Utilities Policy 79 (2022) 101436

Contents lists available at ScienceDirect

Utilities Policy

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

Full-length article

Does the Ukrainian electricity market correspond to the european model?

Magdalena Osińska [a,*], Mykola Kyzym [b], Victoriia Khaustova [c], Olha Ilyash [d], Tetiana Salashenko [c]

[a] Nicolaus Copernicus University in Toruń, Gagarina 13a, 87-100, Toruń, Poland
[b] O. M. Beketov National University of Urban Economy in Kharkiv, Kharkiv, Ukraine
[c] Research Centre for Industrial Problems of Development, NAS of Ukraine, Kharkiv, Ukraine
[d] National Technical University of Ukraine the "Igor Sikorsky Kyiv Polytechnic Institute," Kyiv, Ukraine

ARTICLE INFO

JEL classification:
JEL
L94
Q41
Q43
D42

Keywords:
Competitive electricity markets
A novel model for the Ukrainian electricity market
Electric power systems

ABSTRACT

The paper explores 29 models of the European electricity markets and the degree of their deviation from the single electricity market model established by the trans-European legislation. Although all models correspond to the design of the pan-European single one, they remain significantly differentiated according to trading forms and pricing methods. The electric power system in Ukraine has developed oppositely to the European ones, and the electricity market is quasi-competitive. The study proposes a novel model for the Ukrainian electricity market, which considers the European *acquis communautaires,* the advanced practice in electricity market development, and the specifics of the Ukrainian electric power system.

1. Introduction

Electricity is a unique commodity that is crucial and universally available in modern society. The world will shift to an electrified renewable-rich energy system that requires a reference energy policy based on the development of all forms of system flexibility, such as the enhancement of electrical grids and advanced technologies (IEA, 2021). A state-of-the-art electricity market model must serve as a tool for fostering policy implementation, paving the way for market participants for a desirable future.

In the past, electricity markets fell under direct government regulation; authorities coordinated all electricity flows and prohibited competition. Baumol was the first to assert that competition in electricity markets is possible between producers and suppliers and suppliers and consumers, who perform the commercial operations of wholesale and retail trading. In contrast, transportation functions (transmission and distribution) are not competitive due to their natural monopoly characteristics (Baumol, 1977). So, the unbundling of commercial and physical functions of the electric power system is the primary stage in developing competitive electricity markets (Steiner, 2001; Hattori and Tsutsui, 2004; Jamasb and Pollitt, 2005; Alberto et al., 2005; Silvester and Ortmann, 2008). The electricity markets in the world passed the way from a vertically integrated model, which served public interests, to a multilateral competitive trade in commercial goods (Williams and Ghanadan, 2006; Pollitt, 2019). At the same time, the reform of electricity markets continues. The current stage of development faces obstacles concerning "green" energy transition, which disrupt liberalization processes; therefore, new models are required (Blazquez et al., 2020). The following steps are needed to tackle these issues: (i) reshaping market areas, (ii) trading closer to real-time, and (iii) increasing the elasticity of demand (ENTSO-E, 2021).

The electricity markets in Europe are developing faster and more intensively than others (Peng and Poudineh, 2017; Ilyash et al., 2018; Pollitt, 2019; Kyzym et al., 2019; Chen et al., *2021*; Bichler et al., 2022; Wang et al., 2022). They have passed from a monopolistic model to a multilateral exchange trading over the last three decades. Before 2004, electricity markets operated mainly on a national basis and were characterized by welfare losses of wholesale market value (Newbery et al., 2016). After 2004, despite increased "regulatory convergence" in electricity sectors among EU member states, the emergence of power

* Corresponding author.
E-mail addresses: emo@umk.pl (M. Osińska), m.kyzym@gmail.com (M. Kyzym), v.khaust@gmail.com (V. Khaustova), oliai@meta.ua (O. Ilyash), tisandch@gmail.com (T. Salashenko).

https://doi.org/10.1016/j.jup.2022.101436
Received 21 June 2022; Received in revised form 21 September 2022; Accepted 21 September 2022
Available online 28 September 2022

exchanges, and the deepening of market coupling, the benefits of the EU electricity market liberalization have been modest, and the energy policy of the Union has not been pursued (Politt, 2019). To deal with these challenges, the European Commission adopted the 4th Energy Package, entitled "Clean Energy for all Europeans," in 2018–2019; the heart of it comprises an ambitious goal for the community – to become the first climate-neutral continent, reaching net-zero greenhouse gas emissions by 2050 (European Commission, 2019). An integrated, highly competitive electricity market is regarded as an interlink for a green energy transition between authorities and businesses, facilitating active demand participation, deployment of renewables, efficient cross-border capacity utilization, and trading across shorter timeframes (IEA, 2020a; ENTSO-E, 2021; Khan et al., 2021). It ensures a permanent balance between the physical and commercial electricity flows in all segments of the entire European electricity market space. The EU seeks to extend its initiative to transmit the single electricity market model to other countries to the members of the Energy Community, fostering them to implement the energy *acquis communautaires*.

As a member of the Energy Charter Treaty since 1999 and further as a member of the Energy Community since 2011, Ukraine has had an obligation to implement a competitive electricity market model and has tried to do this three times (Resolution, 2002; Law of Ukraine, 2013; Law of Ukraine, 2017). The last attempt was successful, and Ukraine switched from a single buyer to one with a more competitive market structure, which came into force in July 2019 (IEA, 2020b). Nevertheless, as proven further, the current model is still far from a single European one and needs to be viewed as quasi-competitive. Due to imposed trading restrictions and price cap regulations, it cannot guarantee efficient electricity market conditions and adequate future development of the electric power system. Moreover, the Ukrainian electricity market is highly concentrated on both the supply and demand sides, causing market manipulations.

From Jul 1, 2019, to Feb 23, 2022, the Ukrainian electricity market had been functioning mainly in isolation. It was composed of 2 bidding zones: IPS is the main bidding zone, which was connected to the CIS members, and BEI is the small bidding zone, which was synchronized with ENTSO-E members. Since Feb 24, 2022, the entire Ukrainian electric power system was synchronized with ENTSO-E, and on Mar 16, 2022, Ukraine became an observer of ENTSO-E 1.5 years ahead of schedule. The Ukrainian electric power system is technically ready, but its electricity market still has significant gaps compared to the European one. Therefore, the need to switch from the current electricity market model to an alternative one includes ensuring national interest in reliable electricity supply at reasonable prices and complying with EU *acquis communautaires* on electricity to benefit from the European market coupling.

The paper aims to provide a novel model for the Ukrainian electricity market that combines different trading forms and pricing methods in the same time segment. It also includes the decomposition of market products as they approach real-time delivery, multi-session trading, and the delegation of commercial balancing functions to regional levels.

Based on the parametric identification of European electricity market models, we answer the research question of whether adopting a single European electricity market model caused the unification of the national electricity markets in Europe. We seek to which extent the national markets remain differentiated and continue to develop according to the specifics of national energy policies and the requirements and restrictions of national electric power systems. On that ground, the model of the Ukrainian electricity market is developed.

The paper contributes to the literature by the justification of an organizational framework of a competitive electricity market model in Ukraine based on the European *acquis communautaires*, the advanced European practice, and the specifics of the Ukrainian electric power system. It is the first approach to developing such a contemporary model for the national electricity market in Ukraine. It allows filling the gap related to the country's current and preferred electricity model based on European experiences.

The rest of the paper is organized in as follows. Section 1 includes a literature review, which provides a theoretical background for determining key components of any electricity market model. Section 2 presents the general structure of the research. Section 3 presents the detailed results of the investigation. Subsection 3.1 defines the single electricity market model in the European space, 3.2 focuses on the parametric identification of national electricity market models in the European space, subsection 3.3 provides characteristics of the Ukrainian electric power system, and subsection 3.4 explains the deviations of the Ukrainian electricity market model from the single European one. Finally, 3.5 proposes an alternative electricity market model for Ukraine. The last section discusses and summarizes the main findings of this paper, providing policy recommendations.

2. Literature review

The opening up of the competitive electricity market aims to ensure consumers' free choice of producers and suppliers of electricity who will be able to satisfy their interests at the lowest purchasing cost (Cramton, 2017; Bublitz et al., 2019). There are two approaches to developing the competitive electricity market: centralized and decentralized. The main difference between them is the mechanisms for harmonizing the physical and commercial electricity flows (Matenli et al., 2016; Yin et al., 2019; Ahlqvist et al., 2022). Seven key determinants must be determined to design any electricity market model, including geographical delimitation, a dispatching method, market infrastructure, time scaling, trading forms, pricing methods, and product diversification (Fig. 1).

Consequently, the model of a competitive electricity market must be justified by its key determinants, which condition the efficiency of its functioning.

Thus, the following research question arises what key determinants should form the basis of the Ukrainian electricity market model to comply with the single European one and consider the peculiarities of the national electric power system?

3. Methodological approach

The study's theoretical background is the theory of sectoral markets (Peters et al., 2013; Pedersen and Ritter, 2022) and resource-energy cycles (Mensah and Castro, 2004; Shpilevsky and Lelyuk, 2011). The research is based on the parametric identification method, which implies finding such estimates of parameters of the model which provide the most closeness of the values at the output with the same input values (Ashby, 1957). The methodological approach is based on the following steps.

1. The European legislation was analyzed to define the input parameters of the single electricity market model.
2. For 25 EU countries (except Malta and Cyprus) and the UK, Norway, Switzerland, and Ukraine, the output parameters of the internal electricity market models of the European countries were defined using data from the ENTSO-E, the ACER, the Europex, and data from MO and TSO platforms. All data are available online and can be found on the official websites (see Appendix A).
3. We compared its trends with the European ones from 2001 to 2020, based on the Sankey diagram data analysis of the electricity flows from the Eurostat database, to provide a snapshot of the Ukrainian electric power system. The national trends in the EU member states have different depths. However, the general view on the entire European electric power system helps to understand the main pillars of their development without dipping into details of the national energy policies of individual EU member states and comparing the Ukrainian energy policy in the electric power sector with the general Union view.

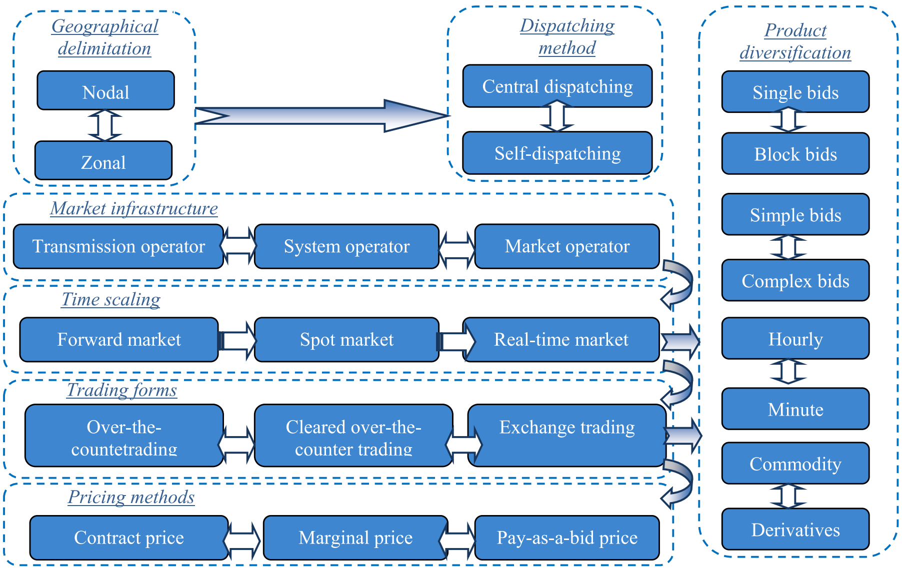

Fig. 1. Key determinants of designing an electricity market model.

1. Geographical delimitation is applied to determine the directions of free physical flows in the electric power system. There are two types of delimitation of local boundaries of an electric power system: nodal and zonal ones – the choice between which depends on the congestion management of transmission networks (Holmberg and Lazarczyk, 2012; Sarfati et al., 2019). However, in practice, there are bottlenecks in each electric power system, which led to the development of a combined type – so-called flow-based market coupling – comprising both (Felten et al., 2021).
2. Depending on the type of geographical delimitation, dispatch methods of electric power systems are selected. These methods include central dispatching and self-dispatching. The first method correlates with nodal delimitation, while the second has zonal delimitation (Barroso et al., 2005; Chao and Huntington, 2013; Sarfati et al., 2019; Ahlqvist et al., 2022).
3. Creating a competitive electricity market also implies introducing rules of its functioning, the observance of which is monitored by certain operators who are formally not involved in the purchasing-selling relationship, building the market infrastructure necessary for its normal functioning. Such operators are the market operator, system operator, and transmission operator. Several types of market infrastructure are distinguished. Among them, the following two types are primarily applied in competitive electricity markets: (i) the transmission system operator (TSO) and market operator (MO); (ii) the independent system operator and transmission operator (Pollitt, 2012; Chawla and Pollitt, 2013; Biancardi et al., 2021).
4. Supply and demand conditions and the traders' desire to hedge risks determine the electricity market timeframe. Different electricity market timeframes pursue other objectives of functioning: forward markets, spot markets, and real-time markets. In the forward markets (FM), financial and commodity trading are applied. The day-ahead market (DAM) and the intraday market (IDM) can coexist in the spot markets. While the balancing market (BM) operates in real-time and implies instant electricity delivery (Meeus, 2011; Cramton, 2017; Pollitt, 2021).
5. Electricity markets exist in different trading forms, based on bilateral over-the-counter trading (OTC), cleared over-the-counter trading (OTC clear), and power exchange (PX) trading; they may have different types (Bichpuriya and Soman, 2010; Meeus, 2011; Biskas et al., 2013; Shah and Chatterjee, 2020).
6. The main goal of developing a competitive electricity market is to establish fair electricity prices free from government regulation. Several pricing methods can meet these requirements using: bilateral contract prices, pay-as-a-bid prices, and marginal prices. The most advanced way is marginal pricing since it allows a single, fair, non-discriminatory price to be determined (El Khatib and Galiana, 2007; Pikk and Viiding, 2013; Akbari-Dibavar et al., 2020).
7. Another determinant is product diversification. Electricity is a homogeneous product of a strictly regulated quality and can be classified only from an economic point of view over time and delivery terms: (I) into single and block bids; (ii) by fulfillment conditions into simple and complex bids, (iii) by the unit of commercial product into 1 h, one-half hour, or one-quarter hour (Gajbhiye and Soman, 2009; Bichpuriya and Soman, 2010; Chen et al., 2021). Moreover, the desire of market participants to hedge the risks of electricity price volatility leads to emerging financial derivatives in the electricity markets, such as futures, options, and spreads (Deng and Oren, 2006; Aïd, 2015).

Source: *constructed by the authors based on the literature review.*

4. The national legislation of the country and its relevant experience were analyzed to determine the pros and cons of the Ukrainian electricity market.
5. Recommendations for reforming the Ukrainian electricity market were provided based on the best practices used in European electricity markets.

4. Research and results

4.1. Definition of a single electricity market model in the european space

Traditionally, it is believed that the European electricity market model is based on the decentralized approach, in which commercial and physical electricity flows are segregated (Pollit, 2019; Yin et al., 2019; Ahlqvist et al., 2022). For a long time, national electricity markets have evolved voluntarily through disseminating successful practices of individual countries in the European market space.

In 2011, Regulation, 2011 established the boundaries of the wholesale energy market for wholesale energy products (Art. 2, para. 6), which include supply contracts and electricity derivatives, regardless of where and how they are traded (Art. 2, para. 4). In fact, Regulation, 2011 recognizes that the wholesale electricity market can exist in two forms: commodity and financial. According to paragraph 9 of Article 2 of Directive, 2019)/944, electricity markets in the EU comprise OTC and PX markets at all timeframes, including forward, day-ahead, and intraday markets.

Regulation, 2013 establishes a zonal approach to the geographical delimitation of electric power systems. The bidding zone is the largest geographic area where market participants can exchange energy without capacity allocation (Art. 2, para. 3).

Regulation, 2015/1222 established the auction process based on the p marginal pricing for the DAM (Art. 2, para. 26 and 28) and continuous trading based on the pay-as-a-bid pricing for the IDM (Art. 2, para. 29 and 31). The importance of Regulation, 2015)/1222 is also in focusing on specifics of the creation and functioning of the market infrastructure for these time market segments, embodied in the nominated electricity market operators (NEMO). According to Article 4, one or more NEMOs are designated in each bidding zone among national and foreign entities. NEMOs are responsible for diversifying products, ensuring operational security (Art. 40 and Art. 53), and ensuring the anonymity of submitted orders in the DAM and IDM (Art. 47 and Art. 59). NEMOs, in cooperation with the TSOs, shall set, upon approval of the regulatory authorities, minimum and maximum prices.

Further, Regulation, 2016/1719 set out the principles of functioning of the forward market (FM). However, this EU Regulation lays down exclusively the rules on forwarding capacity allocation to ensure fair and transparent access of participants to the forward market segments of other countries. Transnational rules on the forms and mechanisms of forwarding trading, as well as methods of pricing in this timeframe segment, were not defined.

The trans-European regulatory framework for functioning the balancing market (BM) began to form only in 2017 and now includes Regulation, 2017a/2195 and Regulation 2017b/1485. The market-oriented mechanism of the BM comprises three components: balancing services, balancing responsibilities, and imbalance settlement. Regulation 2017a/2195 (Art. 30) determines that the BM uses a marginal pricing method for standard products. The main problem with the development of the BM is choosing a dispatch method. Regulation 2017b/2195 considers self-dispatch as a priority method. However, it also allows centralized dispatching within the integrated scheduling process.

These documents found further reflection in the Clean Energy Package, which contains reference norms for each. In addition, the Clean Energy package was complemented by the following norms:

a) Regulation, 2019/943 envisages: the joint responsibility of NEMOs and TSOs for management of DAMs and IDMs; bidding in the spot market segments as close to real-time as possible, at least up to the intraday cross-zonal gate closure; trade-in energy in time intervals, which shall be equal to imbalance settlement period (15 min); the minimum allowable bid sizes, which shall be 500 kW or less; the right of national regulatory authorities and market operators to choose forms and forward-trade electricity products for hedging financial risks; the possibility for TSOs in BMs to delegate commercial functions to MOs.
b) Directive, 2019/943 determines that the financial electricity market shall be traded under the rules specified in Directive, 2014)/65/EU.

Therefore, it can be established that after implementing the Clean Energy Package, the single European electricity market model acquired its final design (Fig. 2).

However, deviations from the single model are allowed: (i) state territory can be divided by TSOs, each of them is a monopolist on their control area; (ii) central dispatching can be applied; (iii) NEMOs can be set as a national legal monopoly; (iv) DAM and IDM rules are obligatory only for cross-border electricity trading, when other rules may exist for intrazonal trading; (v) derogations for specific products are allowed. These lead to a significant differentiation of the internal electricity market model in European countries.

4.2. Parametric identification of internal electricity market models in the european space

According to the key determinants considered in Section 2, the study of European countries' electricity market models made it possible to identify their features (Table 1) (see Table 2).

Most countries' state borders coincided with control areas and bidding zones. The exception for the control areas was the territory of Germany, which was divided between four TSOs, and the UK, where the territory of Northern Ireland was delimitated as a separate control area. Regarding bidding zones, the existing bottlenecks led to fragmentation: Italy was divided into six bidding zones, with two in Denmark, six in Norway, and four in Sweden. At the same time, Northern Ireland was integrated into the Single Electricity Market (SEM) with the Republic of Ireland. Developed transmission networks between Luxemburg and Germany allowed their integration into a single bidding zone. Therefore,

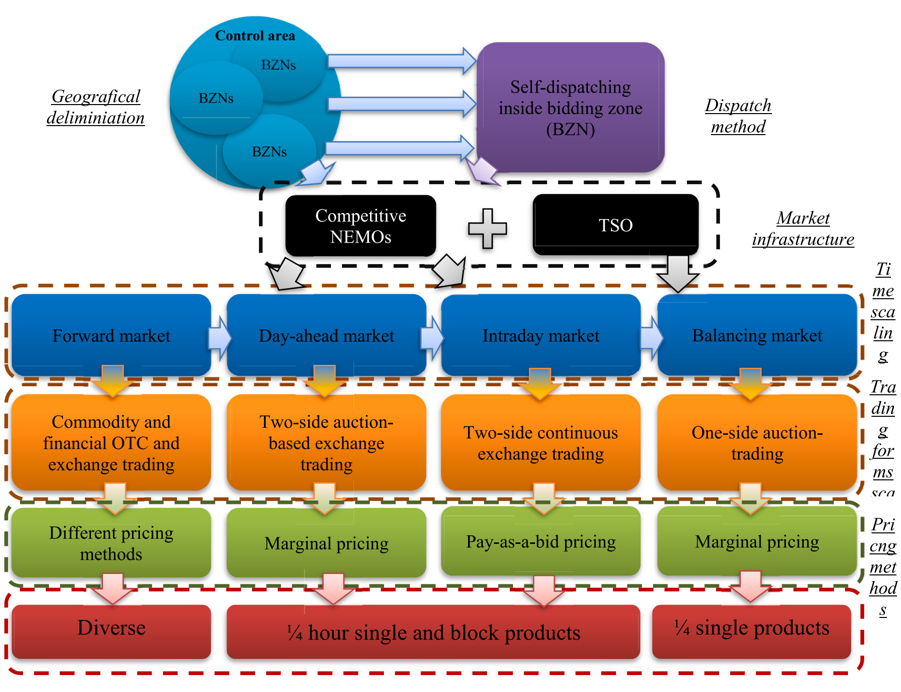

Fig. 2. The single European electricity market model. Note: BZN - bidding zone.
Source: *results obtained by the authors based on the analysis of European legislation.*

Table 1
Parametric identification of the internal electricity markets in the European space.

Country	Control areas	Bidding zones	FM trading forms	Nº of FM opera-tors	Nº of derivatives	Spot market infrastru-cture	Nº of DAM opera-tors	Time scaling of DAM products	DAM pricing	Nº of IDM opera-tors	Time scaling of IDM products	IDM pricing	BM opera-tors	BM pri-cing
DE LU	4 1	1	OTC, OTC cl., FPX	4	22	Comp.	2	h	MP	2	¼ h – h	MP&PaB	jointly by TSOs	Single
FR	1	1	OTC, OTC cl., FPX	3	10	Comp.	2 + 1(p)	h	MP	2	½ h – h	MP&PaB	TSO	Dual
ES	1	1	OTC, OTC cl., CPX, FPX	2	9	Mon.	1	h	MP	1	h	MP& PaB	TSO	Dual
PT	1	1	OTC, OTC cl., CPX, FPX	2	2	Mon.	1	h	MP	1	h	MP& PaB	TSO	Dual
IT	1	6	OTC, OTC cl., CPX, FPX	4	10	Mon.	1	h	weighted average MP	1	h	MP	TSO + DO	Dual
GB	1	1	OTC, FPX	2	3	Comp.	2	½ h – h	MP	1	h	MP	TSO + DO	Single
PL	1	1	CPX, FPX	2	2	Comp.	3	h	PaB&MP	3	h	PaB	TSO	Single
DK	1	2	OTC, OTC cl., FPX	3	8	Comp.	2 + 1(p)	h	MP	2	h	PaB	TSO	Dual
BE	1	1	OTC, OTC cl., FPX	2	7	Comp.	2	h	MP	2	¼ h – h	MP&PaB	TSO	Dual
NL	1	1	OTC, OTC cl., FPX	2	5	Comp.	2	h	MP	2	¼ h – h	MP&PaB	TSO	Dual
FI	1	1	OTC, OTC cl., FPX	3	8	Comp.	2	h	MP	2	½ h – h	PaB	TSO + DO	Single
SE	1	4	OTC, OTC cl., FPX	3	8	Comp.	2	h	MP	2	H	PaB	TSO + DO	Single
NO	1	5	OTC, OTC cl., FPX	3	8	Comp.	2	h	MP	2	H	PaB	TSO + DO	Single
SL	1	1	OTC, OTC cl., CPX, FPX	2	2	Comp.	1	h	MP	1	¼ h – h	MP& PaB	DO	Dual
SK	1	1	OTC, FPX	1	2	Mon.	1	h	MP	1	H	PaB	TSO + DO	Dual
BG	1	1	OTC, CPX	1	0	Mon.	1	h	MP	1	h	PaB	TSO	Dual
HU	1	1	OTC, CPX	2	8	Mon.	1	h	MP	1	h	PaB	TSO	Dual
HR	1	1	OTC	0	0	Comp.	1	h	MP	1	h	PaB	TSO + DO	Single
RO	1	1	OTC, CPX, FPX	2	1	Mon.	1	h	MP	1	h	PaB	TSO	Dual
CZ	1	1	OTC, FPX	1	2	Mon.	1	h	MP&PaB	1	h	PaB	TSO + DO	Dual
AT	1	1	OTC, OTC cl., FPX	1	5	Comp.	3	¼ h, h	MP	2	¼ h, h	MP&PaB	TSO + DO	Single
IE + NIE	2	1	FPX	1	1	Comp.	1	h	MP	1	½ h	MP& PaB	TSO + DO	Differen-tiated
GR	1	1	OTC, CPX	1	2	Mon.	1	h	MP	1	h	PaB	TSO	Single
LT	1	1	OTC	0	0	Comp.	1 + 1(p)	h	MP	1 + 1(p)	h	PaB	TSO	Dual
LV	1	1	OTC	0	0	Comp.	1 + 1(p)	h	MP	1 + 1(p)	h	PaB	TSO	regulated
EE	1	1	OTC	0	0	Comp.	1 + 1(p)	h	MP	1 + 1(p)	h	PaB	TSO	
CH	1	1	OTC, FPX	1	1	Comp.	1	h	MP	1	h	MP&PaB	TSO	Dual
UA	1	1	OTC, CPX	1	0	Mon.	1	h	MP	1	h	PaB	TSO	Dual

Abbreviations: OTC (over-the-counter trading), OTC cl. (OTC cleared), CPX (commodity power exchange), FPX (financial power exchange), Comp.(competitive, Mon. – monopoly, MP (marginal pricing), PaB (pay-as-a-bid, h (hour), DO (delegated operator), (p) (planned).
Source: results collected by the authors based on the monitoring websites of European authorities, TSOs, NEMOs, and energy exchanges.

Table 2
Trends in the development of the electric power system in Ukraine vs. Europe, in 2001–2020.

Indicator	Ukraine				EU-27			
	2001	2011	2016	2020	2001	2011	2016	2020
Final electricity consumption, TWh	122	152	130	119	2356	2571	2565	2462
Electricity consumption per capita, MWh/capita	2.5	3.3	3.1	2.9	5.5	5.8	5.8	5.5
CAGR of final electricity consumption, %		2.2	0.4	−0.1		0.9	0.6	0.2
Household share in electricity consumption, %	18	25	28	31	27	27	28	29
Public share in electricity consumption, %	14	16	16	18	24	28	29	28
Industrial share in electricity consumption, %	46	41	38	38	41	37	36	36
Network losses, TWh	34.1	21.3	16.6	16.4	186.3	182.1	180	174.4
Network losses share from available electricity, %	21.0	11.8	10.9	11.7	6.6	5.9	5.7	5.7
Net electricity generation, TWh	160	180	152	137	2588	2789	2784	2664
CAGR of net electricity generation, %		1.2	−0.3	−0.8		0.8	0.5	0.2
HHI index of electricity generation by resources	3148	3232	3466	3302	1851	1618	1556	1518
RES share in electricity generation, %	7.0	5.7	6.6	11.7	17.6	23.5	31.5	39.8
OFF share in electricity generation, %	49.3	48.1	44.7	37.4	48.8	46.7	41.2	34.7
CHP share in electricity generation, %	11.3	9.7	9.6	11.1	18.5	22.9	22.1	21.9
Efficiency of electricity-only generation[a], %	40.6	38.3	38.8	40.6	40.4	42.8	45.5	49.6
Efficiency of combined heat and power generation[b], %	72.1	66.4	62.8	61.6	61.4	60.9	61.7	62.9
Generation capacities, GW	50.7	51.5	53.4	52.8	587	732	799	946
CAGR of generation capacities, %		0.2	0.1	0.1		2.2	1.5	1.2
Share of intermittent RES in total capacities, %	0.2	0.4	1.5	11.6	2.9	19.3	28.8	33.3
Share of flexible capacities in total capacities, %	10.1	10.7	11.6	11.7	26.9	22.3	20.9	18.5
Capacity utilization factor, %	45.6	43.2	34.9	32.0	41.5	36.2	31.8	25.1
Import of electricity, TWh	2.1	0	0.1	2.7	252	321	363	381
Import dependency by electricity, %	1.7	0	0	2.3	10.7	12.5	14.1	15.5
Export of electricity, TWh	5.2	6.3	3.8	5.1	256	320	363	367
Export dependency by electricity, %	3.3	3.5	2.5	3.7	9.9	11.5	13	13.8
GHG emissions by electricity generation, Mt CO2 eq.	128	131	101	80	1154	1079	944	656
CAGR of GHG emissions by electricity, %		0.2	−1.6	−2.4		−0.7	−1.3	−2.9
CO2 intensity of electricity generation, kg/MWh	802	729	665	561	446	387	389	246

Notes: CAGR - the compound annual growth rate, calculated relative to 2001; CHP - the combined heat and power plant; HHI - the Herfindahl-Hirschman index.
[a] Accounting for electricity generated by only power plants.
[b] Accounting for electricity and heat generated by combined heat and power plants.
Source: calculated by the authors based on the Eurostat database (https://ec.europa.eu/eurostat/data/database, accessed Aug 10, 2022).

all European countries support a zonal approach to geographic delimitation and self-dispatching. The minor exceptions are countries of Central Western European (Germany with Luxemburg, France, the Netherlands, and Belgium), which introduced a zonal approach using the FBMC method, and Switzerland, where combined dispatching was introduced.

The market infrastructure in all European countries is built according to a common type, which implies a distinction between TSOs and NEMOs. In the 29 European countries, there are 33 TSOs (one in each country, except for Germany, which is divided between four transmission.

System operators, and the UK, with two TSOs), and there are 16 NEMOs. Some of the NEMOs function as natural monopolies (such as GTE, HUPX, OMIE, and OKTE), while the activities of others cover the territory of several countries (such as Nordpool and Epex Spot). Seven of the existing NEMOs are directly or indirectly owned by TSOs, five are private-owned, and five are state-owned.

Initially, NEMOs were created as operators of DAMs and IDMs, and most of them currently operate in both segments (except for EXAA). However, some of them have expanded the list of their operating segments. They have implemented trading platforms for the forward market: 1 – financial power exchange (HUPX), 3 – commodity power exchange (IBEX, TGE, GME), and 3 – cleared OTC platform (Borzen, HUPX, GME). In addition, there are separate operators of the futures electricity market in the European space (such as EEX, Nasdaq, and OMIP). Depending on the liquidity of national electricity markets, the number of financial instruments implemented also differs, with the German market having the most at 22. The most popular financial product is power futures traded. Moreover, in seven national electricity markets, the corresponding TSOs delegated their functions of operating BM to other market operators.

European countries are almost unified in selecting the trading forms in spot electricity markets. These segments function in an organized manner as two-sided platforms. All DAMs have introduced auction-based trading on marginal pricing. Still, some of them (Poland and the Czech Republic) also have continuous trading matching based on pay-as-a-bid pricing to account for the peculiarities of the national electric power systems. The European IDMs do not have such a well-established position by the priority trading form. Despite the rules of Regulation, 2015)/1222 on their organization with the continuous trading matching algorithm, nowadays, ten countries combine auction-based and continuous intraday trading.

As for the organization of the forward market, there is no priority trading form in the European space. On the contrary, the least liquid forward electricity markets (Latvia, Lithuania, Estonia, and Croatia) operate exclusively based on OTC trading. The same forward electricity markets combine all four forms (OTC, OTC cleared, commodity, and financial PX), but as competition develops, commodity trading loses its importance and is replaced by financial trading. An exception to this trend is the Polish TGE, which has introduced exclusively organized commodity trading in the forward market and proven its efficiency.

BMs in all European countries operate on an organized basis in the form of one-sided auction platforms, where buyers of bids for loading and unloading are national TSOs.

Pricing methods in European electricity markets correspond to the trading forms. The OTC market uses contract prices, while the forward and futures markets – pay-as-a-bid prices. On the spot segments, depending on the trading algorithm, marginal or pay-as-a-bid pricing is applied, and, on the balancing segment, marginal pricing is used. Notable is the Italian DAM, which operates by applying a weighted marginal pricing method for all six bidding zones.

As for product diversification in the markets, it is generally accepted to trade single and block contracts in units from an hour to a quarter of an hour. Such products exist on DAMs of all countries; however, for the

German, British and Swiss markets, half-hour products have already been introduced, and, for the Austrian market, the EXAA introduced quarter-hour products. IDMs are characterized by broader diversification. As in the case of DAMs, the portfolio is dominated by hourly contracts, which are still traded on all European IDMs. However, eight countries have already implemented fewer size contracts. In general, Europe is still far from the desired goal of reducing the size of the products of spot market segments to the level of the imbalance settlement period.

Consequently, the external design of European countries' electricity market models complies with the single model, whereas their internal design significantly differs. Each European country takes a balanced approach to choosing the key determinants of the internal electricity market model. It can be stated that, in the European space, the DAM models are the most stable, while the IDM models only tend to be so, and at the same time, the forward and balancing markets are still highly differentiated.

The parametric identification and analysis of internal electricity market models in European countries made it possible to form its advanced design (Fig. 2). It is fully consistent with the single European electricity market model, as it does not violate the unified rules of cross-border trading but also considers the specifics of national electric power systems.

Compared to the single European electricity market model, more advanced market models are different in the following ways: (1) decoupling the huge control area onto the several bidding zones; (2) delegating commercial functions for managing the BM to the third party; (3) excluding untransparent bids and developed exchange trading in the FM; (4) combining different pricing methods in the DAM and IDM; (5) ensuring single pricing in the BM.

Notwithstanding the abovementioned modifications, the priority method of electricity dispatching remains the same, self-dispatching of commercial electricity flows, which guarantees a decentralization approach for market participants.

4.3. Overview of the Ukrainian electric power system

The Ukrainian electric power system developed in stark contrast to the European ones, as can be confirmed by numerous trends in electricity consumption, generation, and trading (Tbl 2).

Electricity consumption trends in Ukraine differ from those in the EU. Firstly, electricity consumption per capita was among the lowest in the European space: 2.9 MWh/capita against the EU's 5.5 MWh/capita average. Secondly, the compound annual growth rate (CAGR) of electricity consumption was more extreme in Ukraine. In 2001, the lowest electricity consumption level was fixed since 1991 and till 2020. From 2002 to 2011, electricity consumption increased due to social and economic activity recovery. In 2011, it reached its highest level since the beginning of the XXI century. However, the occupation of some Ukrainian territories in 2014 and losses of its economic potential have led to the reassessment of electricity market volumes and, consequently, to a descending trend in electricity consumption. From 2017 to 2019, the Ukrainian electricity market reached approximately a flat level of 120 TWh, and during the first year of the Covid-19 pandemic, electricity consumption declined by less than 1 TWh compared to 2019. Thirdly, the restructuring of the Ukrainian economy led to shifts in electricity consumption patterns: the total share of the household and public sector in electricity consumption exceeded the percentage of the industrial one in 2011. All these causes have reshaped demand in the Ukrainian electricity market.

Electricity generation had modest CAGRs in the EU and descending trends in Ukraine since 2011. Nevertheless, a sharp decrease in electricity generation in Ukraine was due to decreased electricity consumption and a reduction in network losses, especially in transmission lines. During the last two decades, they have decreased by more than twice; however, they are still significant compared to the EU ones in relative terms. The reason for modest trends in the EU electricity generation was diametrically opposed. It should be explained by broadening the electricity market borders among EU member states, which the import and export dependency levels can prove on electricity in the EU. At the same time, the Ukrainian electricity market remains isolated. Insignificant cross-border electricity flows occurred after reforming the electricity market in 2019, but still, they have been insufficient for integration into the European space due to the lack of interconnector capacities.

Ukraine and the EU also differ in the power generation mix. There are no two identical electric power sectors in the EU, which leads to a low resource concentration of the Union by the HHI index, and the deployment of renewable energy sources (RES) leads to its descending trend. Although different generation units represent the Ukrainian electric power sector, nuclear and coal-fired generation are dominant types, causing its high resource concentration measured by the Herfindahl-Hirschman index (HHI index). The deployment of intermittent RES-generation, especially solar, in Ukraine manifests itself as a "green-coal" paradox, which leads to an ascending trend of the HHI index. Hydropower and hard coal-fired thermal units are used to balance the electric power system. It is common practice to limit the utilization of nuclear power capacities but not use them as flexible units. All this causes disproportions of supply in the Ukrainian electricity market.

The EU energy policy has led to the booming growth of the power generation fleet over the past 20 years. However, over the last ten years, there has been a slowdown in CAGRs. A high share of flexible capacities initially ensured the deployment of renewable-based generation in the EU, and further integration of the electricity markets of the EU member states has made it possible to restrain their CAGRs. Starting from 2016, the share of intermittent RES generation capacities exceeds that of flexible ones. On the other hand, Ukraine has low CAGRs of generation capacities, which are formed under the successful development of intermittent RES capacities and the decommissioning of the old thermal power and CHP units. At the same time, the development of intermittent RES capacities was not supported by the development of flexible capacities. Ukraine's only highly flexible power generation capacity remains from hydropower. In 2020, the share of intermittent RES generation capacities about equaled the share of flexible ones. At the same time, there is a significant decrease in capacity utilization in the EU and Ukraine, which causes payback risks for power generation units under volatile market conditions.

The present state of the electric power sector is determined by the energy efficiency of transforming resources into useful energy. There is a gradual increase in the energy efficiency in the EU electricity sector due to: (1) a continuous rise in the share of intermittent RES, which is an inexhaustible energy source, and therefore, their energy efficiency is considered to be equal to 100%; (2) the introduction of combined generation cycles, such as combined heat and power, and combined gas and steam turbine generation; (3) the improvement to the physical characteristics of resources, energy carriers, and power unit materials. It became possible to reverse the general trend of falling energy efficiency only by increasing the share of intermittent RES generation and partly by transforming thermal power units into supercritical technology. Instead, reverse trends are taking place in Ukraine. The physical obsolescence of conventional power units leads to a constant decrease in energy efficiency. At the same time, the share of cogeneration in the electric power sector of Ukraine is constantly decreasing, both due to the physical obsolescence of CHP plants and changes in the generation proportion between electricity and heat due to a drop in demand for district heating. All these tendencies of energy efficiency negatively affect electricity buyers in Ukraine, who are forced to pay a higher price.

The EU has already made considerable efforts to decarbonize the electricity sector. Over the past two decades, greenhouse gas emissions have decreased by 43% in absolute terms and by 55% in relative terms. It happened against only a 3% increase in electricity generation. At the same time, greenhouse gas emissions in Ukraine decreased by 37% in absolute terms and by 30% in relative terms, and this happened against a 14% drop in electricity generation. However, currently, this factor does not affect the Ukrainian electricity market, as there is no emissions allowance market.

Therefore, the status of the electric power system in Ukraine is considered the main challenge for implementing a competitive electricity market model based on the European approach. It is necessary to ensure consistent coordination of physical and commercial electricity according to the national interests resolving the following issues:

1) Growing unevenness of consumption load and the inability of market participants to manage electricity demand of household and public consumers.
2) Securing internal consumers from market manipulations and allowing external participants to trade in the Ukrainian electricity market.
3) Distinguishing the value of electricity by time and periods of delivery.
4) Integrating RES-based electricity generation in a market-responsible way and allocating it efficiently among suppliers.
5) Ensuring a permanent balance between commercial and physical electricity flows in real time.

4.4. *Specific features of the Ukrainian electricity market model*

As a member of the Energy Community, Ukraine has committed itself to implement the European model of a competitive electricity market. In this regard, the Law of Ukraine "On the Electricity Market" (2017) was entered into force on July 01, 2019. Hence, the national model is still far from the single electricity model.

First, a four-segment model of organizing the electricity market was adopted. It implies splitting it into four segments: bilateral contract market (BCM), day-ahead market (DAM), intraday market (IDM), and balancing market (BM) – the features of each of them have determined the specifics of the national model (Resolution, 2018a, 2018b).

The BCM is defined as the forward segment, which presents OTC trading, where its members, based on closed agreements, define the scope and price of electricity purchase and sale and are only obliged to inform the national TSO of the agreed contracted volumes (Law of Ukraine, 2017; Resolution, 2018a). The implementation of the regulations led to the fragmentation of the BCM into several sub-segments (Resolution, 2018a, 2019a, 2019b):

- OTC trading, where prices remain the subject of closed agreements.
- Commodity power exchange trading, where the Ukrainian Energy Exchange (UEEX) holds electronic auctions.
- A special session in which state-owned enterprises with special obligations sell electricity to an SE Guaranteed Buyer to meet public needs.

The OTC trading and commodity power exchange trading are based on free pay-as-a-bid pricing, while a special session – is on the government-regulated pricing.

To organize spot electricity markets, SE Market Operator was established. The DAM operates based on an auction-based approach, applying marginal pricing, while the IDM trades are based on continuously trading, using pay-as-a-bid pricing. Both segments deal with only single hourly products, while trading in block products was restricted during the Covid-19 pandemic. However, the DAM and IDM function under strict price caps, the lower price cap being ≈87 €/MWh and the top price cap being ≈133 €/MWh for peak hours; and ≈43 €/MWh and ≈67 €/MWh, respectively, for off-peak hours (Law of Ukraine, 2017; Resolution, 2018b). This situation leads to significant market restrictions and manipulations.

In the BM, the TSO purchases quarter-hour contracts for balancing energy, setting the price using the marginal pricing method based on an optimization function to minimize balancing costs. BM price caps are set as a percentage of the DAM price and range from 55% to 115% for the respective settlement period. The BM operates based on self-dispatching. Participation in the BM is mandatory for all balancing service providers, which operate generating units, and shall be to the extent of all residual capacity available, regardless of the sale of any type of reserve (Law of Ukraine, 2017; Resolution, 2018a).

Initially, the territory of Ukraine was defined as a single control area divided into two bidding zones. Still, since February 24, 2022, a single integrated bidding zone has been functional in the whole control area of Ukraine.

In November 2021, the Energy Community estimated the overall progress in the implementation status of the European model of the electricity market in Ukraine at the level of 51%, incl. regarding the formation of a competitive wholesale electricity market at the level of 60%, which, however, is 3% lower than in 2020. The main issues that undermine the development of competition at the wholesale level were identified. They are (i) many and frequent regulatory interventions; (ii) rigorous restrictive price caps and regulated prices of state-owned generation companies; (iii) restrictions on certain market players for trading and special bilateral auctions for some consumers; (iv) non-compliant public service obligations and the absence of defining vulnerability criteria; (v) high debts in the balancing market; (vi) absence transposition of REMIT (Energy Community, 2021).

In addition to the conclusions of the Energy Community, we may note that the lack of deep understanding of the key determinants of the competitive electricity market in Ukraine has led to the distortion of the European model: (i) there is confusion between timeframes and trading forms; (ii) opportunities for organizing a forward financial market are not envisaged; (iii) status of private PXs remain uncertain; (iv) state-owned companies were withheld from the competitive market; (v) price caps pose significant risks of electricity price manipulation. Thus, it is reasonable to call the current model of Ukraine's electricity market a quasi-competitive one since it is far from the single European model, has crucial imperfections and restricts competition (Fig. 4).

4.5. *Alternative model of the Ukrainian electricity market*

In order to amend the quasi-competitive model of the Ukrainian electricity market to make it consistent with the European one, it is necessary to consider the requirements of trans-European legislation, the specifics of the national electric power system, and the successful practices of the European electricity markets. By analogy with Poland, it is proposed that the Ukrainian electricity market will operate exclusively on an exchange basis (excluding closed bilateral contracts). The alternative model of the Ukrainian electricity market is shown in Fig. 5 (see Fig. 6)

The forward electricity market in Ukraine can function as a financial power exchange, where power futures are traded. Its objective should be to ensure transparent and efficient trading in the long term through an effective combination of organized financial and commercial trading on an exchange basis. Power futures must be backed by physical capacity (generation capacity or transmission capacity rights); they can be converted into forward contracts, cascaded for shorter periods, or required financial settlement. To date, European exchanges, such as EEX and Epexspot, have a similar practice, the former trades in power futures, while the latter provides a trading platform for their execution on the DAM. The forward market should be based on the pay-as-a-bid pricing and futures settled by clearing the DAM auction's baseload/peak-load prices. Depending on the validity period, dividing power futures into annual, quarterly, monthly, weekly, and daily ones is advisable.

Although the DAM in Ukraine was formed according to the European model, such a model carries significant risks for Ukrainian consumers. A considerable part of the generation mix is accounted for by old coal-fired thermal power plants, resulting in a high electricity price, low flexibility of the electric power system, and significant emissions into the atmosphere. As a result of marginal pricing, the Ukrainian consumer cannot receive economic benefits from the consumption of cheap low-carbon electricity (nuclear and hydroelectricity) but is forced to pay for all electricity at the price of expensive and dirty thermal generation. This problem can be solved using the best practices of Poland and the Czech Republic, where continuous and auction-based trading is continuously conducted on the DAMs. It is proposed to introduce the functioning of the DAM in Ukraine in two sessions.

- In the first session (DAM1), the Ukrainian electricity generators offer the necessary and sufficient volumes to cover public interests at pay-as-a-bid prices. Continuous trading on the DAM is proposed to be carried out with daily block products (base, peak, and off-peak load).
- The second session (DAM2) is based on an auction with marginal pricing, where single and block hourly products are traded among both internal and external market participants.

The IDM in Ukraine is focused on the residual volumes of electricity declared and non-accepted in the previous market segments. In addition, the Ukrainian electric power system is experiencing a rapid development of intermittent renewable generation, especially solar. Green electricity is sold to the guaranteed buyer who seeks to earn as much as possible by selling it in different market segments, while renewable generators do not participate in the trading, and their responsibility for the imbalances is restricted. Combining green electricity auctions and grey electricity continuous trading on the IDM is proposed to overcome these shortcomings. Participants of IDM auctions are all green electricity generators, which sell their intraday forecasted volumes, while buyers are obliged to buy the required volumes based on pre-set quotas. A similar practice of separating green and grey auctions, but for the DAM, exists in Austria, while Belgium, Norway, Poland, Romania, and Sweden have introduced trade quotas (so-called green certificates). In Ukraine, green IDM auctions can be carried out in 6 sessions, each lasting 4 h, 4 h before physical delivery and 4 h after delivery. It will allow establishing full financial responsibility of green electricity generators for forecasting accuracy. IDM continuous trading, which closes an hour before the physical delivery, will still be carried out at the pay-as-a-bid pricing for all market participants. On the IDM, half-an-hour products should be traded.

The control area of the UA-IPS was initially designed as part of 8 regional electric power systems, which have their power generation complex and different power consumption profiles and are interconnected by transmission links. Delegating commercial functions of operating the balancing market from the central dispatch center to regional ones, which can manage the platform of the balancing market jointly, is proposed to consider the system requirements and restrictions of each regional electric power system. The same experience can be found in Germany, where four TSOs jointly manage the Regelleistung platform.

Given the low flexibility of the Ukrainian electric power system, it is advisable to carry out pre-dispatching by opening an additional market segment - the balancing capacity market. Regulation 2017/2195 confirms such a possibility, and the Italian operator GME confirms the feasibility of its operation. The balancing capacity market functions as one-side auctions with marginal pricing, which are held in the form of 6 sessions: each lasting 2 h, 2 h before delivery, and for the delivery period of 4 h. For each delivery period, the regional operator conducts two auctions for the upward and downward balancing capacity. The winners of such auctions are guaranteed to receive income per balancing capacity, regardless of whether this capacity is activated/deactivated or not. For the nominated balancing capacity provider, the operator can give dispatching upward and downward command without waiting for the IDM gate closure, thereby implementing early dispatching of balancing energy. The balancing energy of the balancing capacity provider, who has been given a dispatching command, is paid at the price of the balancing energy market.

In the balancing energy market, each provider, nominated for loading by the results of the FM, DAM, and IDM, shall submit a step-by-step upward and downward function for each operational period (every 15 min). The operators make decisions and provide dispatch commands to the necessary participants to quickly balance the regional electric power systems tracking transmission bottlenecks and system reliability criteria. Settlements for balancing energy and electricity imbalances are made based on the indicative price of DAM auctions with the discounted/compounded rate to prevent price manipulations in the balancing energy market. A similar practice is currently used in Belgium.

In order to illustrate the need to change the electricity market model, it is necessary to consider how electricity prices will vary with changes in pricing methods and trading forms. The results of the sensitivity analysis for the next 12 months for the forward market and the next 31 days for other markets are presented in Fig. 3.

The power futures prices will be slightly higher than the prices of forward bilateral contracts, but this will guarantee the commercial attractiveness of the first ones. The marginal prices of public services are projected to be significantly lower than the forward prices of state-owned companies. The last one leads to the adjusted marginal price of the DAM auctions, which would be higher than the current one but less volatile. Whereas marginal “green” energy prices will be highly volatile and, in many cases, higher than the guaranteed buyer forward price, which would encourage green energy transition and reduce the burden on the TSO to cover feed-in tariffs/green premiums.

These show that the current model is sensitive to pricing methods. Therefore, implementing an alternative electricity market model in Ukraine will allow preserving the necessary features of the European model, developing competition among all participants, and considering the peculiarities of the national electric power system.

The proposed alternative electricity market model has significant advantages compared to the existing one. They are:

1) Focus on trading as close as possible to real-time: multi-session trading and decomposing market products as they approach real-time.
2) The introduction of exclusively exchange trading in the forward market ensures transparency of transactions and protection against credit risks, and its financial form simplifies the physical planning of electricity flows.
3) Price restrictions in the spot segments of the market are removed due to the combination of different pricing methods.
4) Providers of public interests independently determine the forecast load volume, purchase it at individual DAM sessions, and are responsible for imbalances in the BM. Continuous trading and pay-as-a-bid pricing in the DAM allow them to cover public interests at lower than marginal prices.
5) The artificially created market participant (SE Guaranteed Buyer) is liquidated. Electricity producers with RES independently sell the generated volumes exclusively in the IDM, determining the forecasted generation schedule and bearing financial responsibility for imbalances in the BM. The use of the marginal method of pricing at “green” IDM auctions ensures the efficiency of electricity generation from RES. The tariff on RES development is separated from the transmission tariff, and all suppliers’ payments for renewable-based electricity are proportionally distributed.
6) The commercial functions of the BM are delegated to regional electric power systems, and early balancing is carried out by purchasing the physically necessary balancing capacities before the IDM gate closure, and they can be activated in advance. Balancing energy is priced based on the indicative price of DAM auctions, so market participants are no longer interested in manipulating.

5. Conclusions and policy implications

The analysis confirms our hypothesis by providing the following answers to the questions posed. A single European electricity market

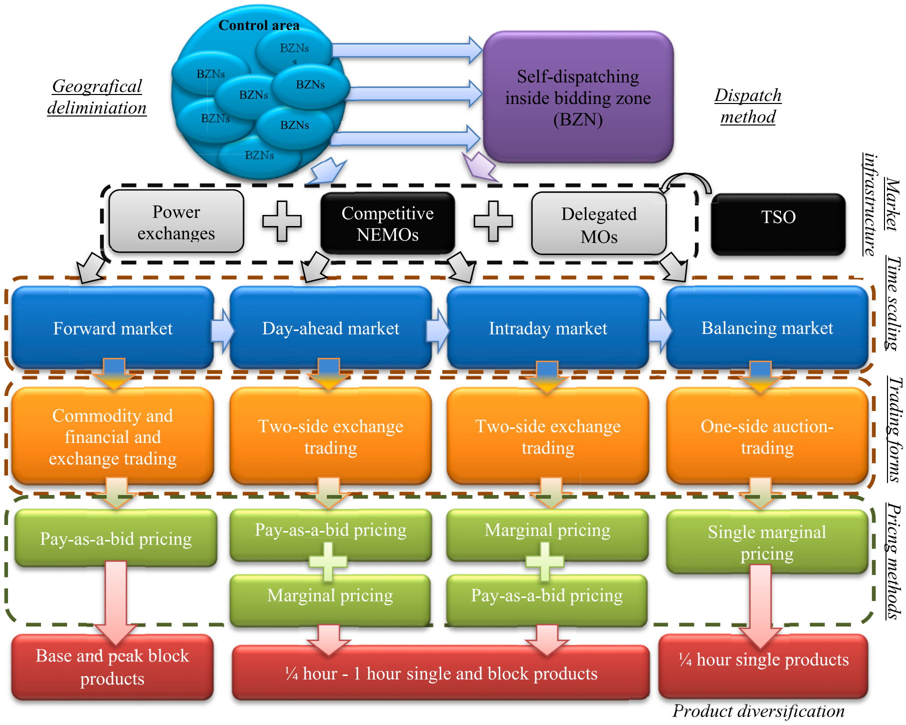

Fig. 3. The advanced European electricity market model.
Source: *constructed by the authors based on the experience of the European countries.*

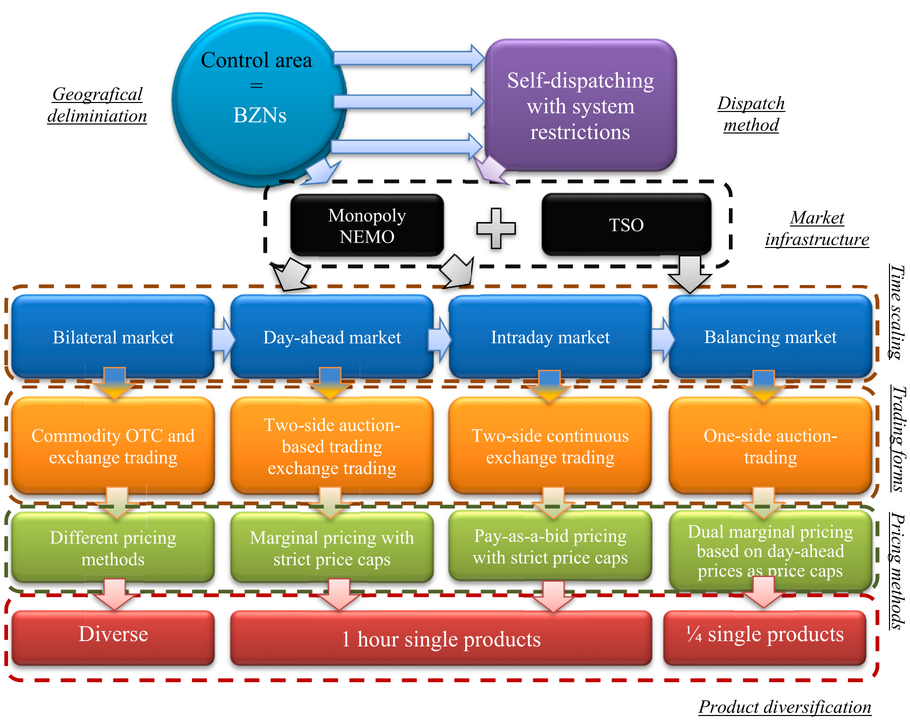

Fig. 4. The Ukrainian electricity market model.
Source: *results obtained by the authors based on the analysis of Ukrainian legislation.*

model was finally defined with the adoption of the Clean Energy Package, which officially consolidated the decentralized approach to its structure, a zonal type of geographic delimitation, a self-dispatching method, a market-oriented type of infrastructure, a four-segment timeframe, priority trading forms, pricing methods, and the degree of product diversification. European electricity markets have a consistent external design but remain internally differentiated. Some variations have peculiarities of geographic delimitation into control areas and bidding zones as well as the organization of the market infrastructure. Still, the main differences in their models are associated with choosing

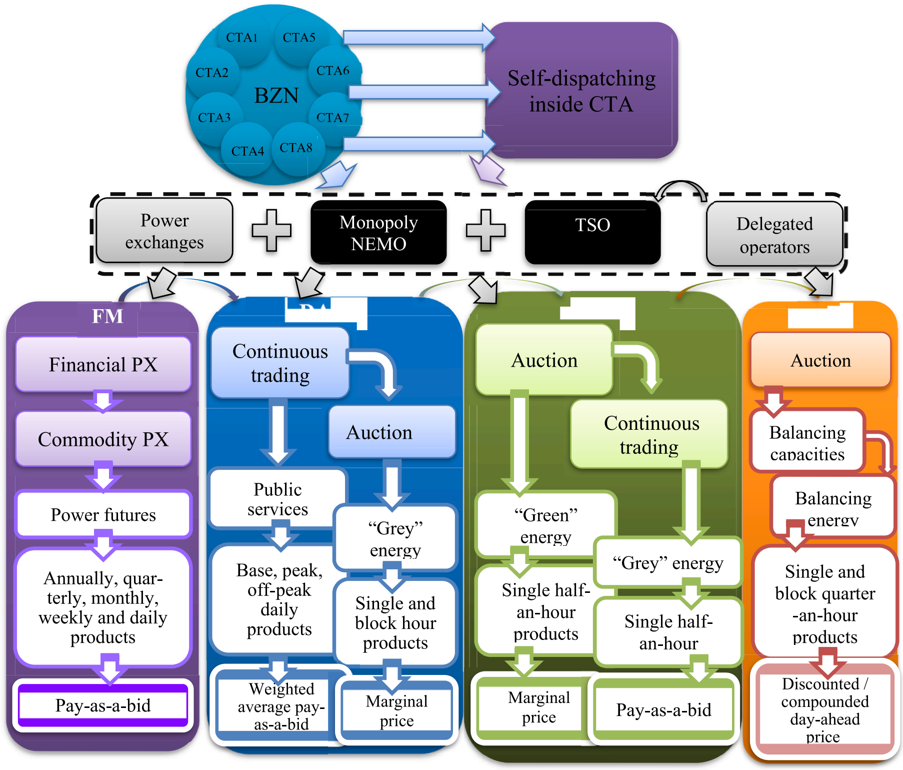

Fig. 5. An alternative electricity market model for Ukraine.
Note: CTA – control area
Source: *proposed by the authors*.

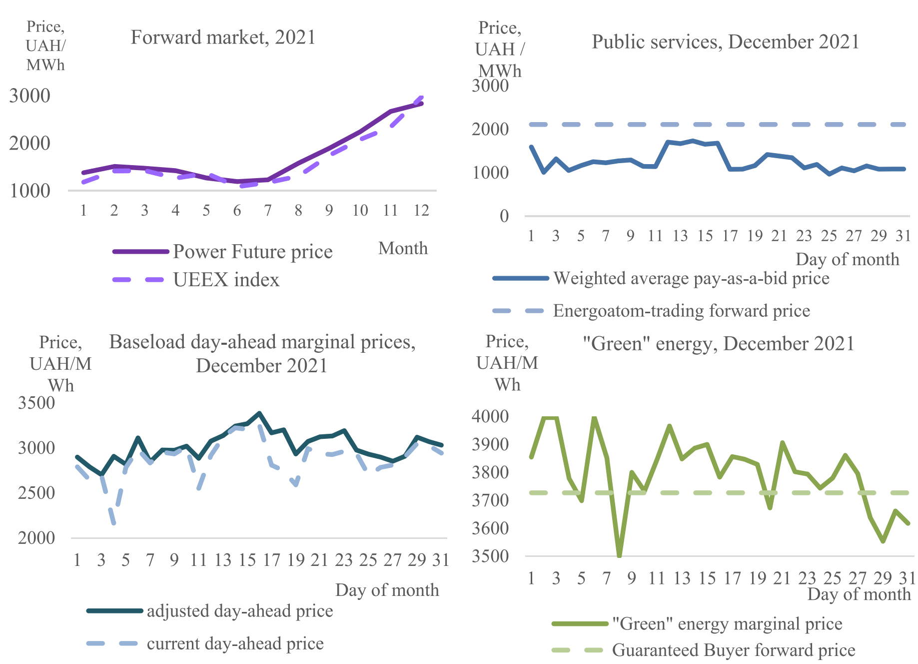

Fig. 6. Actual and adjusted electricity prices in different market segments in the current and alternative electricity market model
Source: *Calculated by the authors based on the OREE* (https://www.oree.com.ua/, accessed Aug 10, 2022) *and UEEX* (https://www.ueex.com.ua/, accessed Aug 10, 2022) *results*.

different trading forms and pricing methods. The most differentiated are forward markets, while DAMs operate mainly according to a single algorithm and differ only in terms of product diversification. The IDM combines continuous trading using pay-as-a-bid pricing and auctions using marginal pricing. In the BMs, the delegation of commercial functions to other market operators is developing, and a transition to single pricing is taking place. The most liquid electricity markets in the European space have highly developed organized trading forms.

Ukraine has implemented the European electricity market model, trying to meet the requirements for its external design. The model implies zonal geographic delimitation, self-dispatching, monopoly market infrastructure, and a four-segment timeframe, in which there is one unorganized market segment, BCM, and three organized ones (DAM, IDM, and BM). However, the current model of the Ukrainian electricity market should be recognized as quasi-competitive due to stringent government regulations and price cap restrictions, the choice of ineffective trading forms in different time segments, and the withholding of a significant amount of electricity to meet the public interest. The above indicates the need for changing the Ukrainian electricity market model.

A novel model of the Ukrainian electricity market proposed in the study considers the requirements of the trans-European legislation, the peculiarities of the national electric power system, and the advanced practices of electricity markets in European countries. It is based on exclusive exchange trading, double-sessional trading at marginal and pay-as-a-bid prices, and time scaling of market products when approaching the physical delivery time. It allows the current barriers of sensitiveness of the pricing method to be overcome.

The reported results allow providing the following recommendations that could be used while reforming the national electricity market:

- To define the legal status of power exchanges and establish the rules for trading in financial derivatives and commodities in the forward electricity market.
- To divide the spot segments of the electricity market (DAM and IDM) into sessions to identify their different pricing methods and the degree of product diversification.
- To separate electricity of public interest and renewable-based electricity as particular products in the electricity market.
- To establish the rules and delegate commercial functions of managing balancing markets to regional transmission operators.
- To recognize the balancing capacity market as a separate segment of the balancing market.

Further research will be related to integrating the Ukrainian electricity markets into ENTSO-E to facilitate cross-border commercial electricity flows in different market segments through the partnership of power exchanges and market operators. In addition, they will be related to the decentralization of the electricity market to foster the introduction of distributed low-carbon generation in a market-responsible way without compromising the reliability of the electric power system. Both issues are also related to strengthening the national security of Ukraine under Russia's military invasion.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Olha Ilyash reports financial support provided by Nicolaus Copernicus University in Torun.

Data availability

Data will be made available on request.

Acknowledgements

Olha Ilyash reports financial support form 'Grant for start' provided by Nicolaus Copernicus University in Torun.

Appendix A

Lists of web sources for providing parametric identification of the internal electricity markets.

Table A.1
European authorities and organizations

Name	Abbr.	Website
European Network of Transmission System Operators for Electricity	ENTSO-E	https://www.entsoe.eu/
Agency for the Cooperation of Energy Regulators	ACER	https://www.acer.europa.eu/
Association of European Energy Exchanges	Europex	https://www.europex.org/

Table A.2
Lists of Transmission System Operators in Europe

Country	TSOs	Country	TSOs
AT	Austrian Power Grid AG –www.apg.at	HU	MAVIR – https://www.mavir.hu/
	http://www.vuen.at/Vorarlberger Übertragungsnetz GmbH -	IE	EirGrid plc –www.eirgrid.com
BE	Elia System Operator SA -https://www.elia.be/	IT	Terna –https://www.terna.it/it
BG	Electroenergien Sistemen Operator EAD –https://www.eso.bg/	LT	Litgrid AB – https://www.litgrid.eu/
CH	Swissgrid ag –https://www.swissgrid.ch/	LU	Creos S.A. –www.creos-net.lu/
CZ	ČEPS a.s. –https://www.ceps.cz/	LV	AS Augstsprieguma tīkls -https://www.ast.lv/en
DE	https://www.transnetbw.de/TransnetBW GmbH –	NI	System Operator for Northern Ireland Ltd -https://www.soni.ltd.uk/
	https://www.tennet.eu/TenneT TSO GmbH –	NL	http://www.tennet.org/TenneT TSO B.V. –
	Amprion GmbH –https://www.amprion.net/	NO	Statnett SF –https://www.statnett.no/en/
	50 Hz Transmission GmbH – https://www.50hertz.com/	PL	Polskie Sieci Elektroenergetyczne S.A. – https://www.pse.pl/
DK	https://en.energinet.dk/Energinet –https://en.energinet.dk/	PT	Rede Eléctrica Nacional, S.A. -https://www.ren.pt/
EE	Elering AS –https://elering.ee/	RO	C.N. Transelectrica S.A. –https://www.transelectrica.ro/
ES	Red Eléctrica de España S.A. –https://www.ree.es/	SE	Svenska Kraftnät – https://www.svk.se/
FI	Fingrid Oyj –https://www.fingrid.fi/	SI	ELES, d.o.o. -https://www.eles.si/
FR	Réseau de Transport d'Electricité –https://www.rte-france.com/	SK	Slovenská elektrizačná prenosová sústava, a.s. –https://www.sepsas.sk/en/
GR	Independent Power Transmission Operator SA –www.admie.gr	GB	NGET – https://www.nationalgrid.com/
HR	HOPS d.o.o. –https://www.hops.hr/	UA	Ukrenergo – https://ua.energy/

Table A.3
Lists of nominated electricity market operators in Europe

PX	Segments: Countries	PX	Segments: Countries
Epex Spot – https://www.epexspot.com/	DAM and IDM: AT, BE, CH, DE-LU, DK, FI, FR, NL, NO, PL, SE	Nord Pool – https://www.nordpool/group.com/	DAM and IDM: AT, BE, EE, LT, LV, DE-LU, DK, FI, FR, NL, NO, PL, SE
EXAA – https://www.exaa.at/	DAM: AT, DE	IBEX – https://ibex.bg/	CPX, DAM, IDM: BG
CROPEX – https://www.cropex.hr/	DAM and IDM: HR	OTE – https://www.ote-cr.cz/	DAM, IDM, BM: CZ
HEnEx – https://www.enexgroup.gr/	DAM and IDM: GR	HUPX - https://hupx.hu/	DAM and IDM: HU
GME – https://www.mercatoelettrico.org/	OTC cl., CPX, DAM, IDM, BM: IT	SEMO - https://www.sem-o.com/	FPX, DAM, IDM, BM: IE + NI
TGE – https://tge.pl/	CPX, DAM, IDM: PL	OPCOM - https://www.opcom.ro/	CPX, DAM, IDM: RO
OMIE – https://www.omie.es/	DAM, IDM: ES, PT	Borzen - https://www.borzen.si	OTC cl., DAM, IDM, BM: SL
OKTE – https://www.okte.sk/	DAM, IDM, BM: SK	OREE – https://www.oree.com.ua/	DAM, IDM: UA

References

Ahlqvist, V., Holmberg, P., Tangerås, T., 2022. A survey comparing centralized and decentralized electricity markets. Energy Strategy Rev. 40, 100812.

Aïd, R., 2015. Electricity Derivatives. Springer International Publishing, Cham.

Akbari-Dibavar, A., Mohammadi-Ivatloo, B., Zare, K., 2020. Electricity market pricing: uniform pricing vs. pay-as-bid pricing. In: Electricity Markets. Springer, Cham, pp. 19–35.

Alberto, A., Ardagna, S., Nicoletti, G., Schiantarelli, F., 2005. Regulation and investment. J. Eur. Econ. Assoc. 3 (4), 791–825.

Ashby, W.R., 1957. Introduction to Cybernetics. Chapman & Hall Ltd, London.

Barroso, L.A., Cavalcanti, T.H., Giesbertz, P., Purchala, K., 2005. Classification of electricity market models worldwide. In: Paper Presented at the International Symposium CIGRE/IEEE PES, 2005, pp. 9–16. New Orleans, LA, USA.

Baumol, W.J., 1977. On the Proper Cost Tests for Natural Monopoly in a Multiproduct Industry, vol. 67. The American Economic Review, pp. 809–822, 5.

Biancardi, A., Di Castelnuovo, M., Staffell, I., 2021. A framework to evaluate how European Transmission System Operators approach innovation. Energy Pol. 158, 112555.

Bichler, M., Buhl, H.U., Knörr, J., Maldonado, F., Schott, P., Waldherr, S., Weibelzahl, M., 2022. Electricity markets in a time of change: a call to arms for business research. Schmalenbach Journal of Business Research 1–26.

Bichpuriya, Y.K., Soman, S.A., 2010. Electricity power exchanges: a review. In: Paper Presented at the 16th National Power Systems Conference. Osmania University, Hyderabad, India, pp. 115–120.

Biskas, P.N., Chatzigiannis, D.I., Bakirtzis, A.G., 2013. European electricity market integration with mixed market designs—Part I: Formulation. IEEE Trans. Power Syst. 29 (1), 458–465.

Blazquez, J., Fuentes, R., Manzanoc, B., 2020. On some economic principles of the energy transition. Energy Pol. 147 (C), 111807.

Bublitz, A., Keles, D., Zimmermann, F., Fraunholz, C., Fichtner, W., 2019. A survey on electricity market design: insights from theory and real-world implementations of capacity remuneration mechanisms. Energy Econ. 80, 1059–1078.

Chao, H.P., Huntington, H.G. (Eds.), 2013. Designing Competitive Electricity Markets, vol. 13. Springer Science & Business Media.

Chawla, M., Pollitt, M.G., 2013. Global trends in electricity transmission system operation: where does the future lie? Electr. J. 26 (5), 65–71.

Chen, Q., Balian, A., Kyzym, M., Salashenko, T., Gryshova, I., Khaustova, V., 2021. Electricity markets instability: causes of price dispersion. Sustainability 13 (22), 12343.

Cramton, P., 2017. Electricity market design. Oxf. Rev. Econ. Pol. 33 (4), 589–612.

Deng, S.J., Oren, S.S., 2006. Electricity derivatives and risk management. Energy 31 (6–7), 940–953.

Directive, 2014. No. 2014/65/εC of the European parliament and of the council of nov 15, 2014, on markets in financial instruments and amending directive 2002/92/EC and directive 2011/61/EU. Retrieved May 10, 2022, from. https://eur-lex.europa.eu/.

Directive, 2019. No. 2019/944 of the European Parliament and of the Council of Dec 5, 2019, on common rules for the internal market for electricity and amending Directive 2012/27/EU. Retrieved May 10, 2022, from. https://eur-lex.europa.eu/.

El Khatib, S., Galiana, F.D., 2007. Negotiating bilateral contracts in electricity markets. IEEE Trans. Power Syst. 22 (2), 553–562.

Entso-E, 2021. Options for the Design of European Electricity Markets in 2030: Discussion Paper for Stakeholder Consultation.

European Commission, 2019. Clean energy for all Europeans packages. Retrieved May 15, 2022, from. https://ec.europa.eu/.

Felten, B., Osinski, P., Felling, T., Weber, C., 2021. The flow-based market coupling domain-Why we can't get it right. Util. Pol. 70, 101136.

Gajbhiye, R., Soman, S.A., 2009. New bid structures for power exchange with modelling in ILP framework. In: Paper Presented at the 6th International Conference on the European Energy Market, pp. 27–29. Leuven, Belgium.

Hattori, T., Tsutsui, M., 2004. Economic Impact of Regulatory Reforms in the Electricity Supply Industry: a Panel Data Analysis for OECD Countries, vol. 32. *Energy Policy*, pp. 823–832, 6.

Holmberg, P., Lazarczyk, E., 2012. Congestion Management in Electricity Networks: Nodal, Zonal and Discriminatory Pricing. Faculty of Economics, University of Cambridge.

Ilyash, O., Dzhadan, I., Ostasz, G., 2018. The influence of the industry's innovation activities indices on the industrial products' revenue of Ukraine. Economics and Sociology 11 (4), 317–331. https://doi.org/10.14254/2071-789X.2018/11-4/21.

International Energy Agency, 2020a. Electricity Market Report - December 2020. IEA, Paris. Retrieved Aug 15, 2022, from. https://www.iea.org/reports/electricity-market-report-december-2020.

International Energy Agency, 2020b. Ukraine Energy Profile. IEA, Paris. Retrieved Aug 15, 2022, from. https://www.iea.org/reports/ukraine-energy-profile.

International Energy Agency, 2021. World Energy Outlook. OECD/IEA, Paris. https://doi.org/10.1787/20725302.

Jamasb, T., Pollitt, M., 2005. Electricity market reform in the European Union: a review of progress toward liberalization & integration. Energy J. 26, 11–41.

Khan, A.M., Kwiatkowski, J., Osińska, M., Błażejowski, M., 2021. Factors of renewable energy consumption in the European countries—the bayesian averaging classical estimates approach. Energies 14 (22), 7526. https://doi.org/10.3390/en14227526.

Kyzym, M., Gryshova, I., Lisin, E., 2019. Leading Trends in the Development of the Electric Power Industry. In: Paper Presented at the International Conference on Social, Economic, and Academic Leadership (ICSEAL-6-2019). Prague, Czech Republic.

Law of Ukraine, 2013. "On the Principles of Functioning of the Electricity Market in Ukraine" No. 663-VII from 10.24.2013. Retrieved Aug 15, 2022, from. https://zakon.rada.gov.ua/.

Law of Ukraine, 2017. "On the Electricity Market" No. 2019-VIII from 13.04.2017. Retrieved May 10, 2022, from. https://zakon.rada.gov.ua/.

Matenli, A., Abbaspourtorbati, F., Cherkaoui, R., Mende, F., Luongo, L., 2016. Centralized and decentralized electricity markets: assessment of operational and economic aspects. In: Paper Presented at the 2016 13th International Conference on the European Energy Market (EEM). Porto, Portugal.

Meeus, L., 2011. Why (and how) to regulate power exchanges in the EU market integration context? Energy Pol. 39 (3), 1470–1475.

Mensah, A.M., Castro, L.C., 2004. Sustainable Resource Use & Sustainable Development: a Contradiction? Center for Development Research, University of Bonn: Bonn, Germany.

Newbery, D., Strbac, G., Viehoff, I., 2016. The benefits of integrating European electricity markets. Energy Pol. 94, 253–263.

Pedersen, C.L., Ritter, T., 2022. Updating the theory of industrial marketing: industrial marketing as a Bayesian process of belief-updating. Ind. Market. Manag. 102, 403–420.

Peng, D., Poudineh, R., 2017. Electricity Market Design for a Decarbonized Future: an Integrated Approach. Oxford Institute for Energy Studies, Oxford.

Peters, L.D., Pressey, A.D., Vanharanta, M., Johnston, W.J., 2013. Theoretical developments in industrial marketing management: multidisciplinary perspectives. Ind. Market. Manag. 42 (3), 275–282.

Pikk, P., Viiding, M., 2013. The dangers of marginal cost based electricity pricing. Baltic J. Econ. 13 (1), 49–62.

Pollitt, M.G., 2012. Lessons from the history of independent system operators in the energy sector. Energy Pol. 47, 32–48.

Pollitt, M.G., 2019. The European single market in electricity: an economic assessment. Rev. Ind. Organ. 55 (1), 63–87.

Pollitt, M.G., 2021. The future design of the electricity market. In: Handbook on Electricity Markets. Edward Elgar Publishing, pp. 428–442.

Regulation, 2011. No. 1227/2011 of the European Parliament and of the Council of Oct 25 2011 on Wholesale Energy Market Integrity and Transparency. Retrieved May 10, 2022, from. https://eur-lex.europa.eu/.

Regulation, 2013. No. 543/2013 of Dec 14 2013 on submission and publication of data in electricity markets and amending Annex I to Regulation (EC) No 714/2009 of the European Parliament and of the Council. Retrieved May 10, 2022, from. https://eur-lex.europa.eu/.

Regulation, 2015. No. 2015/1222 of Jul 24 2015 Establishing a Guideline on Capacity Allocation and Congestion Management. Retrieved May 10, 2022, from. https://eur-lex.europa.eu/.

Regulation, 2016. No. 2016/1719 of Sept 26, 2016, establishing a guideline on forward capacity allocation. Retrieved May 10, 2022, from. https://eur-lex.europa.eu/.
Regulation, 2017a. No. 2017/2195 of Nov 23, 2017, establishing a guideline on electricity balancing. Retrieved May 10, 2022, from. https://eur-lex.europa.eu/.
Regulation, 2017b. No. 2017/1485 of Aug 2, 2017, establishing a guideline on electricity transmission system operation. Retrieved May 10, 2022, from. https://eur-lex.europa.eu/.
Regulation, 2019. No. 2019/943 of the European Parliament and of the Council of Dec 5 2019 on the internal market for electricity. Retrieved May 10, 2022, from. https://eur-lex.europa.eu/.
Resolution, 2002. Of the Cabinet of Ministers of Ukraine "On Approval of the Concept of Functioning and Development of the Wholesale Electricity Market of Ukraine" No. 1789 from 12.11.2002. Retrieved Aug 15, 2022, from. https://zakon.rada.gov.ua/.
Resolution, 2018a. Of the National Energy and Utilities Regulatory Commission of Ukraine "On Approval of Market Rules" from 14.03.2018 No. 307. Retrieved May 10, 2022, from. https://zakon.rada.gov.ua/.
Resolution, 2018b. Of the National Energy and Utilities Regulatory Commission of Ukraine "On Approval of the Day-Ahead Market and the Intraday Market Rules" from 14.03.2018 No. 308. Retrieved May 10, 2022, from. https://zakon.rada.gov.ua/.
Resolution, 2019a. Of the Cabinet of Ministers of Ukraine "On Approval of the Procedure for Conducting Electronic Auctions for the Sale of Electricity under Bilateral Agreements and the Procedure for Selecting the Organizers of Electronic Auctions for the Sale of Electricity under Bilateral Agreements" from 05.06.2019 No. 499. Retrieved May 10, 2022, from. https://zakon.rada.gov.ua/.
Resolution, 2019b. Of the Cabinet of Ministers of Ukraine "On Approval of the Regulations on the Imposition of Special Obligations on Participants in the Electricity Market to Ensure the Public Interest in the Functioning of the Electricity Market" Form 05.06.2019 No. 483. Verkhovna Rada of Ukraine. Retrieved May 10, 2022, from. https://zakon.rada.gov.ua/.
Sarfati, M., Hesamzadeh, M.R., Holmberg, P., 2019. Production efficiency of nodal and zonal pricing in imperfectly competitive electricity markets. Energy Strategy Rev. 24, 193–206.
Shah, D., Chatterjee, S., 2020. A comprehensive review on day-ahead electricity market and important features of world's major electric power exchanges. International Transactions on Electrical Energy Systems 30 (7), e12360.
Shpilevsky, V.V., Lelyuk, O.V., 2011. The sphere of energy consumption and power cycle of Ukraine: analytical aspect. Probl. Econ. 4, 44–54.
Silvester, V.K., Ortmann, A., 2008. The unbundling regime for electricity utilities in the EU: a case of legislative and regulatory capture? Energy Econ. 30 (6), 3128–3140.
Steiner, F., 2001. Regulation, industry structure, and performance in the electricity supply industry. OECD Econ. Stud. 32, 143–182.
Wang, D., Gryshova, I., Balian, A., Kyzym, M., Salashenko, T., Khaustova, V., Davidyuk, O., 2022. Assessment of power system sustainability and compromises between the development goals. Sustainability 14, 2236.
Williams, J.H., Ghanadan, R., 2006. Electricity reform in developing and transition countries: a reappraisal. Energy 31 (6–7), 815–844.
Yin, S., Wang, J., Qiu, F., 2019. Decentralized electricity market with transactive energy–a path forward. Electr. J. 32 (4), 7–13.