RENEWABLE ENERGY IN RUSSIA: SYSTEM ANALYSIS OF BARRIERS

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Considering the current ecological situation in the modern world, the quality of life depends not so much on a stable energy supply as on an environmentally friendly way of producing and consuming energy, which has turned social and research attention to the opportunities of renewable energy systems (RES). In spite of the vital necessity of transitioning to environmentally friendly energy production, the implementation and development of renewable energy technologies face a range of barriers: socio-cultural, technological, economic, institutional and environmental. To overcome these barriers, the authors of this article use the systems approach to gain deeper understanding of RES interconnection and interdependence. They apply STEEP analysis for classification and qualitative analysis of RES development barriers in Russia. The article proposes the analytical methodology, which reveals system specifications of the national RES development barriers and predicts the chain reaction of overcoming particular barriers. Using this methodology, the authors identify the main socio-cultural roots of RES development barriers in Russia: state control of the development of the energy sector, the political stake in hydrocarbons and the lack of consistent policies on RES development. The authors' suggested analysis methodology is appropriate for identifying the root *problems in energy socio-economic systems and for effective decision-making process in the energy sector.*

Keywords: renewable energy; system analysis of barriers; STEEP analysis; graph analysis.

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Introduction

Modern civilization is completely dependent on energy for its technical achievements and production. However, the existing ways of obtaining energy threaten the sustainable development of human civilization because of their increasing burden on the environment and destructive ecological effects.[1] This has led to the worldwide search for alternative ways of producing and consuming energy. The main alternative to producing energy today is the so-called green energy or renewable energy systems (RES). The general concept of RES includes all renewable natural energy resources, which do not have a significant negative impact on the environment and do not require drilling and mining operations:

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1 Oncel S. Suphi, *Green Energy Engineering: Opening a Green Way for the Future*, 142 J. Clean. Prod. 3095 (2017).

energy generated from water, wind and the sun, geothermal energy, and energy derived from biomass or biofuels.[2]

In the past thirty years, a great number of research efforts and political measures have aimed at developing and supporting new, more environmentally friendly technologies that significantly reduce the consumption of hydrocarbon fuels.[3] Scientists consider renewable energy an effective solution for economic development, meeting electricity needs, reducing environmental pollution and increasing the reliability of the energy supply.[4] Additionally, the positive outcomes of RES development have already manifested themselves in the ecological, economic and social spheres or will manifest them in the near future.[5] However, renewable energy development faces multifaceted interconnected barriers: socio-cultural, technical, economic, institutional and environmental,[6] whose commonality, locality and interconnection need to be well understood in order to be overcome, both at the local level and at the global level. Nonetheless, the use of renewables is expected to grow at an accelerated rate in the near-term. For the five-year period 2019 to 2024, capacity is anticipated to increase by 50%, led by solar power systems, and represents an increase of 1,200 GW.[7]

Barriers may be defined as elements that substantially reduce the probability of adoption of renewable energy[8] or as postulated mechanisms that inhibit investment in RES.[9] According to F. Beck and E. Martinot, the main barriers putting RES at a disadvantage in comparison to conventional energy production are of

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2 Luke Gibson et al., *How Green Is 'Green' Energy?*, 32(12) Trends Ecol. Evol. 922 (2017).

3 Zeng Ming et al., *Overall Review of Distributed Energy Development in China: Status Quo, Barriers and Solutions*, 50 Renew. Sustain. Energy Rev. 1226 (2015); International Renewable Energy Agency, Renewable Energy Capacity Statistics (2019) (May 15, 2021), available at https://www.irena.org/publications/2019/Jul/Renewable-energy-statistics-2019.

4 Mita Bhattacharya et al., *The Effect of Renewable Energy Consumption on Economic Growth: Evidence from Top 38 Countries*, 162 Appl. Energy 733 (2016).

5 International Renewable Energy Agency, Global Energy Transformation: A Roadmap to 2050 (2019) (May 15, 2021), available at https://www.irena.org/publications/2019/Apr/Global-energy-transformation-A-roadmap-to-2050-2019Edition.

6 Fredric Beck & Eric Martinot, *Renewable Energy Policies and Barriers* in *Encyclopedia of Energy* 365 (2004); Mohammed Yaqoot et al., *Review of Barriers to the Dissemination of Decentralized Renewable Energy Systems*, 58 Renew. Sustain. Energy Rev. 477 (2016).

7 International Energy Agency, Renewables 2019: Market Analysis and Forecast from 2019 to 2024 (October 2019) (May 25, 2021), available at https://www.iea.org/renewables2019.

8 Kenneth Gillingham & Karen Palmer, *Bridging the Energy Efficiency Gap: Policy Insights from Economic Theory and Empirical Evidence*, Resources for the Future Discussion Paper No. 13-02-REV (October 2013) (May 15, 2021), https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.401.3256&rep=rep1&type=pdf.

9 Patrik Thollander & Jenny Palm, *Barriers to Energy Efficiency: Theoretical Baseline, Previous Research, and Methodological Approaches* in Patrik Thollander & Jenny Palm, *Improving Energy Efficiency in Industrial Energy Systems: An Interdisciplinary Perspective on Barriers, Energy Audits, Energy Management, Policies, and Programs* 35 (2013).

a technical, economic, regulatory or institutional nature.[10] According to M. Jarach, the barriers to RES diffusion can be classified into technical (technological and manufacturing) and non-technical (economic, operative and maintenance, social, institutional and environmental) in nature.[11] Often the major barrier to agricultural biogas production projects is the low price of regular natural gas. RES barriers are often divided into social, economic, technological and institutional or regulatory categories.[12] Nevertheless, the classifications used by scientists are slightly different depending on the concrete context and the focus of the research. For example, in the classification of P. Blechinger et al., technological barriers include natural (environmental) obstacles which require technical solutions.[13] In our research, we adopted M. Yaqoot's et al. classification of RES barriers including socio-cultural, technological, economic, institutional and environmental categories[14] which is in compliance with STEEP[15] analysis.

Socio-cultural barriers include social barriers, for example, group interaction; cultural barriers, for example, traditions, values and social-psychological barriers such as habits and behavior.

Social-psychological barriers are connected with an unwillingness to change established habits which determines consumer choice towards traditional energy.[16] Persistent and entrenched habits and routines of individuals and organizations,[17] and the difficulty of getting used to new heating systems[18] have become sufficient barriers for switching from fossil fuel to renewables. The necessity to switch to conventional energy technologies in periods of renewables' insufficient power generation creates discomfort and negatively influences the customers' attitudes towards

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10 Beck & Martinot 2004.

11 Marta Jarach, *An Overview of the Literature on Barriers to the Diffusion of Renewable Energy Sources in Agriculture*, 32(2) Appl. Energy 117 (1989).

12 Moorthy Seetharaman et al., *Breaking Barriers in Deployment of Renewable Energy*, 5(1) Heliyon e01166 (2019).

13 Philipp Blechinger et al., *Barriers and Solutions to the Development of Renewable Energy Technologies in the Caribbean* in *Decentralized Solutions for Developing Economies* 267 (Sebastian Groh et al., 2015).

14 Yaqoot et al. 2016.

15 Authors' note: STEEP is an acronym for the external sociological, technological, economic, environmental and political factors that may influence an object under study.

16 Munjur E. Moula et al., *Researching Social Acceptability of Renewable Energy Technologies in Finland*, 2(1) Int'l J. Sustain. Built Env't 89 (2013); Katarzyna Byrka et al., *Difficulty Is Critical: The Importance of Social Factors in Modeling Diffusion of Green Products and Practices*, 62 Renew. Sustain. Energy Rev. 723 (2016).

17 Laura Abrardi, *Behavioral Barriers and the Energy Efficiency Gap: A Survey of the Literature*, 46(1) Economia e Politica Industriale 25 (2018).

18 Carl C. Michelsen & Reinhard Madlener, *Switching from Fossil Fuel to Renewables in Residential Heating Systems: An Empirical Study of Homeowners' Decisions in Germany*, 89 Energy Pol'y 95 (2016).

RES.[19] The proximity to a gas network is a key determinant of homeowners for the choice of heating systems.[20] The reluctance of the manufacturer to take into account consumer social-psychological barriers underpins a skeptical attitude towards green energy.[21]

Lack of understanding of the needs, habits, values, cultural mentality and traditions of peoples can be a serious obstacle to the way chosen in promoting renewable energy and the reason for conflict between the interests of different ethnic groups.[22] For example, religious beliefs can come into conflict with the promotion of RES. In particular, biofuel projects inappropriate to local beliefs have not been successful.[23] Aesthetic factors become barriers when the infrastructure of renewables changes the view of natural landscapes associated with national identity and tourist attraction.[24]

I. Lorenzoni distinguishes cognitive, affective and behavioral elements constraining individual engagement in reducing carbon dependency. According to Lorenzoni et al., lack of targeted and tailored information is the main social obstacle to the transition on the part of the consumer to renewable energy resources.[25]

In spite of the great influence of socio-cultural factors on consumer choice, economic factors influence customer behavior to a greater extent. In particular, the social factors of consumer choice sufficiently depend on pro-environ behavior realization costs.[26] The influence of socio-cultural barriers on the dissemination of renewable energy technologies does not reveal clear evidence that environmental concerns affect consumer choice.[27] Nevertheless, the influence of pro-environ values on customer behavior increases with the decreasing of femininity cultural index according to Hofstede's model[28] and with the weakening of hedonistic and egoistic values.[29]

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19 Mehmet E. Biresselioglu et al., *Examining the Barriers and Motivators Affecting European Decision-Makers in the Development of Smart and Green Energy Technologies*, 198 J. Clean. Prod. 417 (2018).

20 John Curtis et al., *Heating System Upgrades: The Role of Knowledge, Socio-Demographics, Building Attributes and Energy Infrastructure*, 120 Energy Pol'y 183 (2018).

21 Biresselioglu et al. 2018.

22 Xiurui Guo et al., *Willingness to Pay for Renewable Electricity: A Contingent Valuation Study in Beijing, China*, 68 Energy Pol'y 340 (2014).

23 Yaqoot et al. 2016.

24 Erik Nordman & Jane Mutinda, *Biodiversity and Wind Energy in Kenya: Revealing Landscape and Wind Turbine Perceptions in the World's Wildlife Capital*, 19 Energy Res. Soc. Sci. 108 (2016); Blechinger et al. 2015.

25 Irene Lorenzoni et al., *Barriers Perceived to Engaging with Climate Change Among the UK Public and Their Policy Implications*, 17(3-4) Glob. Envtl. Change 445 (2007).

26 Byrka et al. 2016.

27 Curtis et al. 2018.

28 Corina Pelau & Nicolae Al. Pop, *Implications for the Energy Policy Derived from the Relation between the Cultural Dimensions of Hofstede's Model and the Consumption of Renewable Energies*, 118 Energy Pol'y 160 (2018).

29 Linda Steg et al., *The Significance of Hedonic Values for Environmentally Relevant Attitudes, Preferences, and Actions*, 46 Env't Behav. 163 (2014).

Among the most important common *technological barriers* to be overcome are: (1) the necessity of an energy-storage solution;[30] (2) the unreliable baseload power of wind turbines and solar cells;[31] and (3) the need to improve the methods of controlling inertia and frequency in variable-speed wind turbines and solar cells,[32] and the need in grid technologies with sensors to detect the changes in non-constant power production by renewables which then automatically increase power from backup sources – either storage or often small natural gas plants. These issues mostly stem from the speed of implementing and disseminating innovations and can be overcome through increasing RES research and development (R&D), the number of qualified specialists and support of developing localized technical standards.[33] High infrastructure construction costs[34] and concerns about the risks involved in moving away from central generation and established business models[35] can be a serious obstacle to RES development.

Technological barriers are closely connected with environmental factors. In particular, the perspectives of specific technology objectively depend on the availability of the required resource (solar, wind, thermals, water bodies, biofuels), climate and landscapes. In addition, cityscapes provide a complex environment, where solar radiation is unevenly distributed.[36] Technological barriers are sufficiently connected with certain social gaps: lack of skills for design and development, manufacturing, installation, operation and maintenance,[37] low level of technological awareness and the competence of users.[38]

In addition, modern renewable technologies are not always safe for people and nature. Some types of RES have a high risk of accidents. Most often, accidents occur at wind power facilities – almost every third case. Man-made disasters at hydroelectric

30 Jang-Yeon Hwang et al., *Sodium-Ion Batteries: Present and Future*, 46(12) Chem. Soc. Rev. 3529 (2017).

31 Wolf-Peter Schill et al., *Solar Prosumage: An Economic Discussion of Challenges and Opportunities* in *Energy Transition* 703 (Jens Lowitzsch ed., 2019).

32 Mohammad Dreidy et al., *Inertia Response and Frequency Control Techniques for Renewable Energy Sources: A Review*, 69 Renew. Sustain. Energy Rev. 144 (2017); Ted Trainer, *Some Problems in Storing Renewable Energy*, 110 Energy Pol'y 386 (2017).

33 Yaqoot et al. 2016.

34 Çiçek Bezir Nalan et al., *Renewable Energy Market Conditions and Barriers in Turkey*, 13(6-7) Renew. Sustain. Energy Rev. 1428 (2009).

35 Biresselioglu et al. 2018.

36 Sara Freitas et al., *Modelling Solar Potential in the Urban Environment: State-of-the-Art Review*, 41 Renew. Sustain. Energy Rev. 915 (2015); Mariano Martín & Ignacio E. Grossmann, *Optimal Integration of Renewable Based Processes for Fuels and Power Production: Spain Case Study*, 213 Appl. Energy 595 (2018).

37 Bhattacharya et al. 2016.

38 Claire Curry et al., *The Potential and Reality of the Solar Water Heater Programme in South African Townships: Lessons from the City of Tshwane*, 106 Energy Pol'y 75 (2017).

power stations are accompanied by the greatest number of deaths – 85% of the total number of fatalities occur in connection with accidents.[39]

The basic *economic barrier* to RES development is low competitiveness compared to other energy sources. According to a great amount of research, the costs of energy production, implementation, maintenance and consumption is a key factor in determining the choice of potential consumers of energy.[40] The uncompetitive price of renewables stipulates the impossibility of their implementation and development without subsidies and benefits.[41] In many European countries, feed-in tariffs have succeeded in fostering markets for grid-connected photovoltaics.[42]

On the national level, the successful upgrading of energy infrastructure highly depends on the adoption of acceptable cost-sharing mechanisms,[43] in particular, subsidies are crucial for heating systems and infrastructural adjustments.[44] Small business in the sphere of renewables often cannot gain long-term competitiveness in the market without governmental support.[45]

In addition, countries with the domination of the energy sector in the GDP structure have additional difficulties in the transition to renewables which can unbalance the economic system and slow down national economic growth.[46] RES economic influence on traditional economies can be ambivalent. In remote areas with traditional economies, RES can be very competitive and beneficial, but simultaneously it can have negative economic effects, for example it can sufficiently

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39 Joshua S. Riti et al., *Does Renewable Energy Ensure Environmental Quality in Favour of Economic Growth? Empirical Evidence from China's Renewable Development*, 52(5) Quality & Quantity 2007 (2018).

40 Paul W.R. Adams et al., *Barriers to and Drivers for UK Bioenergy Development*, 15(2) Renew. Sustain. Energy Rev. 1217 (2011); Gilles Notton, *Importance of Islands in Renewable Energy Production and Storage: The Situation of the French Islands*, 47 Renew. Sustain. Energy Rev. 260 (2015); Ted Trainer, *Can Renewables Meet Total Australian Energy Demand: A "Disaggregated" Approach*, 109 Energy Pol'y 539 (2017); Li Zhang et al., *Turning Green into Gold: A Review on the Economics of Green Buildings*, 172 J. Clean. Prod. 2234 (2018).

41 Lingyun He et al., *Green Credit, Renewable Energy Investment and Green Economy Development: Empirical Analysis Based on 150 Listed Companies of China*, 208 J. Clean. Prod. 363 (2019).

42 Béatrice Cointe & Alain Nadaï, *Turbulence and Reforms in European Renewable Energy Policy After 2008* in Béatrice Cointe & Alain Nadaï, *Feed-in Tariffs in the European Union: Renewable Energy Policy, The Internal Electricity Market and Economic Expertise* 87 (2018); Béatrice Cointe, *From a Promise to a Problem: The Political Economy of Solar Photovoltaics in France*, 8 Energy Res. Soc. Sci. 151 (2015).

43 Bruce R. Huber, *Paying for Energy* in *Energy Law and Economics (Economic Analysis of Law in European Legal Scholarship, 5)* 137 (Klaus Mathis & Bruce R. Huber eds., 2018).

44 Maria Hecher et al., *The Trigger Matters: The Decision-Making Process for Heating Systems in the Residential Building Sector*, 102 Energy Pol'y 288 (2017).

45 Vasilios Anatolitis & Marijke Welisch, *Putting Renewable Energy Auctions into Action – An Agent-Based Model of Onshore Wind Power Auctions in Germany*, 110 Energy Pol'y 394 (2017); Harri Kalimo et al., *Market Definition as Value Reconciliation: The Case of Renewable Energy Promotion under the WTO Agreement on Subsidies and Countervailing Measures*, 17(3) Int. Environ. Agreements 427 (2017).

46 Bhattacharya et al. 2016.

weaken the traditional economy and lifestyle (fishing, hunting, agriculture, etc.) through changing the environment.[47]

Successful RES development is often associated with effective policies and laws. In contrast, *institutional barriers* – ineffective policies and legislation – can serve as hindrances to RES development.[48] Alcazar-Ortega, Manuel et al. point out regulatory policies as the most critical for RES development.[49] In Iran for example, governmental policy determines the focus on the development of conventional national energy services based on hydrocarbons and, consequently, the lack of RES development support. In this particular context, international sanctions turned out to be the only factor which had a sufficiently positive influence on developing renewables in Iran.[50]

The national specifics of institutional barriers also depend on the particular dominate aim of RES development, which can be cleaning air quality, decreasing the anthropogenic influence on climate change, providing energy independence in the absence of domestic energy resources, or providing electricity to remote areas or minimal household amenities.[51]

In some countries, the dissemination of renewables can come into opposition with indigenous peoples' land rights.[52]

Environmental barriers are associated not just with the distribution of renewable sources, but with unpredictable and unstable input power[53] too, and also with the negative environmental effects of the implementation and usage of renewables.[54] Huge territories are required for buildings, construction projects, roads and other

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47 Ashish Gulagi et al., *Electricity System Based on 100% Renewable Energy for India and SAARC*, 12(7) PLOS ONE e0180611 (2017).

48 Luca Rubini, *'The Wide and the Narrow Gate': Benchmarking in the SCM Agreement After the Canada–Renewable Energy/FIT Ruling*, 14(2) World Trade Rev. 211 (2015); Albert Banal-Estañol et al., *How to Achieve Full Electrification: Lessons from Latin America*, 108 Energy Pol'y 55 (2017); Kun-Chin Lin & Mika M. Purra, *Transforming China's Electricity Sector: Politics of Institutional Change and Regulation*, 124 Energy Pol'y 401 (2019).

49 Manuel Alcázar-Ortega et al., *Methodology for the Identification, Evaluation and Prioritization of Market Handicaps Which Prevent the Implementation of Demand Response: Application to European Electricity Markets*, 86 Energy Pol'y 529 (2015).

50 Mustafa Jahangoshai Rezaee et al., *Root Barriers Management in Development of Renewable Energy Resources in Iran: An Interpretative Structural Modeling Approach*, 129 Energy Pol'y 292 (2019).

51 Roberto L. Valer et al., *Issues in PV Systems Applied to Rural Electrification in Brazil*, 78 Renew. Sustain. Energy Rev. 1033 (2017).

52 Ezequiel Zárate-Toledo et al., *Justice, Social Exclusion and Indigenous Opposition: A Case Study of Wind Energy Development on the Isthmus of Tehuantepec, Mexico*, 54 Energy Res. Soc. Sci. 1 (2019).

53 Sunil Luthra et al., *Barriers to Renewable/Sustainable Energy Technologies Adoption: Indian Perspective*, 41 Renew. Sustain. Energy Rev. 762 (2015).

54 Eun-Sung Kim & Ji-Bum Chung, *The Memory of Place Disruption, Senses, And Local Opposition to Korean Wind Farms*, 131 Energy Pol'y 43 (2019).

infrastructure needed for the implementation and dissemination of renewables. The exploitation of these lands has a negative effect on agriculture and biodiversity.[55] The technological specifics of producing renewable energy determine the negative environmental effects: the esthetics of landscape, the impact on biodiversity and other environmental repercussions, for example, unpleasant odors and noise.[56]

Even though the common RES barriers are well known, their specificity, combination, dynamics, refraining power and interdependence are under-investigated. Understanding the barriers and their inter-linkage in consideration of local specifics is a necessary premise for effectively developing and implementing national sustainable development (SD) strategic plans and national energy system development roadmaps. Thus, the purpose of our research is to reveal the specific system of RES development barriers, including their cause-and-effect interrelations in the case of the Russian Federation.

1. Materials and Methods

In this study we used the systems approach which implies the perception of the research object under study as a holistic system consisting of interconnected parts.[57] Thus, RES development barriers are considered to be interrelated elements of the holistic system.

The first step of the study included studying and analyzing the world and national trends in RES development using open analytical and statistical sources such as the International Energy Agency and International Renewable Energy Agency (IRENA). This analysis allowed us to identify a place and structure of the Russian energy market in the world.

The second step included qualitative analysis of the RES development barriers and their interrelations. Using STEEP analysis, the barriers were divided into five categories: socio-cultural, technological, economic, environmental and institutional. For their qualitative analysis, we used various types of research materials: official documents, research articles, analytical reports, statistics, cases and existing polls.

The third step comprised systematizing the results of qualitative analysis in the matrix showing the interrelations between the barriers. Based on the systems

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55 Harshit Vallecha & Prabha Bhola, *Sustainability and Replicability Framework: Actor Network Theory Based Critical Case Analysis of Renewable Community Energy Projects in India*, 108 Renew. Sustain. Energy Rev. 194 (2019).

56 Emmanouil K. Oikonomou et al., *Renewable Energy Sources (RES) Projects and Their Barriers on a Regional Scale: The Case Study of Wind Parks in the Dodecanese Islands, Greece*, 37(11) Energy Pol'y 4874 (2009); Omar Ellabban et al., *Renewable Energy Resources: Current Status, Future Prospects and Their Enabling Technology*, 39 Renew. Sustain. Energy Rev. 748 (2014); Adams et al. 2011.

57 *Пригожин И.Р., Николис Г.* Познание сложного [Ilya R. Prigozhin & Greguar Nikolis, *Knowledge of the Complex*] (1990).

approach,[58] we distinguished root, key problems and consequences and then coded relations between every pair of barriers as: "root problem-consequence" (r-c), "key problem-consequence" (k-c). There might also be relatively independent or "autonomous problems" (a). For example, in the pair of barriers A and B, A was coded as a root problem towards B if A could be characterized as the main cause of developing B according to the results of qualitative analysis of the national RES development barriers and their interrelations. The barrier A was coded as a key one if it sufficiently influenced developing the barrier B together with some other factors; in this case, B is a dependent problem or a consequence which will be eliminated when solving a root problem or key problems affecting it. If A and B do not influence each other, they are considered autonomous.

Finally, we analyzed the system of interrelated RES barriers using matrix and interactive graphs to reveal the specific "nerve node" of the Russian RES development barriers system.

2. Results

2.1. Qualitative Analysis of RES Development Barriers and Their Interrelations

2.1.1. Socio-Cultural Barriers

Historically, the Russian energy sector is characterized by a *high level of state control of the development of the energy sector*. This situation has been stipulated by the typical for Russia context of paternalism – a system of relations in which the authorities provide for the needs of citizens, and citizens, in exchange for this, allow the authorities to dictate patterns of behavior, both public and private. At the beginning of the twentieth century, Russian thermal power stations (TPSs) operated using oil, coal and peat. After the socialist revolution of 1917, the Bolsheviks proposed the GOELRO Plan – the State Plan for Electrification of Russia. It was the first-ever Soviet plan for national economic recovery and development. The plan noted the promising role of electrification in the development of industry, construction, transport and agriculture. It proposed to produce energy using local fuels such as coal, peat, shale, gas and wood.[59] However, the state took the political path of using hydrocarbons, starting the development of oil and gas fields in Western Siberia in the 1960s.

Paternalistic policy, particularly in the energy sector, has led to the situation in which the population takes advantage of the opportunities provided by the state, not caring about the consequences of this policy. As a result, it has led to a *low level of organizational innovation activity and a high level of risk avoidance* at the same time. In 2016, 67% of Russians marked innovations as a possible driver of economic and social

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58 *Лапыгин Ю.Н.* Системное решение проблем [Yuri N. Lapygin, *System Problem Solving*] (2008).

59 *Гвоздецкий В.Л.* План ГОЭРЛО: мифы и реальность // Наука и жизнь. 2005. № 5. С. 102–109 [Vladimir L. Gvozdetskii, *Plan of GOERLO: Myths and Reality*, 5 Science & Life 102 (2005)].

life. The importance of introducing innovative developments was recognized by three-quarters of Russians (76% in 2016 – up from 68% in 2010).[60] The proportion of organizations implementing innovations of at least one type, namely technological, organizational or marketing, to the total number of organizations examined was very low: 8.5% in 2017.[61]

This situation corresponds to the traditional lifestyle and traits of the Russian people described by the Russian philosopher N.A. Berdyaev: collectivism, passivity, inertness.[62] According to the data of opinion polls, Russians continue to be moderate collectivists, and they are prone to work in the command-hierarchical structures with rigid rules and subordination without a tendency to take risks and to act in the face of uncertainty.[63]

Lack of information and interest in innovations is a significant social-psychological factor hindering RES technological progress.[64] There is both an objective shortage of information in Russia about the opportunities, problems and prospects in respect of renewable energy and a subjective lack of interest and demand for this information. In particular, the largest center for the study of public opinion the Russian Public Opinion Research Center (VCIOM) and one of the biggest analytical sociological centers the Levada-Center have to date not conducted surveys studying public attitudes towards RES development and customer factors of choice in the energy market.

Cases of accidents and catastrophes at wind and hydropower stations usually have wide public resonance in the world in general, which facilitates the negative attitude of Russian society towards RES.[65] In the past fifteen to twenty years, a series of major accidents have occurred in Russia: for example in 2002 at the Kashirskaya state district power station; in 2006 at the Reftinskaya state district power station; in 2009 at the Sayano-Shushinskaya hydroelectric station; and the list goes on.[66]

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60 Инновации в России: от идей – к практике // Мониторинг мнений (ВЦИОМ). 17 июня 2016 г. [Innovations in Russia: From Ideas to Practice, Public Opinion Poll (VTsIOM), 17 June 2016] (Jun. 20, 2021) available at https://wciom.ru/index.php?id=236&uid=343.

61 Наука и инновации // Федеральная служба государственной статистики. 2019 [Federal State Statistics Service, Science and Innovations (2019)] (June 20, 2021) available at https://rosstat.gov.ru/folder/14477.

62 Nikolai Berdyaev, *The Fate of Russia* (2016).

63 Innovations in Russia, *supra* note 60.

64 *Городникова Н.В. и др.* Индикаторы инновационной деятельности [Natalia V. Gorodnikova et al., *Indicators of Innovation Activity*] (2018); *Басилян А.А.* Восприятие инноваций и инновационного климата россиянами [Armina A. Basilian, *Perception of Innovation and the Innovation Climate by Russians*] (2013).

65 Riti et al. 2018.

66 *Проскурякова Л.Н., Ермоленко Г.В.* Возобновляемая энергетика 2030: глобальные вызовы и долгосрочные тенденции инновационного развития [Liliana N. Proskuriakova & Georgii V. Ermolenko, *Renewable Energy 2030: Global Challenges and Long-Term Trends in Innovation Development*] (2017).

Thus, high accident rates and the negative consequences for local communities have formed mostly a *negative image of hydroelectric power in Russia*.

About 46% of Russians carefully monitor energy expenditures, but this behavior pattern is more likely to be typical for senior and lower-income people than for young people. Only 3% of those who conserve energy are motivated by the principle of caring for nature. The biggest share of respondents (82%) seek to conserve electricity consumption, but the reason for this conservation *springs mostly from caring about money, not about nature*. The problem of depletion of non-renewable energy resources was considered to be not so significant for Russia by 17% of respondents.[67] This situation means that the increase in tariffs caused by the development of RES technologies will be one of the barriers to RES development in the Russian energy market, which can probably be solved only at the governmental level.

2.1.2. Technological Barriers

Large hydrocarbon resources and state energy policy, oriented at using oil and gas fuel have stipulated *developed infrastructure for mining, transporting and generating energy from hydrocarbon fuels*. This fact is confirmed by the structure of electricity production in Russia. According to official data on Russian statistics, 62.7% of electricity is produced at thermal power stations using traditional fuels (gas, coal and diesel), 19.5% at nuclear power stations, 17.7% at hydroelectric power stations and only 0.1% is produced by using other renewable energy sources.[68] This situation determines consumer choice to a great extent.

Technological barriers for RES development in the Russian energy market can be explained by the structure of the energy system and its historical background. One of the peculiarities of the state policy in the energy sector is an *excess of installed energy capacity* in Russia – only 50.36% of existing capacity was used in 2018.[69] This background significantly decreases the commissioning of new RES-based capacities.

Moreover, *the energy flow from conventional energy sources is more stable than from RES* and generates more power. The installed capacity utilization factor is 87% for gas-fired (thermal power stations (TPSs) but only 35% for wind farms and 25% for solar power stations. Due to the poorly predicted operation of renewable energy sources, *an increase in the maneuverability of conventional generation is required* when the country has a high share of low-maneuverable equipment (nuclear power stations,

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67 Мониторинг мнений: ноябрь–декабрь 2015 // Мониторинг общественного мнения: экономические и социальные перемены. 2015. № 6. С. 79–104 [*Public Opinion Poll (VCIOM): November–December 2015*, 6 Monitoring of Public Opinion: Economic and Social Changes 79 (2015)].

68 Ernst & Young, *Power Market of Russia 2018* (2018) (Apr. 2, 2021), availavle at https://ru.scribd.com/document/401590966/EY-Power-Market-Russia-2018.

69 Отчет о функционировании ЕЭС // Системный оператор единой энергетической системы. 2019 [Report on the Functioning of the Unified Energy System of Russia, System Operator of the Unified Energy System (2019)] (June 5, 2019), available at https://so-ups.ru/index.php?id=ups_reports.

thermal power stations, coal-fired power stations, old gas-fired power stations). The insufficient density of electricity networks significantly limits the possibilities of electricity flow, while current standards require 100% reservation of RES-based power stations capacity.[70]

One of the notable features of the Russian energy sector is outdated equipment: 67.5% of generating equipment at the beginning of 2017 was over twenty-five years old,[71] and which has led to a high risk of *man-made disasters at hydroelectric power stations* accompanied by a great number of deaths and significant environmental damages.

In addition, *there is no complete production cycle in Russia in wind generation and bioenergy, small and medium hydro generation*, which is why more than 80% of RES facilities capital expenditures are spent on imported equipment.[72] This situation makes the RES energy sector highly dependent on foreign policy risks, for example, currency risk or sanctions.

According to the Renewable Energy Market Council, the *competencies of engineers in key technologies in the RES industry are insufficient, which impedes research and development in RES*. Russian power engineers, designers and installers still live in the information paradigm they learned at universities twenty to thirty years ago, which has led to unresolved problems with maintenance and operation in wind energy.[73] Thus, the main objective of the renewable energy development program in Russia to 2035 remains to develop the necessary competencies of employees.[74]

2.1.3. Economic Barriers

The main RES development economic barrier in Russia is *RES low competitiveness* compared to a centralized power supply system based on using conventional energy sources (oil, gas, coal, etc.). This is mostly stipulated by the *high investment costs for launching power stations operating on renewable energy sources in comparison with power stations that run on traditional fuel*.[75] Thus, the capital expenditures for

70 *Дегтярев К.С.* Экономика возобновляемой энергетики в мире и в России // С.О.К. 2017. № 9. С. 86–95 [Kirill S. Degtyarev, *Renewable Energy Economics in the World and in Russia*, 9 S.O.K. 86 (2017)] (June 10, 2021) also available at https://www.c-o-k.ru/articles/ekonomika-vozobnovlyaemoy-energetiki-v-mire-i-v-rossii.

71 *Power Market of Russia 2018*, *supra* note 68.

72 Прогноз научно-технологического развития отраслей ТЭК России на период до 2035 года // Министерство энергетики РФ. 2016 [Ministry of Energy of the Russian Federation, Forecast of Scientific and Technological Progress in the Fuel and Energy Sector Until 2035 (2016)] (June 10, 2021) available at https://minenergo.gov.ru/node/6366.

73 Proskuriakova & Ermolenko 2017.

74 Forecast of Scientific and Technological Progress, *supra* note 72.

75 A. Golub et al., *Quantifying Barriers to Decarbonization of the Russian Economy: Real Options Analysis of Investment Risks in Low-Carbon Technologies*, 19 Clim. Pol'y 716 (2019).

the construction of a TPS powered by gas with a capacity of 620 MW are two times less than the capital costs for the construction of a wind power station on land and three times less than the costs for the construction of a solar power station. At the same time, the installed capacity utilization factor for gas-fired TPSs will be two to three times higher.[76]

Although maintenance of a renewable energy station is almost always cheap due to the virtually zero cost of the raw materials used, the low potential and unstable energy source leads to the increased cost of accumulation and balancing of the energy system. High investment costs related to RES installation and performance subsequently lead to high fixed-operating costs and lower competitiveness of renewables.

In the world, over the past twenty years the cost of RES-based energy has significantly decreased and in some countries price parity in the cost of electricity has been achieved.[77] But there is *no price parity in the cost of RES and traditional energy* in Russia. However, the use of RES is very promising in the most remote areas of the country, as it allows reducing the cost of heat and electricity production which can be thirty times higher than standard electricity tariffs and, consequently, it allows reducing budget expenditure on subsidizing these costs for consumers. For example, in the northern regions of Russia the share of budget expenditures for energy supply exceeds 30%, and in some cases, even 60%. Such a substantial difference in the cost of energy significantly impedes the development of regions and stimulates the search for new energy solutions.[78] According to some experts, RES development combined with increased energy efficiency will save about 100 billion rubles annually.[79]

A significant problem of the Russian energy market is *heavy electricity arrears*. At the end of October 2017, arrears amounted 65.2 billion rubles in the wholesale market and 243 billion rubles in the retail market.[80] This problem can be aggravated by the *further rise of prices on electricity mainly because of planned increases in the share*

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76 Degtyarev 2017.

77 Johannes N. Mayer et al., *Current and Future Cost of Photovoltaics: Long-term Scenarios for Market Development, System Prices and LCOE of Utility-Scale PV Systems*, Fraunhofer ISE (February 2015) (Jun. 10, 2021), available at https://www.agora-energiewende.de/en/publications/current-and-future-cost-of-photovoltaics.

78 Энергетическая стратегия Российской Федерации на период до 2035 // Министерство энергетики РФ. 2017 [Ministry of Energy of the Russian Federation, Energy Strategy of the Russian Federation for the Period Until 2035 (2017) (June 10, 2021), available at https://minenergo.gov.ru/node/1026.

79 *Баринова В.А., Ланьшина Т.А.* Особенности развития возобновляемых источников энергии в России и в мире // Российское предпринимательство. 2016. № 17(2). С. 259–270 [Vera A. Barinova & Tatyana A. Lanshina, *Features of the Development of Renewable Energy Sources in Russia and in the World*, 17(2) Russian Journal of Entrepreneurship 259 (2016)] (Jun. 10, 2021), also available at http://bgscience.ru/lib/34720.

80 *Power Market of Russia 2018*, *supra* note 68.

of more expensive RES-based energy. According to A.B. Chubais, the retail price for the period from 2017 to 2035 may increase from 0.5% to 6.1% due to the program of RES development in Russia.[81]

RES in Russia face *high financial and investment risks* because of the specific, strict requirements of "localization" – a certain proportion of RES components and operations must be produced in Russia. Localization requirements are determined by the Law of the Government of the Russian Federation No. 426 and Decree No. 1472-R, of 28 July 2015. Localization requirements are quite strict in spite of the fact that most components and equipment of generating RES facilities in Russia are not produced in Russia. To be qualified by the government, RES companies often face the problem of building their production facilities within a short period of time after the signing capacity supply agreement. In case of failure to meet the localization requirements, companies pay a penalty in the amount of 85% to 100% of the capacity supply agreement. As a result, the financial and investment risks of renewable energy companies sufficiently increase, which contributes to higher RES-based energy prices.

2.1.4. Institutional Barriers

Historically established paternalistic policy and the government system in Russia determine the big role legal and administrative factors play in the development of Russia's modern energy system. But at the strategic level, there is still no consensus on the purpose, mechanisms, volumes and rates of RES development. The strategy for the scientific and technological development of the Russian energy system for the period up to 2035 predicts, "Russia will not experience a shortage of traditional energy resources in the foreseeable future, moreover, they are relatively inexpensive."[82] Thus, *the focus remains on developing conventional energy systems* and RES are considered to be supplementary ones. Mainly, renewables are noted as reserve energy sources for some Russian regions, and, secondly, as a necessity to prevent Russia from technologically lagging behind world leaders in the production of RES equipment and consequently the opportunity to expand Russian export potential. In the highly regulated energy market, the *lack of consistent policies on renewable energy development* decreases interest in RES development, and organizational RES innovation activities, and creates many contradictions through *numerous legislative gaps* in the RES sphere, including lack of common standards and regulations.[83]

The state support of RES in Russia is weak, its development principally depends on the regional governments. Current support schemes are ineffective since most

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81 *Чубайс А.Б.* Возобновляемая энергетика в России: от прошлого к будущему // Группа РОСНАНО. 2017 [Anatoly B. Chubais, *Renewable Energy in Russia: From the Past to the Future*, RUSNANO Group (2017)] (Jun. 10, 2021), available at https://www.rusnano.com/about/press-centre/news/20181002-rosnano-lektsiya-vozobnovlyaemaya-energetika-v-rossii-iz-proshlogo-v-budushchee.

82 Forecast of Scientific and Technological Progress, *supra* note 72.

83 Golub et al. 2019.

of the constituent entities of the Russian Federation do not have a developed regional regulatory framework to support RES-based energy generation. The present normative legal acts allow regional authorities to make independent decisions on supporting renewable energy generating facilities with a capacity of less than 25 MW, taking into account their economic and environmental feasibility. However, the regions do not have a clear regional policy, since federal law does not determine the list of measures that may be included in RES development programs. Thus, RES projects in the retail markets remain modest.

The support mechanism for generating facilities with operations based on renewable energy is regulated by Federal Law of 3 March 2003 No. 35-FZ "On the Electric Power Industry." According to the law, *only wholesale electricity providers can compete for the conclusion of long-term capacity supply agreements by a selection criterion of the lowest capital cost*, which is a sufficient barrier for entry into the RES market for small-sized innovation companies. This selection criterion together with calculating the costs in 2012 prices but not in market prices lead to artificial understatement of capital costs. As a result, the actual capital costs exceed the planned ones by a great margin. According to the official data of the Center for Financial Settlements JSC, the cost of the capacity supply agreement RES program during its implementation more than doubled from 1.2 to 2.5 trillion rubles in comparison with the originally planned cost and without an increase in capacity. The levelized cost of the electricity rate for renewable energy facilities in Russia is four to seven times higher than the global average. As a result, the government tender system with the criterion of minimizing capital costs stipulates a rise in the actual price of RES-based energy for the end consumer in comparison with its planned price.

A flexible approach to the needs of consumers requires innovative technological and sales decisions on the basis of developing an effective network of institutions and forms of cooperation among the actors of the RES innovation system. The following technological platforms have already been created: "Advanced Technologies for Renewable Energy," "Small Distributed Energy" and "Bioenergy." However, there is a *lack of effective network institutions and forms of cooperation among the actors of the innovation process* in the sphere of RES as historically these networks have been building for the oil and gas industries.

In spite of the fact, that the "Strategy of the Russian Federation 2035" declares the transition from resource-based to resource-innovative development of the fuel and energy complex by means of developing extensive technological chains saturated with innovative technologies, a negligible place is given to renewable energy. Thus, the present *political stake remains in hydrocarbons*, which, in fact, does not favor supporting RES innovation and dissemination.

One of the priority goals of state support is to stimulate domestic production of equipment for RES, which is supposed to be attained with the help of *high requirements for the degree of localization*. Since 2016, the generating equipment of solar power stations should be 70% domestically supplied, but in Russia there is no industrial production of most RES equipment types. For wind power stations and small hydropower stations, the target share of equipment produced locally was 55% in 2018 and since 2019 it has been set 65%. These requirements limit the choice of equipment and increase the risk of violation of the terms of RES facilities' certification, the risk of delaying the commissioning of the RES facilities, and, consequently, increase the risk for financial losses.

In general, the existing government program poorly offers measures for stimulating scientific and technical policies in the energy sector. The State Program of the Russian Federation 'Energy Efficiency and Energy Development' dated 15 April 2014, No. 321, specifies a list of the main measures and legal regulations. According to this program, RES state support is provided only as a tender of a power purchase agreement and an obligation for network companies to buy RES-based energy from qualified generating facilities at regulated regional tariffs. On the local level, the regional government subsidizes the construction cost in RES qualified facilities with an installed capacity of not more than 25 MW.

2.1.5. Environmental Barriers

According to the Institute of Energy Strategy, the potential solar energy that extends across Russian territory over a period of just three days exceeds the energy of the entire annual electricity production in the country. However, the Russian territories spread between 41 and 82 degrees north latitude *have a high variation of the level of solar radiation*: from 810 kWh/m2 per year in remote northern areas to 1400 kWh/m2 per year in the southern regions. *Large seasonal fluctuations* also affect highly uneven solar radiation availability during a year. Most of the installed wind farms are in particular coastal territories (in Kamchatka, in the Caspian, Barents and Okhotsk seas, and on Lake Baikal). These territories have a high level of wind resource and generate a great amount of wind-based electricity, which creates further problems associated with accumulation and distribution.

Installing facilities generating RES-based electricity often implies *alienation of a significant territory*. The construction of solar power stations can occupy vast areas of agricultural land and the building of hydroelectric power stations can raise the problem of resettlement of local populations.

Hydroelectric power stations are associated with the largest amount of damage done to nature from frequent incidents in comparison with other RES-based technologies.[84] These stations are associated with the flooding of large areas, waterlogging, loss of biodiversity and irreversible changes in ecosystems. In the use of wind power installations, some *negative environmental effects* are observed: harm to birds and animals; mechanical and aerodynamic noise and powerful infrasonic vibrations;

84 Proskuriakova & Ermolenko 2017.

and interference with air traffic, and radio and television broadcasting. In general, the negative environmental effects associated with RES should be considered throughout the full production cycle, including the mining of mineral resources necessary for equipment production. The level of CO2 is quite high in the production of biofuels, which has a negative impact on climate change.

2.2. Interrelations of Russian RES Development Barriers

Using qualitative analysis, we classified and coded RES development barriers marked in bold in the previous subsection (2.1), which we present in Table 1 below, and we describe the interrelations between them in the form of a matrix in Fig. 1 below. We visualize the barriers in graphs depicted in Figs. 2–4 below.

Table 1. Main RES development barriers in Russian Energy Sector

SOCIO-CULTURAL BARRIERS	**Code**
State controls much of the development of the energy sector	S1
Low level of organizational innovation activity and a high level of risk avoidance	S2
Lack of information and interest in the RES sphere from all market actors	S3
Negative image of hydroelectric power stations as a result of high accident rates and negative consequences for local communities	S4
Conservation is mostly due to caring about saving money but not about nature	S5
TECHNOLOGICAL BARRIERS	
Developed infrastructure for the extraction and transportation of large hydrocarbon reserves	T1
Excess installed energy capacity	T2
Less stable energy flow and less capacity of RES in comparison with conventional energy sources	T3
Requirements for increasing the maneuverability of conventional energy generation	T4
Lack of a full production cycle in wind generation and bioenergy, small and medium hydro generation	T5
High risk of man-made disasters in hydro generation	T6
Lack of RES R&D and a deficit of the necessary professional skills	T7

ECONOMIC BARRIERS	**E**
RES low competitiveness	E1
High investment cost in comparison with conventional energy generation	E2
No price parity in the cost of RES and the cost of conventional energy generation	E3
Heavy electricity arrears	E4
High financial and investment risks	E5
Growing share of RES increases prices on electricity for the customer	E6
INSTITUTIONAL BARRIERS	
Numerous legislative gaps in the RES sphere	I1
Lack of consistent policies on renewable energy development	I2
Government support for renewable energy innovation is carried by the lowest capital expenditures among participants of the wholesale energy market	I3
Lack of effective network institutions and forms of cooperation among actors of the innovation process	I4
Political stake in hydrocarbons	I5
High localization requirements and the penalty for their non-compliance	I6
ENVIRONMENTAL BARRIERS (EN)	
Different RES availability in Russian regions	En1
RES negative ecological impact (biodiversity, changing ecosystems, pollution of RES equipment production)	En2
Alienation of a significant territory when installing facilities generating electricity from renewable energy sources	En3
Great damage to nature from frequent accidents at hydropower stations	En4

	RES development barriers	S1	S2	S3	S4	S5	T1	T2	T3	T4	T5	T6	T7	E1	E2	E3	E4	E5	E6	I1	I2	I3	I4	I5	I6	EN1	EN2	EN3	EN4	r	k	c
S1	State controls much of the development of the energy sector		r	r	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	r	r	k	r	r	a	a	a	a	6	1	0
S2	Low level of organizational innovation activity and a high level of risk avoidance	c		c	a	a	a	a	k	k	k	a	k	k	a	a	a	a	a	a	c	a	c	a	c	a	a	a	a	0	5	5
S3	Lack of information and interest in RES sphere from the side of all market actors	c	r		a	c	c	c	a	a	a	a	k	a	a	a	a	a	a	a	c	a	c	c	a	a	a	a	a	1	1	7
S4	Negative image of hydroelectric power plants as a result of high accident rate and negative consequences for local communities	a	a	a		a	a	a	a	a	a	c	a	a	a	a	a	a	a	a	a	a	a	a	a	a	c	c	c	0	0	4
S5	Saving energy is not about nature	a	a	r	a		a	a	a	a	a	a	a	r	a	a	a	a	a	a	k	a	a	a	a	a	r	a	a	3	1	0
T1	Developed infrastructure for the extraction and transportation of large hydrocarbon reserves	a	a	r	a	a		r	a	a	a	a	a	r	a	a	k	a	a	a	a	a	a	c	a	a	a	a	a	3	1	1
T2	Excess installed energy capacity	a	a	k	a	a	c		a	a	a	a	a	r	a	a	k	a	a	a	a	a	a	c	a	a	a	a	a	1	2	2
T3	Less stability of energy flow and less capacity of RES in comparison with conventional energy sources	a	c	a	a	a	a	a		r	a	a	a	a	a	r	a	a	a	a	a	a	a	a	a	a	a	a	a	2	0	1
T4	Requirements for increasing the maneuverability of traditional generation	a	c	a	a	a	a	a	c		a	a	a	a	a	a	a	a	r	a	a	a	a	a	a	a	a	a	a	1	0	2
T5	Lack of a full production cycle in wind generation and bioenergy, small and medium hydro generation	a	c	a	a	a	a	a	a	a		a	c	a	a	a	a	r	a	a	a	a	c	c	r	a	a	a	a	2	0	4
T6	High risk of man-made disasters in hydro generation	a	a	a	r	a	a	a	a	a	a		a	a	a	a	a	a	a	c	a	a	a	a	a	a	r	a	r	3	0	1
T7	Lack of RES R&D and the deficit of necessary professional skills	a	c	c	a	a	a	a	a	a	r	a		a	r	a	a	a	a	a	a	a	a	c	a	a	a	a	a	2	0	3
E1	RES low competitiveness	a	c	a	a	c	c	c	a	a	a	a	a		c	c	a	c	r	a	a	a	a	a	a	c	c	a	c	1	0	10
E2	High investment cost in comparison with conventional energy	a	a	a	a	a	a	a	c	a	a	a	c	r		r	a	c	r	a	a	a	a	a	a	c	a	a	a	3	0	4
E3	No price parity in the cost of RES and the cost of conventional energy	a	a	a	a	a	c	c	a	a	a	a	a	r	c		a	a	a	a	a	c	a	a	a	a	a	a	a	1	0	4
E4	Heavy electricity arraears	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a		k	c	a	a	a	a	a	a	a	a	a	a	0	1	1
E5	High financial and investment risks	a	a	a	a	a	a	a	a	a	c	a	a	r	r	a	c		a	a	c	a	a	a	c	a	a	a	a	2	0	4
E6	Growing share of RES increaes prices on electricity for the customers	a	a	a	a	a	a	a	a	c	a	a	a	c	c	a	k	a		a	a	a	a	c	a	a	a	a	a	0	1	4
I1	Numerous legislative gaps in RES sphere	a	a	a	a	a	a	a	a	a	a	r	a	a	a	a	a	a	a		c	a	a	a	a	a	r	a	r	3	0	1
I2	Lack of consistent policies on renewable energy development	c	r	r	a	c	a	a	a	a	a	a	a	a	a	a	a	r	a	r		r	k	c	a	a	a	a	a	5	1	3
I3	Government support wholesale energy producers which declared lowest capital expenditures	c	a	a	a	a	a	a	a	a	a	a	a	a	a	r	a	a	a	a	c		a	a	a	a	a	a	a	1	0	2
I4	Lack of effective network institutions and forms of cooperation among actors of RES innovation system	c	r	r	a	a	a	a	a	a	r	a	a	a	a	a	a	a	a	a	c	a		c	a	a	a	a	a	3	0	3
I5	Historical and contemporary prior political stake on hydrocarbons	c	a	r	a	a	r	r	a	a	r	a	r	a	a	a	a	a	r	a	r	a	k		a	a	a	a	a	7	1	1
I6	High localization requirements and penalty for their non-compliance	c	k	a	a	a		a	a	a	c	a	a	a	a	a	a	k	a	a	a	a	a	a		a	a	a	a	0	2	2
En1	Different resource availability in Russian regions	a	a	a	a	a	a	a	a	a	a	a	a	k	k	a	a	a	a	a	a	a	a	a	a		a	a	a	0	2	0
En2	RES negative ecological impact (biodiversity, changing ecosystems, pollution of RES equipment production)	a	a	a	r	c	a	a	a	a	a	c	a	r	a	a	a	a	a	c	a	a	a	a	a	a		c	c	2	0	5
En3	Alienation of a significant territory when installing facilities generating electricity from renewable energy sources	a	a	a	r	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	r		a	2	0	0
En4	High levels of damage to nature from frequent accidents at hydropower plants	a	a	a	r	a	a	a	a	a	a	c	a	r	a	a	a	a	a	c	a	a	a	a	a	a	r	a		3	0	2
R	**route barrier**	0	4	6	4	0	1	2	0	1	3	1	1	8	2	3	0	2	4	1	2	2	0	1	2	0	5	0	2			
K	**key barrier**	0	1	1	0	0	0	0	1	1	1	0	2	2	1	0	3	2	0	0	1	0	3	0	0	0	0	0	0			
C	**conseqence**	7	5	2	0	4	4	3	2	1	2	3	2	1	3	1	1	2	1	3	6	1	3	8	2	2	2	2	3			

Fig. 1. Matrix of RES development barriers[85]

85 Anastasia Ljovkina et al., *System Analysis of RES Energy Barriers (Matrix)*, Mendeley Data (2019) (June 20, 2021), available at http://dx.doi.org/10.17632/7tgj3vfdf4.1.

Fig. 1 presents coded interrelations between each pair of barriers. For example, if state control (S1) primarily determines a low level of organizational innovation activity and a high level of risk avoidance (S2), S1 is a root problem towards S2, thus the cell "S1-S2" was coded by the letter "r." Respectively, S2 is a consequence of S1, thus the cell "S2-S1" was coded by the letter "c." Key influence of the barriers was coded by "k," and the relationship of mutually independent or autonomous barriers was coded with the letter "a."

We then divided the RES development barriers into three conditional categories by the number of their consequences: primary barriers (the most influential, causing the greatest number of consequences), secondary barriers (very influential) and tertiary barriers that are mostly dependent or predominantly autonomous (Table 2).

Table 2. Groups of RES development barriers by the extent of influence

	Route Barrier	Key Barrier	Consequence
	I.	**Primary barriers (most influential)**	
I5	1	0	8
S1	0	0	7
I2	2	1	6
	II.	**Secondary barriers (very influential)**	
S2	4	1	5
S5	0	0	4
T1	1	0	4
T2	2	0	3
T6	1	0	3
E2	2	1	3
I1	1	0	3
I4	0	3	3
En4	2	0	3
	III.	**Tertiary barriers**	
S3	6	1	2
T3	0	1	2
T5	3	1	2
T7	1	2	2
E5	2	2	2
I6	2	0	2
En1	0	0	2
En2	5	0	2
En3	0	0	2
T4	1	1	1

E1	8	2	1
E3	3	0	1
E4	0	3	1
E6	4	0	1
I3	2	0	1
S4	4	0	0

Grouping the RES development barriers by the number of consequences showed that barrier I5 has the greatest direct influence on the whole system of the barriers. Nevertheless, it has its route reason for barrier S1.

Additionally, we developed special open source software[86] to make graph analysis visualizing the interrelations of RES development barriers. Fig. 2 presents the influence of I5 (political stake in hydrocarbons) on other barriers. Solution of I5 problem influences not only solutions of barriers T2, T1, S3, I2, E6, T7 and T5 and partially – I4, but allows overcoming 18 barriers in total through a chain reaction of their solutions (Fig. 2).

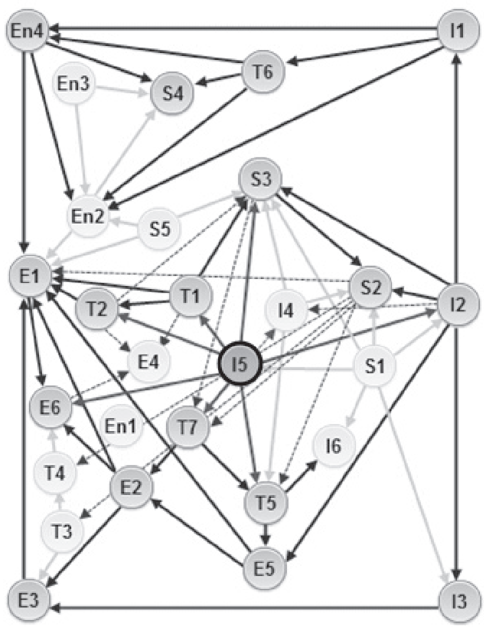

Fig. 2. Graph of the interrelation of the barrier I5 with other RES development barriers

[86] Vadim E. Ljovkin, *Green Energy Graph* (June 20, 2021), available at https://vadimljovkin.github.io/GEG/#!/Graph; https://github.com/VadimLjovkin/Green-Energy-Graph-for-Win.

(The analyzed barrier and its direct impacts are dark grey; other barriers affected by the analyzed barrier directly or indirectly are grey; the solid line represents the relationship "root barrier – consequence" and the dotted line represents the relationship "key barrier – consequence"; barriers and arrows of a light grey color are not included in the net formed by the analyzed barrier.)

In spite of barrier S1 (high state control in the energy sector) directly solving a fewer number of problems than I5, S1 determines I5 and, thus, S1 has a greater effect on the holistic RES development barriers' system by allowing overcoming 21 barriers in total (Fig. 3).

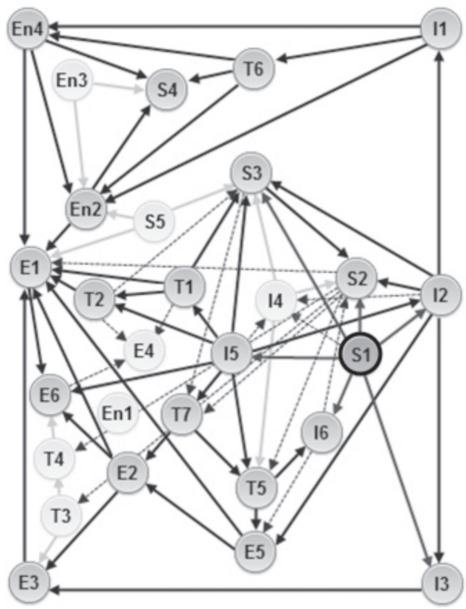

Fig. 3. Graph of the interrelation of the barrier S1 with other RES development barriers

Barrier I2 has a sufficient effect on overcoming RES development barriers but not so great as barriers S1 and I5, being itself a consequence of barriers S1 and I5 (Fig. 4).

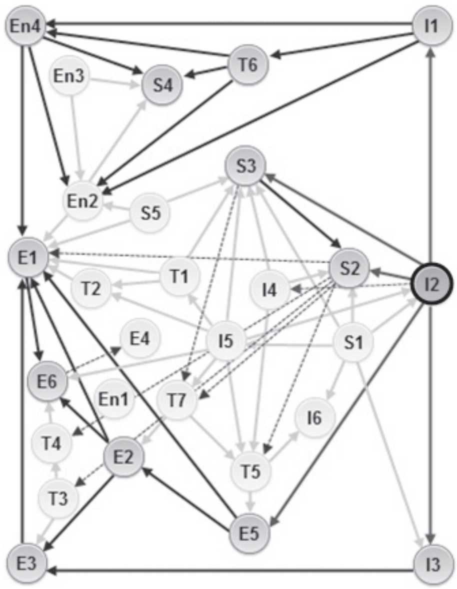

Fig. 4. Graph of the interrelation of the barrier I2 with other RES development barriers

Data availability. Datasets related to this article (Matrix of barriers' interrelations in MS Excel) can be found at http://dx.doi.org/10.17632/7tgj3vfdf4.1, an open-source online data repository hosted at Mendeley Data.

Green energy Graph software can be found at https://vadimljovkin.github.io/GEG (online application), at https://github.com/VadimLjovkin/Green-Energy-Graph-for-Web (an open-source online application), at https://github.com/VadimLjovkin/Green-Energy-Graph-for-Win/releases/download/GEG_v1.0/GEG.exe (windows application) and at https://github.com/VadimLjovkin/Green-Energy-Graph-for-Win (an open-source windows application) hosted at Girhub.

3. Discussion

The findings indicate the high importance of socio-cultural and institutional barriers to RES development in Russia. The significance of these barriers has been noted by many researchers, but the national specifics and interrelations of the barriers have been underestimated[87] and need to be studied for effective solutions to system problems. Our study confirmed that the historical paternalistic system of social relationships in Russia, being in the main context of political decisions, favored much state control of the energy sector and determined unfavorable conditions

87 Beck & Martinot 2004.

for the economic and technological development of renewable energy in Russia. Additionally, the research shows deep-seated reasons for the common national tendency towards risk-avoidance which directly determines an unwillingness to invest in risky RES technologies.[88] In any event, the historically established and continuing paternalistic context in the Russian energy market is not an immutable element. Considering the activeness of people in the formation and development of the consumption culture, we argue that the situation where the state controls much of the development of the energy sector can be changed through social innovations and relevant civil activities. We agree with Biresselioglu that the legitimization of paternalistic policy has psychological underpinnings – an unwillingness to take risk and abandonment of the standard business models,[89] thus changing this mentality will eliminate the social-psychological foundation of paternalism.

Economic barriers to RES development in Russia are mostly determined by the historical and contemporary political stake in hydrocarbons and accordant structure of the national energy system based on oil, coal and gas. As a result of this policy, there is a lack of RES R&D due to a deficit of the necessary professional skills of energy sector specialists, lack of interest and awareness about RES both in the social and in the business spheres, and an absence of effective cooperation for RES development.

The results of our research completely correspond to conclusions made in earlier studies about the role of sufficient awareness of RES[90] and its impact on solving environmental problems[91] in the choice of an energy supplier. The lack of information and interest in the RES sphere of all market actors and the absence of pro-environment motivation to conserve energy are important barriers to the development of the Russian RES market. At the same time, these barriers can be sufficient information and social-psychological resources to change the mentality towards pro-environment decisions in the energy sector. In particular, given the lack of targeted information and understanding of the role of renewable energy in reaching sustainable development goals, it would be difficult for Russian citizens to accept an increase in electricity prices in the event of an increase in the share of RES-based electricity.

The specific feature of the Russian RES development barriers' system is the negative social-ecological image of the hydroelectric power station, which is associated with a series of technological accidents with substantial social and environmental consequences. This negative image is also affected by changes in the environment and lifestyle of the population caused by the construction and operation of power stations. In this context, our research has added to the studies of Gulagi et al. explaining the importance of overcoming specific environmental barriers related to social attitudes.

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88 Bezir Nalan et al. 2009.

89 Biresselioglu et al. 2018.

90 Byrka et al. 2016.

91 Lorenzoni et al. 2007.

Matrix of barriers' interrelations and graph analysis helped to reveal that the lack of consensus on the political goals and mechanisms for RES development is one of the most significant barriers to RES development in Russia, which confirms the conclusions made earlier by researchers about the significant role of institutional barriers.[92] As in other countries, in Russia the absence of consistent political goals in RES development affects regulatory barriers,[93] which worsen economic and technological barriers.

The economic barrier of the low level of RES competitiveness in Russia is typical for most countries, and so is the situation that RES development is highly dependent on state support.[94] This barrier is reinforced by the excess of capacity for electricity production and the well-developed centralized electricity supply in Russia.

The proposed analytic methodology allowed not only characterizing the influence of the root institutional barriers, as was done in the studies of countries with high state control in the energy sector, for example Iran[95] and Russia,[96] but also allowed identifying the main socio-cultural roots of institutional and other barriers, and, in general, predicting the chain reaction of overcoming particular barriers.

Conclusion

The suggested analytic methodology of RES development barriers based on the system approach allowed analyzing RES development as a systemic problem. This methodology includes the existing analytical research techniques and complements existing analytic research on the topic. It allows revealing a specific of the system of national RES barriers through understanding their interrelations and underlying factors that create the pattern which is the necessary condition for creating effective system programs of RES development.

Based on the qualitative analysis of RES development barriers and their interrelations, we revealed that the most influential barrier was an overall context of the high level of state control of the development of the Russian energy sector, which means that the state plays a decisive role in the development of national energy policy and economy. The other two core institutional barriers logically follow from the paternalistic context: historical and contemporary prior political stake in hydrocarbons and lack of consistent policies on RES development. This situation might require a deep societal transition to the "responsible" civil society through socio-cultural changes, the education system and developing mechanisms and instruments of social initiatives.

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92 Banal-Estañol et al. 2017; Lin & Purra 2019.

93 Alcázar-Ortega et al. 2015.

94 Notton 2015; He et al. 2019; Anatolitis & Welisch 2017.

95 Jahangoshai Rezaee et al. 2019; Seetharaman et al. 2019.

96 Golub et al. 2019.

The suggested analytic methodology has some limitations that should be taken into account when using it. In the static models of complex systems, causal relationships between elements determine the structure of the system. In system analysis it is assumed that the cause has a one-sided effect on the result, while the relative significance of each factor affecting the system remains unchanged.[97] However, in real dynamic complex systems (such as social), factors can influence each other, thus the relative importance of each of them changes over time and depends on feedback mechanisms. This means that the list of the barriers and the. structure of the matrix model should be constantly improved, and the interrelation between barriers should be revised with time.

Nevertheless, the suggested analytic methodology has great value for creating the effective system global, national, regional or local programs of RES development considering the specific character of each model and periodical revision of inputs in terms of elements (barriers) and their interrelation.

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[97] Lapygin 2008.

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