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Development of Consumers' Behavior Business Model on Energy Market

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ABSTRACT

The pace of transformation in the electric power industry around the world is gaining momentum due to the rapid development of technology. The possibilities for choosing the electric power company, as well as consumers of their products, are increasing. The role of *the* distributed energy is enhancing, which contributes to the development of supply and demand in this market. In this regard, approaches to management in the energy markets are changing to address the problems of cross-subsidization. The introduction of new technologies in the management of generating and network facilities makes it possible to become "active consumers" in the energy market. The purpose of our study is to assess the impact of cross-subsidies on changing active consumers' behavior in the energy market. We propose a mathematical model of the active consumers' behavior in the energy market, which allows the participants of the energy market to make decisions to "buy" or to "produce their own" electrical energy and provides recommendations for determining the economic benefits for active consumers of the energy market. The results of our study showed that the proposed model could be effective for energy sales companies and regulators that carry out multi-agent modeling of consumers' response to tariff mechanisms of demand-side management; it also can be useful for assessing the economic effect by consumers who participate in demand-side management.

Keywords: Active Consumer, Energy Market, Demand-side Management, Tariff, Mathematical Model
JEL Classifications: D24, Q43, M31

1. INTRODUCTION

In terms of the transformation of electric power industry all over the world, the consumer of the energy market is forced to become an "active consumer" who has the technical capabilities to optimize his/her energy consumption by either "producing" or "purchasing" electricity in the market. This provides a chance to manage both production and distribution of electricity. Electrical energy is a commodity, with the initially defined properties; therefore, the consumers' behavior in the choice of the source will be primarily determined by the price.

However, the evidence suggests that the price for electrical energy is formed due to a variety of factors, among which there are climatic and geographical conditions of the location of electric power plants, specific reference fuel consumption, capacity utilization, but the factor that is most likely to affect the final tariff is cross-subsidization. All these affect the participants' behavior in the energy market, as they can act not only as consumers but also as producers of electricity at the same time.

An "active consumer" becomes a partner in the energy market and creates the requirements for the quality and consumer properties of the goods. This causes changes in the participants' behavior in the electricity market, namely, the concept of interaction with consumers, as the consumer becomes a partner in the energy market.

This paper proposes a model of consumers' behavior in the energy market. It is divided into six sections. In the first section, the urgency of the issue and the purpose of the study are defined. The second section gives a brief review of the literature. The third section covers a brief analysis of the energy market. The fourth section describes the key factors affecting the decision of the "active consumers" of the energy market as well as it provides a mathematical model that allows the participants of the energy market to make decisions as regard to being an active consumer. Section 5 proposes methodological recommendations for modeling the behavior of the "active consumer" in the energy market. Some comments and implications of cross-subsidies that affect the choice of the active consumer's behavior in the energy market are made in the sixth section.

2. LITERATURE REVIEW

The essence of cross-subsidies and the ways of deregulation of the American electric utility industry have been deeply investigated by Peter W. Doren (Wojick, 1997). For instance, there are strict limitations on the internal generation power in the constituent systems in the United States. The balance of flows between regions does not exceed 5% of the electricity produced (John F. Kennedy, 2010). Bogdanov (2006), an analyst of the electric power industry notes that cross-subsidies cannot be a long-term phenomenon in competitive markets, as an "active consumer" can find an alternative supplier that will not charge extra fees.

Bushuev (2013), Eid et al. (2014) claim that owing to the cross-subsidies tactics, the existing network tariff creates precedence for "active consumers" to develop their own generation, to seek to reduce the total of electricity purchased from the centralized electric power grid, which affects market capitalization and the ability to attract borrowed funds from both generating companies and distribution grid companies.

Works by Ryapin (2013; 2016), who is a senior analyst of the Energy Center at Skolkovo Business School, have focused on the burning problem of cross-subsidies. In 2013 the volume of subsidies was equal to 324 billion rubles, which led to a decrease in the growth of industrial production by 3.6 percent. The expert argues that high network tariffs are essential in this case. Snikkars (2017), Director of the Department for the Development of the Electric Power Industry of the Ministry of Energy of Russia, seeks to address the need to make decisions about cross-subsidization, which hinders the development of the Russian economy and electric power industry in particular. As he notes, cross-subsidization emerged as an element of social protection of the population, but in recent decades cross-subsidization has become an obstacle to the development of energy sector. The problem is that the significance of cross-subsidization in the power grid complex is considered in tariffs for electricity transmission services of territorial grid organizations, but is not included in tariffs for the nation's (all-Russian) grid. For example, the proportion of the grid component in the final electricity price for consumers is about 40%, and for consumers of the main power transmission lines, it is 15%. As can be seen, large consumers, whose power receivers are connected to the main power transmission lines, do not usually carry a social burden for cross-subsidization, which creates additional economic preferences for them in relation to SMEs.

Trachuk and Linder (2017) report on the reform of the electric power industry and the development of competition. The issues of the effect of cross-subsidization in electricity and heat power industry on the participants' behavior in the wholesale and retail electricity and heat markets have been examined thoroughly. Also, the researchers give the classification of hidden subsidies, which is as follows:

- Production of heat energy at the central heating and power plant (CHPP), which amounts to 30% of the fuel, including overhead costs, base-load, semi-base and on-peak energy charges from the producer at the expense of heat consumers from CHPP.
- Surplus heat supply costs at the expense of electrical energy costs; firm capacity costs, which are difficult to determine (they are not separately allocated, and by means of cross-subsidization they are included in the transmission tariff).
- Subsidizing the surplus heat costs at the expense of energy production costs; subsidizing new consumers at the expense of "old," which refers to the fifth type.

This is the most hidden and least discussed type of cross-subsidization. It is widely used when connecting new consumers to existing electric and heat power systems; subsidizing socially significant consumers (voters), by the social difference. An example of semi-hidden social subsidies can be regarded as the introduction of various tariffs for natural gas. There are preferential, or so-called limit, gas tariffs for the population and housing and utilities, and over limit tariffs, which are 30-40% higher, for industrial consumers, etc.

The following conditions of implementation of an "active consumer" in the energy market have been investigated: the availability of electric power plants and energy storage devices and own generation of demand-side management in the electrical energy market and generating capacities (Ryapin, 2013); the sale of the accumulated electricity to the consumer and the establishment of conditions for loading of own capacity and the submission of a bid to buy/sell electrical energy (Monitoring the prices in a retail electricity market, 2016). These conditions allow active consumers to optimize costs, and to minimize capital investments and operating costs through the establishment of recordkeeping systems that react during peak periods in the power system; to keep consumers informed about the condition of the power system; to increase prices by reducing energy consumption or switching off a pre-planned list of devices. As soon as "active consumers" appear in the market, it immediately leads to a change in the behavior of energy companies when working with the end user (Summary report, 2014).

The main factors that influence the behavior of the "active consumer" in the energy market were proposed by Bushuev (2013). These are the price of the electricity produced (type of tariff); own generation and potential for supply of electricity to the grid; an estimate of the energy mode expressed in monetary terms.

The concept of an "active consumer" in the energy system is implemented through a mechanism for managing energy consumption (Forecasts for electric power industry up to 2030, 2017), which is classified in terms of the duration of the impact on the consumer's behavior.

3. DESCRIPTION OF DATA

The largest amount of cross-subsidies in the Russian Federation (which is over 8 billion rubles) is concentrated in Sverdlovsk Oblast, Moscow, Moscow and Samara regions (cumulatively in four regions - 40 billion rubles or 17% of the total cross-subsidization) (Figure 1).

Figure 2 shows the dynamics of the amount of cross-subsidies in the electric power industry of the Russian Federation for the period 2008-2015 (the data are given according to the Agency for Forecasting Balance Sheets in the Electric Power Industry).

The capacity in the energy market can be carried out either at free prices, or on power purchase agreement, or through the mechanism of Competitive Capacity Auction (CCA) via the system operator.

CCA carried out operations taking into account the consecutive year from 2008 to 2015. Since 2015, CCA has carried out operations to select capacities for several years to come. In addition, positive effects usually include a decrease in "forced" capacity by 35%. While the negative effect is the set volume of the purchased "forced" capacity in the "forced" mode - up to 14.6 GW, which reduces the share of commercially effective capacity by 5%.

Table 1 shows a forecast for the capacity sales in the wholesale electricity market arranged by the years.

The electricity sale in the wholesale market is carried out by price zones (Figure 3) in the following segments: The main segment (72%), the balancing segment (4%), and under hard-set-volume contracts (14%).

In 2015-2016 the volume of purchases of electricity in the wholesale markets increased by 23.5% in the first segment, and by 20% in the second segment. In the third segment, we can observe an increase in the share of purchases under contracts.

Prior to the reform of the electric power industry (including the functioning of vertically integrated energy companies, the so-called "JSC-Energo"), the cross-subsidies mechanism was implemented through the establishment of the retail (final) electricity prices for the relevant consumer groups in the "required/essential" correlation.

In the context of the division of businesses and having "regulated" and "market" components of the retail price, cross-subsidies

Figure 1: Distribution of the limiting value of cross-subsidies

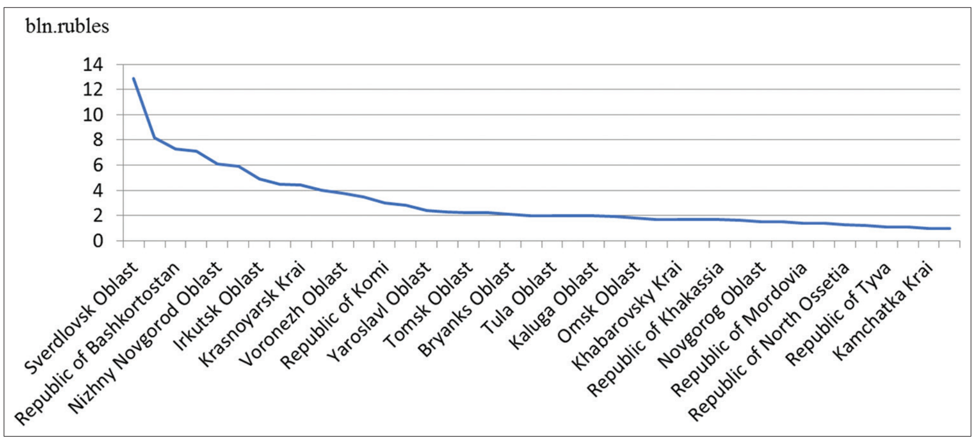


Figure 2: Dynamics of cross-subsidies in the Russian Electric Power Industry, RUB bn. (inc. VAT)

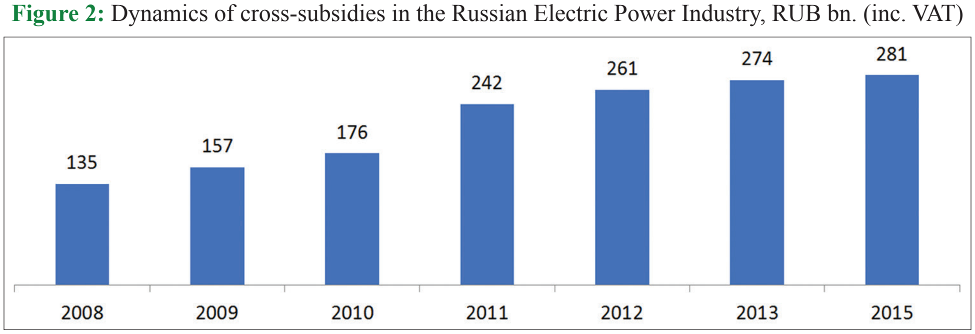


Table 1: The forecast for the capacity sales in the wholesale electricity market

Year	Supply, MW (% to the prev. year) (%)	Due to be paid in the wholesale market, MW (% to the total)				The price acc. To the pricing zone, RUB\ MW per month		
		Total demand (%)	Inc. PPagreement (%)	Inc. the 'forced' status (%)	Inc. CCA selection (%)	1 PZ (% to the prev. year) (%)	2 PZ (% to the prev. year) (%)	Price fixing
2017	200416 (101.1)	201123 (100)	33805 (17)	10011 (5)	157307 (78)	11093 (98)	185740 (103.2)	Acc. to the pricing zone
2018	202416 (100.9)	201123 (100)	33805 (17)	10011 (5)	157307 (78)	110993 (98)	185740 (102.2)	
2019	204246 (100.9)	202353 (100)	35803 (18)	9608 (5)	156942 (78)	110451 (99.5)	190281 (102.4)	

between consumer groups are realized through the implementation of the following pricing mechanisms (primarily, through the regulated components):

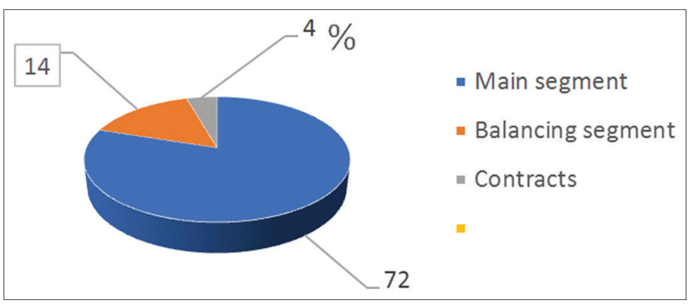
- By redistributing tariff revenue between voltage levels when regulating tariffs on electric grid services for electric power transmission;
- By making the so-called "last-mile" agreements before 2014.

4. METHODS AND MODELS

Based on the existing concept of an "active consumer" (Firsova et al., 2018), one can optimize their behavior by optimizing the benefits of all its participants. Figure 4 shows the assessment of the active consumer's behavior.

We believe that it is necessary to determine the economic benefit for active consumers of the energy market; to schedule the optimum load of the equipment, and to simulate the operation mode of electricity generation taking into account the market-based pricing policy. We found out that it is essential to build a daily load schedule (T- the indicator that determines the number of hours per day and equals 24 h). Then it is essential to determine the number of pieces of equipment included in the calculation of the loading schedule and power consumption. Finally, we calculate the

Figure 3: Electricity sales in the wholesale market according to the pricing zones in segments



specific fuel consumption and build the matrix X_n for the existing equipment n = $\overline{1,N}$ within 24 h.

Each element of the matrix X_n is given in the following way $a_{kt}^{n} \in \{0;1\}$

$k \in \overline{1,R}$ (line)

$t \in \overline{1,T}$ (column)

Where $= \left(a_{kt}^{n}\right)_{t\in\overline{1,T}}^{r\in\overline{1,R}}$

Calculation of the total electricity consumption at any time t

$$V_t = \sum_{n=1}^{N} a_{tz_n}^{n} * P_n^{cons}, \quad (1),$$

Where $\overline{z} = \left(z_1, \ldots . z_N\right)$ - vector of variables corresponding to the set of equipment operating modes;

$n \in \overline{1,N};\ z_n \in \overline{1,R_n};$

P_n^{cons} - power output, consumed by the n-th equipment unit (kW).

Let us consider the equipment operating mode in the form of economic benefit (d_{rn}) for the purchase of electricity:

Schedule $k \in \overline{1,R}$

Selected objects $n \in \overline{1,N}$.

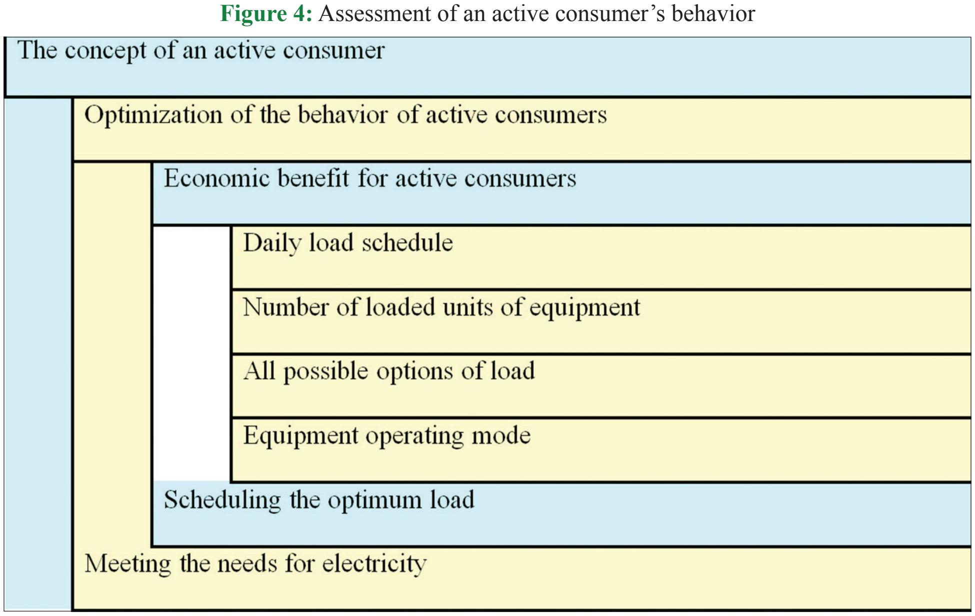
d_{kn} = 0, provided that there are hours when the equipment is entirely off.

$$d_n(t) = \sum_j c_j * P(c_j, t) \quad (2)$$

Where $c_j - j -$ is a –th element of the set C.

In such a way we can to define the operating mode, which is expressed as a set of time modes t, and thus, we get:

Figure 4: Assessment of an active consumer's behavior



$$d_n(k) = \sum_x d(f_x) \tag{3}$$

Where x– is a working time k.

The estimation of the economic benefits of electricity consumption in monetary terms will be subjective, as it reveals a dependence on the operating mode of the enterprise itself and the type of equipment. Consequently, we will estimate economic benefits taking into account the maximum volume of electricity consumption per hour as an option of the choice of the price for energy $\frac{P_i^t}{P_{max}}$

c_j - energy,

T- the period under review,

d_n^t cash equivalent of energy costs

$$d_n^t = \sum_{i=1}^{I} \frac{C_j * \frac{P_j^t}{P_{max}}}{I} \tag{4}$$

We need to consider the process of electricity generation with the help of self-generation equipment to assess the economic benefit.

K- the number of equipment units,

$m \in \overline{1, K}$ – operating mode,

c_m (g_{mt})- the cost value of an electricity unit produced by own generation

g_{mt}– power output.

The total amount of generation is given in the form

$$V_t = \sum_{m=1}^{K} V_{mt}, \tag{5}$$

We can observe that two processes are taking place at the same time: the equipment produces the amount of electricity for own consumption $V_t^I \left(\overline{V^I} = \left(V_t^I\right)\right)$ as well as it produces the amount of electricity transferred to the network $V_t^E \left(\overline{V^E} = \left(V_t^E\right)\right)$. The costs for generating electric power by own generation sources can be expressed by the following formula (6).

$$Q(t) = \sum_{m=1}^{M} c_m\left(t, g_{mt}\right) \tag{6}$$

q_g, - the cost of electricity transmitted to the grid,
q_f - the cost of consumed electricity,
c^I (t,V_t,q_f,W), - the price of the consumed electricity,
c^E $(t,g,{}^Eq_g,W)$. – the price of the generated electricity.

The condition for maximizing the benefit for a participant in the energy market is represented in formula (7).

$$f\left(\overline{z},\overline{V^I},\overline{V^E}\right) = \sum_{n=1}^{N} d_{z_n n} - \sum_{t=1}^{T} c^I * \left[\sum_{n=1}^{N} a_{tz_n}^n P_n^{cons} - V_t^I\right] + \sum_{t=1}^{T} \left[Q^E * V_t^E - \sum_{m=1}^{M} c_m\left(t, g_{mt}\right)\right] \rightarrow \max \tag{7}$$,

The choice of consumer behavior can be presented based on the postulated conditions. In case when $V_t^E = V_t, V_t^I = 0$, then we can assume that the consumer has no preferences whether to use self-generated electricity for his/her own needs or to supply the electricity to the grid.

$$f\left(\overline{z},\overline{V^I},\overline{V^E}\right) = \sum_{n=1}^{N} d_{z_n n} + \sum_{t=1}^{T} \left[\begin{matrix} Q^{IE}(t) \times V_t^E - \\ c^{IE}(t) \times \left(a_{tz_n}^n \times P_n^{cons} - V_t^I\right) - Q(t) \end{matrix}\right] = \sum_{n=1}^{N} d_{z_n n} + \sum_{t=1}^{T} \left[Q^{IE}(t) \times \left(V_t - a_{tz_n}^n \times P_n^{cons} - Q(t)\right)\right] \tag{8}$$

Then,

$$f\left(\overline{z},\overline{V^I},\overline{V^E}\right) = \sum_{n=1}^{N} \sum_{t=1}^{T} [d_{z_n n} / T - Q^{IE}(t) \times a_{tz_n}^n \times P_n^{cons}] + \sum_{t=1}^{T} \sum_{m=1}^{M} \left[Q^E(t) \times V_{mt} - c_m\left(t, V_{mt}\right)\right] \tag{9}$$,

In this case, the optimization associated with electricity consumption will be written as (10), while the optimization of the own electricity production (11):

$$f(\overline{z}) = \sum_{n=1}^{N} \sum_{t=1}^{T} [d_{z_n n} / T - Q^{IE}(t) \times a_{tz_n}^n \times P_n^{cons}] \tag{10}$$

$$f\left(\overline{V^I},\overline{V^E}\right) = \sum_{t=1}^{T} \sum_{m=1}^{M} \left[c^E(t) \times V_{mt} - c_m\left(t, V_{mt}\right)\right] \tag{11}$$

The choice of own generation power $m \in \overline{1, M}$, will depend on the price of electricity in the period under review. If the correlation c_m $(V_m)/V_m(t)$ increases, in such a case, the optimum power should be determined as follows (12):

$$c_m\ (t,V_{mt}) = c^{IE}\ (t) \times V_{mt} \tag{12}$$

From the stated above we can conclude that, given the low cost of generating its own electricity, which is below the market price, it is advantageous for the consumer to produce electricity independently; and vice versa, given low market prices for electricity that is below the cost of production, the active consumer does not need to load its own generation. Moreover, due to own generation, the costs of transmission and distribution of electrical energy are reduced.

5. RESULTS AND DISCUSSIONS

Thus, the optimization of the behavior of the active consumer will consist of maximizing its objective function by choosing for each type of equipment $n \in \overline{1, N}$ the corresponding consumption curve $k \in \overline{1,R}$, for each installed self-generation device $m \in \overline{1,K}$, the graph of its operation for each time period $t \in \overline{1,T}$, the choice of the non-negative number of output power V_{mt}, as well as the amount of electricity transferred to the grid: $V_t^E \le v_t = \sum_{m=1}^{M} V_{mt}$. The limitation on the amount of power consumption can be expressed as $\forall t \sum_{n=1}^{N} V_t \times P_n^{cons} \le V_{max}$. Based on the stated above, we are able to propose recommendations for the behavior of the active consumer in the energy market.

1. Determine the parameters of each equipment unit and to determine the mode of operation of those equipment units. Draw the matrix of equipment operation (the column shows the time of the equipment operation, and the line shows the possible modes of operation of the equipment);
2. Calculate the economic benefits of electricity consumption for each mode;
3. Calculate the cost of own electricity production and compare it with the market indicators.
4. Choose the most optimal option, combining both own generation and the purchase of electricity from the network.

Criteria of optimality are set based on the following parameters:

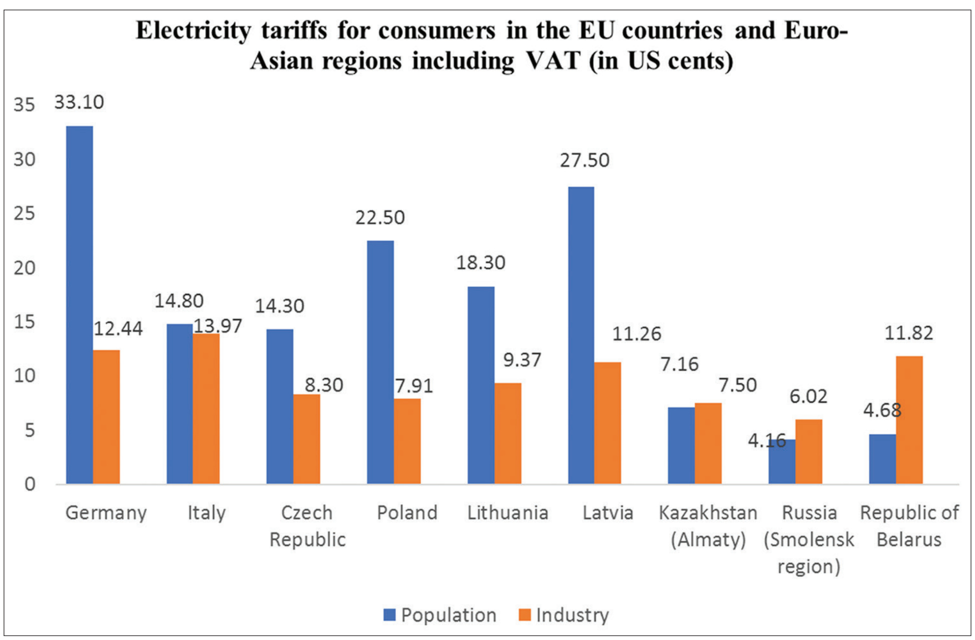
a. An active consumer of the energy market should choose the option of buying electricity and not load his/her own generation, in case when the cost of own generation of electricity exceeds its purchase value from the network;
b. It is worthwhile to produce a volume of electric power that is larger than needed for own needs and sell it in the market if the price of electric power transmitted to the grid is higher than the cost of its production.

An "active consumer" should define his/her own strategy in the energy market, and also cooperate with energy retail companies, which will further allow him/her to create own schedule of aggregate consumption under various tariffs, the so-called "demand response," on the basis of which the sales companies can model the optimal offer of tariffs optimizing the position of all participants in the energy market.

The practice of cross-subsidies system in the Russian electric power industry led to a paradoxical correlation of electricity prices for industrial enterprises to electricity prices for the population. That correlation was 1.34 in 2015, although it should be <1, because during the delivery process of electricity to the population one can observe multiple transformed to a low voltage level with the formation of associated technological losses in the electric grid infrastructure; whereas for industrial consumers, the transformation is carried out mainly to the level of the middle first, middle second or lower high voltage limit (as a comparison of the data).

As an example, let us consider similar correlation on foreign electricity markets: In the United Kingdom – 0.56, in the USA – 0.48) (Figure 5), but also to the additional economic burden, first of all, on the electric power industrial enterprises, which

Figure 5: Correlation of electricity prices for industry and population across the world



Note: Tariffs for industrial consumers are given without VAT. Gas price for energy utilities: The Republic of Belarus – 189.82 $/thousand cub. m

Russia – 62.9 $/thousand cub. m

Kazakhstan – 72.1 $/thousand cub. m

For reference: Prices for the EU countries are shown for the first half of 2015; Smolensk region – as of 1 Jan 2016; Republic of Belarus – annual average tariffs according to estimates for 2016.

The ruble-dollar rate – 78:1

The tenge-dollar rate – 378:1

The Belarussian rouble-dollar rate – 22065:1

Table 2: Transaction electricity sales prices in the wholesale market in 2013-2016, rubles/MW*h

Name of the station	2013		2014		2015		2016	
Market	RA	DAM	RA	DAM	RA	DAM	RA	DAM
Krasnoyarsk State district power station-2	407	704	413	787	415	904		
Cherepovets State district power station	990	1146	1041	1141	-	1146		

include the chemical and metallurgical industries - the conditional component of cross-subsidies in the weighted average price for the retail electricity market is more than 12 %.

We see that the tariffs for the population are higher in EU than in the CIS countries (Eurasian Economic Union), while the EU does not pay for power. In summary, we would like to discuss the "cross subsidization," as we analyzed companies on different markets (regulated agreements (population), the day-ahead market (industrial enterprises, for the most part) and here are our findings (Table 2):

In fact, the difference is not very crucial, and the second question though is that industrial consumers pay for the capacity as well.

In this regard the Ministry of Energy of the Russian Federation in terms of regulating the power grid complex has prioritized the following tasks:
- To ensure transparency and fairness of cross-subsidies burden sharing between business categories, including consumers connected to the nation's (all-Russian) grid
- To decrease gradually the amount of cross-subsidies
- To change the structure of cross-subsidies in order to provide more effective targeted support to low-income and socially protected categories of consumers.

6. CONCLUSION

The government policy of reducing cross-subsidies has not yielded significant results since 1997. On the one hand, we can observe a slight increase in the price of electricity for the population that is neutralized by inflationary processes. On the other hand, we witness that the immediate increase in prices in the electric power industry is constrained by the political factor: The abolishment of cross-subsidies in some regions can cause electricity prices for the population increase by more than twice, and that will result in social tension.

One of the measures aiming at resolving the problem of cross-subsidies was a social rate of electricity consumption for the population in all regions proposed in April 2016 (except for regions, technologically isolated from the unified energy system). This rate was supposed to differentiate the cost of electricity, depending on the amount of its consumption:
- The payment of at least 70%-level of electricity consumption will be made at a preferential tariff, established within 90% and 97% of the level of the respectively established minimum and maximum limit of electricity prices in the previous month before the introduction of the social norm
- The tariff setting limits will increase by 40% more than the social norm.
- The main reason for all existing problems is the lack of marketing in the promotion of energy goods and services, which causes cross-subsidization in the energy sector.

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