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Article

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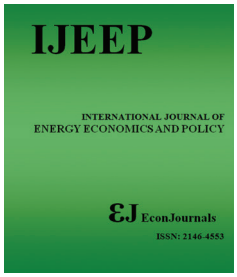

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Conditions for Effective Long-term Energy Supply to the Arctic Areas of the Republic of Sakha (Yakutia)

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ABSTRACT

This paper presents a comparative assessment of the efficiency of electricity production and consumption in the Eastern economic zone (EEZ) of the Republic of Sakha (Yakutia). Based on the analysis, the existing electricity supply risks in the EEZ areas are identified and recommendations for efficient electricity consumption and production in the EEZ areas are developed. The study makes it possible to develop sound recommendations for improving the efficiency of electricity production and consumption in the Oymyakonsky District of the EEZ. No relevant studies of the EEZ, including the Oymyakonsky District in the Republic of Sakha (Yakutia), have been conducted over the past five years. In this regard, the relevance of the study stems from the fact that not only natural but also cost indices of electricity production and consumption are calculated for the first time, and recommendations for efficient electricity consumption are given in the context of the Oymyakonsky district settlements of the EEZ.

Keywords: Electric Power, Electricity Generation and Consumption, Eastern Economic Zone
JEL Classifications: Q4, R0, R1

1. INTRODUCTION

In accordance with the Energy Strategy of the Republic of Sakha (Yakutia) for the period up to 2030, developed by the Government of the Russian Federation (The Scheme for Integrated Development, 2016), the GRP of the Republic of Sakha (Yakutia) is expected to increase by almost 8.5 times by 2030 in comparison with 2005. Such growth will be ensured, first of all, by the implementation of large projects of resource-extracting industries and transport infrastructure, which will determine the republic's industrial development.

In order to define the strategy, it is necessary to form conditions for the development of the republic's fuel and energy complex and balance with regard to the development of non-traditional energy (throughout the Eastern economic zone [EEZ]), which can have a significant impact on economic, social and cultural processes in the republic. In our study, the following analytical materials were used: The Energy Strategy of the Republic of Sakha (Yakutia) for the Period Up to 2030 (The Scheme for Integrated Development, 2016), the Scheme for Integrated Development of Productive Forces, Transport and Energy of the Republic of Sakha (Yakutia) up to 2020 (Petrov, 2005), the General Layout of Power Facilities Up to 2035 (The General Layout of Power Facilities, 2017), Annual Reports of PJSC Kolymaenergo for 2011-2016, Annual Reports of PJSC Magadanenergo for 2011-2016, Annual Reports of PJSC Yakutskenergo for 2011-2016, Annual Reports of Sakhaenergo JSC for 2011-2016, Official materials of the Ministry of Housing and Utilities of the Republic of Sakha (Yakutia), Official materials of the Ministry of Industry and Geology of the Republic of Sakha (Yakutia), Official materials of the State Committee for Price Policy of the Republic of Sakha (Yakutia), The Scheme and Program for the Development of the Energy Industry of the Republic of Sakha (Yakutia) for 2017-2021, The Russian Statistical Yearbook Rosstat data etc.

The research object is the natural resource potential of the extractive and processing industry in the EEZ.

The objectives of the study are as follows:
- To present an analysis of the existing general and specific problems of electricity supply in the Oymyakonsky district of the EEZ;
- To give scientifically grounded proposals and recommendations on efficient electricity consumption and production in the EEZ areas.

2. RESEARCH METHODS AND METHODOLOGY

The problem of conditions for effective long-term energy supply isn't new for the world economic study. E.g., the problem of the efficiency of electric heating and development of renewable energy sources was central for the previous surveys of Elyakova, Koryagina, Pakhomov et al. (Elyakova and Koryagina, 2015; Elyakova et al., 2016; Petrov et al., 2010). This question is also presented in the researches of Mougouei and Mortazavi - they consider a balance between energy supply and demand to be one of the challenges faced by policy makers; according to their study the main objective of energy planning is to achieve the balance and energy models can be used for supply and demand future planning of a country or region (Mougouei and Mortazavi, 2017); Nnaemeka and Boo - their paper reviews the standpoint of efficent energy management with strategic concentration on the demand side energy savings and RE resource potential in Nigeria to ensure sustainable development (Nnaemeka and Boo, 2015); Kinoshita - found that households reduce electricity use if monthly electricity rates increase and if they recognize the possibility of outages that might be effective to announce the possibility of outages or instability of supply to households as a nudge (Kinoshita, 2017).

Such scientific methods are used in the research:
- General scientific methods (the systematic and historical method, the method of analysis and synthesis);
- Specific scientific methods (the method of enquiry, the problem-chronological method);
- Theoretical methods with subsequent analysis and generalization of findings (statistical, observation and comparison, balance and empirical methods).

Statistical collections of the Russian Federation (2000–2016), analytical and static reports of the municipal districts of the Republic of Sakha (Yakutia) (2000–2016) and reports of PJSC Yakutskenergo, JSC Sakhaenergo were used as an information database for the development of the fuel and energy balance.

3. RESULTS AND DISCUSSION

3.1. General Characteristics of Energy Supply to the EEZ

The Oymyakonsky District belongs to the Northern Energy Area (JSC Sakhaenergo), while the Tomponsky and Ust-Maysky Districts are part of the Central Energy Area (PJSC AK Yakutskenergo).

The current and prospective energy supply scheme for the Republic of Sakha (Yakutia) is shown in Figure 1.

The current and prospective energy supply scheme for the EEZ of the Republic of Sakha (Yakutia) is shown in Figure 2.

Electricity supply to consumers from centralized sources (SDPP, HPP, APP and CHP), if they provide electricity to a single network of the power system, is considered to be the most reliable and efficient power supply system, especially in the area of diesel power engineering, where the production cost is very high.

In the Ust-Maysky District, centralized energy supply covers the largest part of consumers (95.6%), in the Oymyakonsky and Tomponsky Districts - 83.3% and 82.9%, respectively. The smallest share of consumers in these regions (4.4–17.1%) is covered by decentralized power supply from local diesel power plants, mainly from basic diesel power plants of JSC Sakhaenergo and reserve diesel power plants of PJSC Yakutskenergo.

In the Tomponsky and Ust-Maysky Districts, centralized power supply is provided from the Yakutsk SDPP through the Central Electric Networks (PJSC Yakutskenergo), and decentralized power supply is provided by JSC Sakhaenergo and PJSC Yakutskenergo.

In the Oymyakonsky District, three settlements (Ust-Nera settlement, Artyk village, Teryut village) are provided with centralized power supply from Kolymskaya and Ust-Srednekanskaya HPPs of PJSC Kolymaenergo through the Western Electric Networks of PJSC Magadanenergo, their share is 83.3% in total electricity consumption. In all other settlements electricity is supplied by the local diesel units of JSC Sakhaenergo.

The volumes of consumption of electric and thermal power, boiler-furnace fuel and coal production in the EEZ districts are presented in Table 1.

3.2. Electricity Consumption

In the Oymyakonsky district, three settlements (Ust-Nera settlement, Artyk village, Teryut village) are provided with centralized power supply from Kolymskaya and Ust-Srednekanskaya HPPs of PJSC Kolymaenergo through the Western electric networks of PJSC Magadanenergo, their share is 96.3% in total electricity consumption. In all other settlements electricity is supplied by the local diesel units of JSC Sakhaenergo (3.62%).

Proceeding from a retrospective analysis of consumption and production of fuel and energy resources of the EEZ in the Oymyakonsky District, we can state that there was a steady increase in 2011-2016, except for a small decrease in 2014 (Table 2).

The indices of electricity consumption from decentralized energy sources of JSC Sakhaenergo by groups of key consumers in the Oymyakonsky district for 2012–2016 are given in Table 3.

Figure 1: The current and prospective energy supply scheme for the Republic of Sakha (Yakutia) (The Scheme for Integrated Development, 2006)

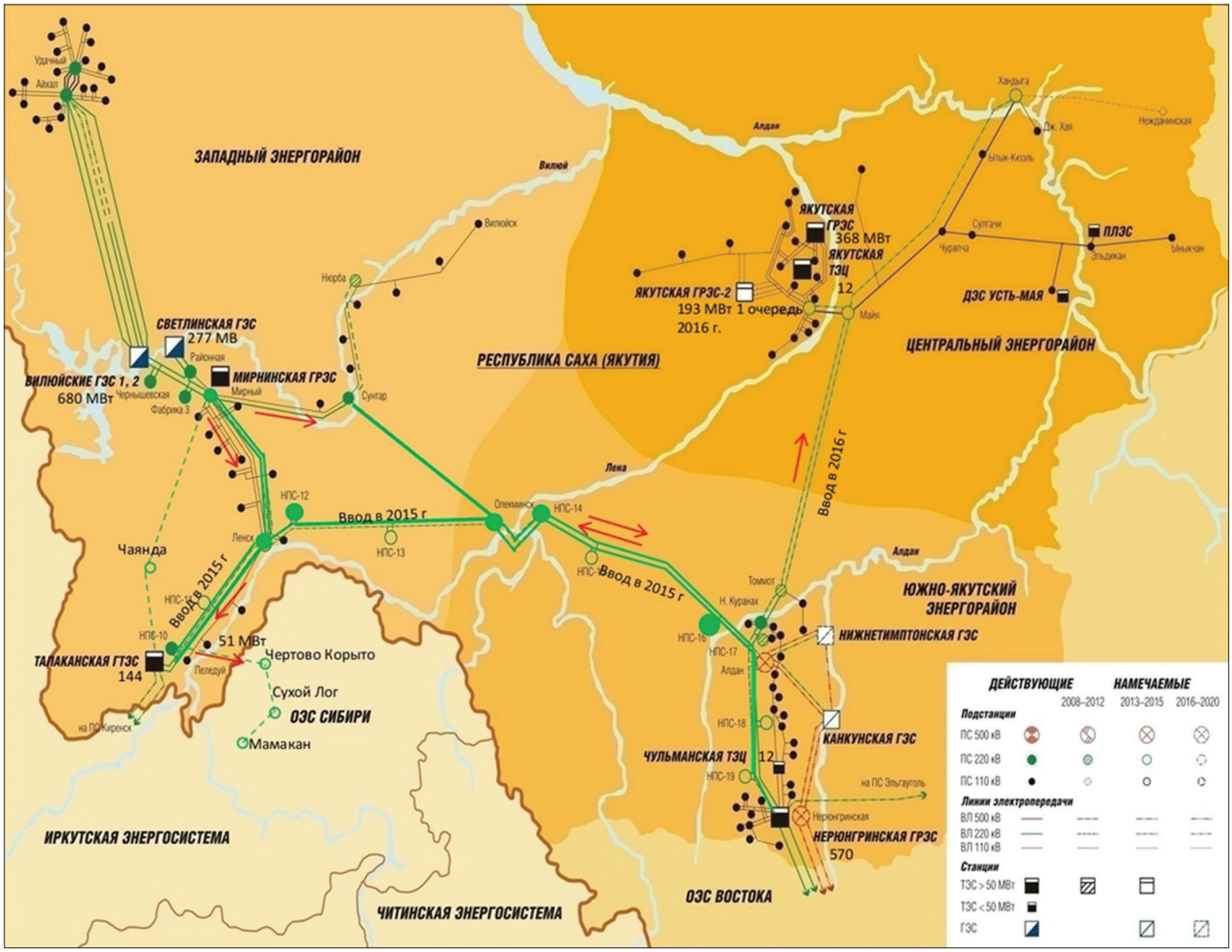

Table 1: The main indices of consumption and extraction (production) of fuel and energy resources of the EEZ (as of 2016)

Index	Oymyakonsky ulus	Tomponsky ulus	Ust-Maysky ulus	Total for EEZ
Extraction (production) of fuel and energy resources				
Thermal energy, thousand Gcal	212	329	208	749
Coal, thousand tons		398		
Consumption of fuel and energy resources				
Electricity, thousand kWh	123683	45469	46295	215447
Thermal energy, thousand Gcal	155	249	142	546
Boiler-furnace fuel, toe, total	45883	96295	41648	183826
Including				
Coal	45868	68884	41648	156400
Oil fuel		3071		3071
Diesel fuel	15	24340		24355
Boiler-furnace fuel, tons, including				
Coal of dzhebariki-khaya coal,	10594	89294	53988	153877
Coal of arcagalinsky	54973			54973
Oil fuel		2122		2122
Diesel fuel	10	16795		16805

Compiled by the authors based on data of the executive authorities of the Republic of Sakha (Yakutia)

There was a slight increase in electricity consumption from decentralized power sources of JSC Sakhaenergo by groups of key consumers in the Oymyakonsky district in 2012–2016. Significant growth was observed inrealization, which was associated with the annual increase in tariffs. In 2016, compared to 2012, tariffs increased by 60% due to budget organizations and enterprises of housing and utilities infrastructure (66%), population (55%) and other consumers (45%). An increase in

Figure 2: Energy infrastructure in the Eastern economic zone

tariffs will probably lead to a reduction in electricity consumption by enterprises and, accordingly, will affect the standard of living of the population.

3.3. Electricity Production

3.3.1. JSC sakhaenergo

According to the main production indices of decentralized power supply of the power networks of JSC Sakhaenergo in the Oymyakonsky district as of 2016, presented in Table 3, the total length of the overhead line in the Oymyakonsky district is 122.1 km, the largest electricity production is 70.1 thousand kWh in Kuydusun, and the smallest - 32.3 thousand kWh - in Yuchyugey SPP-30. The losses in the networks around the district amount to 12.3% (Table 4).

The evaluation of the main electricity production indices of DPPs of JSC Sakhaenergo in the Oymyakonsky District during the period under review shows that small diesel power plants operate in the settlements and transmit electric power to consumers, isolated from centralized supply. In Yuchegey there is a small solar power plant (30,000 kW), functioning along with a diesel power plant. The cost price of all SPPs is high because of the high cost of energy storage, but lower than at DPPs. Specific natural fuel consumption at DPPs and network losses are within the regulatory limits. The volume of imported diesel fuel is 3,079 tons in the amount of 96.4 million rubles (the cost of 1 ton of diesel fuel is 31,309 rubles).

In the Oymyakonsky district, the wearing of the main electrical equipment and DPP buildings is observed (Table 5).

Table 2: Electricity consumption by settlements in the Oymyakonsky district of the EEZ, thousand kWh

Total for Oymyakonsky district	2005	2010	2011	2012	2013	2014	2015	2016	2016/2012, %	Share, %
	-	-	118621	121172	121793	118748	122264	123683	102.1	
Centralized power supply from Magadanenergo										
Total*	-	-	113600	116800	117600	114400	117600	119200	102.0	96.3
Ust-Nera	-	-	-	-	-	-	-	-	-	-
Artyk	-	-	-	-	-	-	-	-	-	-
Teryut	-	-	-						-	-
Decentralized power supply from DPP Sakhaenergo										
Total	5285	4742	5021	4372	4193	4348	4664	4483	102.5	3.62
Kuydusun	568	2751	3028	2611	2345	2360	2496	2308	88.4	8.6
Oymyakon	1286	1143	1113	959	994	1036	1031	1042	108.6	3.9
Orto-balagan	456	435	443	389	429	525	685	661	170.0	2.5
Tomtor	2574									
Yuchyugey	400	413	437	413	425	427	451	472	114.6	1.8

Compiled by the authors based on data of the Ministry of Housing and Utilities of the Republic of Sakha (Yakutia) for centralized power supply and data of JSC Sakhaenergo for decentralized power supply

Table 3: Electricity consumption from decentralized energy sources of JSC Sakhaenergo by groups of key consumers in the Oymyakonsky district

Consumers	2012			2016			2016/2012		
	Volume	Revenue	Tariff	Volume	Revenue	Tariff	Volume	Revenue	Tariff
	Thousand kWh	Thousand rubles	Rubles/ kWt	Thousand kWh	Thousand rubles	Rubles kWt	%	%	%
Total amount	4372	13769	3.15	4483	22578	5.04	103	164	160
Population, total	2081	4224	2.03	2112	6630	3.14	101	157	155
Budget, total	501	2047	4.09	510	3460	6.78	102	169	166
Enterprises of housing and utilities infrastructure	1383	5603	4.05	1465	9813	6.70	106	175	165
Others	408	1895	4.65	396	2675	6.75	97	141	145
Kuydusun									
Total	2611	8499	3.25	2308	12424	5.38	88	146	165
Population, total	1124	2282	2.03	1041	3267	3.14	93	143	155
Budget, total	315	1290	4.09	275	1992	7.25	87	154	177
Enterprises of housing and utilities infrastructure	867	3511	4.05	725	5238	7.22	84	149	178
Others	305	1416	4.65	267	1926	7.21	88	136	155
Oymyakon									
Total	959	2847	2.97	1042	3987	3.83	109	140	129
Population, total	535	1086	2.03	576	1810	3.14	108	167	155
Budget, total	121	497	4.09	121	638	5.27	100	128	129
Enterprises of housing and utilities infrastructure	241	978	4.05	279	1246	4.47	115	127	110
Others	62	287	4.65	66	293	4.44	107	102	96
Orto-Balagan									
Total	389	1099	2.82	661	3644	5.51	170	332	195
Population, total	242	491	2.03	277	870	3.14	115	177	155
Budget, total	32	131	4.09	69	497	7.25	215	381	177
Enterprises of housing and utilities infrastructure	100	405	4.05	280	2022	7.22	280	499	178
Others	16	72	4.65	35	255	7.21	227	352	155
Yuchyugey									
Total	413	1324	3.21	472	2523	5.34	114	191	167
Population, total	180	366	2.03	217	683	3.14	121	187	155
Budget, total	32	130	4.09	46	333	7.25	144	255	177
Enterprises of housing and utilities infrastructure	175	709	4.05	181	1307	7.22	103	184	178
Others	26	119	4.65	28	201	7.21	109	169	155

Compiled by the authors based on data of JSC Sakhaenergo

The wearing of the main electrical equipment of diesel power plantsand electric networks within 75% in the villages of Oymyakon and Orto-Balaganand the high wearing of buildings (120%) in the Oymyakon village indicates that it is necessary to modernize and reconstruct them.

The analysis of the cost price ofelectricity production by DPPs in general for the Oymyakonsky district in 2013–2016 shows that the largest share in the cost price is spent on diesel fuel (64% and 51%) (Tables 6 and 7).

3.3.2. PJSC kolymaenergo and PJSC magadanenergo

To evaluate the reliability of electricity supply to consumers in the Oymyakonsky District, the power and electricity balances of PJSC Kolymaenergo and PJSC Magadanenergo of the Magadan Region of the Russian Federation were considered (Tables 8 and 9).

Table 4: The main production indices of decentralized power supply of DPPs of JSC Sakhaenergo in the Oymyakonsky district

Name	Oymyakonsky district	Kuydusun	Oymyakon	Orto-Balagan	Yuchyugey	Yuchyugey SPP-30
Installed capacity						
MW	4.6	2.0	1.4	0.6	0.5	0.0
Length of overhead lines						
km	122.1	70.1	39.2	7.3	5.5	-
Electricity generation						
Thousand kWh	5832.8	3179.7	1296.5	764.4	559.9	32.3
In-house needs, e/p						
Thousand kWh	223.5	106.8	43.2	25.7	47.8	0.0
%	3.8	3.4	3.3	3.4	8.5	0.0
Net output						
Thousand kWh	5609.3	3072.9	1253.3	738.6	512.1	32.3
Network losses						
Thousand kWh	690.6	402.5	168.9	61.4	57.3	0.5
%	12.3	13.1	13.5	8.3	11.2	1.6
Production needs						
Thousand kWh	138.5	138.5	0.0	0.0	0.0	0.0
Household needs						
Thousand kWh	297.0	224.1	42.3	16.1	14.5	0.0
Net supply						
Thousand kWh	4483.2	2307.9	1042.1	661.1	440.3	31.8
Natural fuel consumption						
tons	1539.5	835.6	369.2	198.0	136.8	0.0
Reference fuel consumption						
toe	2232.3	1211.6	535.3	287.0	198.3	0.0
Specific natural fuel consumption						
g/kWh	276.0	271.9	294.5	268.0	267.1	
Specific reference fuel consumption						
Goe/kWh	400.3	394.3	427.1	388.6	387.2	

Compiled by the authors based on data of JSC Sakhaenergo for 2016

Table 5: The wearing of the main electrical equipment and DPP buildings in the settlements of the Oymyakonsky district for 2016

Index	Kuydusun	Oymyakon	Orto-Balagan	Yuchyugey
Electric power of DPP (kW)	2045	1395	600	530
Wearing of diesel generators (%)	54	76	75	15
Wearing of buildings (%)	40	120	63	15

Table 6: Analysis of the cost of electricity produced by DPPs of JSC Sakhaenergo in the Oymyakonsky district, rubles/kWh

Settlement	2016								
	Cost price, million rubles	Including				Net supply, million kWh	Cost price of 1 kWh, rubles/kWh	Economically justified tariff, rubles/kWh	Average tariff, rubles/kWh
		Fuel, million rubles	Payroll budget with unified social tax, million rubles	Industrial services and materials, million rubles	Other expenses, million rubles				
Total	188.0	96.4	49.8	12.5	29.3	4.9	38.4		5.04
Kuydusun/ tomptor	95.4	53.1	22.4	5.4	14.5	2.6	36.2	39.9	5.38
Oymyakon	47.1	23.5	12.6	4.5	6.5	1.1	41.0	44.8	3.83
Orto-Balagan	24.2	11.4	7.2	1.8	3.8	0.6	38.1	41.5	5.51
Yuchyugey	21.4	8.4	7.6	0.9	4.5	0.5	44.1	47.8	5.34

According to the presented indices of the electricity balance of PJSC Kolymaenergo, there is a constant excess for the period under review within the range of 455–495 MW due to the actual lack of demand for electrical loads associated with a sharp reduction in electricity consumption mainly because of the closure of gold mining enterprises in the Magadan Region. Thus, the Magadan power system has two HPPs with significant idle discharges due to the lack of consumers. The tariffs for electricity produced by PJSC Kolymaenergo amounted to 1.11 rubles/kWh in the first half of 2017 and to 1.29 rubles/kWh in the second half of 2017 (the cost of electricity generation at the Vilyuyskaya HPP cascade is 0.49 rubles/kWh, its transfer to the Western electric networks –136 rubles/kWh, and the economically justified tariff in the EEZ–3.5 rubles/kWh).

The effective electric capacities of the Arkagalinskaya SDPP and Magadanskaya HPP of PJSC magadanenergo provide for

Table 7: Analysis of the cost of electricity produced by DPPs of JSC Sakhaenergo in the Oymyakonsky district, million rubles

Index	2012	2013	2014	2015	2016	2016/2012, %	Share 2016, %
Oymyakonsky district							
Cost price, including	117	154	156	181	188	160	100
Fuel	54	99	75	99	96	180	51
Payroll budget with unified social tax	34	40	44	48	50	148	26
Industrial services and materials	8	12	11	12	13	158	7
Other expenses	22	4	26	21	29	133	16
Kuydusun/tomptor							
Cost price, including	59	80	79	91	95	160	100
Fuel	32	48	43	47	53	164	56
Payroll budget with unified social tax	13	16	18	20	22	168	24
Industrial services and materials	4	6	6	7	5	134	6
Other expenses	10	11	12	16	14	147	15
Oymyakon							
Cost price, including	28	37	38	46	47	167	100
Fuel	12	37	18	21	24	191	50
Payroll budget with unified social tax	9	10	11	13	13	147	27
Industrial services and materials	2	4	3	3	4	196	10
Other expenses	5	−15	6	9	6	127	14
Orto-Balagan							
Cost price, including	16	20	21	23	24	152	100
Fuel	5	7	7	9	11	244	47
Payroll budget with Unified Social Tax	6	8	8	7	7	112	30
Industrial services and materials	1	1	1	1	2	191	8
Other expenses	4	4	4	5	4	98	16
Yuchyugey							
Cost price, including	14	17	18	21	21	158	100
Fuel	4	7	6	21	8	194	39
Payroll budget with unified social tax	5	6	7	8	8	143	36
Industrial services and materials	1	1	1	1	1	123	4
Other expenses	3	4	4	-9	5	142	21

Compiled by the authors based on data of JSC Sakhaenergo for 2016

Table 8: The electricity balances of PJSC Kolymaenergo, MW

Balance item	Year							
	2010	2011	2012	2013	2014	2015	2016	2016/2010
Installed capacity of PJSC Kolymaenergo, total	900	900	900	1068	1068	1068	1068	119
Kolymskaya HPP	900	900	900	900	900	900	900	100
Ust-Srednekanskaya HPP	0	0	0	168	168	168	168	-
Available capacity of PJSC Kolymaenergo, total	887	881	877	937	975	959	980	110
Kolymskaya HPP	887	881	877	888	878	880	893	101
Ust-Srednekanskaya HPP	0	0	0	48	97	80	87	-
Excess (+)/deficiency (-)	507	480	410	455	479	507	495	98

Compiled by the authors based on data of PJSC Kolymaenergo and PJSC Magadanenergo for 2010–2016

Table 9: The electricity balances of PJSC Magadanenergo, MW

Balance item	Year							
	2010	2011	2012	2013	2014	2015	2016	2016/2010
Installed capacity of PJSC magadanenergo, total	320	320	320	320	320	320	320	100
Arkagalinskaya SDPP	224	224	224	224	224	224	224	100
Magadanskaya HPP	96	96	96	96	96	96	96	100
Available capacity of PJSC magadanenergo, total	320	320	320	320	320	320	320	100
Arkagalinskaya SDPP	224	224	224	224	224	224	224	100
Magadanskaya HPP	96	96	96	96	96	96	96	100
Excess (+)/deficiency (-)	0	0	0	0	0	0	0	-

Compiled by the authors based on data of PJSC magadanenergo for 2010–2016

the in-house needs of the Magadan Region and operate at a minimum load, because electricity production at hydroelectric stations is much cheaper than at SDPPs and HPPs. In the long-term plan, the 2nd and 3rd stages of the Ust-Srednikanskaya HPP will be commissioned, and its installed capacity will reach 369 MW instead of the currently installed 168 MW. Consequently, the

excess of PJSC Kolymaenergo will increase to 696 MW. Electricity is planned to be consumed by developing mining enterprises and consumers of the Chukotka Autonomous Okrug when the Bilibinskaya NPP is closed in connection with the development of the service life of nuclear reactors.

The construction of 110–220 kV electric networks in the direction of Maya-Khandyga-Dzhebariki-Khaya is a strategically important starting point for the unification of the Yakutsk and Magadan energy systems and the operation of the Magadan energy system in parallel with the UES of Russia.

For the Oymyakonsky District, it will be possible to transfer five settlements to centralized power supply from PJSC Magadanenergo, which are located in the decentralized power supply zone of JSC Sakhaenergo, during the construction of VL-220 to the Taryn gold ore company. Currently, the Development Corporation of South Yakutia prepared a feasibility study for its construction.According to preliminary calculations, the project cost is more than 3 billion rubles.

The annual electricity balance is formed on the basis of a comparison of the demand for electricity with the possibilities of generating electricity at the in-house power plants of the energy system and obtaining it from other energy systems.

The annual operating mode of power plants of the Magadan energy system for a number of retrospective years is quite stable and is covered by the available capacities (Table 10).

The electricity production of Kolymskaya and Ust-Srednekanskaya HPPs amounted to 95% of the total electricity production in the region in 2016 (Table 11).

An analysis was made of the main types of electricity supply risks and their consequences for the Oymyakonsky district of the EEZ of the Republic of Sakha (Yakutia).

4. CONCLUSIONS

The following specific technical threats were identified in the Oymyakonsky district:

- Absence of power transmission lines from a centralized energy source like PJSC Kolymaenergo and PJSC Magadanenergo

Table 10: The electricity balances of PJSC Kolymaenergo, million kWh

Balance item	Year							
	2010	2011	2012	2013	2014	2015	2016	2016/2010
Output, total	1979	2033	2030	2045	1931	1953	2001	101
Including Kolymskaya HPP	1979	2033	2030	1924	1558	1673	1663	84
Ust-Srednekanskaya HPP				121	373	281	337	-
Consumption, total	65	50	44	48	55	57	44	68
Including Kolymskaya HPP	24	24	23	24	23	24	24	100
Ust-Srednekanskaya HPP				2	7	8	8	-
Electricity supply to the network, total	1914	1983	1987	1997	1877	1896	1957	102
Including Kolymskaya HPP	1914	1983	1987	1881	1516	1628	1633	85
Ust-Srednekanskaya HPP				116	361	268	324	-
Electricity losses in energy networks, total	10	9	8	9	12	13	12	124
Useful energy consumption, total	1914	1983	1987	1997	1877	1896	1957	102
Including Kolymskaya HPP	1914	1983	1987	1881	1516	1628	1633	85
Ust-Srednekanskaya HPP				116	361	268	324	-

Compiled by the authors based on data of PJSC Kolymaenergo for 2010–2016

Table 11: The balance of electricity production and consumption of PJSC Magadanenergo, million kWh

PJSC Magadanenergo	2011	2012	2013	2014	2015	2016	2016/2011
Electricity production (million kWh)	142.6	145.7	160.5	179.3	162	105.4	74
Arkagalinskaya SDPP	34.5	37	42.2	32	28.4	19.8	57
Magadanskaya HPP	108.1	108.7	118.3	147.3	133.6	85.6	79
Electricity consumption (million kWh)	376.2	390	390.4	398.7	386.5	373.2	99
Electricity supply (million kWh)	311.1	320.3	327.2	326.7	323.2	317.5	102
Electricity losses in energy networks (million kWh)	65.2	69.7	63.2	71.9	63.3	55.7	85
Electricity losses in energy networks (in % to supply to the network)	17.3	17.9	16.2	18	16.4	14.9	86
Electricity purchased from PJSC Kolymaenergo	1983	1987	1997	1877	1896	1957	102
Useful electricity supply with regard to electricity purchased from PJSC kolymaenergo (million kWh)	1963.8	1972.3	1997.9	1906	1316.4	1712.3	87.2
Losses in networks (million kWh)	360.4	334.9	328.6	395.6	297.6	301.1	83.5
Electricity losses, %	18.35	16.98	16.48	20.75	22.6	17.58	95.8

Compiled by the authors based on data of PJSC magadanenergo for 2013–2016

(energy-excessive Kolymskaya and Arkagalinskaya HPPs) with cheap cost between technologically energy-insulated settlements;
- Only 3 settlements (Ust-Nera, Artyk and Teryut) are covered by a centralized power supply with low tariffs for electricity from PJSC magadanenergo;
- High degree of deterioration of the energy production building in the village of Oymyakon.
- Possible consequences of these threats can be
- Lack of security of electricity supply to consumers;
- Impossibility of transferring excess energy and capacity to PJSC Kolymaenergo and PJSC Magadanenergo;
- Occurrence of accidents and emergencies in the energy sector;
- Accidents on power transmission lines, including high accident rates of electrical networks on wooden supports due to their wear and tear (breakdown of power transmission lines);
- Restriction of power supply to consumers;
- Threat of freezing settlements and villages, losses of electricity producers and consumers.

Specific economic threats were also revealed for the Oymyakonsky district:
- Absence of financing sources for the construction of VL-220 to the taryn gold deposit and its prolongation to 5 settlements of the district to reduce the import of diesel fuel;
- Growth of electricity production costs;
- Growth of tariffs for diesel fuel and an outstripping increase in prices for diesel fuel in comparison with tariffs for electricity.

Environmental threats for the Oymyakonsky district of the EEZ were also identified and analyzed:
- Gross emissions of pollutants into the air;
- Direct and indirect emissions of greenhouse gases (CO2, N2O in CO2eq., CH4 in CO2eq.);
- Discharge of pollutants with sewage from thermal power plants.

The long-term effective electricity supply to the EEZ, including the Oymyakonsky district, can be achieved under the following conditions:

1. To effectively provide electricity with regard to its supply to consumers, the development projects of perspective fuel and energy balances of the VEZ areas should be compiled in conjunction with complex social and economic development programs, not only in natural indices, as before, but also in cost ones, and, most importantly, in the context of each settlement. This is possible with the effective interaction of science, education, technology and production.
2. The advanced development of the basic branches of the fuel and energy complex should be carried out in accordance with the Strategy for the development of the fuel and energy complex of the Republic of Sakha (Yakutia) with regard to the country's perspective fuel and energy balances for EEZ settlements, including the balance of power and electricity consumption, compiled in natural and costindices, for a comprehensive assessment of their effectiveness using the economic-mathematical model (in the form of a software product).
3. Development programs including investment projects should be elaborated with regard to effective mechanisms for their implementation in EEZ settlements:
   - Institutional mechanisms - in order to ensure the effective functioning and development of the republic's fuel and energy complex, a management structure in the form of the Ministry of Fuel Industry and Energy of the Republic of Sakha (Yakutia) is needed. It should implement strategic planning and monitoring of the provision of fuel and energy resources and compilation of the fuel and energy balance of the Republic of Sakha (Yakutia), including in EEZ settlements;
   - Technological and technical mechanisms - scientific and industrial support in providing effective fuel and energy resources and drawing up a rational base and long-term balance of fuel and energy resources of specific areas of the regions in interconnection with each other and with economic zones;
   - Economic mechanisms - significant support in providing fuel and energy resources through tax regulation, budgetary policy, tariff and price policy at the republican and municipal level;
   - Investment mechanisms - the effective provision of fuel and energy resources for settlements depending on the republic's investment policy on the development and implementation of investment and energy-efficient projects for providing fuel and energy resources in settlements;
   - Environmental policy in the sphere of production and use of fuel and energy resources among producers of fuel and energy resources and among consumers, including the population, which ensures the preservation of the natural environment for the population and ecosystems of the region in the production and consumption of fuel and energy resources.
4. The maximum coverage of consumers by centralized power supply. In the Oymyakonsky ulus, the following activities are recommended: Connection to the centralized power supply system from PJSC Magadanenergo; construction of VL-220 kV; modernization of electrical equipment and reconstruction of power facilities.
5. Boiler houses using coal and diesel fuel and a private residential sector using firewood in the Oymyakonsky ulus should be transformed to electric heating using cheap electricity from PJSC Kolymaenergo and PJSC Magadanenergo for the production of thermal energy.
6. The following recommendations are also proposed for the development of renewable energy sources (RES), including the combined generation of electricity from diesel power plantsin conjunction with solar and wind power plants, in the Oymyakonsky District: To establish preferential tariffs for the use of electricity from RES; to provide state support for the purchase of RES installations and to provide tax incentives (along with high taxes/fines for traditional energy); to grant concessional loans and to subsidize investments for RES; to support research in the field of renewable energy. The development of RES will reduce fuel costs for diesel power plants, which will lead to a reduction in the cost of electricity production.

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