Development of electric power systems based on the use of intelligent technologies

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Abstract. The development of retail electricity markets was specific in different countries. There is an important condition for further development of an electric power system with active consumers and prosumers’ participation and the integration of renewable energy sources (RES), other innovative technologies and smart solutions. This study is aimed at observation of tracks of development and of retail electricity market characteristics in some countries through introducing a uniform framework for comparison. The results can help both experts and authorities to better understand the tasks and the conditions for the processes of energy transition.

1. Introduction
Recent changes in the global power energy sector have been mostly shaped by the transformation of the global economy, energy policy in the developed countries and technological advances in electricity-related technologies. The previously unavailable technologies to the actors of the sector are digital power electronics; technologies for bulk data storage (cheaper drives), its processing (networks and network equipment with higher bandwidth) and security (blockchain algorithms). There are also technologies for real-time demand-response; tools for multivariate modelling of power systems and their components; technologies for automation of commercial relationships in the market (including smart contracts) [1].

These advances, in their turn, re-shape the organizational basis of the industry through changes in the structure of stakeholders (emergence of prosumers and demand aggregators, dissemination of demand response practices and various complementary services) and nature of their collaboration. Alongside with above-mentioned new participants of the market, nowadays there is a constellation of new-entrants, providing various complementary services. These are digital data operators (who process the data, collected from smart metering devices, installed within the system and allow revealing consumption patterns and optimizing the whole system); providers of forecasting and prognostic services, etc. [2–5].

The described above changes lead to the situation when traditional electric utility market models, despite being considerably reliable and verified, are no longer able to fulfill all the requirements of the participants and to cope with the dynamic environment. This, in turn, brings to the necessity of elaboration of a new model, enabling to take into account mentioned changes, provide value to the actors involved, and stay sustainable in the long-run way.
Meanwhile, such changes require a corresponding external environment, which would allow actors of the power sector to adapt to these trends. This environment should be flexible and incorporate a certain degree of competitiveness. Therefore, it could create adequate stimuli for the participants to invest in new technologies and re-shape their business models. We suggest a uniform framework for the comparison of different models of retail electricity market that would allow for a meaningful analysis of the experience of different countries.

2. Methodology and approach
The practical implementation of the described models varies from country to country. This paper will pay particular attention to the retail markets of the following countries: USA, China, Singapore, Germany, and Russia, which represent both transition and developed economies. The choice was determined by the availability and by cohesiveness of information provided in open sources.

It is worth mentioning that the analysis of each case will start with the retrospective timeline of institutional and industrial changes of the power sector, as they are essential for understanding the backbone of the model applied at a certain country.

This paper has the following structure:
- literature review of theoretical electricity retail models, applied at the moment;
- tracks of retail electricity markets development provided;
- characteristics of retail markets in different countries to be studied: a mechanism of price regulation at the retail market; a level of concentration within the generation segment; a market share of power supply companies; a degree of value chain integration; a choice of power supply company for consumers.

3. Major models for retail electricity markets
For a substantial period of time most of the electricity markets were vertically integrated, when all the elements of the value chain (starting with generation and up to the electric power supply) were controlled by a single firm (often state-owned). Gradual democratization and globalization processes were followed by the implementation of competitive elements into the existing retail market mechanisms, including the changes in the participants and cooperation between market agents.

Conducted analysis of open data on the topic of electricity market liberalization [6–9] allowed one to outline three major models of retail electricity market differentiated by the level of liberalization: Monopoly, Single buyer, Competition in retail.

Each of the models incorporates a unique market structure and channels for the participation of the members. Positive and negative sides of the described models are provided in the following tables (Table 1-3).

| Table 1. Advantages and disadvantages of the monopoly model for the electricity retail market |
|----------------------------------|----------------------------------|
| **Advantages**                    | **Disadvantages**                |
| Greater control of regulators over the whole system | Lack of choice for end-consumers (high dependence on the power supply company functioning in the area) |
| Ability to implement various state policies (absence of resistance) | Lack of incentives for vertically-integrated companies to modernize and increase their efficiency |
| Simplicity | Possible state interventions in pricing mechanism |
| Greater coordination on the side of supply | All price risks on the side of consumers |
### Table 2. Advantages and disadvantages of the single buyer model

| Advantages                                                                 | Disadvantages                                                                                           |
|----------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------|
| • Competition among generation companies (incentives for modernization and optimization) | • Artificial long-term price-setting (long-term contracts may inadequately cover arising additional costs of energy suppliers) |
| • Price averaging through long-term contracts                               | • Absence of supplier choice for end-consumers                                                          |
| • Regulated tariffs (determined in long-term contracts), providing sufficient investments into capacity | • All price risks on the side of consumers                                                              |

### Table 3. Advantages and disadvantages of the competition in the retail model

| Advantages                                                                 | Disadvantages                                                                                           |
|----------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------|
| • Competitive pricing (based on the supply-demand equilibrium in dynamics)  | • Necessity for complicated structural and legal transformations for implementation of the model         |
| • Choice of supply conditions for end-consumers                            | • Necessity for complex infrastructural support of the system                                            |
| • Possibility for creation of the deregulated market (competition based)    | • Complication of the metering system                                                                    |

Described models of the retail electricity market are the most common in modern practice. They vary by the level of market liberalization and availability of the choice for consumers. More centralized ones are easier to control and manage, while liberalized models are more flexible and efficient in a stable institution and macroeconomic situation. Nevertheless, it is an open question on which model to choose that will be adjustable and stable under the condition of energy transition and global transformation. However, the choice of the model rests upon certain factors – both of institutional and industrial nature. These factors will be studied in detail in the following sections of the paper.

### 4. Comparative analysis of retail electricity markets in different countries

Thorough study of the models in every chosen country will be done in this section of the paper. Country tracks of retail electricity markets development and characteristics of retail markets will be observed.

#### 4.1. USA

The development of the USA retail electricity market represents a transition from the local competitive microsystem in the early years to creation of large monopoly and after to a partial competition. Nowadays the market functions in the form of a partially competitive one, as just over 20 states have adopted this model [10] (Figure 1). It is worth mentioning that the specificity of the USA energy sector is determined by the tight bonds between electricity and gas markets, most of which is still exposed to high levels of state intervention.

Power companies are regulated both at the federal and state levels. FERC (Federal Energy Regulatory Commission) is responsible for retail electricity market and interstate transmission, while state commissions are governing the state level market – distribution and sales segments in particular. And one more important fact is that in integrated states (where power companies are vertically integrated) transmission tariff and sales premium are calculated by state commissions basing on the economic rules. At the same time, in deregulated states (where generation is competitive, and sales premium is market-determined) transmission and distribution tariffs are regulated by state commissions [11, 12].
Figure 1. Transformation of the USA retail electricity market (Source: Authors’ summary of [10]).

In such manner, by nowadays the USA has adopted two models of the major retail electricity market—centralized market (in two forms) and bilateral contracts (Table 4).

Table 4. USA retail electricity markets [13, 14].

| Centralized Market | Bilateral Contracts (3) |
|--------------------|-------------------------|
| **Mechanism of consumers’ price calculation** | **Retail choice (2)** | **Contract** |
| State-regulated ("costs plus" basis) | Generation tariff is market-determined and transmission tariff is regulated | Determined (either bundle or customized proposition) |
| **Concentration in generation**<sup>c</sup> | 5 major generating companies occupy 22% of the market |  |
| **Number of power supply companies**<sup>c</sup> | 5 major power supply companies occupy 56% of the market |  |
| **Value chain integration** | VIC Generation Transmission Distribution + Sales | VIC |
| **Consumers’ choice of power supply company** | No | Yes |
| **Model** | **Monopoly** | **Competition** | **Monopoly** |
| AR*, CA, IA*, CT, DE, IL, MA, MD, ME*, AK, AL, AZ, CO, FL, IN, KS, KY*, MI, NH, NJ, NY, OH, OR, PA, GA, HI, ID, MS, NC, NV, LA*, MN, MO, RI, TX | AR*, CA, IA*, CT, DE, IL, MA, MD, ME*, AK, AL, AZ, CO, FL, IN, KS, KY*, MI, NH, NJ, NY, OH, OR, PA, GA, HI, ID, MS, NC, NV, LA*, MN, MO, RI, TX | AR*, CA, IA*, CT, DE, IL, MA, MD, ME*, AK, AL, AZ, CO, FL, IN, KS, KY*, MI, NH, NJ, NY, OH, OR, PA, GA, HI, ID, MS, NC, NV, LA*, MN, MO, RI, TX | SC, TN, UT, WA, WY |
| **Implemented in** | MT*, NE*, NM*, OK, SD*, VA, VT, WI, WV |  |
| **Market share of the model**<sup>b</sup> | 32% | 41% | 27% |

<sup>a</sup>: VIC – Vertically integrated company.
<sup>b</sup>: market share is calculated basing on the number of consumers living in the mentioned states.
<sup>c</sup>: CR<sub>i</sub> – concentration ratio of generating companies with the biggest market share;
<sup>*</sup>: these states use a hybrid model.
Within the *monopoly* model VICs use “cost plus” pricing, which is criticized by many experts (not only from the power sector) \([15]\) as this mechanism may lead to overinvestments and creates not enough stimuli for increasing efficiency. The *competition* model, on the other hand, provides consumers with the ability to choose the supplier and tariff plan and to develop other active strategies, including demand response, becoming prosumers, implementing energy effective solutions, etc.

Independent power supply companies determine their own competitive rates for production and services, but network tariffs are still regulated by the government. This model was implemented as a reaction to the strongly regulated electricity prices (compared to the relative costs level) in certain states. A lot of consumers find this model to be rather attractive as competitive prices are usually lower compared to those at the regulated markets. However, critics of this model stress the fact that a lot of generators do not consider households as an attractive segment (due to its relatively small share in consumption) and are rarely involved into competition due to a low level of the profit margin \([14]\). Fast developing new sectors (innovative energy ecosystem, intellectual integrated energy systems, prosumers’ generation, energy storage, smart microgrid, etc.) change and complicate the retail electricity market structure, strategies of participants and rules.

### 4.2. China

China activity for developing of power sector was extensive and ambitious in last thirty years and the country catches up the other leaders except for the competitive retail market model. Starting from the 1980-s key processes of the changes there was decentralization and deregulation with the shift away from a state-regulated vertically-integrated monopoly and creation of a competitive market \([16, 17, 18]\) (Figure 2). However, these shifts are still in progress.

![Figure 2. Transformation of the Chinese retail electricity market \([16–21]\)](image)

The retail sector of the Chinese electricity market is not competitive at the moment (state owned enterprises still supply over 80% of the electricity) and consumers have no choice other than purchasing it from local power supply companies (Table 5).
Table 5. The model of the Chinese retail electricity market [19, 21, 22].

| Mechanism of consumers’ price calculation | Long-term (20 years) contract for power supply company |
|------------------------------------------|------------------------------------------------------|
| Concentration in generation\(^a\) | 5 major generating companies occupy 100% of the market \(\text{CR}_i = 1.00\) |
| Number of power supply companies | 5 (affiliated with generators) + 300 local (function nominally) MS:~20\% |
| Value chain integration | Generation + Transmission + Distribution + Sales |
| Consumers’ choice of power supply company | No |
| Model | Single buyer |

\(^a\): CR\(_i\) – concentration ratio of \(i\) generating companies with the biggest market share

However, market transformation is ongoing at the moment and fast development of RES, smart city projects and other innovative sectors in energy support it. In 2016 the National Commission of Development and Reforms (2015a) published the document, which implicates further development of a competitive retail market: shift from direct supplies to competition and implementation of the “Internet of Energy” concept [23].

4.3. Singapore

The creation of a competitive retail electricity market model in Singapore was executed in a rather abrupt time period, caused by massive foreign investment attraction, which required a corresponding infrastructure. For the period between 1995 and 2003 the country was able to shift from regulated monopoly to a competition in retail (Figure 3).

Figure 3. Transformation of the Singapore retail electricity market [24, 25].

Note: PUC – Public Utilities Committee

At the moment, the market model can be described as a partial competition, when only a certain part of the consumers has choice of a supplier (Table 6).

However, even under the following conditions a considerable share of consumers has a choice of a power supplier, what, coupled with the openness of the government, makes the whole system more flexible and attractive for doing business.
### Table 6. Singapore retail electricity markets models [25]

| Mechanism of consumers’ price calculation | When power supply companies are market participants (1) | When power supply companies are not market participants (2) |
|------------------------------------------|------------------------------------------------------|-----------------------------------------------------------|
| **Mechanism of consumers’ price calculation** | Competitive (price auction) | State regulation |
| **Concentration in generation** | 5 major generating companies occupy 78% of the market | |
| **CR<sub>5</sub>** | CR<sub>5</sub> = .78 | |
| **Number of power supply companies** | 26 | |
| **MS<sub>i</sub>** | MS<sub>i</sub>=3.8% | |
| **Value chain integration** | Zero (all activities are decoupled) | |
| **Consumers’ choice of power supply company** | Yes (for accepted): Via power supply company; Directly on the wholesale market (requires registration); Via SP | No |
| **Model** | **Competition** | **Single buyer** |
| **Market share of the model** | 70% | 30% |

<sup>a</sup>: “accepted” are the companies with the monthly average consumption over 2,000 kWh (or bill over $400). They have an ability to decline the standard power supply and choose the supplier (data of the Energy Market Authority).

<sup>b</sup>: market share is calculated basing on the volume of consumption, generated by the mentioned segment of the consumers: market and non-market participants [26].

<sup>c</sup>: CR<sub>i</sub> – concentration ratio of <i>i</i> generating companies with the biggest market share

### 4.4. Germany

The pre-reform power sector of Germany was different from all other European countries – a state monopoly on the major activities was absent per se. The market included companies with various forms of ownership – both state and private, while vertically integrated structures prevailed. Due to this, the liberalization of the market was executed via two stages. First National Power Law established a competitive model, which in practice was not viable due to a lack of essential legislative bodies. That is why later development can be described as a parallel liberalization of all value chain elements and creation of fully functional competitive market model by 2011.

![Figure 4](image-url)  
**Figure 4.** Transformation of the Germany retail electricity market [27–29].
Currently, the retail market is functioning within the competitive model with non-concentrated ownership of the assets and end-consumers have an ability to choose a power supply company (Table 7).

Table 7. Germany retail electricity market model [30]

| Mechanism of consumers’ price calculation | Price auction |
|-------------------------------------------|--------------|
| Concentration in generation*              | 5 major generators occupy 45% of the market CR₅ = .49 |
| Number of power supply companies          | Around 900 |
|                                           | MSᵣ~1%      |
| Value chain integration                   | Generation + Distribution + Sales |
|                                          | Transmission |
| Consumers’ choice of power supply company | Yes          |

The current market includes a sufficient number of participants for supporting the competition: 4 big generating companies (EnBW, E.On, RWE, Vattenfall) and 1000+ small ones; 4 transmission lines operators (Ampirion, EnBW, Tenet, 50 Hertz Transmission); 890 distribution lines operators and 900+ power supply companies.

Still, the German model differs from the traditional competition by the fact that generation, distribution and sales are integrated (via generators’ subsidiaries) and transmission is performed by independent operators. Innovative energy sectors (especially RES and green energy solution) have significant promotion for the development and transformation of the retail electricity market model.

4.5. Russian Federation

The development of the Russian electricity market represents the transition from regulated monopoly, which constitutes a heritage of the GOELRO plan and later comprehensive plans for energy, economy, and cities in 1950-1990, implemented in the USSR, to a single buyer / competitive model (Figure 5). Now this model need to be transformed due to developed innovative solutions in the energy sector, but this process moves slower than that in many other countries.

The government support the development of RES and other innovative energy niches in both zones with the retail electricity market and grid-off inhabited localities. For example, over the last years rules to support and implement domestic production of equipment for RES, payment for RES capacity and energy on the all retail electricity markets were established. But this activity meets a lot of obstacles, conflict of interests and lack of investment due to high risks and transactions costs.

RAO “ES Vostoka”, “Gazprom” and other state and private companies install RES capacities or hybrid diesel-RES capacities in north regions and in grid-off inhabited localities [31]. Some of the national parks (Kenozero and Russian Arctic in Arkhangelsk region, Basegi in Perm Krai, Tigirekskij in Altai Krai and many others) use solar panels for heating and lighting, and some other technologies of alternative energy.

But at the same time majority of urban areas need significant modernization of energy supply systems, and Arctic region, Russia’s Far East and some other regions need infrastructure development. This is an opportunity to transform energy systems and retail electricity energy markets on the base of new technologies.
Figure 5. Transformation of the Russian retail electricity market [32, 33].

Currently, the retail market operates in both the single buyer and competitive models with the dominance of the former (Table 8).

Table 8. Russian retail electricity market model [32–34].

| Mechanism of consumers’ price calculation | When electricity is bought from a guaranteeing supplier (1) | When the electricity is bought from an independent power supply company\(^a\) (2) |
|------------------------------------------|----------------------------------------------------------|-------------------------------------------------|
| Concentration\(^d\) in generation \(^c\) | 8 major generators occupy 70% of the market CR\(_i\) = .64 | 93% |
| Number of power supply companies | Local power supplier at each territory (720 in total) MS\(_t\) ~1% | |
| Value chain integration | Generation + Sales Transmission + Distribution (UES’ subsidiaries) | |
| Consumers’ choice of power supply company | No\(^b\) | Yes |
| Model | Single buyer | Competition |
| Market share of the model | 69% of overall consumption\(^c\) 93% | 5% of overall consumption\(^c\) 7% |

\(^a\): this ability is available only to non-household consumers
\(^b\): in some cases, households purchase electricity not from the guaranteeing supplier – for instance, when it was liquidated. But these cases are very rare
\(^c\): the overall consumption of electricity in Russia is distributed in the following way: bulk consumers – 26%, guaranteeing suppliers – 69%, independent power supply companies – 5%.
\(^d\): CR\(_i\) – concentration ratio of \(i\) generating companies with the biggest market share

Consumers, attributed to households, do not have an opportunity to choose the supplier of energy. They have to purchase it from the guaranteeing supplier, although at a regulated price, which is lower comparing to that one for industrial and other corporate consumers (so called “cross-subsidization”, when lower price for households is compensated by higher prices for other consumer categories). At the same time, corporate consumers are functioning within the competitive model when they are able
to choose their supplier under specific conditions. Large industrial consumers can participate on the wholesale market. In these cases, pricing is purely market-driven.

5. Conclusion
The above-mentioned trends in the power energy industry determine the transformation of retail electricity markets around the globe. Moreover, the cornerstone is reaching flexibility, which has to provide an adequate reaction of the market to the changes in the dynamic environment.

This process of the industry liberalization is heavily dependent on the individual characteristics of national power energy sectors and economy, the specificity of state energy and economic policies, level of development of the national institutional systems, and certain external factors including technological advancement and other institutional pressures.

All considered markets move to the competition. But they have the different tracks and different levels of liberalization and concentration of generation and sales.

A monopoly model is still in use especially in countries with large territories and grid-off locations (USA, Russia).

The government and companies with state participants play an important role for the next transformation of retail electricity markets in Russia and in China.

We may conclude that further transformation of retail electricity markets will have significant specificity in each country. Innovative technologies and solution will change participants and their strategies, structure and rules of retail electricity markets. Probably characteristics and the structure of these markets will be different and the considered comparative model for analysis need further development.

Further research may focus on models of the electricity retail market in other countries, including identifying patterns in the development of these models and factors of influence. In doing so, the future studies can be based on both the framework proposed in the current article and a new expanded approach. It is of particular interest to consider the transformation of models of the electricity retail market in the studied countries under the current energy transition.

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