Energy Future of the Russian Far East: Low-Carbon Development Potential

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Abstract — **The paper discusses the current and future-oriented models of development of the energy sector of the Russian Far East. We demonstrate that the current model is aimed at maximizing the external rent and resource rent, and it is characterized by a low priority of the environmental policy and actually ignores the global trend of the energy transition. We assess the risks of sticking to the current model and "no action taken" development of the energy sector. We review institutional conditions and identify barriers to the development of low- and zero-carbon technologies in the current model. The future-oriented model aims to preserve the advantages of the current model and complement it with high-tech production facilities in the energy sector along with the transformation of the economy and energy in line with the energy transition trends. It is nowadays common to distinguish between two main groups of technologies that are part of the future-oriented model: hydrogen technologies and renewable energy. By focusing on the former, we analyze the conditions for the development of hydrogen technologies as applied to the subjects of the Far Eastern Federal District and identify competitive advantages and limiting factors.**

Index Terms: **energy transition, hydrogen technology, renewable energy sources (RES), institutional conditions, energy sector, the Russian Far East.**

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I. Introduction

Against the current background of the strengthening of the global climate agenda, the Government of the Russian Federation has declared the goal of achieving carbon neutrality of the country by 2060. Given the great social importance of energy supply, the high inertia inherent in industries of the energy sector, the speed and the possibility of achieving the established benchmark in Russia in principle will depend on the quality of institutions and resources that can be provided as part of state support. Given the large scale of the country and the managerial complexity of the task, it seems reasonable to focus on one of major territorial entities at the first stage, where it would be possible to put to test key managerial solutions to effectively support and stimulate the development of low- and zero-carbon energy sources.

In our opinion, the Russian Far East is one of the most promising testing grounds for applying new technological and institutional solutions to the energy sector. First, the development of this aggregated region has been recognized as a national priority, which is already reflected in a broad portfolio of institutional innovations in the economy. Second, a number of issues have accumulated in the region's energy sector, which are already in conflict with the tasks of accelerated socio-economic development of this macroregion and call for addressing them. Third, the Russian Far East remains an outlet for Russian energy resources targeting APAC markets. On the one hand, this imposes strict requirements on the standards of organization of production, logistics, and service to maintain its competitive edge in the markets of importing countries. On the other hand, it provides ample opportunities for increasing (or at least maintaining) the scale of energy resource production (and transit) in the long term.

The purpose of this study is to assess from the strategic standpoint the low-carbon development potential of the energy sector of the Russian Far East in the context of the

Table 1. Specific Consumption and Power Grid Losses in the Russian Far East and the Russian Federation as a Whole (in Coal Equivalent Terms)

Metric	Russian Far East	Russia
Actual consumption per unit of production, kg/MWh (in coal equivalent terms)	393.6	298.8
Actual consumption per unit of production, kg/Gcal (in coal equivalent terms)	161.5	156.8
Electricity losses in grids, % of electricity generated	11.9	9.2
Heat losses in networks, % of heat produced	14.7	8.8

Source: compiled by the authors based on the data in [18, 20].

global "green" energy transition. The first part describes the specifics of the implementation of state policy to improve energy efficiency and the development of renewable energy sources (RES) in the macroregion. It also identifies barriers to the development of low- and zero-carbon technologies. The second part of the article examines the institutional conditions for the establishment and development of a new model for the development of the energy sector in the Russian Far East. The study concludes with a comparison of key parameters of the current and future-oriented models of development of the energy sector of the macroregion. Conclusions are made on the challenges to be faced in the transition from one model to the other.

II. Literature Review

A large body of research published in this country and abroad has been devoted to analyzing the issues of the energy transition. The process of the energy transition itself is complex, cross-disciplinary, and involves many aspects. Oftentimes, the energy transition is seen in the broader context of the environmental agenda ("sustainable development") and the transition to a green economy. Published research on this subject mainly deals with the analysis of future trajectories of greenhouse gas emissions depending on scenario conditions [1–5].

A feature unique to the current energy transition is multiple technological breakthroughs that back the transition to new energy carriers. As a rule, studies on this subject discuss technologies that are basic for the actual implementation of the energy transition: RES, technologies for improving energy efficiency and development of energy saving, industrial-grade energy storage, dissemination of electric vehicles, technologies of CO2 sequestration, use and disposal, hydrogen energy. The fundamental role of RES dominates the views on the development of energy transition trends [6].

The significant role of the energy sector in Russia's economy necessitates an assessment of changes in its contribution to the economy under the influence of energy transition trends, including from the standpoint of prospects for entering new markets, risks of losing traditional market niches, the threat of technological backwardness of the country, etc. [7–10]. Scholars in the field are unanimous in that the current model of economic and energy sector development in Russia has exhausted itself and cannot ensure the country's accelerated development, while global trends in energy transition present not only a challenge for Russia's economy, which is based on the production and exports of energy sector products, but also new opportunities.

III. The Current Model of the Russian Far East Energy Sector in the Context of the Energy Transition

For many decades, the problem of high energy intensity of the national economy has received little attention in this country [8]. The state policy of increasing energy efficiency and energy saving started to intensify in 2008, when the President of the Russian Federation set a goal of reducing the energy intensity of the country's GDP in 2020 by at least 40% compared to 2007. The legal basis for implementation of this policy was provided by Federal Law No. 261-FZ of November 23, 2009 "On Energy Saving and Enhancing Energy Efficiency and on Amendments to Certain Legislative Acts of the Russian Federation". In 2014, the federal state program "Energy Efficiency and Energy Development," which includes the subprogram "Energy Saving and Energy Efficiency Enhancement," was adopted. However, four years later, in 2018, this subprogram was phased out, and the reference to energy efficiency disappeared from the name of the state program. Thus, the issue of high energy intensity of the economy and the need to enhance its energy efficiency was once again excluded from the priorities of the state policy. Since 2019, no specialized state program (subprogram) aimed at improving energy efficiency in Russia has been implemented.

It should be noted that some measures and initiatives to improve energy performance are carried out by corporations as part of the modernization of their production facilities based on the principles of commercial feasibility. In particular, this includes projects to modernize Russian refineries, including two in the Russian Far East. Despite considerable capital investment and improved production specifications, the indicators of consumption (in coal equivalent terms) per unit of output for the Russian Far Eastern refineries are still lower than the national average (Russia – 59.2 kg c.e., Far Eastern Federal District – 71.9 kg c.e.).

Another example is the state program to modernize Russia's thermal power industry, which included 6 thermal power plants (TPPs) of the Russian Far East with a total electric power capacity of about 2 GW, and a thermal capacity of over 2 500 Gcal/h. The modernization program assumes improvement in fuel consumption specifications. In 2023–2027 the program envisages the construction of the 2nd phase of Yakutskaya TPP-2, Khabarovskaya TPP-4, and Artemovskaya TPP-2, the modernization of Vladivostokskaya TPP-2, the expansion of Neryungrinskaya TPP and Partizanskaya TPP. As of today, thermal power plants in the Russian Far East are noticeably inferior to the national average in terms of energy efficiency, and power and heating networks are characterized by a higher level of losses (Table 1).

Another key element of the energy transition is renewables. Since 2013, Russia has been implementing individual measures of state support, differentiated by segments of the electricity market. The actual effectiveness of these measures leaves much to be desired. Russia lags far behind the leading countries in the scale of RES development and the amount of state support provided by them. As of 01.01.2022, the share of renewables in the installed capacity of the Unified National Power System of the country was only 1.6%, in the amount of electricity generated – 0.5% [11].

The current system of RES support in Russia is aimed at addressing two main issues: the development of own RES generation technologies and the establishment of production of corresponding equipment with deliveries to domestic and foreign markets. Accordingly, support measures focus on financing the construction of generating capacity rather than incentivizing green electricity sales as in most advanced countries [12].

The wholesale electricity (capacity) market enjoys the most favorable conditions in terms of state support. With the exception of the Republic of Buryatia and Trans-Baikal territory, which are included in the 2nd price zone of the wholesale market, the remaining regions of the Russian Far East cannot take advantage of state support measures for the development of RES operating in this type of market. More modest measures that are effective in retail markets also do not cover the entire macroregion: they are available only to the southern regions and parts of the Republic of Sakha (Yakutia) that are included in the Integrated Power System (IPS) of the East. In geographically isolated power systems (Sakhalin, Kamchatka, Magadan region, Chukotka autonomous district, and most of Yakutia) these measures prove ineffective. There it is only possible to claim state support provided for the modernization of inefficient generation facilities using the mechanism of energy service contracts.

These features of state support determined the spatial distribution of RES facilities in the macroregion. The most development of RES has taken place in the Republic of Buryatia and Trans-Baikal territory, where they were introduced as part of the support program for the wholesale market. In addition, significant RES generation capacity is characteristic of the Kamchatka territory, where 3 geothermal power plants (GeoTPP) operate, which, however, were built long before the modern stage of RES development.

In general, it can be stated that for the macroregion of the Russian Far East, with the exception of Yakutia and Buryatia, as well as Trans-Baikal territory, state support for the development of RES facilities is virtually not practiced.

Thus, the main directions of the energy transition, including enhancing energy efficiency, developing energy saving and low- and zero-carbon energy sources in Russia in general and in the Russian Far East in particular, are declarative in nature, the target indicators are very modest, and state support measures are clearly insufficient to stimulate large-scale development in these directions.

For the Russian Far East, we can identify several institutional barriers to improving energy efficiency and the development of low- and zero-carbon sources:

- lack of a unified policy on low-carbon development, including goals, priorities, and directions of development, as well as measures of state support that would take into account the specifics of the Russian Far East;
- the non-competitive nature of the procedures for selecting TPP modernization projects in the macroregion, which does not leave even the theoretical possibility of competition between alternative types of capacity and the existing ones;
- the pervasive dominance of monopolistic market structures that do not encourage cost reduction and efficiency growth at thermal power plants of the Russian Far East;
- different opportunities with respect to access to measures of state support for RES development depending on the geographical location and specifics of the functioning of regional power systems;
- the complexity and inefficiency of the mechanism of participation of municipal institutions in the program of modernization of inefficient generation facilities in isolated areas.

IV. Prerequisites for the Formation of a New Model of Development of the Energy Sector of the Russian Far East

Along with the development of RES, hydrogen technologies are considered another promising area as part of the energy transition [4, 9, 13]. Although Russia is at an early stage of development of such technologies, the government and industry experts of the country are already paying increased attention to this area.

Several fundamental strategic documents have been adopted that have prioritized the development of hydrogen technologies with a focus on foreign markets. Russia's Energy Strategy sets the goal of becoming one of the world leaders in hydrogen production and exports. According to the strategy's targets, hydrogen exports from the country should be 0.2 million tons per year by 2024 and 2 million tons per year by 2035. These targets have been detailed in the Action Plan for Hydrogen Energy Development to 2024. The Vision statement for hydrogen energy development in Russia, adopted last year, sets the guidelines for the

Table 2. Main Characteristics of the Announced Hydrogen Production Projects in the Russian Far East (as of 2021)

Federal subject of the Russian Federation	Product	Annual capacity	Process flow	Initiated by
Republic of Sakha (Yakutia)	NH_3	2026 – 3 million tons 2030 – 6 million tons	Steam conversion with CO_2 capture technology	"Northeast Alliance" Research and Manufacturing Corp.
Sakhalin region	H_2, NH_3	2024 – 30 thousand tons 2030 – 100 thousand tons.	Steam conversion with CO_2 capture technology	SC Rosatom Air Liquide PJSC Gazprom
	H_2	no data	Electrolysis, wind turbines	SC Rosatom
		2024 – 16 thousand tons 2030 – 150 thousand tons.	Electrolysis, wind turbines	H4 Energy
		2025 – 50 thousand tons	Electrolysis, wind turbines	H2 Chistaya Energetika
		2025 – 10 thousand tons	Electrolysis, wind turbines	H2
Magadan region	H_2	2025 – 16 thousand tons	Electrolysis, HPP	H2 Chistaya Energetika
Amur region	H_2	2027 – 110 thousand tons	Electrolysis, HPP	Regional Agency for Investment Promotion
Khabarovsk territory	H_2	2035 – 350 thousand tons.	Electrolysis, tidal turbines	
Kamchatka territory	H_2	2031 – 5 million tons	Electrolysis, tidal turbines	H2 Chistaya Energetika
Trans-Baikal territory	H_2	2023 – 3.2 thousand tons.	Electrolysis, SPP	Unigreen Energy, SKTBE JSC

Source: compiled by the authors based on the data in [4].

Table 3. Characteristics of Factors of Site Location of Hydrogen Production Projects in the Russian Far East (as of 01.01.2022)

Characteristic of site location factors	Republic of Sakha (Yakutia)	Sakhalin region	Amur region	Magadan region	Khabarovsk territory	Kamchatka territory
Installed capacity, incl., MW	3 233.1	1 565.5	4 386.5	1 754.2	2 808.6	758.5
HPP	957.5	1.4	3 660.0	1 327.5	-	47.1
other RES	2.9	14.2	1.3*	0.01	1.2	76.2
CUF, %	36.1	33.4	49.3	19.6	36.6	30.2
Average electricity purchase price, % of the national average	177	242	115	157	117	215
Natural gas reserves, billion cubic meters	2 971.4	1 524.7	-	-	-	7.8
Gas production, billion cubic meters	15.7	32.1	-	-	-	0.3
Water reserves, thousand cubic meters per day.	642	373.5	570.5	393.7	802.2	530.6
Actual water production, thousand cubic meters per day.	84	85	166	12	75	97
Distance to the border with China, thousand km	2.6	2.2	1.4	3.2	1.8	3.5

Note: * PV panels at HPPs

Source: compiled by the authors based on the data in [20, 27].

Table 4. Characteristics of Development Models for the Energy Sector of the Russian Far East

Metric	Current	Future-oriented
Objective function	maximization of external and resource rents	creation of new product niches for energy sector products
Type of rent	resource, external	resource, external, technological
Environmental policy priority	low	high
Hierarchy of interests	dominance of national over regional	balancing regional and national interests
Priority development of energy sector industries	extractive	processing
Linking of energy sector industries to the rest of the economy	poorly integrated into the regional economy	stimulating the development of regional demand for energy sector products
The role of the Russian Far East in the country's development strategy	a resource base and transit area	a platform for the introduction of new technologies and institutions

Source: compiled by the authors.

industry development to 2050 and envisages creation of four territorial clusters: North-West, East, Arctic, and South. In accordance with these documents, it is planned to implement a number of pilot projects in the field of hydrogen energy at nuclear power plants, gas production facilities, and raw material processing plants by 2024. The Comprehensive Program for the Development of the Low-Carbon Hydrogen Energy in the Russian Federation to 2050 is currently being developed [14–15].

Thus, today Russia has the basic institutional prerequisites for the further transformation of the energy sector, including through the development of hydrogen energy as one of the promising areas of low- and zero-carbon economy. The regulatory and legal framework has been largely formed, there are significant reserves of energy resources, including renewable resources, there is idle generating capacity (the installed capacity utilization rate is 51.5% on average in the UES of Russia), and the scientific and technological potential has been consolidated.

All these prerequisites for the creation of hydrogen production facilities are also in place in the Russian Far East. At the beginning of 2022, the total number of prospective investment projects for hydrogen production in Russia exceeded forty. Eleven projects were planned to be located in the Russian Far East macroregion ("Eastern hydrogen cluster"), of which five were in the Sakhalin region (Table 2). It is planned that the development of export-oriented industries will make it possible to optimize the power supply to domestic consumers in isolated and remote communities of the macroregion.

At the same time, zero-carbon ("green") hydrogen production projects are very electricity- and water-intensive, require significant capacities, and focus on the low cost of consumed electricity. Our analysis of the main location factors as applied to the above-mentioned regions, for which projects have been declared, allows us to highlight both advantages and disadvantages of the Russian Far Eastern territories as sites of hydrogen production (Table 3).

The main advantages of the Russian Far East with respect to the location and development of hydrogen production facilities there are its abundant resource base (both in terms of natural gas and water) and the short shipment leg distance to the main markets in the APAC region (primarily China). The downsides include poor RES development, lack of capacity of existing generation facilities, high electricity prices in the macroregion.

It is also important to note the risks involved. The main advantage of the creation of the "Eastern hydrogen cluster" being the proximity to the main hydrogen consumption markets is not immutable. Even though initially Russia's hydrogen energy development strategy considered three potential markets in the APAC region: China, Japan, and the Republic of Korea, in the changed environment, at least in the short and medium term, only China can become such a market. At the same time, China's strategy for the development of hydrogen technologies, unlike Japan and the Republic of Korea, is focused primarily on domestic hydrogen production [17].

V. Results

The outlines of the current model for the development of the energy sector in the Russian Far East were defined in the early 1990s. With the transition from centralized planning to a market economy, the economic system of the macroregion of the Russian Far Eastern was gradually transformed based on making use of its comparative advantages in international (cross-regional) trade. The abundance of natural resources that are in demand in the global market, the geographical proximity to the world's largest economies that are consumers of these resources in the context of low density of economic activity in the aggregated region, small population size, and remoteness from the central regions of the country, have predetermined the structure of the economy and the composition of energy sector industries as we know it today. The energy sector is a major export-oriented segment of the Russian Far East economy. The current model of sector development is focused mainly on maximizing the resource rent from the exports of primary energy resources, the scale of production of which is determined by the demand in global markets and the capacity of mining and transport infrastructure.

The current moment can be considered historic: the economy of the Russian Far East in general and that of the energy sector in particular are at the crossroads of choosing the future development path. Making the most of the opportunities that come with the "green" economy, which open up in connection with the need to achieve the goal of carbon neutrality, may allow to form a different model (paradigm) of development of the energy sector of the Russian Far East thus changing the system of priorities, interests, relationships, and the role of the energy sector in the economy. The key characteristics of the models under consideration are summarized in Table 4.

The future-oriented model is based on the departure from the colonial nature of the development of energy resources of the macroregion and the transition to a more nuanced model of the use of resources that reconciles regional and national interests. In addition, the new model involves the structural transformation of the sector with an increase in the share of processing industries: electricity generation based on RES, hydrogen, gas and oil refining products, gas- and petrochemicals.

In any case, the availability of abundant energy resources will remain a competitive advantage for Russia and the Russian Far East in global markets, hence the traditional specialization of the energy sector will probably be preserved, but it will need to be supplemented with new low- and zero-carbon products. The inertia of development inherent in the energy sector will not allow a forced transition to the future-oriented model. At the same time, it is necessary to accelerate progress in this direction in order to maximize the benefits that come with the green energy transition and mitigate the risks of falling into the "trap" of the "no action taken development if the window of opportunity is not taken advantage of.

VI. Discussion

Our assessments of the risks of development of the Russian Far East's energy sector under the "no action taken" scenario are in line with the claims voiced by those researchers in the field who argue that the energy sector is limited in its ability to serve as a source of funding for the national economy in the long term [8, 10].

In our opinion, the main barriers to the transition to a new, future-oriented model of energy sector development in the macroregion are weak institutions, which is consistent with the results of other studies [18]. The latter is especially critical for Russia, where the main driving force behind the implementation of the "green" energy transition is the state. At the same time, research contributions in the field of assessing the effectiveness of the quality of institutions in the industry-specific energy markets of fuel and energy are extremely scarce. In particular, an attempt was made to assess the effectiveness of institutions in stimulating RES development in Russia [19–21]. It is the study of the quality of institutions in the context of the formation and development of a new model of the Russian Far East energy sector that can become a promising area for further research in order to identify favorable conditions and reduce barriers to the development of a low-carbon economy in the Russian Far East.

These authors' views on the general outline of the future-oriented model for the development of the energy sector of the Russian Far East, which is based on renewable energy and hydrogen technology, align well with the vision of most foreign and Russian experts [4, 5, 9, 17]. Quantitative assessment of possible scenarios of formation and development of a new model of the energy sector of the macroregion of the Russian Far East can be carried out using simulations and will be a logical continuation of the present study.

VII. Conclusion

The current model for the development of the energy sector in the Russian Far East fails to ensure the accelerated development of the macroregion's economy. Sticking to this model preserves the technological backwardness of the sector and is accompanied by an increasing conflict between the logic of accelerated socio-economic development of the macroregion's economy and the energy backbone of this development.

The main constraint for the low-carbon development of the Russian Far East energy sector is the institutional environment, which must be transformed on a par with the adopted approaches to economic development. The energy sector of the Russian Far East should become a testing ground for the introduction of new technological and institutional solutions.

The regions of the Russian Far East have competitive advantages in creating hydrogen production, but their development is possible only in cooperation with APAC countries.

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