate both the cost of congestion and the cost of energy in each inner bidding area. Consequently, implicit auctions guarantee that electricity flows from areas with a surplus towards areas with a deficit, which eventually leads to price convergence. The sequence of the markets, accompanied by the basic features of every market, is illustrated in Fig. 1.

3.2. Introduced markets structure

In line with the Third Energy Package, the transition to the new target model of the European wholesale energy market includes the voluntary formation of PXs in parallel with the existence of over-the-counter (OTC) bilateral contracts. The HEE operates in this exact way by permitting participants to submit different orders for the supply of electricity for different production levels and time intervals. At the same time, the HEE keeps a record of all OTC contracts with physical delivery. In that context, the HEE is assigned various responsibilities, such as (i) the daily operation of the markets, (ii) the smooth function and maintenance of the transaction system, (iii) support for the settlement of physical delivery, (iv) retention of statistics and comparative data, (v) supervision of the wholesale market and (vi) cooperation with the national TSO and Clearing House (EnEx Clear). Regarding the basic characteristics of the introduced PX, standardization, transparency, low transaction cost and elimination of counterparty risk are some of the features important to its function. In contrast to the existing mandatory pool, the new PX is anticipated to provide a fair, secure and regular transaction process.

Registered participants are obliged to pay fees for the trading services provided by the HEE. The overall fees comprise the following components. a) An annual fee, separate for each market (day-ahead, intraday and forward). This component represents the cost of trading services for participation in the markets; it is a fixed amount per year. b) A membership fee which is again separate for all markets. c) Transaction fees for each MWh traded—both bought and sold—by each registered participant. Another crucial feature of the HEE is the wholesale market structure. Fig. 2 illustrates how the market structure incorporates all the components that form the new framework. The two pillars of the market structure are PX services and OTC transactions. Both pillars comprise spot and derivative markets that lead to either physical or financial settlements.

Even though the PX's operation and OTC contracts function in a complementary way, numerous differences exist between them. Namely, the dynamic two-sided OTC contracts are available only to a limited number of participants. Since their supervision and regulation are problematic, as the transactions are opaque, both participants encounter high levels of counterparty risk. On the other side, the existence of EnEx Clear in the function of the HEE eliminates any chances of counterparty risk. Yet the prices across the two markets are highly intertwined, since the prices formed in any PX function as benchmark or

[3] Subsequent to the official formation of the PX, LAGIE was renamed DAPEEP, which is the new entity responsible for the management of RES.

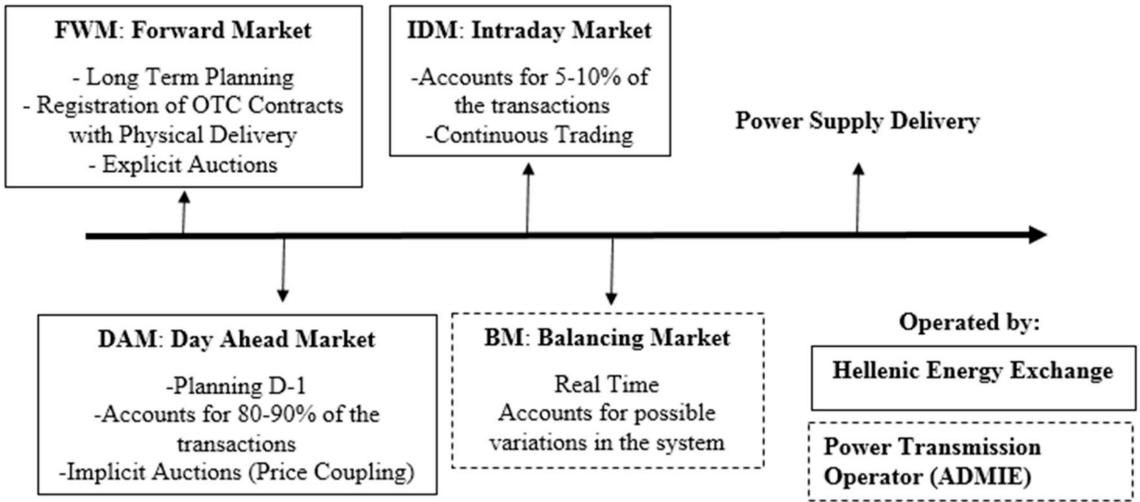


Fig. 1. Sequence of the introduced markets in the HEE.

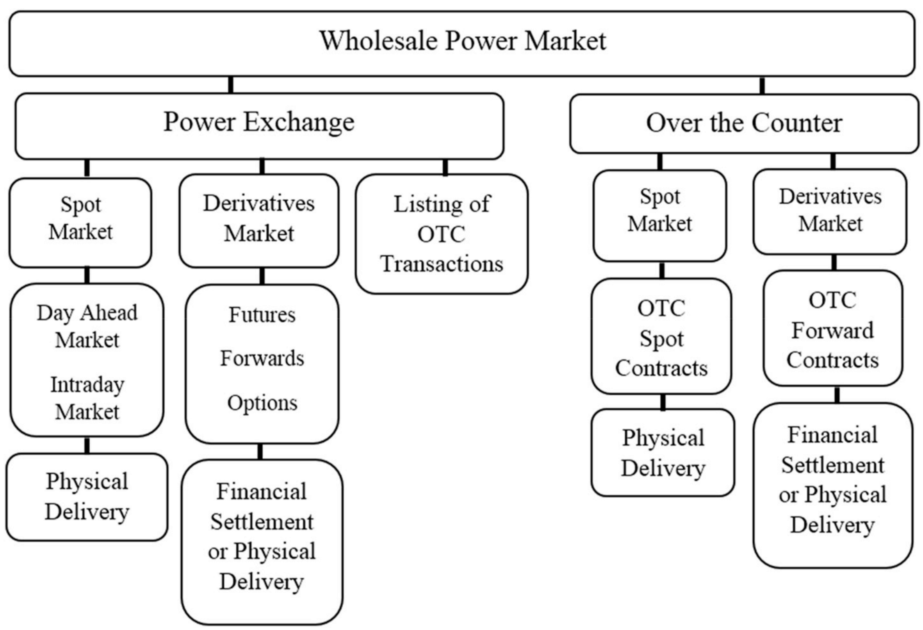


Fig. 2. Wholesale market structure.

reference prices are for those shaped in the corresponding OTC market.

Furthermore, EnEx Clear is a legal entity that is planned to be established following the formation of the HEE, which will undertake the responsibilities of clearing, settlement and transaction coverage. Given that participants will be required to maintain margin accounts, EnEx Clear will be interposed between counterparties to guarantee financial reliability. Thus, it adopts the role of buyer compared to each seller and seller compared to each buyer. The foremost responsibility of EnEx Clear is to keep a record and archive of all transactions. According to the European Market Infrastructure Regulation (EMIR, Regulation (EU) No 648/2012) the clearing house manages the settlement fund, which covers the possibility of default by any market participant.

Fig. 3 illustrates the interface between new and existing entities that will function in the forthcoming market structure. The direction of the arrows denotes the flow of services, starting from the bottom level of infrastructure and support towards the middle level of clearing, and finally reaching the upper level of market operation. All the entities depicted in Fig. 3 will need to comply with various European licenses such as the Regulation on Wholesale Energy Market Integrity and Transparency (REMIT), the EMIR, the Markets in Financial Instruments

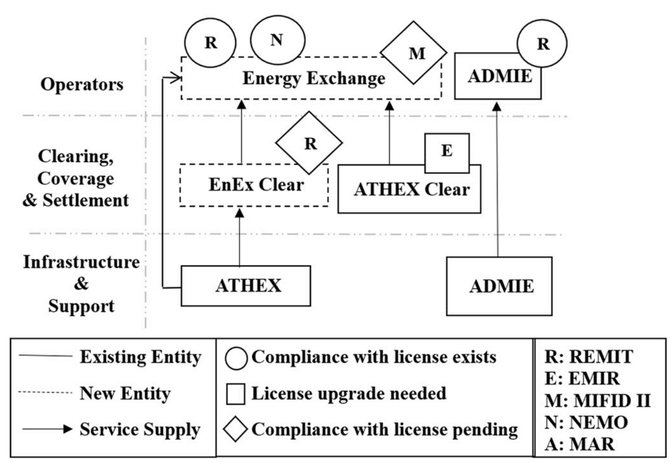


Fig. 3. Flow of services and licenses under the new market structure.

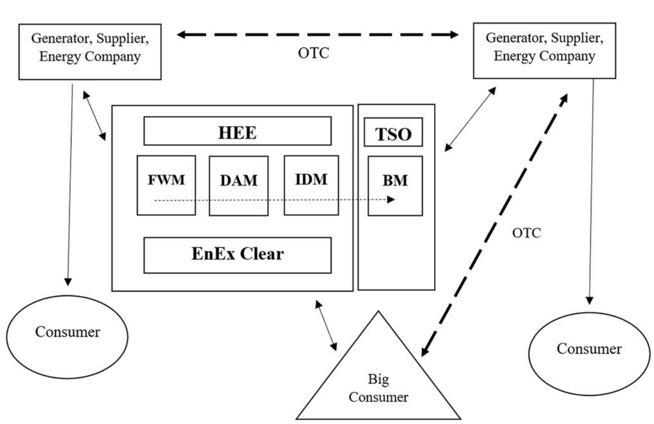
Table 2
Functional breakdown by entity in spot and derivative markets.

	SPOT Markets			Derivative Markets	
Functions	Day Ahead	Intraday	Balancing	Physical Delivery	Cash Settlement
Trading	Hellenic Energy Exchange	Hellenic Energy Exchange	ADMIE	Hellenic Energy Exchange	Hellenic Energy Exchange
Clearing,Settlement,Risk Management	EnEx Clear	EnEx Clear	ADMIE	ATHEX Clear	ATHEX Clear
Technical and Operational Support	ATHEX	ATHEX	ADMIE	ATHEX	ATHEX

Directive (MIFID II), the Market Abuse Regulation (MAR) and the Nominated Electricity Market Operator (NEMO). Those licenses are specifically directed by the EU through numerous regulations and directions that form the regulatory framework which controls the operation of the wholesale electricity market (Regulation (EC) 713/2009, Directive 2009/72/EC, Regulation (EC) 1227/2011, Directive, 2014/65/EC, Regulation, (EC) 1348/2014, Regulation (EC) 2015/1222). This framework is closely supervised by both national (the RAE and the Hellenic Capital Market Commission) and European regulators (ACER and ESMA). The circles, squares and rhombuses indicate the condition of licensing that each entity is currently facing.

Table 2 depicts the various functions of the new market structure and the corresponding allocation of the entities that are responsible for the smooth functioning of the spot and derivative markets. Fig. 4 demonstrates the four markets included in the HEE and their linkages with OTC bilateral agreements and the rest of market participants. The participants described in Fig. 4 have either a natural or financial interest in electricity. Those who have a natural interest obtain a short position when they need electricity or a long position when they encounter a surplus.

For instance, an electrical generation company is naturally long, whereas an aluminium smelter is naturally short. Participation in the market relates to the management of these short or long positions. A participant characterized by natural interest will utilize the market to balance its position. This process removes much of the risk from alternations in electricity prices and allows companies to focus on their core business. From this perspective, the HEE is expected to act as a central risk-taking and risk-management platform for all market participants, enabling them to diversify their variable costs and pricing policy. Given the forthcoming radical change in the market structure, all participants will undoubtedly seek to enhance their expertise in energy trading and develop risk-taking and risk-management strategies.



(FWM: Forward Market, DAM: Day-Ahead Market, IDM: Intraday Market, BM: Balancing Market, OTC: Over the counter)

Fig. 4. Interconnections throughout the market structure
(FWM: Forward Market, DAM: Day-Ahead Market, IDM: Intraday Market, BM: Balancing Market, OTC: Over the counter).

3.3. Day-ahead market

A day-ahead market refers to wholesale transactions during each D-1 calendar day, where electricity supply contracts are auctioned for each market time unit (1 h) of physical delivery on day D. The delivery day (D) consists of twenty-four purchased time units, starting at 01:00 Eastern Europe Time (EET) on calendar day D and ending at 01:00 EET on the next calendar day D + 1. The gate opens at 10:30 (D-1) and remains open for 150 min, closing at 13:00 (D-1). Typically, the trading mechanism is a regular binary auction (generation and demand). In that way, the system manages to match transactions for every hour at a single price. The trading products are hourly contracts with a specific value (€/MWh) and size (MWh). The most common type of bids in PXs are hourly bids and the essential information required on each bid includes characteristics such as the following: price, quantity, type of bid (sale or purchase), participant's details and the hour of the day.

Participants allowed to enter the HEE's platform—such as suppliers, traders, distributors, generators, RES aggregators and large consumers—submit their bids through the transaction system, defining the price and quantity they want to buy or sell. Following the bids' receipt, confirmation and authentication procedures are performed. The quantity and corresponding price that each seller is willing to supply electricity at is specified by each sale bid. On the other side, each purchase bid contains the desired quantity and the maximum price at which buyers are willing to pay.

Elmaghraby and Oren (1999) argued that when generators are permitted to bid for load slices, this outperforms an auction design in which generators submit bids for different hours in the day. In the following subsections, we outline several conditions or complex bids that participants can exploit during their bidding process in the HEE, depending on the market in which they are trading. The anonymously submitted bids are collected in the transaction system until the predetermined closure time, and following a specific procedure of auction algorithm computation, a clearing price is determined for every hour. The clearing or matching price for every hour is settled when demand and supply curves aggregate and intersect. In this way, demand is covered for 24 h per day, 7 days per week.

In this process, the net seller surplus on a quantity unit sold is defined as the difference between the actual sale price received by the seller for a specified unit and the seller's reservation value for that unit. This is the area between the horizontal line at the price level and the true total supply schedule, at the point where market clearing volume and market clearing price cross. The difference between the buyer's reservation value for a unit and the actual price paid by the buyer for that unit is the net buyer surplus on a quantity unit bought. (Tesfatsion, 2009). In case the aggregate supply and demand curves fail to intersect, then a second round of bid submission could be activated. In addition, the outcome of the simple bid matching might provide a surplus at the market clearing price.

Based on the above scenario, the algorithm chooses the bids with time priority or the volumes of bids with the market clearing price as limits are proportionally curtailed. Eventually, all conditions fail to be satisfied and the price solution is not valid. Under this condition the price calculation runs again with one of the unfulfilled bids abolished. This checking process is repeated until all the remaining bids are fulfilled. After the completion of the above process in the HEE's platform, the TSO is responsible for checking the traded volumes of the matched bids compared to the transmission grid capacities. If transmission constraints are identified, the schedules are adjusted either by splitting the market into several areas or by balancing the trade volumes and running the repeated bid matching again. Eventually, the following types of orders can be submitted by participants in the day-ahead market: step-wise orders, linear piecewise orders and block orders (ECCO-International, 2017).

3.4. Intraday market

The intraday market refers to wholesale trading on each calendar day D, where contracts are traded in: a) local intraday auctions (1-h, 24 market time units), b) complementary intraday auctions (1-h, 24 market time units) and c) continuous intraday trading (30 min, 48 market time units). The market time units of physical delivery in day D start at 01:00 EET on calendar D and end at 01:00 EET on the next calendar day D + 1. According to the RAE's Decision 67/2017, the implementation of an intraday market in the HEE will take place in two phases. During the first phase, three local intraday auctions will be implemented within Greece, according to the number and timing of the corresponding local and complementary regional intraday auctions of the second phase. The design of the Greek intraday market will be adapted to implement pan-European continuous intraday trading through the already agreed intraday solution, in combination with one local intraday auction and two supplementary regional intraday auctions.

Continuous intraday trading is the procedure allowing transactions in which orders may be executed as soon as they are placed in the frame of the intraday market. Single intraday coupling is based on a continuous matching process of sale orders and purchase orders. The orders with the highest buying price and the lowest selling price get served first, given also that the cross-zonal capacity constraints are respected in case the orders are submitted in separate bidding zones. In addition, the price limit of the sale order must be equal to or below that of the purchase order—that is, the intersection of the two order execution ranges may not be empty. In Fig. 5 below, we summarize the timetables of local and complementary intraday auctions, while Fig. 6 depicts the timetable of continuous intraday trading.

As well as the step-wise, linear piecewise and block orders that are available in local and complementary intraday auctions, continuous intraday trading includes the following general types of orders: hourly orders, half-hourly orders, predefined block orders and user-defined block orders. The trading platform automatically generates hourly and half-hourly and makes them available for trading one day before the delivery day at a specified time. Moreover, the continuous trading matching algorithm is designed to support the following order types: limit orders, linked orders and iceberg orders. The following order execution restrictions are also available: none, fill or kill, immediate or cancel and all or nothing. Finally, the trading matching algorithm of the intraday market supports the following order validity restrictions: good for session and good till date.(ECCO-International, 2017).

3.5. Forward market

The forward market refers to agreements between two participants to buy or sell a specific quantity of electricity on a specified future date at a specific price. The elements included in such a contract are standardized and comprise the underlying title, the delivery date and the contract size. However, the settlement price of forward contracts is not recorded in the transaction system. The buyer of the contract has the commitment to buy a prespecified quantity of electricity, while the seller of such a contract has a commitment to sell a certain quantity of electricity at a certain price, on an agreed future date. The products available in the forward market are separated by timing into: base (24 h), peak (8:00–20:00) and off-peak (20:00–8:00). For instance, a monthly contract peak would equal [1 MW * 31 days * 12h = 372 MWh], while a quarterly base contract equals [1 MW * 31 days * 3 months * 24h = 2232 MWh].

A supplier participating in the forward market may pre-determine today the price and the agreed quantity that they are required to deliver according to the agreed contract, which in terms of the HEE is designed to be a monthly, quarterly or yearly standardized contract. At the same time, the participant has the flexibility to differentiate their position within that horizon. In this way the fundamentals are shaped for exploitation of price fluctuations, leading to a significant diversification of costs. The types of orders that could be submitted in the forward market

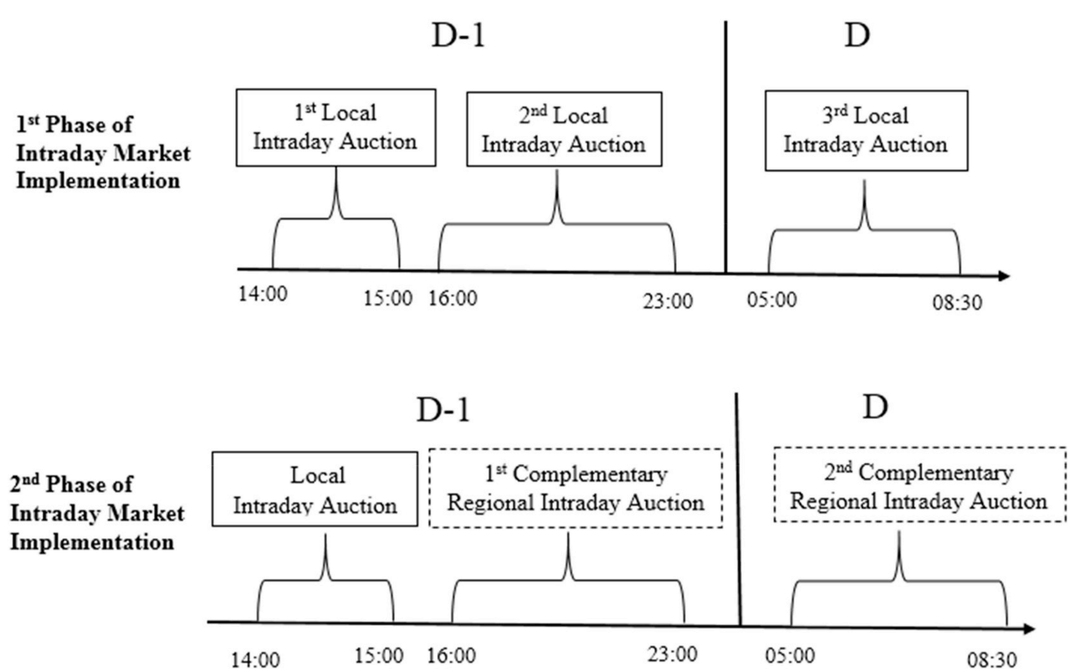


Fig. 5. Timetable of local & complementary intraday auctions.

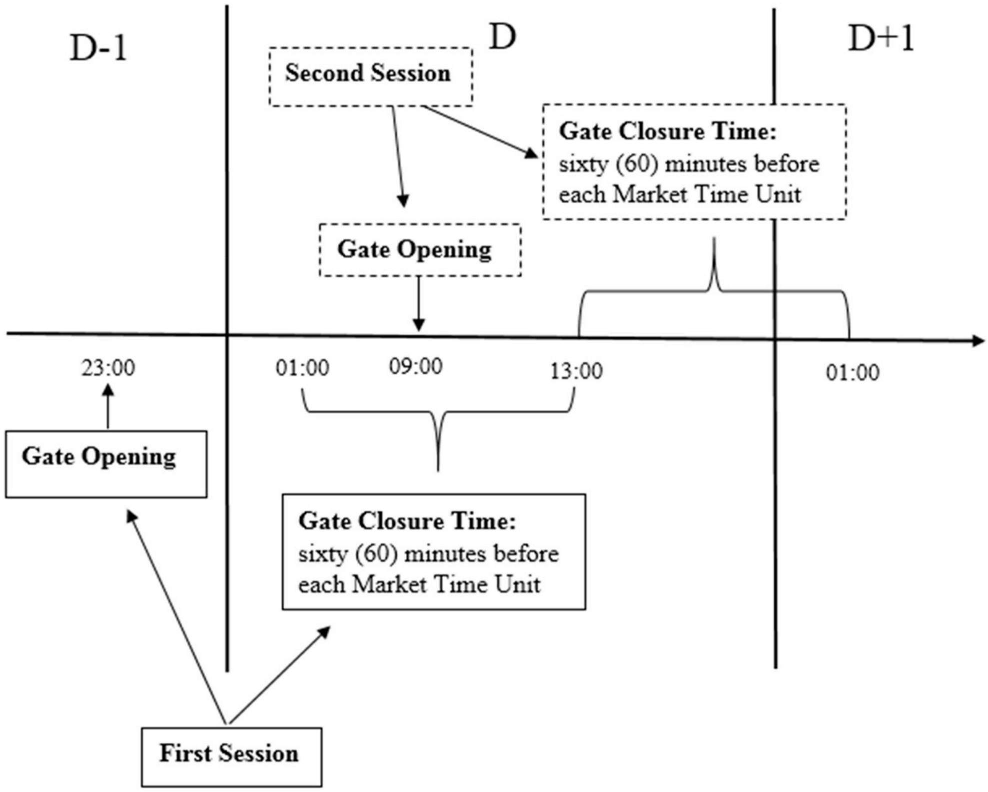


Fig. 6. Timetable of continuous intraday trading.

are the following: market order, limit order, linked order and iceberg order. Furthermore, an order may be submitted with the following execution and time requirements: good for the day, good till cancelled, good till date, immediate or cancel, fill or kill, all or none and stop order.

Transactions in the forward market of the HEE are designed to occur on the days set in the trading days calendar. Two months before the end of each year, the HEE is obliged to issue the trading days calendar of the following year. Forward electricity contracts will be traded in a continuous transaction, with trading hours that will last from 10:30 EET to 15:30 EET on each trading day contained within the calendar. Information regarding market characteristics, such as the price of the last transaction or the market depth, will be constantly available to market participants. Transactions will be published in real time and all trading and clearing activities will be carried out anonymously. At the completion of the forward contract, the physical delivery day consists of 24 physical settlement delivery hours, starting at 00:00 EET on each calendar day and ending at 24:00 EET on the same calendar day.

In addition, the forward market structure involves the registration of bilateral OTC contracts with physical delivery obligations at the HEE's platform. In the case of bilateral trading, all forward contract specifications included in a bilateral OTC contract are at the sole discretion of the two participants involved, except for those affected by power mitigation rules as decided by the RAE. Finally, standard year contracts and standard quarterly contracts are designed to be further fragmented through a cascading mechanism. Standard year contracts cascade into corresponding standard quarterly contracts spanning the same delivery period as the standard year contract on the expiry date. Standard quarterly contracts cascade into corresponding standard month contracts. However, standard month contracts are not subject to any further splitting. The price of the cascaded contracts equals the final settlement price of the original contract on its expiry date (ECCO-International, 2017).

It is also worth mentioning that in the case of HEE there will be a maximum percentage of quantities via energy financial product transactions or other transactions concerning wholesale energy products with obligation of physical delivery to be entered in the day-ahead market. Besides, participation in the day-ahead market is optional for all participants except for the producers. In terms of the intraday market, the implementation takes place in two phases, which are met only in the case of the HEE. Finally, central dispatch on unit based instead of self-dispatch on portfolio basis was selected for balancing energy and reverse capacity. However, as already occurs for the majority of power exchanges in Europe and in line with the Target Model directions, once the HEE reaches a certain level of maturity, the above would no longer hold since participants will be responsible for balancing of their own units.

4. Conclusions and policy implications

In recent years, the growth of power exchanges in Europe has been rapid. This study describes the theoretical perspectives of power exchanges, separated into three discrete topics. In particular, the literature was reviewed in terms of (i) the broad concept of power exchanges, (ii) the market design of PXs and (iii) the PXs' imminent integration towards a single European energy market. Given that a plethora of previous studies have examined the market design of PXs as applied in many European countries, this study focused on increasing Greece's contribution to the existing literature, since it is the first study that analyses the market design and structure of the Hellenic Energy Exchange.

A comprehensive overview of the recent developments in the Greek wholesale market structure was presented, followed by a careful investigation of its structure in terms of day-ahead, intraday and forward market functions. In particular, concepts such as bidding system modelling, timetables, auction mechanisms and order types were examined. Given the fundamental transformation in the forthcoming market structure, the majority of participants will seek to enhance their expertise in electricity trading and develop risk-taking and risk-management strategies.

In line with the directions imposed by the Target Model, the market design implemented in Greece considered the latest experiences and evidence on the most effective characteristics. Our analysis provides a significant level of detail on how the HEE is structured, and at the same time, highlights how the implemented market design in Greece considers the experience and knowledge available from prior studies. Furthermore, the study highlights how the Greek energy exchange differs from recent implementations in other countries. In terms of the foreseeable benefits from the choices made during the implementation process, we identify three points that could assist the optimal participation of RES and Demand Response resources in the system. First, the implementation of Continuous Trading with gate closure as close as possible to real-time. Second, the introduction of short-term trading products along with block products and third, the wide price boundaries that provide more opportunities for profitable trades in the intraday market.

The establishment of the HEE is a reform that will introduce Greece into the map of mature energy markets. The initial stages of this process have already begun, and multiple benefits are expected to emerge followed by its formation. The HEE is anticipated to act as a central risk-taking and risk-management platform for all market participants. At the same time, the HEE is expected to encourage competition, guarantee transparency and enhance liquidity. This study will be of interest to policy makers and regulators, as understanding the mechanism of PXs is essential for the development of appropriate policies and could assist the further integration of the internal European energy market. The implementation of this knowledge is the goal of policy design.

In general, this study offers useful information and insight into both the EU and Greek energy markets. Finally, the major implication derived from this particular research is that the formation of HEE facilitates the integration of Greece with the other South-Eastern European electricity markets. Further research on this topic should be directed towards the incorporation of other energy commodities, such as the natural gas, into the Hellenic Energy Exchange, and towards the empirical investigation of the potential advantages that are expected to emerge from regional market coupling.

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Appendix A. Supplementary data

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