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Managing Electricity Costs in Industrial Mining and Cryptocurrency Data Centers

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ABSTRACT

2022 has seen a significant decline in global cryptocurrency ratings, especially bitcoin. As it is known, one of the key components of the cryptocurrency's cost is the amount of electrical energy spent by the computing equipment of the mining data centers. In the context of declining bitcoin rates, the management of the data centers' energy costs becomes critical for maintaining the profitability and investment return of the mining projects. Russia is among the top-3 leading producers of cryptocurrencies, providing 11% of the global primary bitcoin transactions. In this regard, the management of the data centers' costs related to the purchase of electricity in the Russian wholesale and retail electricity (capacity) markets presents a high scientific and practical importance. This article analyzes the pricing mechanisms for the purchase of electricity in Russia's wholesale and retail electricity (capacity) markets on an industrial scale given the specifics of the hourly demand-based pricing. This paper suggests a new metrics system, including a capacity demand management coefficient and a transmission cost management coefficient, which allow setting specific price parameters for the different components of the electricity price based on demand analytics. Simulation of different parameters of the energy cost management in mining data centers demonstrated that the ultimate electricity price can, on average, be reduced by 70% of the initial level across all regions of the Siberian Federal District of Russia. The suggested energy cost management model takes into account both internal and external factors of industrial data centers as well as monitoring of their operations along with the price factors of the wholesale and retail electricity markets. This material may be useful to specialists in the field of management of mining data centers who are involved in the operation and/or design of such facilities across various regions of Russia.

Keywords: Mining Energy Consumption, Bitcoin Energy Consumption, Energy Cost Management, Cryptocurrency, Bitcoin Mining
JEL Classifications: Q43, P18, L94

1. INTRODUCTION

The cryptocurrency production technology is based on the consumption of large volumes of electrical energy which is used by industrial video card equipment and cooling systems that are directly involved in the mining. Whereas the production of cryptocurrency can be carried out anywhere in the world, miners are gradually concentrating in countries with the most favourable conditions for operating their equipment. These conditions include, first of all, the low cost of electrical energy; secondly, high-speed Internet connection; and thirdly, no legal restrictions on the mining activity. Due to the presence of all of the above favourable conditions, Russia became a top-3 bitcoin producer in 2021, with its share in the global volume of bitcoin transactions over 11%. The number one producer was the United States (35% of the total global volume) followed by Kazakhstan with the share of 18%. China, on the contrary, imposed legal restrictions on the production of cryptocurrencies in 2021 after which the bulk of China's mining operations moved to the territory of Russia. According to various experts, the volume of cryptocurrency production in Russia takes from 700 MW to 1 GW of electrical capacity of Russia's grid. Taking into account the significant scale of the mining activities in Russia, the research and development of various methodologies for managing the mining data centers' energy costs in the context of Russian wholesale and retail electricity (capacity) markets present as very relevant.

Modern research has produced many studies looking into various aspects and opportunities of energy management in the field of the cryptocurrency production. Notably, domestic and international research of miners' electricity demand management follow rather different trajectories.

Specifically, the foreign research focuses more on improving the eco-friendliness of the cryptocurrency production and its impact on the decarbonization of the economy and climate change. Examples of the studies done in the field of renewable energy for bitcoin mining include the works of Naeem and Karim (2021), Malfuzi et al. (2020), Li et al. (2019), Nikzad and Mehregan (2022), etc. Their research explores the possibilities of expanding renewable energy to the cryptocurrency production emphasizing the need for more environmentally sustainable solutions. The studies by Niaz et al. (2022), Sarkodie et al. (2022), Asumadu and Owusu (2022), Truby (2018), and Yan et al. (2022) focus on the problem of reducing the carbon footprint due to the growing electricity demand on the part of the cryptocurrency mining systems. The researchers emphasize the exacerbation of the problem due to the growing number of mining farms and suggest various solutions for the bitcoin decarbonization up to the development of legislative mechanisms to stimulate the production of cryptocurrencies through green energy. Some researchers express concerns regarding the impact of bitcoin mining capacities on climate change. These include the studies by Atkins (2022), Baur and Oll (2022), Ren and Lucey (2022), Zhang et al. (2018), etc. Also, a significant portion of scientific research is devoted to the interrelations between cryptocurrency production and energy markets. Examples include the studies by Corbet et al. (2021), Karmakar et al. (2021), Schilling and Uhlig (2019), Das and Dutta (2020), Aalborg et al. (2019), Ji et al. (2019), etc. These researchers analyze the impact of the mining activity on the fluctuations of the electricity price in energy markets, the impact of the electricity price on the cost of cryptocurrency production and the profitability of bitcoin mining, and the impact of the electricity price on the exchange price of bitcoin.

Russian research largely focuses on such issues as the introduction of mining farms, the growing electricity demand due to cryptocurrency production, impact of the mining activity on the operations of the Russian grid, the stability of the electricity distribution systems, the energy balance of regional energy systems, improvement of the energy efficiency and environmental friendliness of the mining processes.

Examples of the studies focusing on the impacts of the cryptocurrency production systems on the operating modes of the Russian grid and energy security include the works by Prokopieva (2021), Grachev and Pimkin (2022), Zakharov (2019), Artyushevskaya and Kovzel (2022), Zateeva (2018), etc. In their works, the authors emphasize the likely decrease in the reliability of the grid and energy security of the Russian economy due to adding the new mining capacities. In their works, Gavrikov (2018), Zaborskikh (2017), Serkin et al. (2017) study the specifics of electricity consumption by cryptocurrency mining systems. Researchers Sapozhnikov and Industriev (2019), Kolesnikov et al. (2021), Sapozhnikov and Industriev (2019), and Egii and Ofoegbu (2021) study the environmental impacts of using cryptocurrency mining systems in Russia, including the increased load on traditional sources of electricity, and identifying ways to reduce the environmental impact of mining farms. In their studies, Senchenko et al. (2017), Samokhin et al. (2019), Solomennikov et al. (2021), and Maslennikova et al. (2022) emphasize the importance of energy saving and improving energy efficiency of mining farms. The authors emphasize the high degree of energy intensity of cryptocurrency production, including high heat losses during the operation of mining equipment, which defines the need for high reserves in order to secure energy efficiency of cryptocurrency production.

However, few Russian studies pay attention to the role of electricity costs on the cost of producing cryptocurrencies and the need to find solutions to reduce energy costs in the process of purchasing electricity for mining farms. These include the works by Aleksandrov et al. (2021), Sazonova (2018), and Ponamorenko et al. (2022). However, the above referenced studies are limited to emphasizing the relevance of the role of the electricity cost parameters in the production of cryptocurrencies and the need to manage the related energy costs.

Therefore, given the high energy intensity of the mining processes, one of the important areas of scientific research in the field of cryptocurrency production in Russia and globally should be, in our opinion, energy cost management solutions specifically developed for the cryptocurrency production systems and targeting electricity purchase on the energy markets. In Russia, the wholesale and retail electricity (capacity) markets have been operating since 2006. Their mechanisms allow reducing the acquisition cost of electricity based on demand response. The researchers have conducted several studies focusing on the price-dependent demand management of electricity at industrial enterprises operating in the conditions of the Russian energy markets. However, these studies do not reflect the specifics of the cryptocurrency production systems, which requires separate studies and the development of separate methodological approaches to the management of electricity acquisition costs, specific for the mining systems.

2. THE RELEVANCE OF MANAGING ELECTRICITY COSTS IN MINING DATA CENTERS

Some of the key factors stimulating the growth of cryptocurrency mining in Russia include the following:

1. Relatively low cost of electricity in the national grid compared to the electricity prices in most other countries
2. Availability of free-to-use electrical capacities at industrial enterprises in Russia
3. Availability of free electrical capacities for technological connection of electricity consumers in local grids
4. Availability of vacant land plots in the areas designated for industrial use

5. Availability of high-speed Internet connection channels
6. Absence of legislative restrictions on mining
7. Favourable climate for the operation of the mining equipment (lower temperatures, moderate rainfall).

The relatively low price of electricity for large consumers plays the most critical role in stimulating the growth of mining in Russia. Figure 1 shows a diagram of prices per 1 kWh of electricity for industrial customers in various countries of the world in H2 2021. As follows from the diagram below, the industrial electricity price in Russia is 2 times less than in Serbia and the Czech Republic, 3 times less than in Poland, and more than 5 times less than in Italy, Germany or Greece. Therefore, main cost item in the production of cryptocurrency is several times less in Russia than in most countries of the world, which significantly increases the economics of the mining farms operating in Russia.

The low electricity price in Russia is due to several key factors:
1. Availability of all types of primary energy resources which are sourced locally
2. Low cost of primary energy resources used domestically
3. High share of relatively cheap natural gas in the total energy mix of the country
4. Full availability of the energy infrastructure (CHPPs, district power plants, transmission and distribution networks) which was built in the times of the USSR and which does not require high investments to maintain its functioning
5. Low utilization of the existing energy capacities of the national grid coupled with a high margin of safety, allowing an incident- and restriction-free operation
6. Combined generation of electrical and thermal energy at power plants during the fall and winter period, which allows allocating some of the costs of electricity generation to heat production
7. Russia's electric power industry exists within the framework of a wholesale electricity market system, which allows utilizing those generators which offer the cheapest price for consumers
8. Comparatively low wage rates in Russia, resulting in relatively lower labour costs compared to other countries; and
9. Strict control and regulation of any changes in the electricity price by the Russian government.

The analysis of the factors affecting the relatively low price of electricity in Russia suggests that it will continue in the longer term, which, again, emphasizes the relevance of locating mining facilities in Russia.

2.1. Relevance of Electricity Cost Management for Mining in 2022

2022 saw a significant decline in the exchange prices of the global cryptocurrencies. Figure 2 below shows a diagram of the bitcoin per 1 USD fluctuations during 2015-2022. As follows from the diagram, if in Q4 2021, the price of bitcoin on the global exchange trading exceeded 68,000 USD, already by June 2021, it fell to 20,000 USD. Thus, the profitability of the cryptocurrency production over the specified period decreased by more than 3 times. Therefore, in these conditions, one of the key elements for ensuring profitability of mining is the management of the energy costs.

In this situation, we believe that one of the main directions for increasing the efficiency of cryptocurrency mining should be increasing the energy efficiency of electricity consumption.

Traditionally, the lowest electricity prices for industrial customers in Russia concentrate in the regions of the Siberian Federal District. This is due to the concentration of several major hydroelectric power plants in Siberia, which have the lowest cost of electricity generation. Figure 3 below shows a diagram of the electricity prices at the wholesale electricity (capacity) market in different regions of the Siberian Federal District (the SFD) for consumers with constant demand curves, as of June 2022. As follows from the diagram, the electricity prices in the SFD are not the same across all 10 regions, and differ significantly relative to each other. For example, the price of electricity in

Figure 1: Price per 1 kWh of electricity for industrial customers in various countries of the world in H2 2021

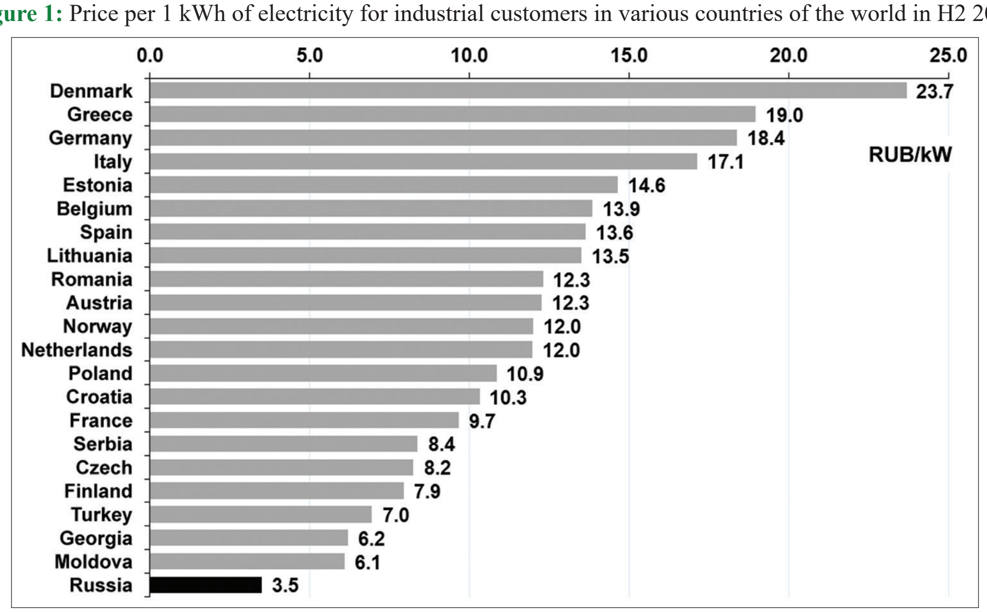


Figure 2: Fluctuation of the bitcoin per 1 USD during 2015-2022

Figure 3: Electricity prices in the wholesale electricity (capacity) market in different regions of the Siberian Federal District for electricity consumers with a constant demand curve, as of June 2022

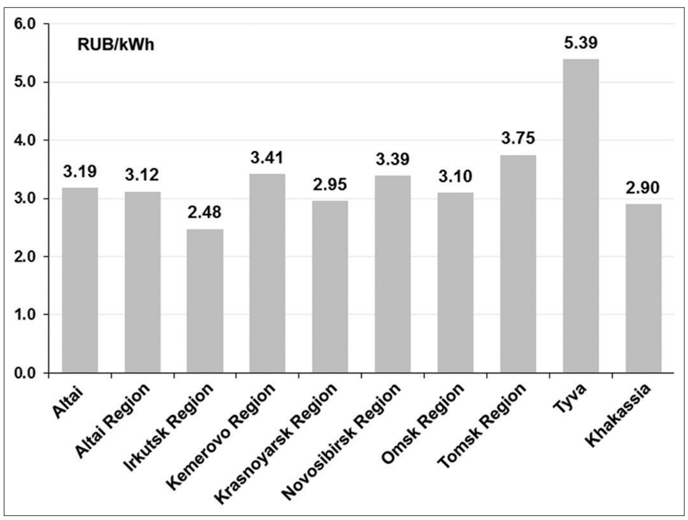
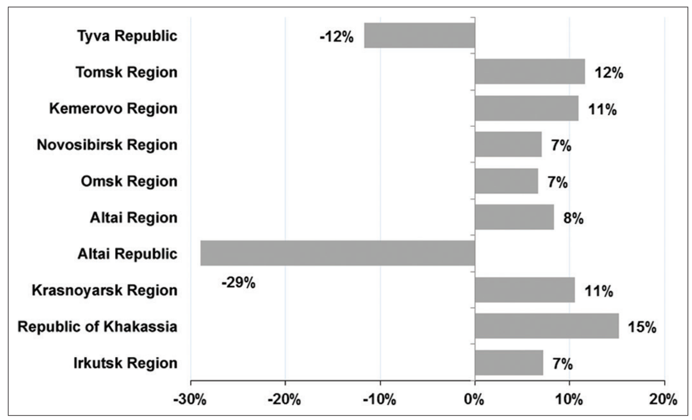


Figure 4: Electricity price dynamic in different regions of the Siberian Federal District in the period from June 2021 to June 2022



the Irkutsk Region and the Republic of Tyva differ by more than 2 times. Also, in the Kemerovo, Novosibirsk and Tomsk Regions, electricity prices are on average 10% higher than in the Krasnoyarsk Region and the Republic of Khakassia. Therefore, the placement of mining facilities in different regions of the Siberian Federal District may result in different cost indicators of the purchased electricity.

Also, the electricity prices in Russia and in the Siberian Federal District in particular are characterized by continuous change. Figure 4 below shows a diagram of indicators of the price dynamic in different regions of the SFD in the period from June 2021 to June 2022. As follows from the diagram, the price dynamics in the analyzed year is mainly characterized by growth, 9% on average. At the same time, several regions of the SFD, specifically, the Republics of Altai and Tyva, on the contrary, demonstrate a decrease in the price index, by up to 30% of the respective prices in June 2021.

Given the results obtained, the efficiency of cryptocurrency production in Russia may differ depending on the location of electricity-consuming facilities as well as time. Therefore, in order to manage the costs of purchasing electricity in cryptocurrency production facilities operating in the Siberian Federal District, one should take into account a wide range of factors related to the territorial specifics, types of energy tariffs, as well as other specifics that impact the price of electricity supplied to the miners.

2.2. Features of Data Center Electricity Consumption

Mining data centers demonstrate some distinct specifics of electricity consumption, such as:

1. Electricity costs have a very high share in miners' cost structure
2. Constant demand curve, with no intraday or seasonal variations
3. Mobility of the cryptocurrency mining equipment, which determines its location flexibility
4. Container-type layout of mining equipment, which enables quick installation and quick connection to electrical networks
5. Mining equipment is powered by the 380V network, which is a universal connection in all electrical networks operated in Russia

6. Modular configuration of the main equipment, which enables quick repair of failed units as well as demand management; and
7. Quick and flexible management of the composition of the running equipment without compromising operational modes nor the quality of technological processes.

Figure 5 below shows the charts of hourly demand curves of various types of consumers on a typical operation day. Figure 6 also shows an illustrative hourly chart of electricity consumption of a mining data center. As follows from the diagram below, different types of industrial consumers have demand curves with different volatility, which is due to equipment shifts, sequential activation of units, changes in the daylight time, etc.

On the contrary, demand curves of mining data centers are characterized by a relatively even level, not only within a day, but also during a month. The constant nature of the data centers' hourly demand curves is explained by the fact that mining equipment operates around 24/7 in the same operational mode and as such is not dependent on equipment or labour shifts nor on the working days and days off. The constant demand curve coupled with the modular configuration of mining farms, which allows decommissioning part of the equipment, opens up new opportunities for managing the costs of purchasing electricity in Russian wholesale and retail electricity (capacity) markets.

Among the modern solutions for mining data centers operated in Russia, there are several key areas which, in our opinion, should be tapped into in order to bring down the electricity acquisition costs:

1. Purchase electricity (capacity) directly from the wholesale market bypassing any local providers and their fees. This allows reducing the cost of purchased electricity by 3-11%, depending on the region of operation and the purchase terms
2. Participation in the demand response management project implemented by the Russian National Grid Operator. This allows reducing the cost of purchased electricity by 1-7%
3. Connect mining data centers to the integrated grids to enable the lowest possible tariff for the transmission fee (HV tariff, tariff for the common grid transmission services provided by the Federal Grid Company). This allows reducing the cost of purchased electricity by 5-30%
4. Connect to the electric networks of electricity (capacity) generators bypassing the fee for the technological losses as part of the electricity (capacity) transmission service. This allows saving up to 3% of the cost of purchased electricity
5. Install autonomous sources of electricity to avoid transmission fees of local grid operators. This measure allows reducing the cost of purchased electricity by another 10-20%
6. Price-dependent management of demand for electricity (capacity) purchased from the wholesale and retail electricity markets. This allows reducing the cost of purchased electricity by 5-40%.

Figure 5: Hourly graphs of electricity demand of various types of consumers in a typical operation day

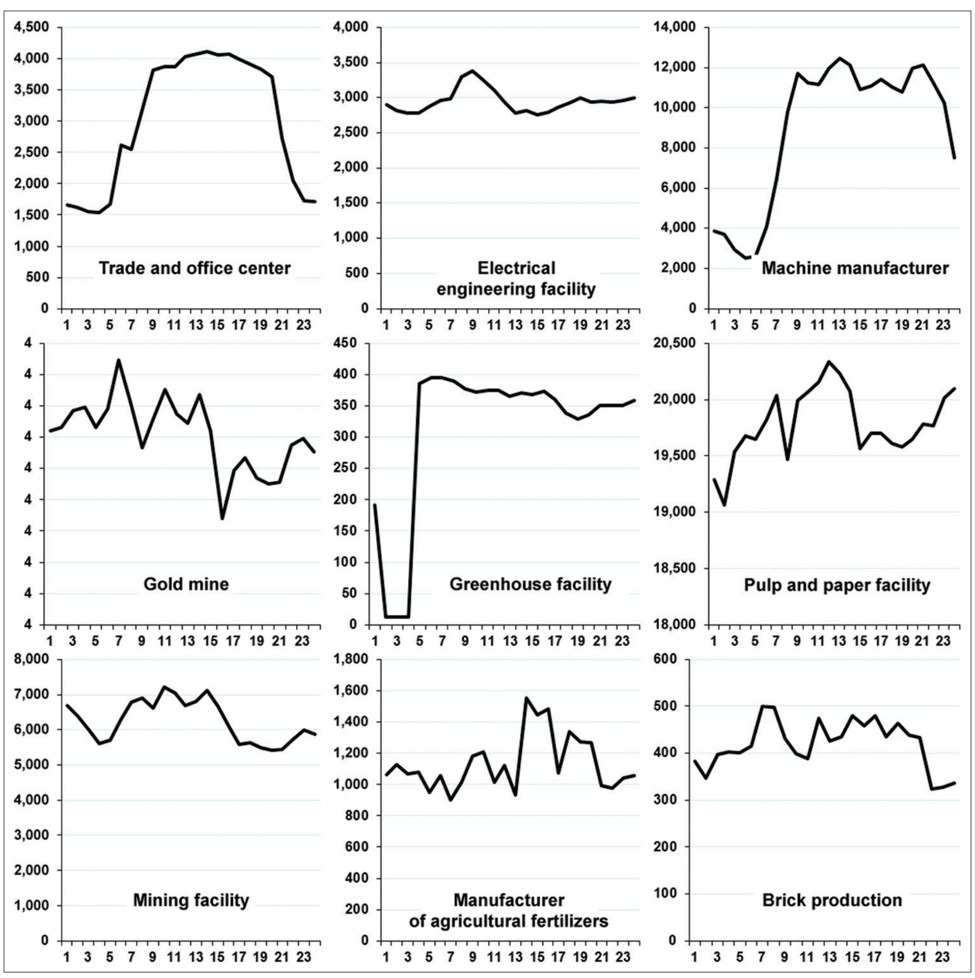
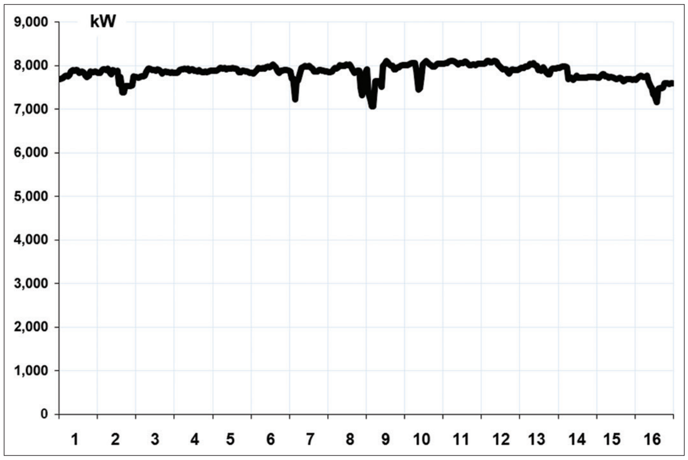


Figure 6: Example of an hourly graph of electricity consumption of a typical mining data center



In our opinion, in the context of a significant drop in the bitcoin exchange rates and the current conditions existing at Russia's energy market, price-dependent electricity (capacity) demand management presents itself as the most effective lever of cost management.

3. DEMAND SCHEDULE CONTROL PRICE MODEL

The price of the electrical energy P purchased by industrial consumers in Russia's wholesale and retail electricity (capacity) market is estimated using Formula (1) below:

$$P = SX + SY + SZ \quad (1)$$

where *SX* is the cost of the component charged for the consumed electrical energy in the given month (in RUB);

SY is the cost of the component charged for the consumed capacity in the given month (in RUB); and

SZ is the cost of the component charged for transmission service in the given month (in RUB).

3.1. The Cost of the Component Charged for the Consumed Electrical Energy

SX in the given month is calculated using Formula (2) below:

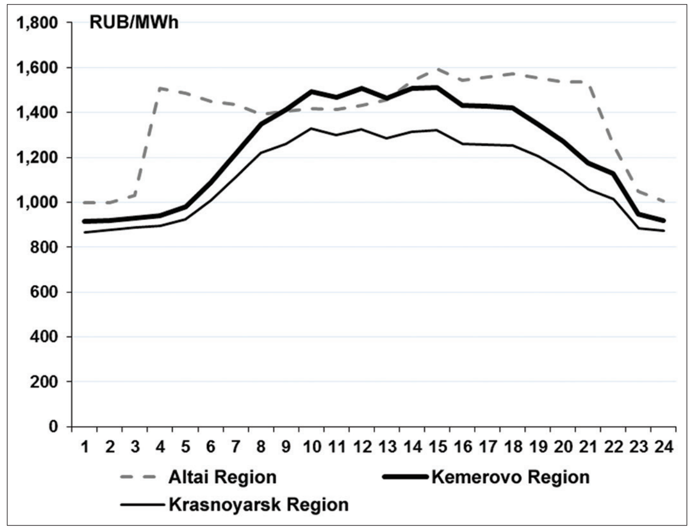
$$SX = \sum WHM \times XHM \quad (2)$$

where *WHM* is the amount of electricity consumed by the consumer at each hour of the day in the given month (kWh); and

XHM is the prices of the electricity purchased by the consumer at every hour of the day in the given month (in RUB per kWh);

Figure 7 below shows the hourly prices of the electricity component in a typical operation day on the wholesale electricity market in select regions of the Siberian Federal District in June 2022. As follows from the diagrams, electricity prices are not even every hour of the day and are cyclical. At night, when the demand for electricity decreases in the grid, the price goes down as well, and vice versa, during a period of increased daily demand, the hourly electricity prices increase too. The range of volatility in hourly electricity prices between night and day can reach up to 60%, which is significant. If an industrial consumer cannot impact the hourly prices that are formed in the electricity market, it can impact its costs attributed to the purchased electricity. The price and cost of the component charged for the consumed electrical energy *SX* is directly dependent on the nature of the demand curve *WH*, and can be managed by controlling the company's electricity consumption *WH* (Formula 3).

Figure 7: Hourly prices of the electricity component in a typical operation day in the wholesale electricity market in select regions of the Siberian Federal District, as of June 2022



$$SX = F(WHM \in PEAKS) \quad (3)$$

where *PEAKS* is daily periods with the peak cost of electric energy;

During daily price peaks, the consumer can reduce its demand by shifting electricity consumption to the least-priced hours and thereby reduce its costs charged for the consumed electricity.

In the example below (Figure 8), the mining data center adjusts its demand curve depending on the cost of the electricity component. As follows from the illustration below, management of the demand response during peak price hours allows consumers to most effectively reduce their costs related to purchasing electricity.

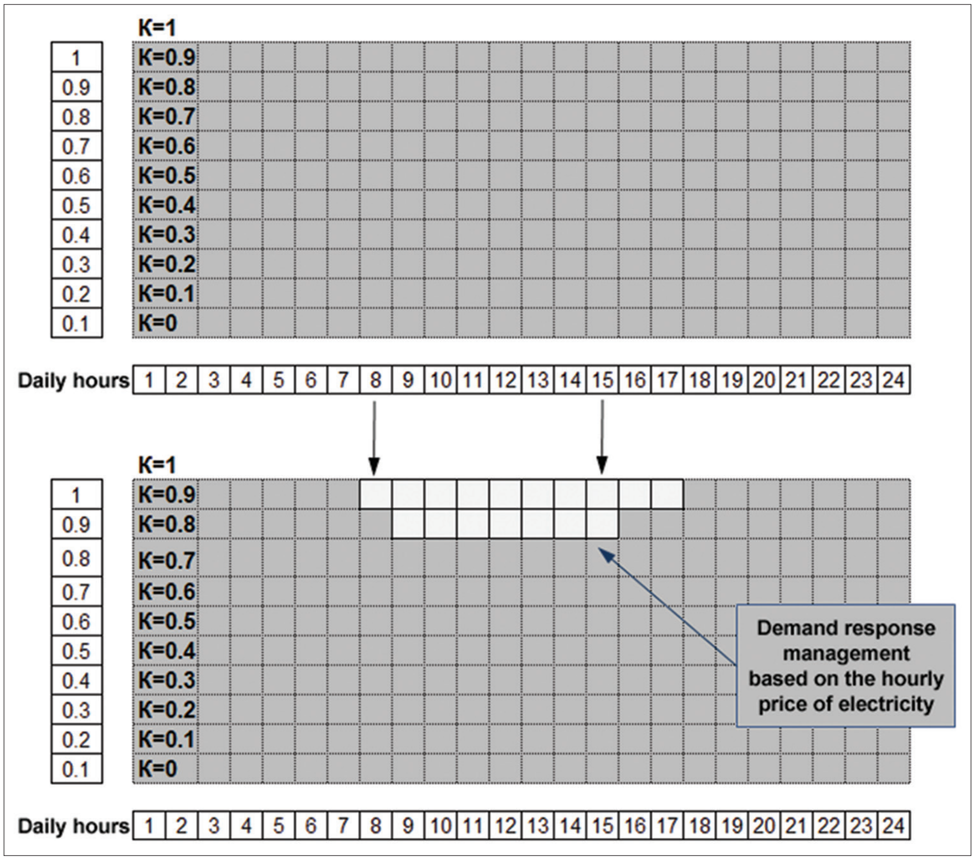
3.2. The Cost of the Component Charged for the Consumed Capacity

SY in the given month is calculated using Formula (4) below:

$$SY = \sum WM \times XHM \quad (4)$$

where *WM* is the amount charged to the consumer for the electric energy consumed in a given month (MW); it is calculated according to Formula (5) below;

Figure 8: Example of demand response management based on the electricity price



XHM is the price of the capacity payable by the consumer in a given month (RUB/MW per month)

$$WM = \sum [WHM \in LocGridDayPeakHrs] \Big/ \#WorkDaysMo \quad (5)$$

where *LocGridDayPeakHrs* is the hours of the local grid's daily consumption peaks during business days of a given month when the consumer purchased electricity. The grid's daily peak hours are planned by the National Grid Operator for each region specifically (Formula 6)

$$LocGridDayPeakHrs \in SchPeakHrs \in WorkDaysPeriods \quad (6)$$

SchPeakHrs is the scheduled peak consumption periods as defined by the National Grid Operator for each region specifically;

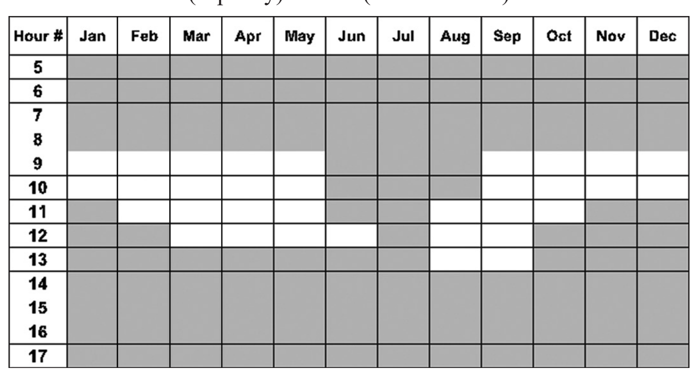
WorkDaysPeriods is periods of working days of a given month according to the national occupational calendar approved by the Government of the Russian Federation for each year;

#WorkDaysMo is the number of working days in a given month;

WM is calculated on a monthly basis based on the results of capacity trading at the wholesale electricity (capacity) market;

Figure 9 below shows the intervals of the grid's scheduled peak hours in the second price zone of the wholesale electricity (capacity) market, which includes the Siberian Federal District,

Figure 9: Periods of scheduled peak hours in 2022 as established for consumers operating in the 2nd price zone of the wholesale electricity (capacity) market (Moscow time)



as approved by National Grid Operator for 2022. As follows from the diagram below, the intervals stably cover a period equal to 13 h of a day and include gaps between the daytime hours. These intervals are approved for the forthcoming year and are known to consumers before the beginning of the year.

Figure 10 shows the actual hours of the daily peak consumption in local grids of the Siberian Federal District in June 2022. Thus, in June 2022, the intervals of the scheduled peak hours constituted 12 h (the first period is from 5 to 11 am Moscow time, and the next period is from 1 to 5 pm Moscow time). Noteworthy, the numbers of hours of the local grid's daily peaks diverged only in part from the planned interval.

Figure 10: Actual hours of the daily peak consumption of electricity in the regional grids in the Siberian Federal District, as of June 2022

Peak hour #	Altai Republic	Altai Region	Irkutsk Region	Kemerovo Region	Krasnoyarsk Region	Novosibirsk Region	Omsk Region	Tomsk Region	Tyva Republic	Republic of Khakassia
5	0	0	1	0	0	0	0	0	3	0
6	0	0	0	0	2	0	0	2	1	4
7	9	10	4	2	8	10	0	2	0	3
8	8	2	0	1	6	6	10	12	0	2
9	3	0	4	1	0	1	5	0	3	2
10	0	8	0	2	0	3	0	5	3	0
11	0	1	1	0	2	1	6	0	2	0
13	0	0	0	1	1	0	0	0	2	6
14	0	0	0	2	1	0	0	0	0	2
15	1	0	0	12	0	0	0	0	2	1
16	0	0	1	0	1	0	0	0	2	0
17	0	0	10	0	0	0	0	0	3	1

For example, in the Republic of Altai, the hours of the local grid's daily peaks occurred only at 7, 8, 9 am and 3 pm Moscow time. In the Republic of Tyva, the number of hours with the local grid's consumption peaks was greater.

Therefore, if an industrial consumer is unable to directly or significantly impact the capacity price *XHM*, it definitely can directly impact the amount of its costs related the purchased capacity.

The price and cost of the component charged for the consumed electrical capacity *SY* is directly dependent on the nature of the demand curve *WH*, and can be managed by controlling the consumer's electricity consumption *WH* during the scheduled peak hours *SchPeakHrs* or the local grid's daily peaks *LocGridDayPeakHrs* (Formula 7).

$$SY = F(WHM \in [SchPeakHrs \in WorkDaysPeriods]) \quad (7)$$

During the scheduled peak hours on working days *SchPeakHrs* or the local grid's daily peaks on working days *LocGridDaysHrs*, industrial consumers can reduce their demand by shifting electricity consumption to the hours with the lowest cost of electricity, and thereby reduce the amount charged for the capacity component.

Figure 10 shows an illustration of managing the electricity acquisition costs of a mining data center depending on the capacity coefficient. For this example, the local grid's peak hour falls on 4 pm. To manage the costs related to the capacity component, the consumer adjusts its demand only for the hour which is the local grid's peak hour.

In the example below (Figure 11), the electricity demand curve is adjusted by 50% of a typical consumption of the mining data center system. Therefore, given the possibility of a step-by-step adjustment of various consumption parameters, and, hence, the amounts charged for the consumed capacity, we recommend to introduce a metric that would reflect the degree of the demand adjustment, and to call it the "capacity demand management coefficient" (Formula 8).

$$CapMngmt\ Coeff = \frac{\overline{WHMafter} \in [SchPeakHrs \in WorkDaysPeriods]}{\overline{WHMbefore} \in [SchPeakHrs \in WorkDaysPeriods]} \quad (8)$$

where $\overline{WHMafter}$ is the capacity charged for a given month after the demand response management (MW);

$\overline{WHMbefore}$ is the capacity charged for a given month before the demand response management (MW).

The capacity demand management coefficient allows consumer not only to account for the charged capacity fee, but also to more accurately plan their cost management parameters in the process of managing the electricity demand in mining data centers.

Figure 12 shows parameters of the average capacity prices paid by mining data centers in various regions of Russia's wholesale electricity (capacity) when adjusting their demand response using the capacity coefficient. As follows from the diagrams, as the *CapMgmtCoeff* decreases, so slowly does the capacity component of the mining data centers' average electricity prices. As follows from the diagrams, with the *CapMgmtCoeff* = 0, the value of average prices is zero. At the same time, the value of the capacity component included in the average electricity prices is different for each region of the Siberian Federal District, and the value of their consistent decrease also varies with a different elasticity as *CapMgmtCoeff* changes. This should be taken into account in the demand response management when driven by the capacity management coefficient.

3.3. The Cost of the Component Charged for Transmission Service

The *SZ* component can be calculated in two ways when selecting consumers, using either a single-price or a two-price tariffs on electricity transmission (///). Industrial consumers seeking to manage their remand response should use the two-price transmission tariff, which is detailed further.

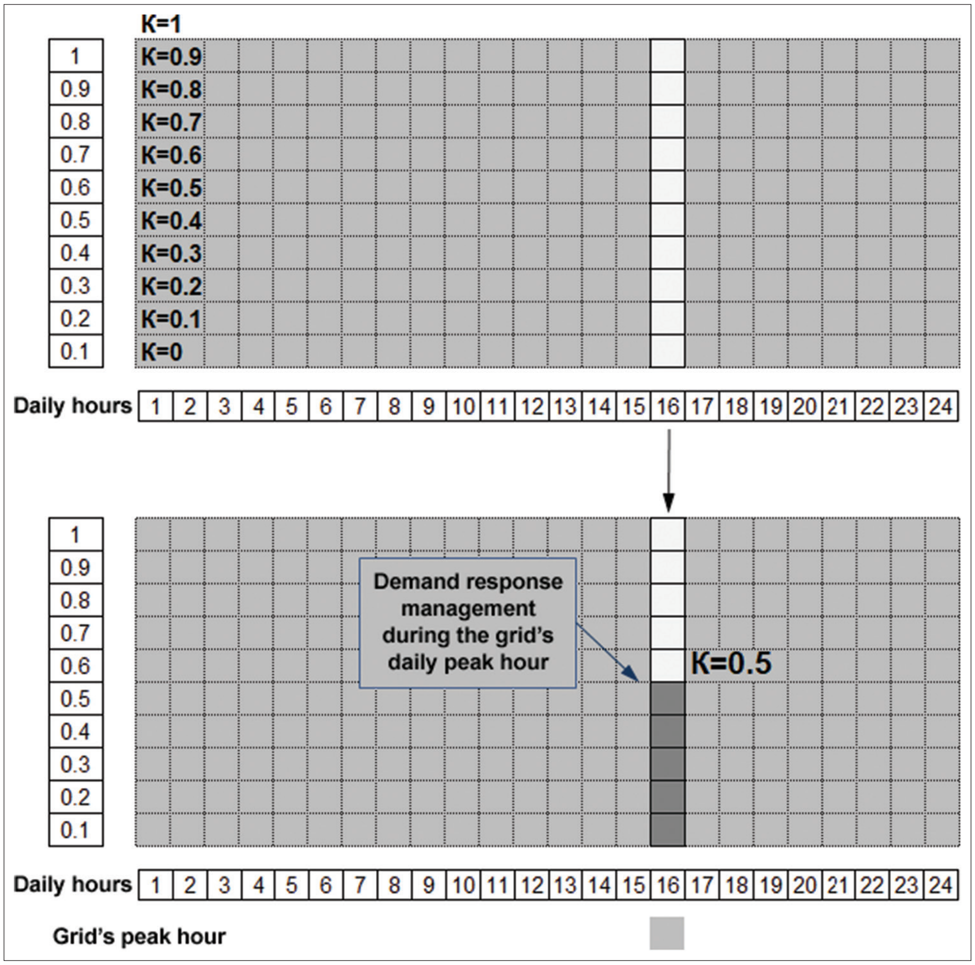
SZ in the given month is calculated using Formula (9) below:

$$SZ = SZMNtwMaint + SZMTechLoss \quad (9)$$

SZMNtwMaint is the component that reflects the cost of maintaining electrical networks as part of the transmission fee paid in a given month (in RUB) (Formula 10)

SZMTechLoss is the component that reflects the cost of technological losses in electrical networks as part of the transmission fee paid in a given month (in RUB) (Formula 12)

Figure 11: Example of demand response management using the capacity management coefficient



$$SZMNtwMaint = XNtwMaint \times WNtwMaint \quad (10)$$

where *XNtwMaint* is the fee charged for the maintenance of electrical networks as part of the two-price transmission tariff (in RUB/MW per month);

WNtwMaint is the amount of monthly capacity fee as part of the grid maintenance charge (MW) (Formula 11);

$$WNtwMaint = \sum \left[\begin{array}{l} MAX\_WHM \in SchPeakHrs \\ \in \text{WorkDaysPeriods} \end{array} \right] \Big/ \#WorkDaysMo \quad (11)$$

where MAX_WHM is the hourly threshold measured as the interval of the grid's scheduled peak load hours and established by the National Grid Operator for the working days of a given month based on the annual occupational calendar issued by the Government of the Russian Federation (MW).

$$SZMTechLoss = \sum WHM \times XTechLossRate \quad (12)$$

where *XTechLossRate* is the rate charged for the technological losses in electrical networks as part of the two-price transmission tariff (in RUB/MW per month);

The price and cost of the component charged for the transmission services *SZ* is also directly dependent on the nature of the demand curve *WH*, and can be managed by controlling the company's electricity consumption *WH* during the scheduled peak hours *SchPeakHrs* (Formula 13).

$$SZ = F(WHM \in [SCHPEAKHRS \in WORKDAYSPERIODS]) \quad (13)$$

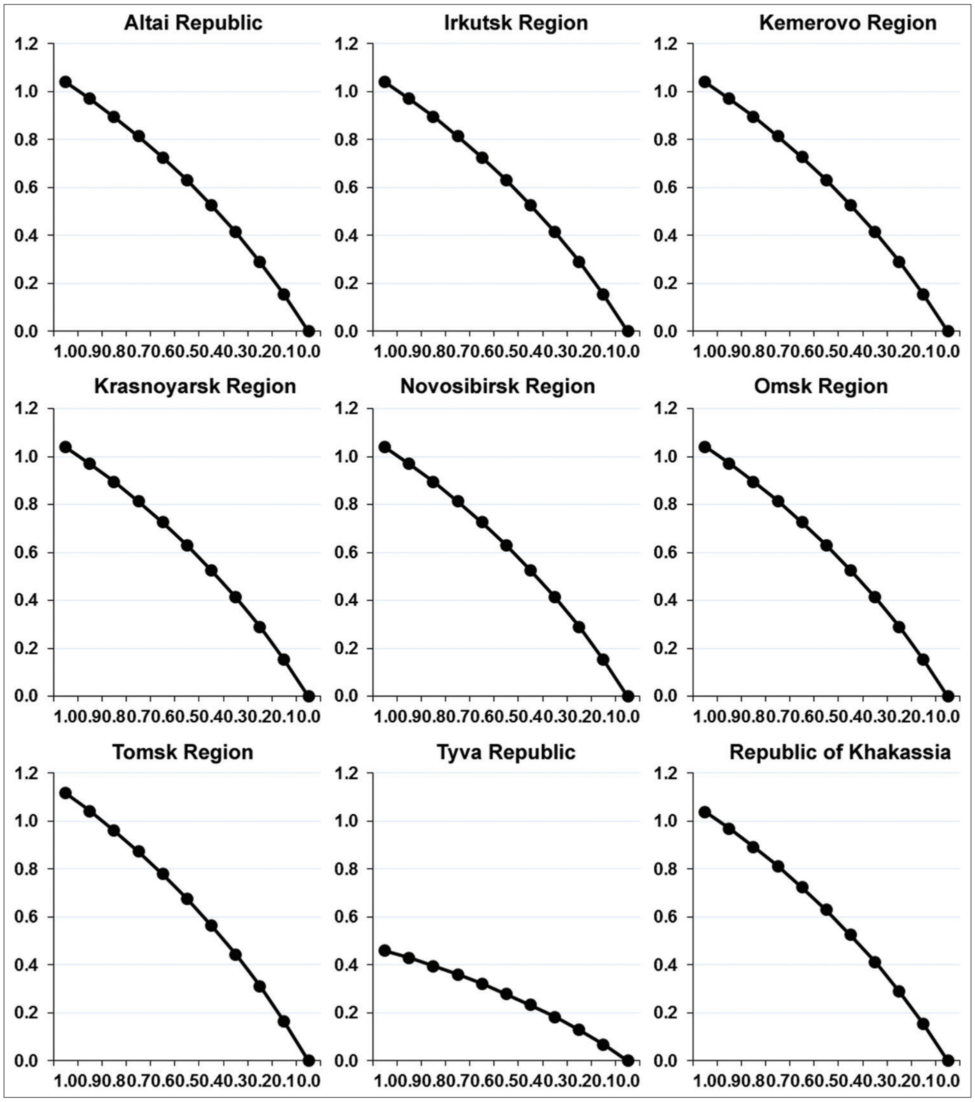
During the scheduled demand peaks on working days *SchPeakHrs*, the consumer can reduce its demand by shifting electricity consumption to the least-priced hours and thereby reduce its costs charged for transmission services.

4. DATA CENTER POWER PURCHASE COST MANAGEMENT EXAMPLE AND MODEL

4.1. Data Center Power Purchase Cost Management Example

Figure 13 below is an illustration of managing the electricity purchase costs in mining data centers in June 2022 using the transmission cost management coefficient. As follows from the diagram, the period of scheduled peak hours is from 5am to 11am and from 1pm to 5 pm. Based on Formulas (5) and (6) above, in order to manage energy costs using the transmission cost

Figure 12: Indicators of the average prices for the capacity component purchased by data centers in the wholesale electricity (capacity) market in various regions of Russia vs. the capacity demand response management (vertical axis – price for capacity in RUB per kWh; horizontal axis – the capacity demand management coefficient)



management coefficient, it is necessary to reduce the demand during all intervals of scheduled peak hours. If the demand is not reduced in all of these intervals, the indicator *WM* will take into account the demand in the hour when such reduction was not made.

In this example (Figure 13), the consumer reduces its demand in all intervals of the scheduled peak hours, with the reduction of up to 70% of the base electricity consumption of the mining data center. Therefore, given the possibility of a step-by-step adjustment of various consumption parameters, and, hence, the amounts charged for transmission services, we recommend to introduce a metric that would reflect the degree of the demand adjustment, and to call it the *"transmission cost management coefficient"* (Formula 14).

$$\begin{matrix} Transm \\ MngmtCoeff \end{matrix} = \frac{\overline{WHPafter} \in \begin{bmatrix} SCHPEAKHRS \in \\ WORKDAYSPERIODS \end{bmatrix}}{\overline{WHPbefore} \in \begin{bmatrix} SCHPEAKHRS \in \\ WORKDAYSPERIODS \end{bmatrix}} \qquad (14)$$

where $\overline{WHPafter}$ is the capacity charged for a given month after the demand response management (MW);

$\overline{WHPbefore}$ is the capacity charged for a given month prior to the demand response management (MW).

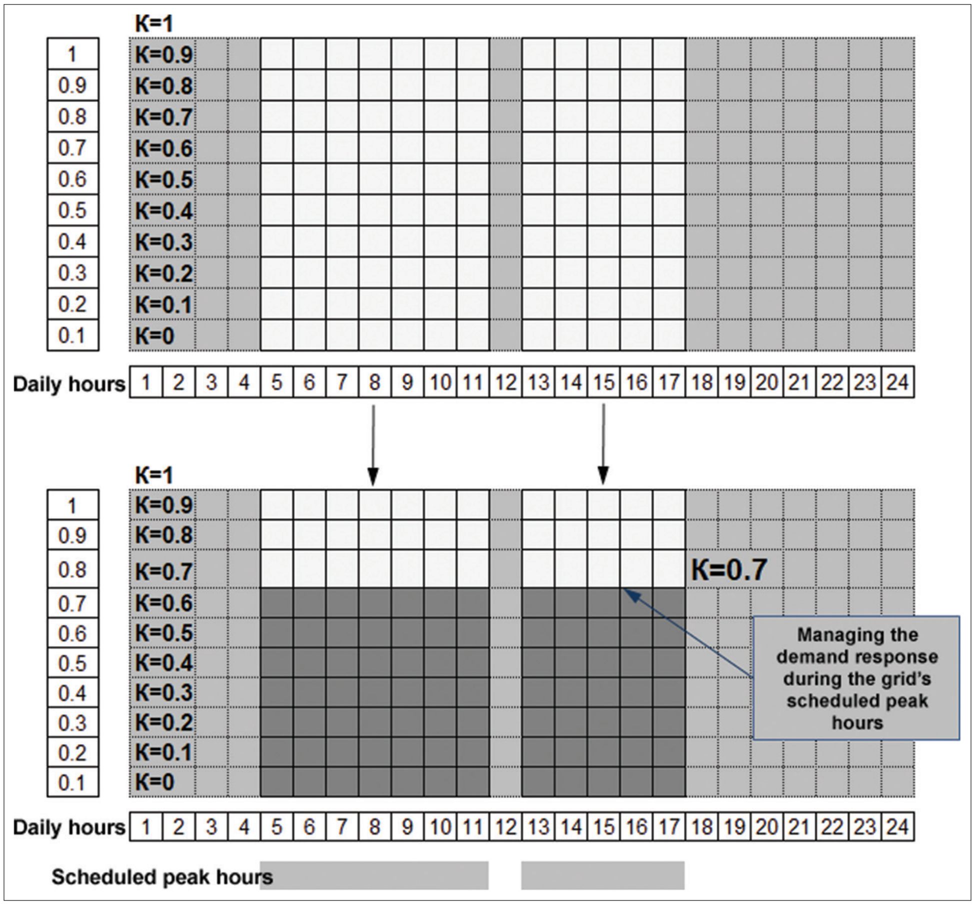
The transmission cost management coefficient allows consumer not only to account for the charged capacity fee, but also to more accurately plan their cost management parameters in the process of managing the electricity demand in mining data centers.

Therefore, by managing their demand, large industrial consumers can bring down their electricity acquisition costs across all of its components: the electricity fee, the capacity fee and the transmission fee in a given month (Formula 15).

$$P = SX + SY + SZ = F(WHM) \qquad (15)$$

By managing their demand curve while also taking into account the pricing specifics of each of the electricity price's components,

Figure 13: Example of demand response management based on the transmission price, as of June 2022



industrial consumers, including mining data centers, can effectively manage their energy costs.

Figure 14 below shows the parameters of the average prices for the electricity purchased by mining data centers in the wholesale electricity (capacity) market in the constituent regions of the Siberian Federal District based on the management of the transmission cost management coefficient during the grid's scheduled peak hours. The price of electricity consumption is calculated for all components of the electricity using Formula (16) below.

$$PM = P / \sum WHM \quad (16)$$

where *PM* is the average price for the purchase of electrical energy by the consumer in a given month (in RUB/kWh);

P is the price of the electrical energy purchased by industrial consumer in Russia's wholesale and retail electricity (capacity) market in a given month (Formula 1 above) (in RUB).

As follows from the calculations of the electricity prices at different transmission cost management coefficient values during the grid's scheduled peak hours, the demand response management allows reducing the average electricity price. The demand response management results in a lower ultimate price of the purchased electricity across all regions – by 70% of initial value. E.g., the reduction reached 95% in the Republic of Tyva vs. 78% in the Tomsk Region. The difference in the price ranges when managing the demand response is due to the specifics of the components constituting the cost of electric energy in each region and the Siberian Federal District in particular.

Also, the pricing specifics of the electricity price's components impacts the elasticity with which *TransmMngmtCoeff* impacts the *PM* indicator. Figure 15 below shows a diagram of the indicators of the electricity price elasticity in the regions of the Siberian Federal District vs. managing the demand response coefficient from 1 to 0.9.

As follows from the coefficient elasticity diagrams, the degree of change in the price of purchased electricity when managed using *TransmMngmtCoeff* varies across different regions of the Siberian Federal District. This should also be taken into account by the mining data centers as they perform demand response management.

Therefore, when managing the costs related to purchasing electricity in mining data centers operating in the Siberian Federal District of Russia, the consumers should take into account some important pricing specifics, such as:

1. Local prices on the constituent components of the electricity price – the component charged for the consumed electrical energy; the component charged for the consumed capacity; and the component charged for transmission services;
2. The specifics of hourly consumption of electrical energy by the mining data centers;

Figure 14: Indicators of the average prices for electricity purchased by data centers in the wholesale electricity (capacity) market in various regions of the Siberian Federal District vs. the transmission price response management (vertical axis – price for capacity in RUB per kWh; horizontal axis – the demand management coefficient during scheduled peak hours)

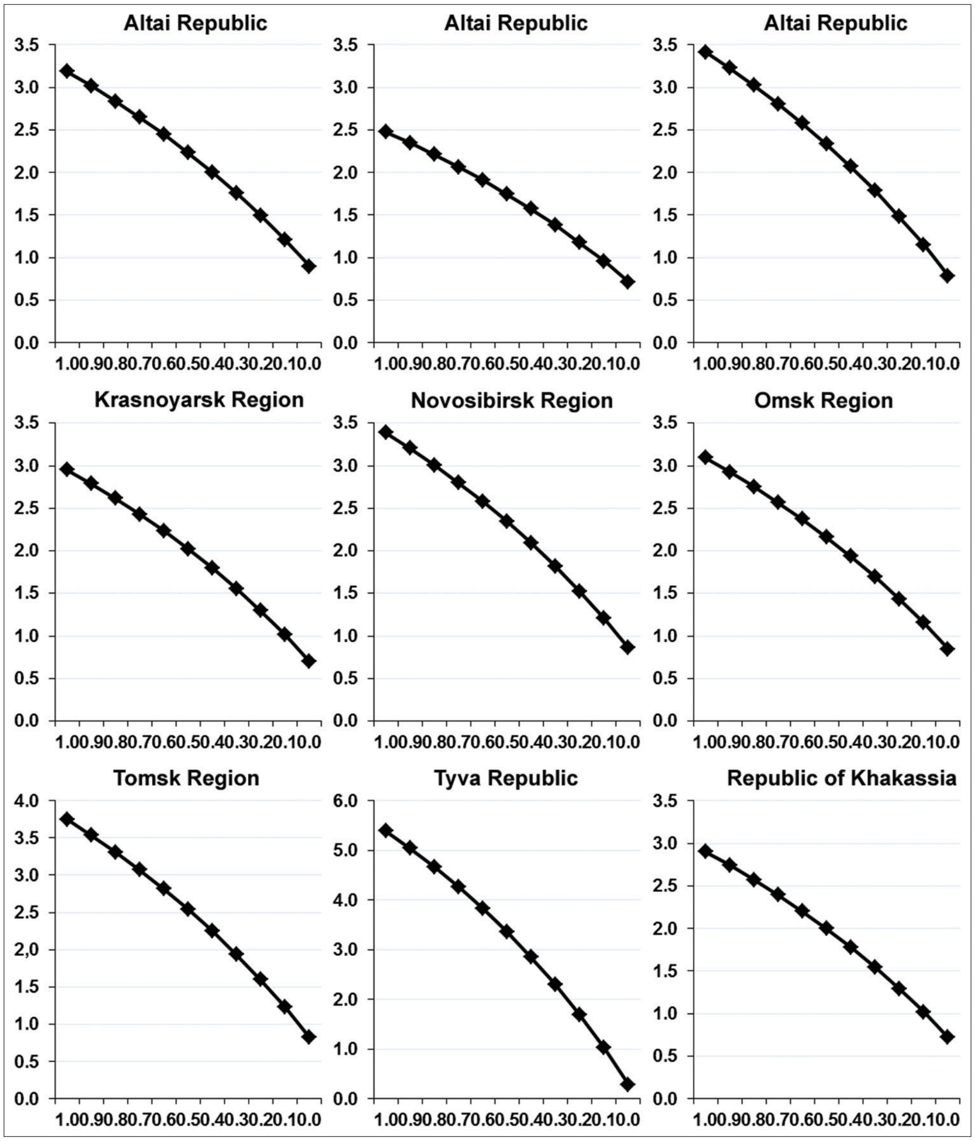
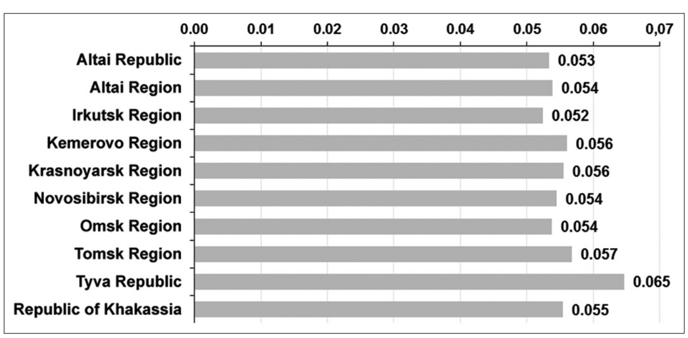


Figure 15: Indicators of the electricity price elasticity in the regions of the siberian federal district versus managing the demand response coefficient from 1 to 0.9



3. Periods of the grid's scheduled peak load hours;
4. Hour intervals with the local grids' daily peaks;
5. Daily intervals with the peak cost of electric energy;
6. Coefficients for managing the demand curve (the capacity demand management coefficient and the transmission cost management coefficient);
7. Parameters of the average electricity prices when using the demand response management coefficients; and
8. Elasticity coefficients reflecting the degree of impact on the electricity prices.

However, the above parameters take into account only the external specifics of electricity pricing and disregard the internal specifics of demand the response management actions.

Whereas mining data centers have constant demand curves throughout a day, shifting the demand to a different time interval is not always feasible. Therefore, mining data centers should also take into account the potential losses from their demand response management actions, which are calculated using Formula (17) below.

$$DRMngmtLoss = MaintExp + LP + OtherExp \quad (17)$$

where *DRMngmtLoss* is the losses due to the demand response management actions in a given month (in RUB);

MaintExp is the estimated maintenance expenses due to the downtime (in RUB);

LP is the estimated lost profit due to the mining farm downtime (in RUB);

OtherExp is other expenses associated with the non-return of investments in equipment and labour costs for the period of equipment downtime (in RUB).

Losses from the implementation of demand response management action in a given month are then compared with the resulting savings in electricity purchases which are calculated using Formula (18) below:

$$ElecSavingM = BasicElecP - DRMngmtElecP \quad (18)$$

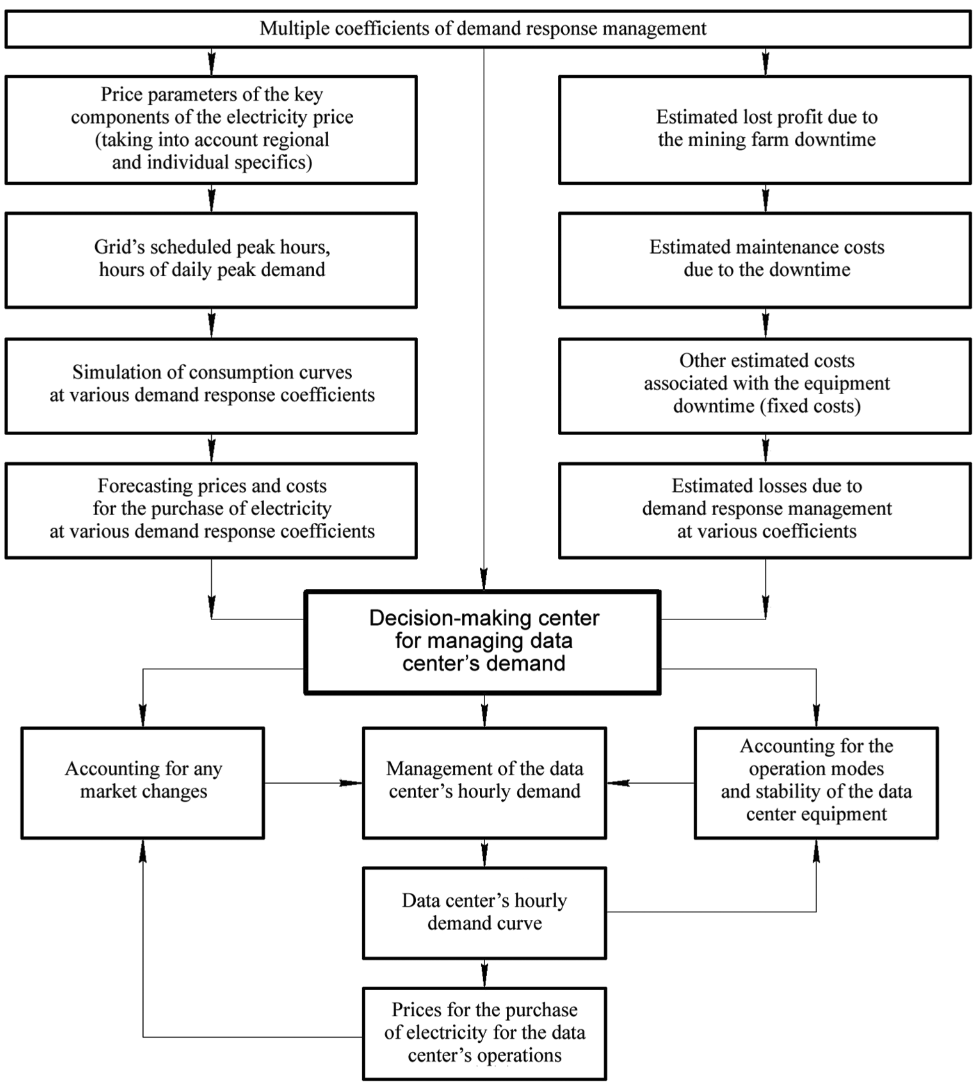
where *ElecSavingM* is the amount of savings in electricity purchases as a result of the demand response management actions undertaken in a given month (in RUB);

BasicElecP is the basic price of purchased electricity before demand response management in a given month (in RUB); and

DRMngmtElecP is the price of purchased electricity after demand response management in a given month (in RUB).

Once the losses from the implementation of demand response management actions in a given month are estimated, mining data centers should then run a simulation to compare different options of adjusting their demand curves. Based on the comparison of the parameters of demand response management, internal costs associated with it and the external effect in the form of saving in electricity purchases, consumers then select the required demand management coefficients and implement further demand management actions and operational adjustments in their operations.

Figure 16: The model of managing electricity costs in mining data centers



4.2. Electricity Purchase Cost Management Model

Figure 16 below shows the integrated model of the electricity cost management for mining data centers operating in the Siberian Federal District. As follows from the figure above, the model consists of two blocks of analysis: (1) the analysis of environmental factors, including parameters that affect the electricity pricing in the energy market, and (2) the impacts of internal factors, including the costs incurred by a mining farm due to the downtime of its mining equipment during the period of active demand response management. The data on the external and internal factors are used in simulations and forecasting with varying demand management parameters, after which they are summarized in a single decision-making center of a given mining farm. When making demand response management decisions, mining data centers perform hourly demand management, which in turn impacts the hourly demand in the wholesale or retail electricity (capacity) markets and, hence, directly impacts the electricity price ultimately paid by the mining data center.

Also, the management of mining data centers' operations involves operational monitoring of their equipment's stability and response adjustments to the demand curve. Moreover, mining data centers monitor price fluctuations and the energy market in general, which involves pro-active simulations and timely response adjustments to the centers' operating regimes.

5. CONCLUSION

In the presented work, an in-depth study of the possibilities of managing the costs of purchasing electricity for computing data processing centers for the production of cryptocurrencies was carried. It based on price-dependent control of the power consumption schedule in the conditions of the electricity market. As a result of the study, significant opportunities were identified for regulating prices for the purchase of electrical energy, which, in the context of a decrease in world exchange prices for cryptocurrency in 2022, allows large and medium-sized global players to maintain financial stability and profitability in the production of cryptocurrencies.

Modern research in the field of managing the mining data centers' operations lacks sufficient focus on the issue of reducing energy costs of the mining farms. However, given the downward trend in the cryptocurrencies exchange rates, the issue of reducing energy costs related to electricity acquisition by mining technologies presents high relevance and practical significance. A study of the structure of the global market for the production of cryptocurrencies showed that Russia's economy has a number of economic and geographical specific features that contribute to the favourable climate for the cryptocurrency production systems. These include: a relatively low cost of electricity from the national grid compared to most other countries; the availability of free-to-use electrical capacities at industrial enterprises in Russia; the availability of free electrical capacities for technological connection of electricity consumers in local grids, etc.

Taking into account the high potential of hydro generation, the lowest prices for electricity supplied by large consumers of electricity in Russia are concentrated in the regions of the Siberian Federal District. This is due to the concentration of a large number of high-capacity hydroelectric power plants in the Siberian grid. At the same time, electricity prices vary significantly across different regions of Siberia, which is due to several factors. The price of electricity is impacted by internal factors of the consumer, such as individual energy tariff and demand curves, which should be taken into account when managing the costs of purchasing electricity from industrial data centers for the production of cryptocurrencies, which are characterized by the constant nature of electricity load schedules and the possibility of decommissioning parts of equipment.

The formation of the cost of electricity purchased on the wholesale and retail electricity markets in Russia is formed on the basis of three main cost components: the amount of payment obligations for consumed electric energy, the amount of payment obligations for consumed electric power, and the amount of payment obligations for the electricity transmission service.

The cost and price of each component is based on the hourly demand of each industrial consumer. Using the suggested parameters of the capacity demand management coefficient and the transmission cost management coefficient, mining data centers are able to manage their electricity acquisition costs.

The results of the calculations showed that adjusting the value of the coefficient for managing the payment for the cost of electricity transmission services makes it possible to manage the indicators of average prices for the purchase of electricity for computing data centers operating in all territories of the Siberian Federal District of Russia. At the same time, when managing the demand for electricity in computing data centers, the final prices for the purchase of electricity in all regions are on average reduced to 70% of their original value. In the Republic of Tyva, prices are reduced by 95%, in the Tomsk region by 78%. The difference in the ranges of price changes when managing load schedules is associated with the specifics of the components of the cost of electric energy in each region of Russia and the Siberian Federal District in particular.

When managing the mining data centers' energy costs, one should take into account the impacts of environmental factors, including parameters that affect the electricity pricing in the energy market, as well as the impacts of internal factors of a given data center system, including the costs incurred by a mining farm due to the downtime of its mining equipment during the period of active demand response management. The suggested energy cost management model takes into account both internal and external factors of a mining data center as well as monitoring of its operations along with the price factors in the wholesale and retail electricity markets, and pro-active demand adjustments.

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