frontiers | Research Topics

Sustainable and environmental development of energy economics based on smart grids and energyTech

Edited by
Elena G. Popkova, Bruno Sergi and Aleksei V. Bogoviz

Published in
Frontiers in Energy Research

ISSN 1664-8714
ISBN 978-2-83252-152-6
DOI 10.3389/978-2-83252-152-6

About Frontiers

Frontiers is more than just an open access publisher of scholarly articles: it is a pioneering approach to the world of academia, radically improving the way scholarly research is managed. The grand vision of Frontiers is a world where all people have an equal opportunity to seek, share and generate knowledge. Frontiers provides immediate and permanent online open access to all its publications, but this alone is not enough to realize our grand goals.

Frontiers journal series

The Frontiers journal series is a multi-tier and interdisciplinary set of open-access, online journals, promising a paradigm shift from the current review, selection and dissemination processes in academic publishing. All Frontiers journals are driven by researchers for researchers; therefore, they constitute a service to the scholarly community. At the same time, the *Frontiers journal series* operates on a revolutionary invention, the tiered publishing system, initially addressing specific communities of scholars, and gradually climbing up to broader public understanding, thus serving the interests of the lay society, too.

Dedication to quality

Each Frontiers article is a landmark of the highest quality, thanks to genuinely collaborative interactions between authors and review editors, who include some of the world's best academicians. Research must be certified by peers before entering a stream of knowledge that may eventually reach the public - and shape society; therefore, Frontiers only applies the most rigorous and unbiased reviews. Frontiers revolutionizes research publishing by freely delivering the most outstanding research, evaluated with no bias from both the academic and social point of view. By applying the most advanced information technologies, Frontiers is catapulting scholarly publishing into a new generation.

What are Frontiers Research Topics?

Frontiers Research Topics are very popular trademarks of the *Frontiers journals series*: they are collections of at least ten articles, all centered on a particular subject. With their unique mix of varied contributions from Original Research to Review Articles, Frontiers Research Topics unify the most influential researchers, the latest key findings and historical advances in a hot research area.

Find out more on how to host your own Frontiers Research Topic or contribute to one as an author by contacting the Frontiers editorial office: frontiersin.org/about/contact

Sustainable and environmental development of energy economics based on smart grids and energyTech

Topic editors

Elena G. Popkova — Peoples' Friendship University of Russia, Russia

Bruno Sergi — Harvard University, United States

Aleksei V. Bogoviz — Independent researcher, Russia

Citation

Popkova, E. G., Sergi, B., Bogoviz, A. V., eds. (2023). *Sustainable and environmental development of energy economics based on smart grids and energyTech*. Lausanne: Frontiers Media SA. doi: 10.3389/978-2-83252-152-6

Table of contents

05 Editorial: Smart grids and EnergyTech as a way for sustainable and environmental development of energy economy
Elena G. Popkova, Aleksei V. Bogoviz and Bruno S. Sergi

09 Perspective Directions of Corporate Social Responsibility of Energy Companies of EnergyTech for Sustainable and Environmental Development of Energy Economy
Anastasia A. Sozinova, Tatyana N. Litvinova, Victoria N. Ostrovskaya and Galina V. Vorontsova

13 Community Renewable Energy in the Czech Republic: Value Proposition Perspective
Viera Pechancová, Drahomíra Pavelková and Petr Saha

27 Problems of EnergyTech Financing in the Context of the COVID-19 Crisis and the Post-Pandemic Period and the Prospects for Their Solution
Vladimir S. Osipov, Alexander N. Alekseev, Nelia A. Deberdeeva and Antonina A. Seregina

32 An Institutional Approach to the Decarbonization of the Economy and the Transition to Clean Energy Based on EnergyTech
Yuliya V. Chutcheva, Alexander V. Semenov, Galina N. Semenova and Suzana L. Balova

37 Marketing Mix of Energy Companies of EnergyTech From the Positions of Their Contribution to Sustainable and Environmental Development of Energy Economics
Lyudmila V. Borisova, Yuliya G. Tyurina, Irina A. Morozova and Oksana N. Momotova

41 Eco-Friendly Energy Production: The Influence of Price Factors in the Regions of Russia
Natalia Roslyakova and Elena Vechkinzova

48 Sustainable and Environmental Development of Energy Economy in Smart Regions of Russia
Sergey V. Muzalev, Sergey N. Kukushkin, Olga A. Grazhdankina and Anastasia V. Nikolaenko

53 Smart Grid: Leading International Experience of Marketing and its Contribution to Sustainable and Environmental Development of Energy Economy
Timur A. Mustafin, Lyudmila M. Kuprianova, Anastasiya Yu Ladogina and Oksana N. Pyatkova

58 Global Monitoring of the Development of Digital Energetics Based on the Technologies of Industry 4.0: IoT, Blockchain, Robots, and Artificial Intelligence
Valery I. Khoruzhy, Vladimir V. Lebedev, Natalya Farkova and Elena L. Pozharskaya

64 Improving the quality of project management at energytech through marketing in support of sustainable and environmental development of energy economics
Olga Vasilyevna Fokina, Anastasia Andreevna Sozinova, Anna Gennadyevna Glebova and Natalia Valeryevna Nikonova

70 Corporate Social Responsibility of Energy Companies: International Experience and Polycriterial Evaluation of Technological Innovations' Effectiveness
Sergei G. Vagin, Bogdan Vasyakin, Mikhail Y. Zakharov and Irina E. Shaker

75 Scenarios of the alternative energetics development in the age of the fourth industrial revolution: Clean energy prospects and policy implications
Tatiana M. Vorozheykina, Aleksandr V. Averin, Elena I. Semenova and Aleksandr V. Semenov

83 Advanced HRM practices and digital personnel for digital energetics based on the technologies of Industry 4.0
Aleksei V. Bogoviz, Svetlana V. Lobova and Alexander N. Alekseev

89 The contribution of clean energetics based on energy technology (EnergyTech) to the reduction of production waste and the fight against climate change: Legal regulation issues
Elena G. Popkova, Elena V. Karanina, Galina V. Stankevich and Timur R. Shaimardanov

94 The modern capabilities of monitoring of sustainable and environmental development of the energy economy based on big data and datasets
Veronika Yankovskaya, Svetlana V. Lobova, Valentina V. Grigoreva and Alena Y. Fedorova

TYPE Editorial
PUBLISHED 28 March 2023
DOI 10.3389/fenrg.2023.1145234

OPEN ACCESS

EDITED AND REVIEWED BY
Michael Carbajales-Dale,
Clemson University, United States

*CORRESPONDENCE
Elena G. Popkova,
elenapopkova@yahoo.com

SPECIALTY SECTION
This article was submitted to Sustainable Energy Systems, a section of the journal Frontiers in Energy Research

RECEIVED 15 January 2023
ACCEPTED 20 March 2023
PUBLISHED 28 March 2023

CITATION
Popkova EG, Bogoviz AV and Sergi BS (2023), Editorial: Smart grids and EnergyTech as a way for sustainable and environmental development of energy economy.
Front. Energy Res. 11:1145234.
doi: 10.3389/fenrg.2023.1145234

Editorial: Smart grids and EnergyTech as a way for sustainable and environmental development of energy economy

Elena G. Popkova[1]*, Aleksei V. Bogoviz[2] and Bruno S. Sergi[3,4]

[1]Peoples' Friendship University of Russia (RUDN University), Moscow, Russia, [2]Independent Researcher, Moscow, Russia, [3]Harvard University, Cambridge, MA, United States, [4]Department of Economics, University of Messina, Messina, Italy

KEYWORDS

sustainable and environmental development, energy economy, decade of action, smart grid, EnergyTech

Editorial on the Research Topic
Smart grids and EnergyTech as a way for sustainable and environmental development of energy economy

Introduction

Sustainable and environmental development of the energy economy remains a strategic priority of today's economy, shaped by the United Nations' environmental initiatives. This priority, indicative of a progressive society and with the enormous power of uniting the world community to overcome common problems, is underpinned by a series of Sustainable Development Goals (SDGs).

Sustainable and environmental development of the energy economy ensures universal energy security (SDG 7 "affordable and clean energy") and environmental friendliness (SDG 13 "climate action"), achieved through the economic extraction of fossil fuel energy to preserve the heritage for future generations (Popkova et al., 2021; Popkova and Sergi, 2021). Other priorities are environmentally safe transportation to care for ecosystems (SDG 14 "life below water" and SDG 15 "life on land"), responsible consumption and production, and the development of clean energy (as an energy system) (SDG 12 "responsible production and consumption") (Isiksal and Assi, 2022; Sun et al., 2022; Tang et al., 2022; Wang et al., 2022).

Smart grids and EnergyTech have enabled sustainable and environmental development, unlocking the potential of industrialization 4.0, digital innovation, and smart infrastructure (SDG 9 "industry, innovation and infrastructure"). Smart Grids optimize the production and distribution of energy in utility systems through advanced metering (smart meters) and automated Big Data Research Topic through ubiquitous computing (UC) and the Internet of Things (IoT) and their analytics by artificial intelligence (AI) (Qin et al., 2022). EnergyTech is a high-tech fuel and energy complex that uses breakthrough technologies, including robots and blockchain, to balance energy markets and ensure responsible environmental management (Li et al., 2022; Mahboob Ul Hassan et al., 2022).

This Research Topic aims to showcase that the most convenient solution is not invariably the right one. Instead, it offers Smart Grids and EnergyTech as a new, non-controversial way of sustainable and environmental development of the energy economy that balances the interests of society, economy, and governments (Popkova, 2022). What makes this path unique represents the high flexibility to keep the extraction and use of fossil fuel energy where needed and to switch to clean energy wherever possible.

Sustainable and environmental development of the energy economy in the decade of action

The Decade of Action began with the COVID-19 pandemic, the most acute phase of which occurred in 2020, the ripple effect of which continues to this day: early in the second half of 2022, the prospects for completion are uncertain. The shutdown of production under lockdown cut down energy consumption and restrictions on transport links and other measures that reduced the economy's carbon footprint. However, the effect was short-lived (Zhou and Li, 2022).

Energy companies must continually develop production facilities in which complex and injury-prone business processes are automated, and control and decision-making are performed remotely. This requires social sanitation requirements in the current energy economy, which has become more complicated because of the COVID-19 crisis that has added concerns to the global energy crisis.

Global climate change manifests in abnormal temperatures and natural disasters in all corners of the planet, representing a severe challenge of our time (Liu et al., 2022). Industry 4.0 is also in its heyday in the Decade of Action. Digital economy programs in most countries are focused on the period until 2024–2025. The Fourth Industrial Revolution is expected to be completed by 2030. Although many advanced technologies have improved energy efficiency characteristics, automation increases the economy's energy intensity and limits clean energy applications. This fact calls for further efforts in energy efficiency management.

Overview of the Research Topic

This Research Topic systematised theoretical knowledge in the sphere of energy economics and shed light on and discussed in detail the leading international experience of sustainable and environmental development of the energy economy under the influence of the Fourth Industrial Revolution. The key idea of the Research Topic is that under the conditions of Industry 4.0 and the digital economy, sustainable and environmental development of the energy economy takes place based on Smart Grids and EnergyTech. This thought was described in the papers included in this Research Topic.

In their paper, Pechancová et al. proposed a promising approach to developing renewable energy based on local communities' broad involvement and active participation in this process. The leading experience of the Czech Republic and the new "triple bottom line value proposition canvas" formed a blueprint for environmentally responsible communities' reaching the carbon neutrality of the economy.

Roslyakova and Vechkinzova elaborated on the influence of price factors on the production of clean energy in the regions of Russia. This paper includes a non-parametric data envelopment analysis method (DEA). It states that the "green policy" leads to a slight growth of prices and significant savings of energy resources, i.e., to sustainable and environmental development of the energy economy.

Muzalev et al. performed a large-scale study using smart Russian regions, showing that EnergyTech and Smart Grid markets maintain technological and territorial borders. This allows the authors to identify the specifics of the region as an economic system in which sustainable, environmentally friendly development of the energy economy based on smart eco-innovations takes place. Due to this, the paper demonstrated a novel aspect of examining sustainable and environmental development of energy—from the position of the spatial (regional) economy.

Sozinova et al. described the intended directions of corporate social responsibility of EenrgyTech companies that facilitate the sustainable and environmental development of the energy economy. These directions include increasing energy availability for the population, reducing natural rents in the GDP and reducing energy exports. Due to this, the paper provided a new view of the transition to clean energy from the position of energy companies as society's guides on the path to sustainable and environmental development of the energy economy. The paper also offered a perspective managerial tool for this—corporate social responsibility.

Osipov et al. determined the fundamental financing problems of EnergyTech amid the COVID-19 crisis and in the post-pandemic period and outlined the prospects for resolving them. The paper presented a novel view of the COVID-19 pandemic and crisis, which created challenges and threats. It established assured tendencies in the financing of green energy technologies. The authors' conclusions will help forecast the consequences of future epidemics, pandemics, and economic crises caused by them for EnergyTech and manage these consequences.

Vorozheykina et al. identified in their paper the scenario of alternative energetics development in the age of the Fourth Industrial Revolution. The author proved the trend for reducing the share of alternative and clean energy and the economy's growing dependence on fossil energy in disseminating the high technologies of Industry 4.0 (robots and artificial intelligence). The authors recommend changing this tendency and implementing the scenario of sustainable and environmental development of the energy economy in Industry 4.0.

Chutcheva et al. developed a novel institutional approach to the decarbonisation of the economy and transition to clean energy based on EnergyTech. Their paper contains a thorough overview and analysis of statistics on developed and developing countries. The authors' approach allows using the institute of state regulation and energy technologies to ensure decarbonisation.

Borisova et al. developed the marketing mix for energy companies of EnergyTech, which stimulates the maximisation of their contribution to the sustainable and environmental development of the energy economy. Viewing energy companies from the marketing position allowed the authors to demonstrate the difference between oil and gas companies and EnergyTech companies. The proposed authors' recommendations allow for empowering energy companies' environmental management.

Fokina et al. proved that marketing improves project management in EnergyTech and ensures sustainable and environmental development of the energy economy. The authors proposed methodological recommendations for the transition to a new marketing approach to quality management in EnergyTech, which ensures the most considerable support for the sustainable and environmental development of the energy economy.

Khoruzhy et al. monitored the global digital energetics development based on Industry 4.0 technologies. Their paper promotes the discussion on the energy economy's sustainable and environmental development and how leading technologies (IoT, blockchain, robots and AI) promote this development. A breakthrough conclusion is about the priority of energetics' sustainability over its digitalization and developing digital energetics based on Industry 4.0 technologies.

Mustafin et al. employed the leading international experience to specify and model (with the application of the economic and mathematical tools) and cause and effect links of Smart Grid development. The authors equally developed an algorithm for sustainable and eco-friendly development of the energy economy based on Smart Grid. The authors' algorithm allows raising the effectiveness of the management of Smart Grid development with the help of more active involvement of state regulators in this process.

Vagin et al. formulated a new conclusion in their paper: technological innovations play a role in the system of corporate social responsibility of energy companies. More significantly, the authors came up with a methodological approach to assessing energy companies' compliance with the criteria of EnergyTech. Energy companies can set their priorities in developing technological innovations, increasing innovations' management and their influence on corporate social responsibility and the transition to EnergyTech.

Yankovskaya et al. described the leading capabilities of monitoring sustainable and environmental development of the energy economy based on big data and datasets. The authors demonstrated a successful model of sustainable and green development of the energy economy in the Eurasian Economic Union (EAEU) in 2021 and the practical experience of implementing this model in Kazakhstan and Kyrgyzstan.

Bogoviz et al. presented a comprehensive overview of the leading practices of human resources management and, in particular, digital personnel in digital energetics based on the technologies of Industry 4.0. It was proposed to improve this practice through better consideration of each company's specifics: its corporate culture and organisational structure. This will make EnergyTech more accessible and successful in developed and developing countries. For this, the authors proposed a broad range of the leading methods of personnel management in digital energetics (increase in labour safety, creation of science-intensive jobs, training of personnel and stimulation of effectiveness growth) based on the technologies of Industry 4.0: AI, IoT, AR/VR, 3D printers and 3D models, big data, mobile applications and linear programming.

Popkova et al. developed and adopted an institutional approach to research the transition to clean energetics based on EnergyTech and the analysis of reducing production waste and the fight against climate change. This paper reveals the network effect of institutes and their promising role as a bridge between high technologies and sustainable development of energetics. The paper revealed the prospects for developing clean energy based on institutes of EnergyTech.

Prospective directions for smart grids and EnergyTech towards sustainable and environmental energy economy in the decade of action

The prospects for combating the noted issues in the Decade of Action are related to the spread, progress, and effective use of Smart Grids and EnergyTech in support of sustainable and environmental development. The first direction represents the development of renewable energy. This direction is set by the case experience of the Czech Republic, China, Russia and countries of the Eurasian Economic Union (EAEU), particularly Kazakhstan and Kyrgyzstan.

The second direction is related to alternative renewable energy, which received a renewed impetus for development in the context of the Fourth Industrial Revolution.

The third area remains the digital modernization of the fuel and energy complex in innovative regions because the development of Smart Grid occurs at the level of territories. The fourth direction is to increase the level of corporate social responsibility of energy companies, a vital component of which is environmental responsibility and the implementation of the SDGs.

The fifth direction is to improve the marketing management of energy companies with a focus on enhancing quality and efficiency. All identified favourable recommendations for developing Smart Grids and EnergyTech for a sustainable and environmental energy economy in the Decade of Action are reflected in this Research Topic.

Conclusion

The Research Topic "Sustainable and Environmental Development of Energy Economics based on Smart Grids and EnergyTech" developed a systemic view of technological advances in energy in the Decade of Action. The literature's Research Topic consists of developing views of the Theory of energy economy by clarifying the cause-effect relationship of its sustainable and environmental development based on Smart Grids and EnergyTech.

The theoretical significance of the Research Topic is to identify the potential of Smart Grids and EnergyTech and a methodology for sustainable and environmental development of the energy economy. The significance of the Research Topic is the extensive discussion of the best international practices of energy companies and the recommendations to public and corporate governance of Smart Grids and EnergyTech to assist an environmentally sustainable energy economy.

Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

References

Isiksal, A. Z., and Assi, A. F. (2022). Determinants of sustainable energy demand in the European economic area: Evidence from the PMG-ARDL model. *Technol. Forecast. Soc. Change* 183, 121901. doi:10.1016/j.techfore.2022.121901

Li, T., Zhao, H., Song, S., Yang, C., Du, C., and Liu, Y. (2022). Fifth generation mobile communication technology network attack defense based on software defined network technology in power internet of things. *Front. Energy Res.* 10, 950611. doi:10.3389/fenrg.2022.950611

Liu, Z., Li, L., Wang, S., and Wang, X. (2022). Optimal design of low-carbon energy systems towards sustainable cities under climate change scenarios. *J. Clean. Prod.* 366, 132933. doi:10.1016/j.jclepro.2022.132933

Mahboob Ul Hassan, S., Ramli, M. A. M., and Milyani, A. H. (2022). Robust load frequency control of hybrid solar power systems using optimization techniques. *Front. Energy Res.* 10, 902776. doi:10.3389/fenrg.2022.902776

Popkova, E. G. (2022). *Advanced issues in the green economy and sustainable development in emerging market economies (Elements in the economics of emerging markets)*. Cambridge, UK: Cambridge University Press. doi:10.1017/9781009093408

Popkova, E. G., Inshakova, A. O., Bogoviz, A. V., and Lobova, S. V. (2021). Energy efficiency and pollution control through ICTs for sustainable development. *Front. Energy Res.* 9, 735551. doi:10.3389/fenrg.2021.735551

Popkova, E. G., and Sergi, B. S. (2021). Energy efficiency in leading emerging and developed countries. *Energy* 221, 119730. doi:10.1016/j.energy.2020.119730

Qin, M., Gao, Y., Hou, B., Wang, H., Zhou, W., and Yao, Y. (2022). Research on efficient channel decoding algorithm for memory channel and short packet transmission in smart grid. *Front. Energy Res.* 10, 949453. doi:10.3389/fenrg.2022.949453

Sun, Y., Chen, M., Yang, J., Ying, L., and Niu, Y. (2022). Understanding technological input and low-carbon innovation from multiple perspectives: Focusing on sustainable building energy in China. *Sustain. Energy Technol. Assessments* 53, 102474. doi:10.1016/j.seta.2022.102474

Tang, J., Zhao, Y., Wang, M., Wang, D., Yang, X., Hao, R., et al. (2022). Circadian humidity fluctuation induced capillary flow for sustainable mobile energy. *Nat. Commun.* 13 (1), 1291. doi:10.1038/s41467-022-28998-y

Wang, P., Zhu, Y., Liu, J., Yu, P., and Huang, L. (2022). Is the secondary consumption of renewable energy sustainable? Empirical evidence from the photovoltaic industry in China. *Energy Rep.* 8, 6443–6456. doi:10.1016/j.egyr.2022.04.081

Zhou, M., and Li, X. (2022). Influence of green finance and renewable energy resources over the sustainable development goal of clean energy in China. *Resour. Policy* 78, 102816. doi:10.1016/j.resourpol.2022.102816

frontiers | Frontiers in Energy Research

OPINION
published: 31 May 2022
doi: 10.3389/fenrg.2022.908489

Perspective Directions of Corporate Social Responsibility of Energy Companies of EnergyTech for Sustainable and Environmental Development of Energy Economy

Anastasia A. Sozinova[1]*, *Tatyana N. Litvinova*[2], *Victoria N. Ostrovskaya*[3] and *Galina V. Vorontsova*[4]

[1]*Faculty of Management and Service, Vyatka State University, Kirov, Russia,* [2]*Department of Management and Logistics in the Agro-Industrial Complex, Volgograd State Agricultural University, Volgograd, Russia,* [3]*Head of the Center for Marketing Initiatives, Stavropol, Russia,* [4]*Department of Economics and Management, North Caucasus Federal University, Stavropol, Russia*

Keywords: corporate social responsibility, energy companies, Energytech, sustainable and environmental development, energy economy

Edited by:
Bruno Sergi, Harvard University, United States

Reviewed by:
Aidarbek T. Giyazov, Batken State University, Kyrgyzstan
Ladislav Zak, Independent Researcher, Prague, Switzerland

***Correspondence:**
Anastasia A. Sozinova
1982nastya1982@mail.ru

Specialty section:
This article was submitted to Sustainable Energy Systems and Policies, a section of the journal Frontiers in Energy Research

Received: 30 March 2022
Accepted: 20 April 2022
Published: 31 May 2022

Citation:
Sozinova AA, Litvinova TN, Ostrovskaya VN and Vorontsova GV (2022) Perspective Directions of Corporate Social Responsibility of Energy Companies of EnergyTech for Sustainable and Environmental Development of Energy Economy. Front. Energy Res. 10:908489. doi: 10.3389/fenrg.2022.908489

INTRODUCTION

The adoption of Sustainable Development Goal 7 (SDG 7) “affordable and clean energy” has made the sustainable and ecological development of energy economics a pressing issue. Strong corporate social responsibility of EnergyTech energy companies is necessary to achieve this goal. However, the problem is that the formulation of this SDG focuses on social and environmental advantages without taking into account the capabilities and benefits of energy companies.

This causes a gap between theory and practice of sustainable and environmental development of energy economics. To overcome this gap, it is necessary to rethink the corporate social responsibility of EnergyTech energy companies from the standpoint of effectiveness and choose the most effective direction for the manifestation of this responsibility.

Corporate social responsibility of energy companies has two manifestations: internal and external. The external manifestation is based on the important global mission of energy companies in large energy economies to ensure an uninterrupted supply of their products to those countries that are experiencing energy shortages. That is, in this case, it is a matter of responsibility to their consumers.

The trends of recent years in the global energy resource market have determined the specificity of the external manifestation of the corporate social responsibility of energy companies. The environmental agenda of the European Union countries, which are among the key consumers of energy resources in the world, plays an important role in this context. These countries have announced that an environmental tax on the carbon footprint from mining and export of energy resources will soon be introduced. This has transformed the modern idea of the external manifestation of the corporate social responsibility of energy exporting companies for supporting the sustainability of energy from preventing its shortage (“affordable energy”) to ensuring its environmental friendliness (“clean energy”).

This has brought the traditionally isolated external manifestation as close as possible to the internal manifestation of the corporate social responsibility of energy companies associated with their responsibility to the population and the environment of the territory in which they conduct their business activities. Therefore, in this article, attention is focused on the internal manifestation of responsibility, which has become the main factor at the present time. The purpose of this study is to identify promising areas of the corporate social responsibility of energy companies EnergyTech in support of sustainable and environmental development of energy economics.

EXISTING DIRECTIONS OF CORPORATE SOCIAL RESPONSIBILITY OF ENERGY COMPANIES

The study is based on the fundamental provisions of the theory of sustainable energy. According to it, EnergyTech is interpreted as the economic activity of energy companies for efficient, safe, and environmental-friendly economical extraction, transformation, transportation, storage, and use of energy (Yang et al., 2021; Alabugin et al., 2022; Wang and Nam-gyu, 2022).

That is, the criteria for assigning energy companies to EnergyTech are high effectiveness, safety of their activities for humans, and low environmental costs. Therefore, corporate social responsibility has laid the basis of EnergyTech, and it is reasonable that this responsibility should be the determining factor of its current boundaries and prospects for further development.

This study discusses four promising areas of corporate social responsibility of energy companies EnergyTech for sustainable and environmental development of energy economics identified and studied in detail in the existing literature.

The first direction is connected with the development of clean energy. Clean (i.e., renewable) energy enables reducing the depletion of natural resources and preserving the legacy of future generations (Wu et al., 2022a; Jia et al., 2022). A statistical indicator of the practical implementation of this direction is renewable electricity output (according to the World Bank calculations, 2022).

The second direction is to increase the availability of energy. Priority satisfaction of domestic demand is one of the main expectations of society from energy companies. The difficulty lies in the fact that governments often establish price limits for the sale of power resources on the domestic market, making it less profitable for energy companies (Popkova and Sergi, 2021; Popkova et al., 2019; Melin et al., 2022). Therefore, the practice under consideration belongs to the field of corporate social responsibility. The statistical indicator of the practical implementation of this direction is access to electricity (according to the World Bank calculations, 2022).

The third direction is to reduce the natural resource rent in the GDP. The reduction in the extraction of energy resources makes it possible to impede the rate of the depletion of natural resources of energy economies; therefore, it is important for society and environmental protection (Agboola et al., 2021; Awosusi et al., 2022; Wu et al., 2022b). The statistical indicator of the practical implementation of this direction is the total natural resource rents (according to the World Bank calculations, 2022).

The fourth direction is to reduce the export of energy resources. This direction is designed to prevent the so-called Dutch disease that threatens energy economies. Within the framework of this direction of corporate social responsibility, the extracted energy resources are designed to cater to the internal needs of the economy, supporting the development of diversified domestic production (Day and Day, 2017; Chamberlain and Kalaitzi, 2020). The statistical indicator of the practical implementation of this direction is fuel exports (according to the World Bank calculations, 2022).

In the available literature, the essence of the aforementioned directions of corporate social responsibility of energy companies is disclosed in detail. However, their attitude toward EnergyTech in order to achieve sustainable and environmental development of energy economics remains poorly understood and unclear. In this study, in order to fill the identified gap, when determining the promising areas of the corporate social responsibility of energy companies EnergyTech to achieve sustainable and environmental development of energy economics, the criterion of economic effectiveness of these directions is taken into account, allowing the assessment of their consequences (compare costs and benefits) for energy companies.

RETHINKING EXISTING DIRECTIONS OF CORPORATE SOCIAL RESPONSIBILITY OF ENERGY COMPANIES FROM THE POSITIONS OF ENERGYTECH

To rethink the existing directions of the corporate social responsibility of energy companies from the standpoint of EnergyTech, this study uses the methodology of Game Theory. Using the chosen methodology, a comparative analysis of the implementation of each of the four identified directions is carried out and from the standpoint of their effectiveness through the ratio of the expected economic benefits for energy companies and the economy as a whole (gross domestic product, calculated by the International Monetary Fund, 2022) to the required costs (investment in energy with private participation according to the World Bank calculations, 2022).

To reflect the experience of EnergyTech, the research in this study is carried out on the example of the world's largest energy economies (energy exporters) from among OPEC and OPEC+, the sample of which is formed according to the criterion of the availability of statistical data (**Table 1**). Since data for 2021 are still being calculated, this study is based on data from 2020, which makes it possible to assess the potential contribution of the directions of the corporate social responsibility of energy companies to support the economic growth of energy economies in the context of the COVID-19 pandemic and crisis. According to the calculations of the World Bank, the decline in global GDP in 2020 amounted to 5.2%. Therefore, when comparing the directions of corporate social responsibility, their potential in preventing this decline is assessed.

The data were obtained from references to the International Monetary Fund (2022) and the World Bank, 2022.

According to **Table 1**, the investment in energy with private participation in the major energy economies of the world in 2020 averaged \$0.60 billion, and the gross domestic product averaged \$436.14 billion. Therefore, the economic effectiveness of energy economies was 726.79 (436.14/0.60). This means that the GDP exceeded investments in the energy sector with private participation by 726.79 times. The target rate of GDP growth for all the areas under consideration is 5.20%, that is, the GDP should amount to \$458.83 billion (436.14*1,052).

Based on the statistics collected in **Table 1**, an econometric model (1) was obtained using the regression analysis method:

TABLE 1 | Statistics of energy economies in 2020.

Country category	Country	Investment in energy with private participation (million current US$)	Renewable electricity output (% of total electricity output)	Access to electricity (% of population)	Total natural resource rents (% of GDP)	Fuel exports (% of merchandise exports)	Gross domestic product, current prices, and billions current US$
		z	x_1	x_2	x_3	x_4	y
OPEC	Algeria	30.30	0.32	99.50	16.40	96.00	147.600
	Angola	112.00	53.17	45.70	26.20	95.00	58.376
	Venezuela	60.00	63.70	100.00	11.80	98.00	47.255
	Iraq	500.00	3.73	100.00	39.8	100.00	169.488
	Iran	94.50	5.10	100.00	23.6	69.00	835.351
OPEC+	Azerbaijan	145.20	7.04	100.00	25.5	87.00	42.607
	Kazakhstan	265.48	8.87	100.00	17.6	58.00	171.240
	Malaysia	95.03	9.96	100.00	6.30	11.00	337.008
	Mexico	4211.50	15.39	100.00	2.20	4.00	1073.915
	Russia	486.95	15.86	100.00	13.10	42.00	1478.571

[a] *The lower the value of the Pollution index, the better.*

$$y = -5,5214x_1 + 537,27. \quad (1)$$

According to the obtained model (1), the first identified direction of corporate social responsibility associated with the development of clean energy is ineffective for energy companies and damages the economic growth of energy economies. Therefore, this direction contradicts the criteria of EnergyTech and will not be further considered in this work (it is not promising).

For the second direction of corporate social responsibility of energy companies in energy economies (increasing energy availability), a system of **Eq. 2** is obtained:

$$\begin{cases} y = 7,7997x_2 - 301,08 \\ x_2 = 10,115z - 355,96 \end{cases}. \quad (2)$$

According to the obtained system of **Eq. 2**, with the growth of access to electricity by 1% of the population, the growth of the gross domestic product by $ 7.7997 billion is achieved, but this requires an additional $10.115 million investment in energy with private participation. According to **Table 1**, in 2020, access to electricity among the energy economies averaged 94.52%. Based on the revealed regression dependencies **Eq. 2**, it was found that to increase the GDP to the target $458.83 billion, it was necessary to increase access to electricity by 3.08% (up to 97.43% of the population), which will require an increase in investment in energy with private participation by 4.90% (up to $ 629.52 million). In this case, the effectiveness of this direction of corporate social responsibility will be 728.85 (458.83/0.63).

For the third direction of corporate social responsibility of energy companies in the energy economies (reduction of natural resource rent in GDP), a system of **Eq. 3** is obtained:

$$\begin{cases} y = -19,121x_3 + 785,1 \\ x_3 = -54,228z + 1589,8 \end{cases}. \quad (3)$$

According to the obtained system of **Eq. 3**, with the reduction of total natural resource rents by 1% of the GDP, the growth of the gross domestic product by $ 19.121 billion is achieved, but this requires an additional $54.228 million investment in energy with private participation. According to **Table 1**, in 2020, the total natural resource rents averaged 18.25% of the GDP among the energy economies. Based on the revealed regression dependencies **Eq. 3**, it was found that in order to increase the GDP to the target $458.83 billion, it is necessary to reduce total natural resource rents by 6.50% (up to 17.06% of GDP), which will require an increase in investment in energy with private participation by 10.73% (up to $664.48 million). In this case, the effectiveness of this direction of corporate social responsibility will be 690.51 (458.83/0.66).

For the fourth direction of corporate social responsibility of energy companies in the energy economies (reduction of energy exports), a system of **Eq. 4** is obtained:

$$\begin{cases} y = -8,8533x_4 + 1020,5 \\ x_4 = -21,359z + 2009,8 \end{cases}. \quad (4)$$

According to the obtained system of **Eq. 4**, with a decrease in fuel exports by 1% of merchandise exports, an increase in the GDP by $8.8533 billion is achieved, but this requires an additional $21.359 million investment in energy with private participation. According to **Table 1**, in 2020, fuel exports among the energy economies averaged 66% of merchandise exports. Based on the revealed regression dependencies in Eq. 4, it was found that in order to increase the GDP to the target $458.83 billion, it is necessary to reduce fuel exports by 3.88 (to 63.44% of merchandise exports), which will require an increase in investment in energy with private participation by 9.11% (to $654.74 million). In this case, the effectiveness of this direction of corporate social responsibility will be 700.78 (458.83/0.65).

DISCUSSION AND CONCLUSION

Thus, the results show that the most promising direction of the corporate social responsibility of energy companies to achieve sustainable and environmental development of energy economics from the standpoint of EnergyTech is the direction involving increasing the availability of energy for the population–its effectiveness was estimated at 728.85 and even higher than in 2020.

Attention should also be paid to less effective, from the standpoint of EnergyTech, but also promising areas of corporate social responsibility of energy companies for sustainable and environmental development of energy economics: a reduction of natural rents in the GDP and reduction of energy exports. Their effectiveness was estimated at 690.51 and 700.78, respectively. The effectiveness of these directions is lower not only in comparison with the selected most promising direction but also in comparison with 2020, although both of these directions have the potential of economic crisis management of energy economies. The direction associated with the development of clean energy proved to be unpromising.

The contribution of this study to the literature consists in rethinking the existing directions of corporate social responsibility of energy companies to achieve sustainable and environmental development of energy economics from the standpoint of EnergyTech. This helped identify the most promising direction (increasing the availability of energy for the population), which allows balancing the interests of society and environmental protection with the interests of energy companies.

The practical significance of the conclusions is that they can serve as a practical guide on the corporate social responsibility of energy companies in large energy economies. The proposed most promising direction of corporate social responsibility will allow increasing its economic effectiveness and ensure a massive transition of energy companies in large energy economies to EnergyTech.

In conclusion, it should be noted that the focus of this study was on large energy economies (energy exporting countries), and the study conducted is limited by their experience. The experience of other countries, in particular, large energy consumers dependent on their exports, deserves special consideration. Most likely, the corporate social responsibility of energy companies in these countries will have its own specifics and its own promising directions of EnergyTech, which should be studied in the future.

AUTHOR CONTRIBUTIONS

AS and TL contributed to the conception and design of the study. GV organized the database. VO performed the statistical analysis. AS wrote the first draft of the manuscript. TL, VO, and GV wrote sections of the manuscript. All authors contributed to manuscript revision and read and approved the submitted version.

REFERENCES

Agboola, M. O., Bekun, F. V., and Joshua, U. (2021). Pathway to Environmental Sustainability: Nexus between Economic Growth, Energy Consumption, CO2 Emission, Oil Rent and Total Natural Resources Rent in Saudi Arabia. *Resour. Policy* 74, 102380. doi:10.1016/j.resourpol.2021.102380

Alabugin, A. A., Liming, H., and Shishkov, A. N. (2022). Formation of the Energy-Efficient Platform of Hi-Tech Development of Renewable Power. *Smart Innovation, Syst. Technol.* 272, 1–9. doi:10.1007/978-981-16-8759-4_1

Awosusi, A. A., Mata, M. N., Ahmed, Z., Coelho, M. F., Altuntaş, M., Martins, J. M., et al. (2022). How Do Renewable Energy, Economic Growth and Natural Resources Rent Affect Environmental Sustainability in a Globalized Economy? Evidence from Colombia Based on the Gradual Shift Causality Approach. *Front. Energy Res.* 9, 739721. doi:10.3389/fenrg.2021.739721

Chamberlain, T. W., and Kalaitzi, A. S. (2020). Fuel-Mining Exports and Economic Growth: Evidence from the UAE. *Int. Adv. Econ. Res.* 26 (1), 119–121. doi:10.1007/s11294-020-09766-4

Day, C., and Day, G. (2017). Climate Change, Fossil Fuel Prices and Depletion: The Rationale for a Falling Export Tax. *Econ. Model.* 63, 153–160. doi:10.1016/j.econmod.2017.01.006

International Monetary Fund (2022). *World Economic Outlook Database: October 2021*. Washington, DC: International Monetary Fund. Available at: https://www.imf.org/en/Publications/WEO/weo-database/2021/October.

Jia, W., Jia, X., Wu, L., Guo, Y., Yang, T., Wang, E., et al. (2022). Research on Regional Differences of the Impact of Clean Energy Development on Carbon Dioxide Emission and Economic Growth. *Humanit Soc. Sci. Commun.* 9 (1), 25. doi:10.1057/s41599-021-01030-2

Melin, K., Nieminen, H., Klüh, D., Laari, A., Koiranen, T., and Gaderer, M. (2022). Techno-Economic Evaluation of Novel Hybrid Biomass and Electricity-Based Ethanol Fuel Production. *Front. Energy Res.* 10, 796104. doi:10.3389/fenrg.2022.796104

Popkova, E. G., Inshakov, O. V., and Bogoviz, A. V. (2019). Regulatory Mechanisms of Energy Conservation in Sustainable Economic Development. *Lect. Notes Netw. Syst.* 44, 107–118. doi:10.1007/978-3-319-90966-0_8

Popkova, E. G., and Sergi, B. S. (2021). Energy Efficiency in Leading Emerging and Developed Countries. *Energy* 221, 119730. doi:10.1016/j.energy.2020.119730

Wang, Y., and Nam-gyu, C. (2022). Research on Performance Layout and Management Optimization of Grand Theatre Based on Green Energy Saving and Emission Reduction Technology. *Energy Rep.* 8, 1159–1171. doi:10.1016/j.egyr.2022.02.047

World Bank (2022). *Indicators: Energy & Mining*. Washington, DC: World Bank. Available at: https://data.worldbank.org/indicator.

Wu, Y., Shi, Z., Lin, Z., Zhao, X., Xue, T., and Shao, J. (2022b). Low-Carbon Economic Dispatch for Integrated Energy System through the Dynamic Reward and Penalty Carbon Emission Pricing Mechanism. *Front. Energy Res.* 10, 843993. doi:10.3389/fenrg.2022.843993

Wu, Y., Zhou, Y., Liu, Y., and Liu, J. (2022a). A Race between Economic Growth and Carbon Emissions: How Will the CO2 Emission Reach the Peak in Transportation Industry? *Front. Energy Res.* 9, 778757. doi:10.3389/fenrg.2021.778757

Yang, Y., Zhang, Q., Yu, H., and Feng, X. (2021). Tech-economic and Environmental Analysis of Energy-Efficient Shale Gas and Flue Gas Coupling System for Chemicals Manufacture and Carbon Capture Storage and Utilization. *Energy* 217, 119348. doi:10.1016/j.energy.2020.119348

Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

frontiers | Frontiers in Energy Research

ORIGINAL RESEARCH
published: 31 May 2022
doi: 10.3389/fenrg.2022.821706

Community Renewable Energy in the Czech Republic: Value Proposition Perspective

Viera Pechancová[1,2], Drahomíra Pavelková[1] and Petr Saha[2]*

[1]*Faculty of Management and Economics, Tomas Bata University in Zlín, Zlín, Czechia,* [2]*University Institute, Tomas Bata University in Zlín, Zlín, Czechia*

The community renewable energy offers much potential for sustainable projects differing in terms of regional governance, technology, social, and economic settings. However, the energy sector often lacks a systematic approach to community energy project data, and community projects are based on diversified value proposition designs. This study introduces a new concept of value proposition canvas. Four regional case studies provide essential inputs for the novel community renewable energy value proposition canvas based on the triple bottom line concept. The argument of this study is that energy communities bring together multiple positive local impacts. Moreover, we offer a novel, structured way of looking at its value propositions in the form of triple bottom line value proposition canvas. The study results might serve for the new entrants to the low carbon energy communities and decision-making authorities in energy policy.

Keywords: community renewable energy, renewable energy sources, business model, value proposition canvas, energy transition

OPEN ACCESS

Edited by:
Elena G. Popkova,
Moscow State Institute of International Relations, Russia

Reviewed by:
Huaping Sun,
Jiangsu University, China
Muhammad Mohsin,
Jiangsu University, China

Correspondence:
Viera Pechancová
pechancova@utb.cz

Specialty section:
This article was submitted to Sustainable Energy Systems and Policies,
a section of the journal Frontiers in Energy Research

Received: *24 November 2021*
Accepted: *19 April 2022*
Published: *31 May 2022*

Citation:
Pechancová V, Pavelková D and Saha P (2022) Community Renewable Energy in the Czech Republic: Value Proposition Perspective. Front. Energy Res. 10:821706. doi: 10.3389/fenrg.2022.821706

INTRODUCTION

Energy sector transformation is tightly connected with global changes. Mature societies struggle with economic, technological, political, and social transformations, and local energy systems could provide a potential contribution toward climate objectives. According to Subbarao and Lloyd (2011), many energy projects have been found with active community involvement taking the form of cooperatives. The local community is the most natural and suitable environment for a consumer-prosumer shift in economic, social, and political empowerment.

The European Union's (EU) aspiration to become a global leader in climate change has placed pressure on European policymaking to pursue an ambitious internal climate policy (Solorio and Jörgens, 2020). The EU's climate and energy policy framework was first introduced in 2009, setting its goals in the three areas of energy efficiency, renewable energy, and greenhouse gas emissions reductions. Central and Eastern European countries have been regarded as climate and energy policy laggards objecting to more ambitious EU decarbonization targets (Ćetković and Buzogány, 2019). EU's energy policy is thus one of the most sensitive areas of the Europeanization process (Wach et al., 2021).

The Czech energy sector has been going through a rapid transition in recent years, and effective business models in support of the decarbonization process have been envisaged. One of those mechanisms is represented by local sustainability initiatives in the form of community renewable energy (CRE) projects. However, the CRE projects are tightly connected to the national energy policy in the Czech Republic, and they are based on diversified value proposition designs. Identification of factors influencing the implementation of renewable energy (RE) at the community level in the

Czech Republic is still in its initial phase. There is also a lack of practical insights into local energy business modeling. Hence, considering national socio-technical settings, one-size-fits-all approaches are not the solution. Central and Eastern European countries, including Czechia, which focus on municipal-led RE projects, have different needs compared to countries with strong grassroots' RE cooperative bases such as Germany (Hoicka et al., 2021).

Recent literature review on community energy projects and value creation in CRE projects has led the authors to the following research question: How is the value proposition of selected CRE projects structured and in what way is it created? The aim of the presented research is the conceptualization of community energy value propositions by employing a business model canvas framework, originally elaborated by Osterwalder et al. (2010), respecting the theoretical concept of the triple bottom line, which has been implemented by an increasing number of organizations (Elkington, 2018).

The multiple case study approach to CRE projects is applied, supporting the understanding of the socio-economic complexity of the researched problem. The data for the four case studies were obtained from publicly available sources [Energy Regulatory Office (ERO)] and *via* semi-structured interviews of CRE projects' stakeholders. As a result, a novel approach to the CRE value proposition canvas is proposed.

The remainder of this study is organized as follows: after the comprehensive theoretical review, the research methodology is introduced. The results are presented in the next chapter, followed by a discussion and future perspectives, and the final chapter concludes the paper.

THEORETICAL BACKGROUND

Triple Bottom Line of Community Renewable Energy

Sustainability is often understood as a three-legged stool with economic, environmental, and social legs, and it is relevant to enterprises and societies (Willard, 2012). Elkington (1997) titled the combination of the three dimensions of sustainable development—a triple bottom line (3BL), whereby the economic growth cannot be achieved without considering environmental and social aspects (D'Agostino and Moreno, 2019; Fankhauser et al., 2013). This holistic approach measures the impacts of business or, more generally, any organization on profit, people, and the planet (Tiba et al., 2019). Energy sustainability is an integral part of the concept of an energy trilemma of energy security, sustainable development, and financial effectiveness. Because of having many variations, the recently accepted interpretation is the central point of energy policy and laws, which ideally should balance all three elements (Heffron et al., 2015).

The energy transition challenge toward sustainability is to find appropriate RE systems in terms of concrete technology, territorial "fitting," ownership structures, scale, and actors participating as producers, consumers, prosumers, or any other relation (Frantál and Nováková, 2019). Better opportunities for citizens to participate in the energy transition belong to the features recognized in community energy (Hansen, 2021). Moreover, CRE represents an innovation that aims to create more sustainable energy systems. While there is no consensus as to what the term community energy should mean (Brummer, 2018), according to Walker and Devine-Wright. (2008), different levels of involvement in decision-making and sharing of benefits are significant to CRE projects. Walker (2008) argued that there are various community ownership models, including those established by local governments and local entrepreneurs. However, Petersen (2016) puts more attention to place-based communities such as cities, municipalities, or neighborhoods. Klein and Coffey (2016) made an effort to define community energy with a grassroots focus as a project initiated by a group of people.

With its climate change leadership (Oberthür and Dupont, 2021) and commitment to forming an Energy Union, the EU offers an opportunity for stakeholder engagement and a way to decentralize energy governance (Tosun et al., 2019). Two Europeanization pathways of EU policies are relevant to the RE development: the EU renewables policy, outlined in the renewables directives, and the EU rules on state aid (Boasson et al., 2020). The Clean Energy Package specifically allows actively engaging consumers with the energy sector and introducing two legislative concepts in community energy: i) renewable energy communities as a part of the revised Renewable Energy Directive RED II (Directive, 2018) and ii) citizen energy communities included in the revised Internal Electricity Market Directive (IEMD) (Directive, 2019). Caramizaru and Uihlein (2020) stated that the concepts of citizen energy communities and renewable energy communities contain common conceptual elements such as governance, ownership, control, and purpose. On the other hand, the concepts differ in activities, participants, autonomy, and effective control. The RED II specifically refers to the local renewable energy nature of energy communities, and its aim is "to facilitate the development of renewable energy communities" (RED II Art. 22 para. 4). Lowitzsch et al. (2020) highlighted that both Europe-wide governance models for energy communities concentrate on environmental, economic, or social community benefits rather than profits.

According to Creamer et al. (2018), community energy projects are entangled with the interaction of actors within three contested domains: private sector, state (central or local government), and community. These domains do not have strict boundaries, and there are interactions among them. In some countries, such as the Netherlands, Belgium, and parts of Germany, it is compulsory for the developer to offer a certain share of the prepared RE project to the local community (individuals, municipalities, agricultural companies, and small businesses). National policymakers should be encouraged to promote domestic innovative capabilities and technologies (Sun et al., 2021b), accessibility of green energy technology funds (Zhang et al., 2021), and micro-financing (Sun et al., 2021a). Potentially, spatial spillover effects on supporting

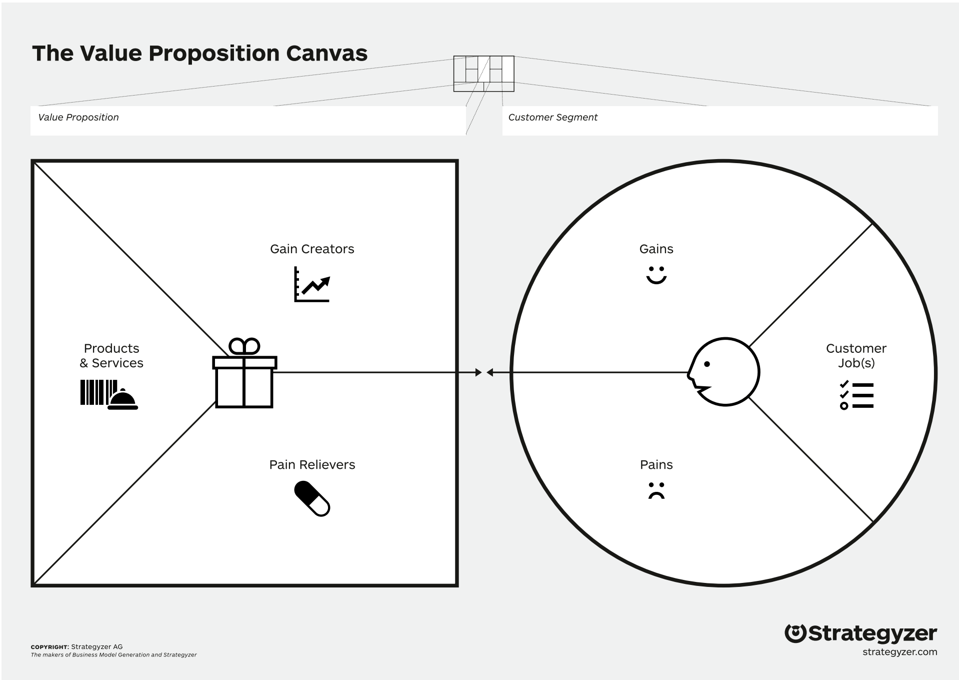


FIGURE 1 | Value proposition canvas and its relation to the business model canvas (based on Osterwalder et al. (2014), Strategyzer.com, and with copyright by Strategyzer AG).

innovation efficiency in other regions could play a role (Fang et al., 2022).

Value Perspective of the Community Renewable Energy Business Models

A widely used definition formulated by Osterwalder and Pigneur (2010) defined a business model (BM) as "the process of how an organisation creates, delivers, and captures value." One of the tools supporting innovation for sustainability in different fields of application is the Business Model Canvas (BMC), elaborated in the works of Osterwalder et al. (2005) and Osterwalder and Pigneur (2010). The BMC is a graphical template consisting of nine building blocks aiming at driving the innovation of any organization, private, public, or non-profit. Osterwalder et al. (2005) elaborated the BMC into the "plug-in" tool value proposition canvas zooming in detail on how the value is created for the customers and giving insights into one's imagination about their customers' thinking. This tool highlights competitive value creation, focusing on the value proposition for customers' activities and resources (**Figure 1**). The authors emphasized the value proposition canvas principle as a value map, which meets the customer's needs. The organization defines how the positive effects of a product/service are created (gain creators) and negative effects diminished (pain relievers).

Due to the flexibility and application strengths of BMC, it remains the most widely used approach for business description. Therefore, it will be used in the scope of this work to conceptualize the CRE projects in the Czech Republic.

While both barriers and drivers have gained attention in the CRE research (Bauwens, 2016; Bauwens et al., 2016; Herbes et al., 2017), systemic research on CRE local values is lacking. In particular, value creation in CRE is still underrepresented, despite studies shedding light on CRE's purpose (Becker et al., 2017), impacts (Berka and Creamer, 2018), and benefits (Hartmann and Apaolaza-Ibáñez, 2012; Berka and Creamer, 2018). Hicks and Ison (2018) distinguished benefits and motivations, indicating that not all motivations are delivered as benefits and vice versa. Although their STEEP framework (social, technical, economic, environmental, and political/policy categories of motivation) builds on a triple bottom line, it also considers technical and policy factors.

CRE projects exhibit diverse activities, institutional forms, goals, and values, which are not always related directly to energy (Seyfang et al., 2014). The value propositions of the energy utility are the products or services offered to the end customer. CRE might differ in the value proposition design compared to for-profit organizations due to the different understanding of value creation and capture. There are also attempts to explore the principles of sustainability-oriented business models, such as the triple bottom layered BMC by Joyce and Paquin (2016), who add two layers to the economic layer: an environmental one with a lifecycle perspective and a social one. Karami and Madlener (2021) concentrated on creating economic, social, and environmental values for private customers of retail electricity suppliers utilizing BMC in a specific segment.

Although applying the business model concept to CRE is challenging, the process of value creation also applies to communities (Herbes et al., 2017). The presented study aims to shed light on the processes through which CRE projects lead to positive local impacts and minimize negative effects *via* structuring the value propositions into economic, social, and environmental dimensions. Even though CRE research has been already advanced, the study of values and long-term local impacts of CRE beyond energy generation is still needed (Creamer et al., 2019). The business model view and value proposition canvas, together with the 3BL framework, might contribute to the above-mentioned challenges.

Community Renewable Energy in the Czech Context

During the last decades, the Czech Republic has gone through a complete market transition that has impacted the energy sector as well. Several legislative documents for the energy policy adopted in 2000 have built the main pillars.[1]

The Czech energy policy is committed to the RE targets of the European Union (EU). The Czech 2030 target level for RE share on gross final energy consumption is 22%, compared to the EU level target of 32%. Renewable energy sources (RES) are supported by regulatory policy and fiscal incentives. The national RES support is covered by the Act on Supported Energy Sources (Act no. 165/2012).[2] The energy-producing companies with an installed capacity higher than 10 kW are required to have a license, whereby two types of licenses are possible: up to 200 kW and those exceeding 200 kW. The micro-generation units with self-consumption up to 10 kW do not require a license or permit in case electricity is not fed into the grid. The promotion of electricity production is based on the following main regulatory instruments: investment support, subsidies, purchase prices in the form of feed-in tariffs (FiT), green premium payment, which is paid on top of the market price, and tax regulation. RES generation is also exempt from real estate tax.

The feed-in energy policy has been a vital part of national support for renewables, often for the promotion of small-scale renewable energy systems. Within this scheme, distribution system operators or transmission system operators are obliged to purchase the complete amount of electricity generated by RES. In the case of green bonuses, the producer needs to seek a purchasing party on his own, whereby it may be the final consumer or the energy trading company. Since the beginning of 2014, support for new RE plants has been discontinued for several years due to collapsed national energy policy incentives in the whole Central Eastern European region (Sokołowski and Heffron, 2022). The above-mentioned FiT tariffs applied only to residual projects with an authorization issued until October 2013 and small-scale installations.

In the Czech Republic, little research has been done in the field of CRE. For instance, cooperatives that were common in the Czech Republic after 1989 predominantly continue with the activities of socialist cooperatives in the agriculture or house of tenants. According to Malý et al. (2019), municipalities have played a major active role in CRE even though their role has been more of project initiation of energy efficiency measures and less of RES installations so far. However, overall, 130 municipalities own and operate electricity generation plants with a total output of 23.5 MW, whereby the largest share of municipal RES is represented by rooftop solar or PV (Duha, 2020). According to the Hnutí DUHA—Friends of the Earth Czech Republic, there are 34 municipal biomass heating plants and five municipal biogas heating plants in the Czech Republic.

RESEARCH DESIGN

This study aims to propose a novel approach toward the structuring of value proposition and creation of CRE projects, respecting the 3BL sustainability concept. The theoretical framework of the research is built on BM theory and value proposition canvas concerning the sustainability concept of 3BL and the conceptualization and classification of CRE projects as a part of the energy sector transition process (Frantál and Nováková, 2019). In order to understand the complexities of CRE projects, the BMC and value proposition canvas, originally elaborated by Osterwalder and Pigneur (2010), was chosen. The multiple-case study research method was applied on the basis of a combination of a "typical case" and "stratified" purposeful sampling methods (Patton, 2002; Palinkas et al., 2015; Irfan et al., 2022), as it captures major differences without identification of a common pattern.

The selection of case studies was performed as follows. First, projects were selected from the Energy Regulatory Office (ERO) license holder database, consisting of electricity generation license holders involved in electricity production, distribution, and trading. The community engagement is evidenced in the ERO database overwhelmingly in the limited liability companies (LLC), collectives, and municipal projects. LLC was chosen in some municipal projects, as this legal form is most transparent with a relatively simple structure, minimal requirements on capital, and any natural person or legal person might be the company representative, whereby they are visible in the business register. The most diversified institutional structure is attributed to biogas collectives with a not negligible share of involvement of agricultural and landowner collectives. Additional 43 city-based projects were found together with four wind energy municipalities and four hydro energy projects. Second, the projects were clustered according to the following parameters: i) ownership structure, ii) RE technologies, iii) localities, and iv) segments. Afterward, professionals from the energy field were asked for their expert opinion: Chamber of Renewable Energy Sources

[1]Energy Management Act (Act no. 406/2000 Coll., on Energy Management as of 25 October 2000), and Czech Energy Act (Act no. 458/2000 on Business Conditions and on the Exercise of State Administration in the Energy Sectors and on the Amendment to Certain Acts, the Amendment to the Energy Act by Act no. 131/2015 Coll).

[2]Act on Promoted Energy Sources and on the amendment to some laws "POZE" (Act no. 165/2012 Coll. as of 31 January 2021).

and DUHA, Czech Friends of the Earth organization, which resulted in a list of four CRE projects:

A combination of organizational and stakeholder structures with community involvement (municipality, municipal energy service company ESCo, non-profit, municipal association, digital platform);
A variety of RE technologies (solar, PV, and bioenergy);
Geographical spread across the Czech Republic;
Different energy value chain segments such as energy generation, supply, consumption, distribution (electricity and heating networks), and energy services.

Second, semi-structured interviews were conducted with the CRE project representatives of top management. Qualitative data analysis involved finding patterns and themes in the data collected for the evaluation with respect to the project's added value, infrastructure, financial aspects, customers, and stakeholders. The targeted interviews occurred between November 2018 and August 2019, based on personal, telephone, and email conversations with representatives of the CRE projects (mayors, municipality representatives, or project managers). In addition, data related to project descriptions were also enhanced by publicly available data sources, such as project websites. Common patterns from case studies were then clustered into three sustainability dimensions in the municipality CRE value proposition canvas.

The municipal projects build the most visible and active CRE in the Czech Republic. Reflecting this, in 2016, the Czech Community Coalition for promoting RE was started and gathered more than 60 cities and municipalities, associations, and industrial partners. The projects with different characteristics of ownership and management structures are demonstrated by four case studies presented in the following chapter.

COMMUNITY RENEWABLE ENERGY REGIONAL CASE STUDIES

The selected case studies demonstrate the economic, social, and environmental aspects of the CRE in detail and represent different settlements of regional public authorities, municipalities, and local stakeholders, which are active in CRE. The projects with different characteristics between ownership and management structures are demonstrated by the following four CRE case studies:

- Municipal ownership and management
- Municipal ownership and municipal ESCo management
- Combined municipal/not-for-profit (NPO) ownership and management
- Combined municipality union ownership and management.

The following part of the study is devoted to the four case studies: municipality-based ownership and management: Měňany in the Central Bohemian region; municipal ESCo case study with municipal ownership and ESCo management: Kněžice in the Central Bohemian region; municipality organization/NPO case study with combined municipal/NPO ownership and management: Hostětín in the Zlín region; and municipality union ownership and management case study: Dolní Lhota in the Zlín region. The canvas tool is used as a template for qualitative data structuring. Each case study consists of a description of the geographical location, the energy system setup, and finally, the individual value proposition canvas based on the customer needs and tasks, which must be performed.

Municipality-Based Case Study

The village of Měňany belongs to the protected landscape area of Český kras in the Central Bohemian region. The village with 308 inhabitants is located in a valley surrounded by hills causing air pollution to be retained at a time when people mostly used to burn low-quality brown coal and waste.[3] Connection to natural gas infrastructure was therefore considered in 2003. According to the natural gas company, the village was a too small municipality for the natural gas infrastructure investment, and a municipal heating plant was therefore proposed as a solution.

A municipal hot water biomass heating plant with a heat distribution project for the whole village was initiated in 2003 and has been in operation since 2008. The total installed heat output is 1,120 kW with three boilers (2 × 450 kW and 220 kW). The annual fuel consumption is 540 t, and 3,000 GJ heat/a is produced. The fuel used includes sawdust, tree bark, wood chips, and waste from nearby sawmills, either from their municipality resources or bought externally. The village also considered growing sorrel as a biomass source.

The proposal for constructing a biomass boiler house has received almost 100% support from the local council and among the citizens. Except for a few locals, the whole community has been involved in the project: "We encouraged the citizens actively to participate at the publicly held council meetings so that they are involved in the process right from the beginning" (interview with the mayor, 15 July 2019).

In terms of finance, the heat generated by the plant is not only environmentally convenient but also perceived by citizens as cheap, according to the mayor. The total investment of 1.5 mil. EUR was financed by the State Environmental Fund (0.65 mil EUR) and the municipality budget (0, 1 mil EUR), and the municipality had to take a loan (0.76 mil EUR). The ownership and management structures are solely dependent on the municipality itself.

The environmental issues, namely, air quality during the heating season (when the cheapest brown coal or even waste used to be burned), and financial aspects were most relevant to this project. However, increased comfort (i.e., replacement of electric boilers) as an additional benefit for the citizens was mentioned as well. The municipality-based value proposition canvas (**Figure 2**) depicts the product and service part as a municipality-based renewable energy thermal energy supply. The customer jobs include thermal energy consumption for heating and hot water and biomass waste disposal. The value

[3]Měňany (©2020); http://www.menany.eu.

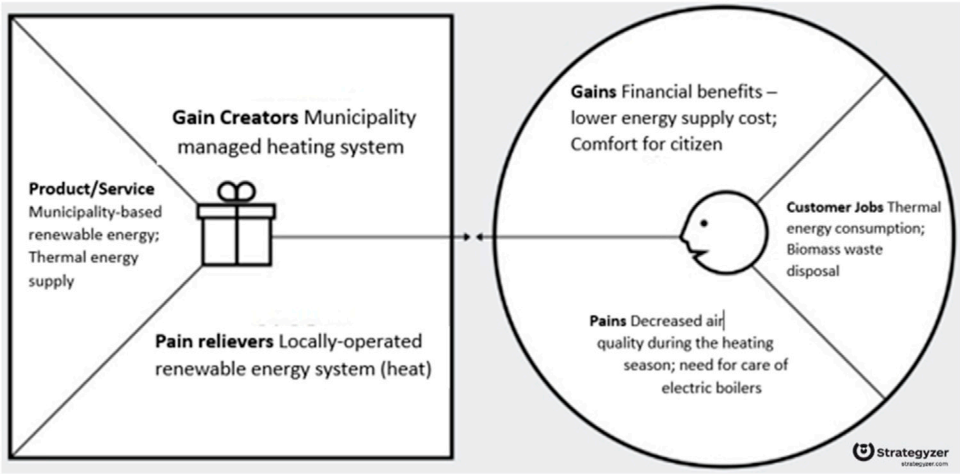


FIGURE 2 | Value proposition canvas (municipality-based) based on Osterwalder et al. (2014), Strategyzer.com, and with copyright by Strategyzer AG.

proposition has been identified as thermal energy affordability at lower cost (economic dimension), assuring comfort for the local citizen (social dimension) and air quality during the heating season (environmental dimension).

Municipal Energy Service Company Case Study

Kněžice at Městec Králové is a village located in the central part of the Czech Republic (Central Bohemian region) in the Nymburk District. The villages in the region are not connected to the natural gas infrastructure, nor is a sewage system available. There are 410 inhabitants living in the central part of the village and approximately 100 people in two distant areas.[4]

The Kněžice energy technology complex is based on a combined heat and power (CHP) unit with a municipal heating plant. The biogas station operates with a CHP electrical output of 330 kW and thermal output of 405 kW. Part of the electricity produced is consumed by their own CHP unit and part for the whole biogas station, and the residual amount (approximately 83%) is delivered to the electricity distribution grid (22 kV). Electricity is sold to an energy company utilizing the green bonus scheme. The electricity for their own consumption is bought from the market. The average annual electricity production is 2,600 MWh/a, the grid delivery is 2,200 MWh/a, and the annual consumption is 2,000 MWh/a. The heat power plant operates with two automatic boilers of 800 kW (straw and sorrel) and 400 kW (wood chips and wood waste) during the heating season (October–April usually).

The biogas station is operated by the municipal ESCo Energetika Kněžice, s.r.o. (Ltd.), which is 100% owned by the municipality and managed by the municipal ESCo. The municipal ESCo is responsible for the technology complex management and related energy services. The municipal authority is the technology complex owner and possesses the decision-making rights in case of crucial project changes, periodical assessment, and monitoring; approves the final report; and communicates the project externally. It is also responsible for personal organization, including ESCo. The financing scheme of the total investment cost of 5.3 mil EUR is based on a combination of national and international public subsidies (3.6 mil EUR) and bank loans (1.7 mil EUR). Avoided cost for the sewage system for wastewater cleaning and biodegradable waste disposal was considered before the project started.

The ESCo-based value proposition (**Figure 3**) can be interpreted as a combination of energy affordability (economic dimension), "back to the roots" philosophy with historical and traditional relation to the local community (social dimension). Local generation and consumption close to the natural environment and processes with better land use are supported (environmental dimension). The customer jobs include domestic hot water and central heating, electricity appliance use (incl. cooking) and lighting, consumption of products, and clean water utilization. The matching products and services result in community-led energy commodity supply (thermal energy supply to end-customers), energy commodity supply (electricity power), electricity generation delivered to the distribution network, and waste management—waste processing and fertilizer production, residual biogas material, and ash from the biomass plant (by-product donated to the local suppliers). The municipality is also very actively involved in the communication with regional and national authorities, non-profit organizations, and academia.

> "We initiated the project together with local activists and municipal government, but the most important success factor in the initial phase was convincing the inhabitants. We organized intensive personal meetings with citizens and municipality representatives, which were needed to explain and discuss arguments for the

[4]Kněžice (©2020); http://www.obec-knezice.cz/.

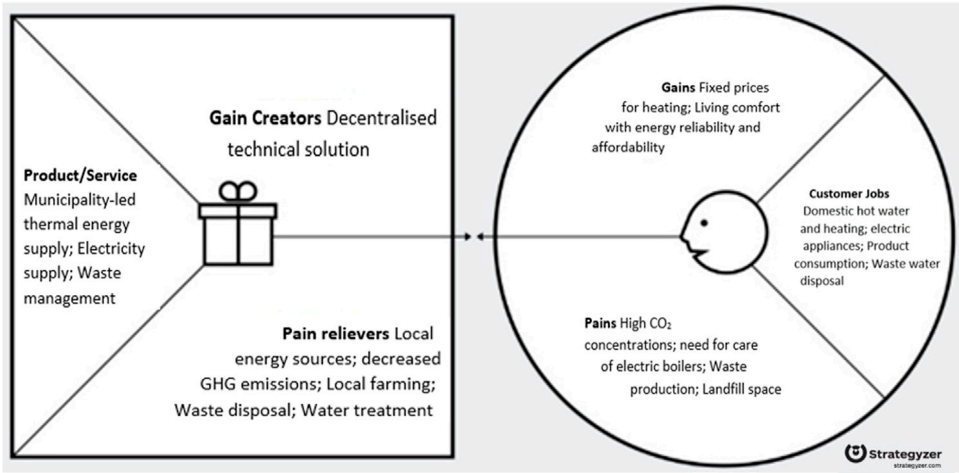


FIGURE 3 | Value proposition canvas (municipal ESCo.) based on Osterwalder et al. (2014), Strategyzer.com, and with copyright by Strategyzer AG.

installation" (interview with the mayor, 26 November 2018).

Municipality: Not-for-Profit Case Study

The third case study is based in Hostětín, a village located in the White Carpathians in the Zlín region. The number of inhabitants in this small village amounts to approximately 240. Hostětín CRE projects are based on sustainable local development activities initiated by the NPO Center Veronica Hostětín (ZO ČSOP Veronica). Initially, a reed bed sewage system was built to treat wastewater with bacteria living on the plant roots (Božková et al., 2013). Later, several other sustainable energy, food production, and agriculture projects were added: the municipal biomass heating plant, public lighting system, the Veronica Centre building passive house, natural garden, and apple juice plant. Solar thermal collectors are located at the local juice plant and Veronica center building, and several PV systems are installed at the juice plant, next to the biomass plant, and at nine family houses.

The municipal biomass heating plant supplies heat almost to the entire village of Hostětín. It has an installed capacity of 732 kW and was put into operation in 2,000. Annual heat energy production amounts to 3,500 GJ. The heat distribution network (2.8 km long) is connected to 83% of the households as customers (70 heat exchanger stations out of 86 buildings in the village). The plant is burning wood chips and waste from sawmills and forests. The municipality is the technology complex owner, responsible for operational and management services. The biomass heating plant is community-owned, as well as 1/4 of the PV panels at the heating plant. The remaining PVs are either private or NPO-owned.

The financing structure corresponds to the public grant structure, which includes investment in part of the boiler, its installation, annual service, and resources for the information campaign. The total investment of 1.4 mil EUR was financed by the State Environmental Fund (0.75 mil EUR for biomass plant infrastructure), the Netherland government *via* the SENTER agency (0.4 mil for biomass plant), and Czech Environmental Agency (0.1 mil EUR for heat distribution network). The remaining 0.08 mil EUR were citizen payments for grid connection. Similar to the previous study case, the financing schemes involved different stakeholders. The collaboration between the municipality representatives, the NPO Veronica Hostětín, and foreign partners was described by the NPO director as one of the most important initial success factors.

The project initiator in the pre-project phase was the municipality office Uherské Hradiště, with their strategy for biomass utilization in the Beskydy region. The NPO Veronica Hostětín played an essential and active role, communicating the idea to the community, contributing to knowledge sharing with the Austrian energy sector, organizing seminars, and promoting the idea of local energy sourcing in the pre-investment phase.

"The initial support of inhabitants was 50% only. Based on the unique partnership of the municipality authority and the NPO Veronica Hostětín, we organized seminars to raise citizen awareness" (interview with the NPO Veronica Hostětín director, 9 November 2018). Moreover, information campaigns were conducted, and best practice examples were explained and shown. Later, technical problems appeared, such as insufficient material supply as the wood chip suppliers changed and no long-term supplies could have been agreed on.

The value proposition canvas, as shown in **Figure 4**, includes both the overall community energy supply (heat supply to end customers) and electricity generation for individual consumption or delivered to the distribution network. Fixed energy prices for heating, energy reliability, and affordability are related to the economic dimension, resulting in reducing the heating cost. On the contrary, one of the "pains" was the high unemployment rate in the municipality. The multiplication effect of the initial project idea was achieved by additional activities, such as local farming (juice plant). New jobs were thus created directly in the local renewable industry and at the juice plant, which turned out to lower the rate of population decrease (social dimension). The most important environmental dimension of the project is related

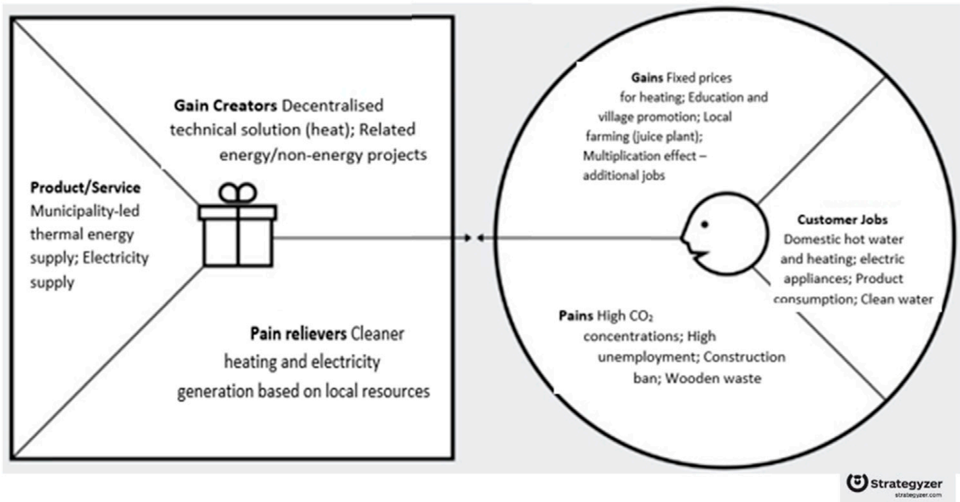


FIGURE 4 | Value proposition canvas (municipality-NPO) based on Osterwalder et al. (2014), Strategyzer.com, and with copyright by Strategyzer AG.

to the construction ban in the 1990s when the village was out of the main natural gas pipeline route. Significantly cleaner air was thus achieved by a complex of RE technology solutions.

Based on the case study analysis, the CRE value, in this case, is based on local business support and in line with the sustainable development principles. Related positive effects of energy self-sufficiency with decentralized local RE sources and other non-energy projects contributed to the multiplication effect of the whole project.

Municipality Union Case Study

The fourth case study is represented by the PV plant at the wastewater treatment plant (WWTP) in the Union of municipalities of the agglomeration Dolní Lhota near Valašské Klobouky (Union of municipalities). Initially, a contract on the voluntary creation of the Union of municipalities was signed in 2007. The purpose was the contractual settlement of particular activities related to the construction, operation, maintenance, and development of sewerage in favor of members of the Union of municipalities. The contractual parties include the municipalities of Dolní Lhota, Horní Lhota, Sehradice, and Slopné. The conclusion of the contract, including the Articles of Association, was discussed with the citizens and approved by the councils of all member municipalities.[5]

The WWTP produces 350 to 500 kWh of electricity, depending on the load and wastewater inlet. All produced energy is consumed directly at the WWTP; the distribution network counter flow is zero in this case. Sewage wastewaters lead to a common mechanical biological WWTP, which is built in the village of Dolní Lhota. The WWTP is designed as completely covered with the exhaust of air through the deodorizing filter, with sludge drainage installed. The WWTP capacity is 2,870 equivalent persons with 29.9 km line length (sewers and discharge pipes) and two filling stations.

[5]Dolní Lhota (©2020); http://www.aglomerace.cz/

The installed capacity of the PV power plant is 29.9 kW, and the electricity is consumed by the WWTP technological equipment. The project was realized in 2012 using the member municipalities' financial resources. The total payback period is 9 years, with a planned lifetime of 25 years. The PV plant operating costs equal zero, and the capital cost was 40 thousand EUR. Based on the contract, the members of the Union of municipalities undertake to finance the project of the sewerage system owned by the Union and share its total costs respecting mutually agreed rates for particular municipalities: Dolní Lhota 23.6%, Horní Lhota 21.9%, Sehradice 30.6%, and Slopné 23.9%.

Important project aspects are published on the Union website and the website of individual municipalities, including publishing the resolution of the member meetings. "The members of the Union of municipalities are informed about all activities from the very beginning of the plan up to the implementation. Municipalities have the opportunity to comment or disagree, [*sic*] however, the project is generally supported and positively viewed on" (interview with the mayor, 13 December 2018).

The value proposition canvas is presented in **Figure 5**. As a complex wastewater treatment including a RE source (PV). Cost-effective water cleaning and local wastewater treatment represent the economic dimension of the project. The social dimension includes future considerations about living standards. Complex wastewater treatment is considered the relevant service matched with clean water utilization (environmental dimension), together with RE-based energy consumption.

One of the most limiting barriers the Union of municipalities encountered in the implementation and operation of the project was the capacity performance limitation of the PV plant. "Major obstacle was the installation capacity limit, so we decided on a procedure without an energy licence. Considerable pre-implementation and subsequent administration would be otherwise needed" (interview with the mayor, 13 December 2018). The potential

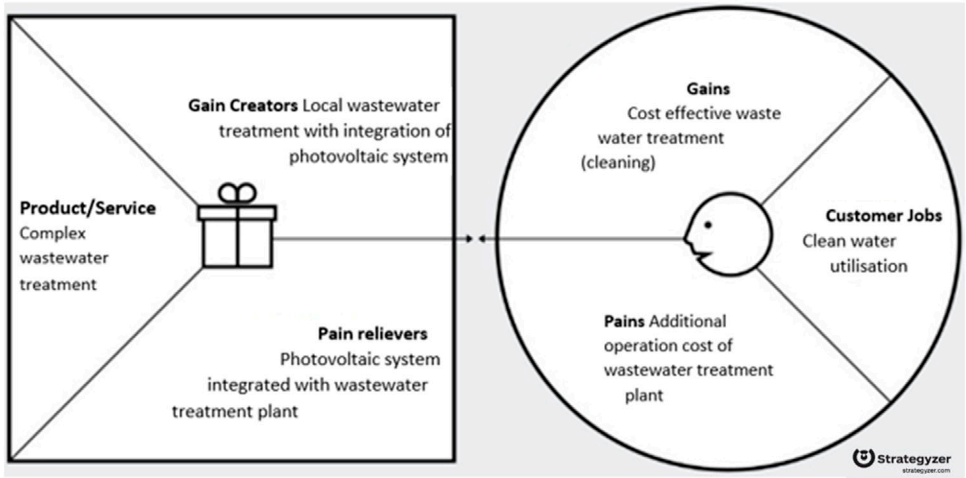


FIGURE 5 | Value proposition canvas (union of municipalities) based on Osterwalder et al. (2014), Strategyzer.com, and with copyright by Strategyzer AG.

administrative load on the project exceeding 30 kW of installed capacity discouraged the municipality from applying for a special energy generation license from the Energy Regulatory Office.

Municipality Community Renewable Energy Value Proposition Canvas

Resulting from the four case studies elaborated in the previous chapter, the value propositions of CRE projects are systematically captured by the complex value proposition canvas. While the value proposition is the plug-in part of the business model canvas, both tools are tightly interconnected, as proposed by Osterwalder et al. (2014). The community-based RES value propositions respecting the presented case studies are summarized in alignment with the 3BL approach. As a result, in the case of CRE projects, the 3BL approach is an integral part of the value proposition canvas, as proposed in **Figure 6**.

A novel approach for structuring value propositions and creation is demonstrated in four case studies. These cases represent different settlements of local public authorities, municipalities, and other stakeholders, which are active in Czech CRE projects. On the "customer" side of the scheme, the CRE jobs are summarized through "gains" and "pains" lenses. The product side represents the gain creators and pain relievers to CRE.

The most important considerations about the economic, social, and environmental dimensions of the value proposition canvas are elaborated as follows:

- Economic value dimension as cost-effective energy generation, delivery, and storage.

On the one hand, insufficient, mostly public financial resources are available for CRE, and complicated project administration is considered a burden. On the other hand, CRE projects might generate additional budget revenue for the municipality, directly due to the sale of electricity or indirectly due to savings resulting from the use of own electricity or heat for own needs.

- Social value dimension is community-led energy generation, delivery, and storage.

Some of the initiatives go beyond the core CRE project providing sustainable food, products, and services, including housing, education, health care, sports, and entertainment (described as the multiplication effect of the CRE project).

- Environmental value dimension as renewable energy generation, delivery, and storage.

As a result of fossil fuel replacement, greenhouse gas emissions are declining, and local air pollution is reduced. A cleaner environment also encourages biodiversity. Environmental education has also gained attention, and within many projects, cooperation with academic and research institutions has been developed.

DISCUSSION

The business model framework focusing on the value proposition canvas is newly applied in Czech community renewable energy projects in municipalities. In line with Herbes et al. (2017), applying the business model concept to CRE projects is challenging and relevant as the process of value creation applies to energy communities as well. CRE value propositions are elaborated into 3BL dimensions reflecting on the case study results. However, compared to Herbes et al. (2017), who identified the morphology elements of RE cooperatives' business models, we propose a municipality CRE value proposition canvas interconnected with 3BL. Based on the

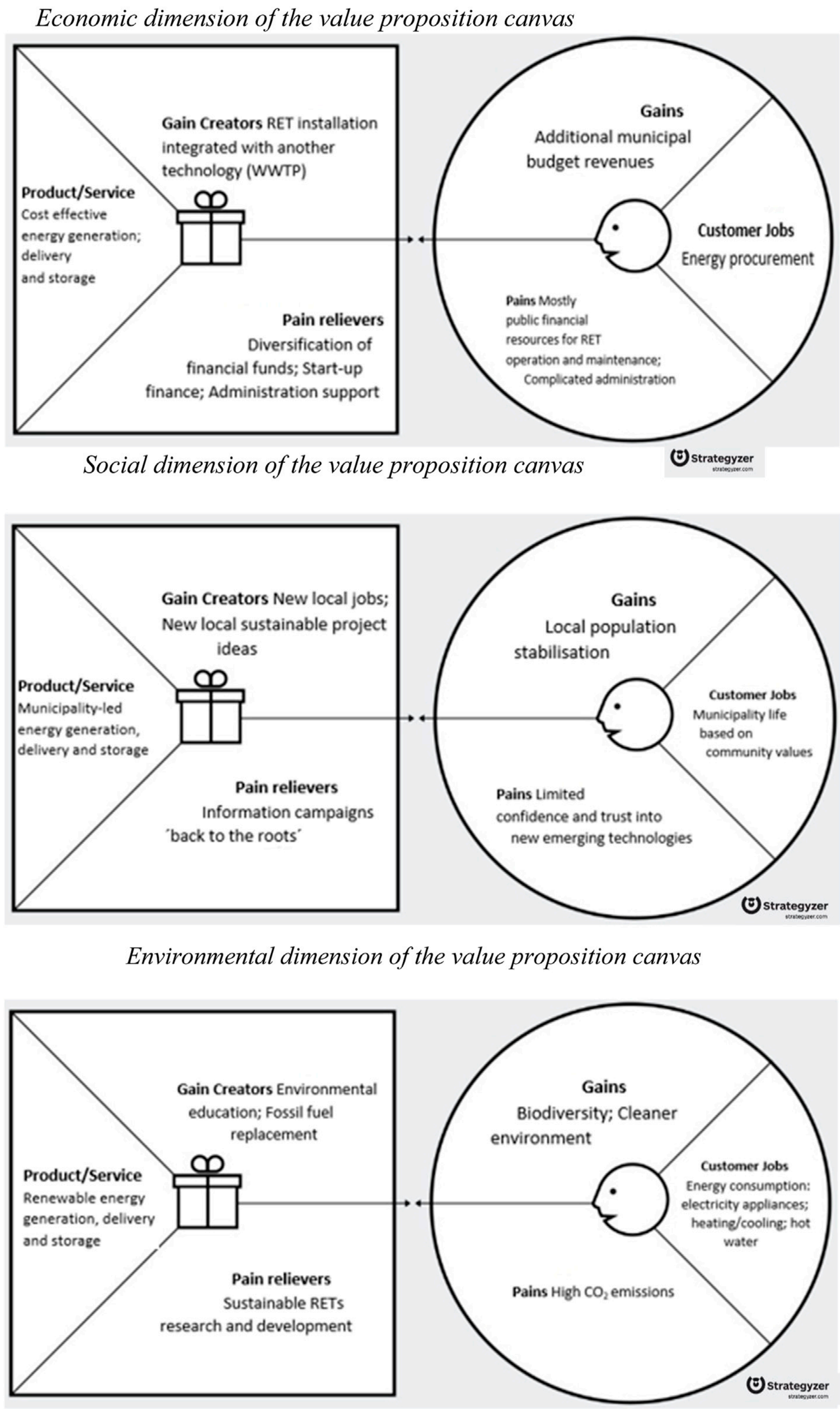


FIGURE 6 | Municipality CRE value proposition canvas based on Osterwalder et al. (2014), Strategyzer.com, and with copyright by Strategyzer AG.

previous research and the presented results, the municipal CRE is strongly oriented toward complex 3BL value propositions. Compared to the research on motivations and values in the CRE presented by Hicks and Ison (2018) as the STEEP model and Holstenkamp and Kahla (2016) using a socio-technical perspective, we used the 3BL concept (Elkington, 1997) with a priority set in economic-social-environmental value propositions.

Bioenergy is considered the most successful CRE sub-sector in the Czech Republic, with strong emphasis especially on the environmental dimension. Many community energy projects to date have focused on the heating sector. Examples were also presented in electricity production. Often, bioenergy utilization not only offers environmental benefits but also creates multiplication or spillover effects in rural areas (Fang et al., 2022). In line with the social business model by Yousuf et al. (2017), biogas is integrated biotechnology that offers social, economic, and environmental benefits. On the contrary, according to Irfan et al. (2022), the availability of an adequate subsidy policy is crucial for the further development of the sub-sector. The most common municipal use of RES in the Czech Republic is in the form of a biomass heating plant. The village of Kněžice is often set as an example of an energy self-sufficient municipality thanks to a biogas plant and a biomass plant.

The key common characteristic of the presented project case studies is the fact that they are strongly interconnected with municipalities in the form of direct municipal ownership and management, municipal ESCo, or a municipal or regional authority organization (schools, cultural centers, etc.), With respect to ownership and legal status, the majority of projects were initiated by municipalities in cooperation with a variety of actors. According to the research results, either individuals or local public authorities in municipalities are active in CRE. It was observed that municipality representatives, in some cases together with local activists, were active in the community, initiating and taking active roles in community energy projects. Community involvement in the broader context of regional authorities represents successful energy projects (Subbarao and Lloyd, 2011). Although the flat ownership collectives might represent an initial point to build on dedicated CRE collectives, they still have barriers in terms of citizen active roles in the Czech Republic, focusing mostly on the combination of energy efficiency and retrofitting of apartments (Malý et al., 2019). Private sector engagement in CRE is evidenced on both sides of the prosumer relationship as local energy producers offering services to the local citizens and energy consumers within the industrial production process. However, no significant active role has been evidenced. Klein and Coffey (2016) also called for solutions of a classification system for CRE projects at all societal and institutional levels.

The Hostětín project represents a strong involvement of the local community in the initial project idea formulation (NPO); its long-term partnerships with regional, national, and international organizations; and effective communication with the public. This CRE project exhibits diverse activities, which are directly or indirectly related not only to energy but also to agriculture and sustainable food production (Seyfang et al., 2014).

The cases of Kněžice and Měňany demonstrate individual personal involvement of municipality representatives together with favorable energy policy setup in the pre-investment phase as crucial factors of project success. Furthermore, the Union of municipalities Dolní Lhota is an example of successful cooperation among several neighboring villages.

POLICY IMPLICATIONS

In general, clear definitions on the EU and national level defining terms such as RE community, local energy community, low carbon community, or positive energy community are needed. The Czech definition of community RE should take the national specifics into account, and digital platforms of communities (private and publicly financed) should be envisaged. Unlike businesses, communities and especially municipalities have not only different motivations but also possibilities and conditions for the preparation of RES projects.

It is worth mentioning that the clear majority of municipal RE projects originated before 2013 due to unexpected changes in state energy policy related to RE support. In 2013, the Czech government decided to stop the FiT scheme for new RE with only a few exceptions. Respecting the European directive on the promotion of the use of energy from renewable sources 2018/2001/EU (RED II), the directive transition to the Czech law in 2021 was prepared—consumers, households, and communities will have the possibility to engage in energy production, storage, and consumption. The national authority, the Ministry of Industry and Trade, has been preparing an amendment to Act no. 165/2012 and an amendment to the Energy Act, which aims to relaunch the RES development. Both amendments should set new rules for developing RES in the Czech Republic and should also anchor energy storage systems in the Czech legislation.

The concrete steps taken by the Czech government include the launch of the National Climate and Energy Plan of the Czech Republic in 2020,[6] which identifies CRE as carriers of economic, environmental, and social benefits on a local and national scale. Moreover, new financial instruments are proposed in the Modernization Fund, which should provide financial resources to CRE projects. This should be a significant step, which could lead to the creation of new wind, biomass, or PV power plants in the Czech Republic. Following policy implications of CRE, future developments for CRE projects are divided into economic, social, and environmental dimensions.

Economic Implications

According to Zhang et al. (2021), public spending on human resources and research of green energy technologies prompts a sustainable green economy. The municipalities with their renewable energy projects may apply for both auctions and green bonuses for smaller projects. However, experience with auctions from the Western European countries shows that, in tendering procedures, municipalities cannot compete with

[6]National Climate and Energy Plan of the Czech Republic as of 13 January 2020.

commercial projects. Municipalities, unlike commercial developers, need more time to prepare a project, and they do not dispose of risk management expertise developed over the years. Organizational support for the interests of CRE (Herbes et al., 2017), such as a group of municipalities requiring better conditions for community projects and administrative support for project preparation, would certainly help. On the other hand, municipalities often own brownfields and other non-agricultural areas suitable for building renewable electricity generating plants. PV power plants built on these sites could be an important source of finance for the municipal budget (municipal power plants). On the techno-economic level, the operation of the local electricity distribution system would be another big step further.

Social Implications

Moreover, a multisectoral partnership might be supported. The municipal authority could use or rent the area or a roof (e.g., its own, typically at the school building), and the citizens are offered a project share, such as civil power plants. These settings might contribute to the spillover and multiplication effect of the projects (Fang et al., 2022), creating new value propositions for the local people, engaging local communities, not just municipal authorities, in different types of activities, and creating new jobs locally. Besides municipalities, another opportunity is energy collectives, traditionally related to block of flats ownership in the Czech Republic. Efforts should be made toward CRE awareness-raising with information campaigns.

Environmental Implications

Similarly to Geels et al. (2017), complementary innovations need to be considered, such as energy storage (batteries, flywheels, and pumped hydro), smarter grids (grid flexibility and management), demand response, and new market arrangements. The innovation in services, where the end user is a part of the system, requires a targeted behavioral approach, shifting from designing products to designing new business models. In the middle term, public sector incentives will still play a role in the energy sector. However, according to the Solar Dominance Hypothesis (Goodstein and Lovins, 2019), solar-based energy coupled with storage and related technology innovations will contribute 50% to electricity generation by 2030. Therefore, it is important to develop and test energy storage systems of different physical and chemical natures potentially suitable for different scales. The shared regime of stationary energy storage for the energy community or individual storage solutions with small decentralized energy generation will develop in the future.

CONCLUSION

Technologies, policies, and mindsets need to change and adapt to new business model types to achieve energy goals. Previous research results have repeatedly proven that one of the key parameters for the successful development of RES is the question of who owns and operates them. Moreover, we argue that the understanding of value proposition creation and structure is a vital part of successful CRE projects. Public sector involvement is relevant in the most important project phases and tends to be the key success factor in the case of financial planning. Collective ownership in energy communities is still not widely spread in the Czech RE projects, as can be seen in the Austrian and German municipalities. The expansion of energy cooperatives is still lacking behind its potential due to scarcity or limited need for "green" energy and because of missing persons or groups to promote this idea.

Our study contributes to the blooming literature on the business model canvas building blocks framework. Moreover, this study provides insights into the value proposition background and the 3BL concept based on those factors influencing value creation and value capture. The key contribution to the theory is thus the multidisciplinary integration of the business model theory with theories from other scientific fields and their application in the energy sector.

The methodological limitation of the presented study is attributed to the chosen case study method, which main advantage is an in-depth knowledge of the analyzed topic. However, the representativeness of the results might be an issue. Similarly, the regional geospatial comparisons would still need more detailed data collection. Data processing problems emerged due to the difficulty in finding community energy-related projects. It was also found that there is no systematic way to extract data for thermal RES generation and distribution license holders in the Czech Republic.

The CRE field offers much potential for projects differing in terms of economic, social, and environmental settings. A very promising research direction seems to be transdisciplinary research combining STEM and SSH aspects of energy-related topics. Communities and social networks might have a higher positive impact on behavior change than individually aimed policies.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusion of this article will be made available by the authors upon request without undue reservation.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

FUNDING

This work was supported by the Ministry of Education, Youth and Sports of the Czech Republic-DKRVO (no. RP/CPS/2022/005).

REFERENCES

Bauwens, T. (2016). Explaining the Diversity of Motivations Behind Community Renewable Energy. *Energy Policy* 93, 278–290. doi:10.1016/j.enpol.2016.03.017

Bauwens, T., Gotchev, B., and Holstenkamp, L. (2016). What Drives the Development of Community Energy in Europe? the Case of Wind Power Cooperatives. *Energy Res. Soc. Sci.* 13, 136–147. doi:10.1016/j.erss.2015.12.016

Becker, S., Kunze, C., and Vancea, M. (2017). Community Energy and Social Entrepreneurship: Addressing Purpose, Organisation and Embeddedness of Renewable Energy Projects. *J. Clean. Prod.* 147, 25–36. doi:10.1016/j.jclepro.2017.01.048

Berka, A. L., and Creamer, E. (2018). Taking Stock of the Local Impacts of Community Owned Renewable Energy: A Review and Research Agenda. *Renew. Sustain. Energy Rev.* 82, 3400–3419. doi:10.1016/j.rser.2017.10.050

Boasson, E. L., Leiren, M. D., and Wettestad, J. (2020). *Comparative Renewables Policy: Political, Organizational and European Fields*. 2020th ed. London and New York: Routledge.

Božková, B., Filemonová, J., Fojtů, K., Gaillyová, Y., Hollan, J., Labohý, J., et al. (2013). *Co Přinesly Projekty V Hostětíně*. Ekologický institut Veronica [online].

Brummer, V. (2018). Community Energy – Benefits and Barriers: A Comparative Literature Review of Community Energy in the Uk, Germany and the Usa, The Benefits It Provides for Society and the Barriers it Faces. *Renew. Sustain. Energy Rev.* 94, 187–196. doi:10.1016/j.rser.2018.06.013

Caramizaru, A., and Uihlein, A. (2020). *Energy Communities: An Overview of Energy and Social Innovation*. London and New York: Publications Office of the European Union.

Ćetković, S., and Buzogány, A. (2019). The Political Economy of EU Climate and Energy Policies in Central and Eastern Europe Revisited: Shifting Coalitions and Prospects for Clean Energy Transitions. *Polit. Gov.* 7, 124–138. doi:10.17645/pag.v7i1.1786

Creamer, E., Eadson, W., van Veelen, B., Pinker, A., Tingey, M., Braunholtz-Speight, T., et al. (2018). Community Energy: Entanglements of Community, State, and Private Sector. *Geogr. Compass* 12, e12378. doi:10.1111/gec3.12378

Creamer, E., Taylor Aiken, G., van Veelen, B., Walker, G., and Devine-Wright, P. (2019). Community Renewable Energy: What Does it Do? Walker and Devine-Wright (2008) Ten Years on. *Energy Res. Soc. Sci.* 57, 101223. doi:10.1016/j.erss.2019.101223

D'Agostino, L. M., and Moreno, R. (2019). Green Regions and Local Firms' Innovation. *Pap. Reg. Sci.* 98, 1585–1608. doi:10.1111/pirs.12427

Directive (EU) (2018). *2018/2001 of the European Parliament and of the Council of 11 December 2018 on the Promotion of the Use of Energy from Renewable Source, 2018*. Luxembourg: Publications office of the European Union.

Directive (EU) (2019). *2019/944 of the European Parliament and of the Council of 5 June 2019 on Common Rules for the Internal Market for Electricity and Amending Directive 2012/27/EU, 2019*. Luxembourg: Publications office of the European Union.

Duha, H. (2020). *Obecní Obnovitelné Zdroje Energie. Přehled Českých Projektů*. Ekologický institut Veronica.

Elkington, J. (2018). 25 Years Ago I Coined the Phrase "Triple Bottom line." Here's Why It's Time to Rethink it. *Harv. Bus. Rev.* 25, 2–5.

Elkington, J. (1997). *Cannibals with Forks. The Triple Bottom Line of 21st Century*. Ekologický institut Veronica.

Fang, Z., Razzaq, A., Mohsin, M., and Irfan, M. (2022). Spatial Spillovers and Threshold Effects of Internet Development and Entrepreneurship on Green Innovation Efficiency in China. *Technol. Soc.* 68, 101844. doi:10.1016/j.techsoc.2021.101844

Fankhauser, S., Bowen, A., Calel, R., Dechezleprêtre, A., Grover, D., Rydge, J., et al. (2013). Who Will Win the Green Race? in Search of Environmental Competitiveness and Innovation. *Glob. Environ. Change* 23, 902–913. doi:10.1016/j.gloenvcha.2013.05.007

Frantál, B., and Nováková, E. (2019). On the Spatial Differentiation of Energy Transitions: Exploring Determinants of Uneven Wind Energy Developments in the Czech Republic. *Morav. Geogr. Rep.* 27, 79–91. doi:10.2478/mgr-2019-0007

Geels, F. W., Sovacool, B. K., Schwanen, T., and Sorrell, S. (2017). Sociotechnical Transitions for Deep Decarbonization. *Science* 357, 1242–1244. doi:10.1126/science.aao3760

Goodstein, E., and Lovins, L. H. (2019). A Pathway to Rapid Global Solar Energy Deployment? Exploring the Solar Dominance Hypothesis. *Energy Res. Soc. Sci.* 56, 101197. doi:10.1016/j.erss.2019.05.007

Hansen, P. (2021). Optimising Shared Renewable Energy Systems: An Institutional Approach. *Energy Res. Soc. Sci.* 73, 101953. doi:10.1016/j.erss.2021.101953

Hartmann, P., and Apaolaza-Ibáñez, V. (2012). Consumer Attitude and Purchase Intention toward Green Energy Brands: The Roles of Psychological Benefits and Environmental Concern. *J. Bus. Res.* 65, 1254–1263. doi:10.1016/j.jbusres.2011.11.001

Heffron, R. J., McCauley, D., and Sovacool, B. K. (2015). Resolving Society's Energy Trilemma through the Energy Justice Metric. *Energy Policy* 87, 168–176. doi:10.1016/j.enpol.2015.08.033

Herbes, C., Brummer, V., Rognli, J., Blazejewski, S., and Gericke, N. (2017). Responding to Policy Change: new Business Models for Renewable Energy Cooperatives – Barriers Perceived by Cooperatives' Members. *Energy Policy* 109, 82–95. doi:10.1016/j.enpol.2017.06.051

Hicks, J., and Ison, N. (2018). An Exploration of the Boundaries of 'Community' in Community Renewable Energy Projects: Navigating Between Motivations and Context. *Energy Policy* 113, 523–534. doi:10.1016/j.enpol.2017.10.031

Hoicka, C. E., Lowitzsch, J., Brisbois, M. C., Kumar, A., and Ramirez Camargo, L. (2021). Implementing a Just Renewable Energy Transition: Policy Advice for Transposing the New European Rules for Renewable Energy Communities. *Energy Policy* 156, 112435. doi:10.1016/j.enpol.2021.112435

Holstenkamp, L., and Kahla, F. (2016). What Are Community Energy Companies Trying to Accomplish? An Empirical Investigation of Investment Motives in the German Case. *Energy Policy* 97, 112–122. doi:10.1016/j.enpol.2016.07.010

Irfan, M., Elavarasan, R. M., Ahmad, M., Mohsin, M., Dagar, V., and Hao, Y. (2022). Prioritizing and Overcoming Biomass Energy Barriers: Application of AHP and G-TOPSIS Approaches. *Technol. Forecast. Soc. Change* 177, 121524. doi:10.1016/j.techfore.2022.121524

Joyce, A., and Paquin, R. L. (2016). The Triple Layered Business Model Canvas: A Tool to Design More Sustainable Business Models. *J. Clean. Prod.* 135, 1474–1486. doi:10.1016/j.jclepro.2016.06.067

Karami, M., and Madlener, R. (2021). Business Model Innovation for the Energy Market: Joint Value Creation for Electricity Retailers and Their Customers. *Energy Res. Soc. Sci.* 73, 101878. doi:10.1016/j.erss.2020.101878

Klein, S. J. W., and Coffey, S. (2016). Building a Sustainable Energy Future, One Community at a Time. *Renew. Sustain. Energy Rev.* 60, 867–880. doi:10.1016/j.rser.2016.01.129

Lowitzsch, J., Hoicka, C. E., and van Tulder, F. J. (2020). Renewable Energy Communities under the 2019 European Clean Energy Package - Governance Model for the Energy Clusters of the Future? *Renew. Sustain. Energy Rev.* 122, 109489. doi:10.1016/j.rser.2019.109489

Malý, V., Šafařík, M., and Matoušek, R. (2019). "Consumer (Co-)Ownership in Renewables in the Czech Republic," in *Energy Transition: Financing Consumer Co-ownership in Renewables*. Editor J. Lowitzsch (Cham: Springer International Publishing), 201–222. doi:10.1007/978-3-319-93518-8_10

Oberthür, S., and Dupont, C. (2021). The European Union's International Climate Leadership: towards a Grand Climate Strategy? *J. Eur. Public Policy* 28, 1095–1114. doi:10.1080/13501763.2021.1918218

Osterwalder, A., Pigneur, Y., Bernarda, G., and Smith, A. (2014). *Value Proposition Design: How to Create Products and Services Customers Want*. London and New York: John Wiley & Sons.

Osterwalder, A., and Pigneur, Y. (2010). *Business Model Generation: A Handbook for Visionaries, Game Changers, and Challengers*. London and New York: John Wiley & Sons.

Osterwalder, A., Pigneur, Y., and Tucci, C. L. (2005). Clarifying Business Models: Origins, Present, and Future of the Concept. *Cais* 16, 1–25. doi:10.17705/1CAIS.01601

Palinkas, L. A., Horwitz, S. M., Green, C. A., Wisdom, J. P., Duan, N., and Hoagwood, K. (2015). Purposeful Sampling for Qualitative Data Collection and Analysis in Mixed Method Implementation Research. *Adm. Policy Ment. Health* 42, 533–544. doi:10.1007/s10488-013-0528-y

Patton, M. Q. (2002). *Qualitative Research and Evaluation Methods*. Thousand Oakes: CA: Sage Publications.

Petersen, J.-P. (2016). Energy Concepts for Self-Supplying Communities Based on Local and Renewable Energy Sources: A Case Study from Northern Germany. *Sustain. Cities Soc.* 26, 1–8. doi:10.1016/j.scs.2016.04.014

Seyfang, G., Hielscher, S., Hargreaves, T., Martiskainen, M., and Smith, A. (2014). A Grassroots Sustainable Energy Niche? Reflections on Community Energy in the UK. *Environ. Innovation Soc. Transitions* 13, 21–44. doi:10.1016/j.eist.2014.04.004

Sokołowski, M. M., and Heffron, R. J. (2022). Defining and Conceptualising Energy Policy Failure: The when, where, Why, and How. *Energy Policy* 161, 112745. doi:10.1016/j.enpol.2021.112745

Solorio, I., and Jörgens, H. (2020). Contested Energy Transition? Europeanization and Authority Turns in EU Renewable Energy Policy. *J. Eur. Integration* 42, 77–93. doi:10.1080/07036337.2019.1708342

Subbarao, S., and Lloyd, B. (2011). Can the Clean Development Mechanism (CDM) Deliver? *Energy Policy* 39, 1600–1611. doi:10.1016/j.enpol.2010.12.036

Sun, H., Awan, R. U., Nawaz, M. A., Mohsin, M., Rasheed, A. K., and Iqbal, N. (2021a). Assessing the Socio-Economic Viability of Solar Commercialization and Electrification in South Asian Countries. *Environ. Dev. Sustain* 23, 9875–9897. doi:10.1007/s10668-020-01038-9

Sun, H., Edziah, B. K., Kporsu, A. K., Sarkodie, S. A., and Taghizadeh-Hesary, F. (2021b). Energy Efficiency: The Role of Technological Innovation and Knowledge Spillover. *Technol. Forecast. Soc. Change* 167, 120659. doi:10.1016/j.techfore.2021.120659

Tiba, S., van Rijnsoever, F. J., and Hekkert, M. P. (2019). Firms with Benefits: A Systematic Review of Responsible Entrepreneurship and Corporate Social Responsibility Literature. *Corp. Soc. Resp. Env. Ma* 26, 265–284. doi:10.1002/csr.1682

Tosun, J., Zöckler, L., and Rilling, B. (2019). What Drives the Participation of Renewable Energy Cooperatives in European Energy Governance? *Polit. Gov.* 7, 45–59. doi:10.17645/pag.v7i1.1782

Wach, K., Głodowska, A., Maciejewski, M., and Sieja, M. (2021). Europeanization Processes of the EU Energy Policy in Visegrad Countries in the Years 2005-2018. *Energies* 14, 1802. doi:10.3390/en14071802

Walker, G., and Devine-Wright, P. (2008). Community Renewable Energy: What Should it Mean? *Energy Policy* 36, 497–500. doi:10.1016/j.enpol.2007.10.019

Walker, G. (2008). What Are the Barriers and Incentives for Community-Owned Means of Energy Production and Use? *Energy Policy* 36, 4401–4405. doi:10.1016/j.enpol.2008.09.032

Willard, B. (2012). *The New Sustainability Advantage: Seven Business Case Benefits of a Triple Bottom Line*. London and New York: New Society Publishers.

Yousuf, A., Sultana, S., Monir, M. U., Karim, A., and Rahmaddulla, S. R. B. (2017). Social Business Models for Empowering the Biogas Technology. *Energy Sources, Part B Econ. Plan. Policy* 12, 99–109. doi:10.1080/15567249.2016.1255677

Zhang, D., Mohsin, M., Rasheed, A. K., Chang, Y., and Taghizadeh-Hesary, F. (2021). Public Spending and Green Economic Growth in BRI Region: Mediating Role of Green Finance. *Energy Policy* 153, 112256. doi:10.1016/j.enpol.2021.112256

Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

frontiers | Frontiers in Energy Research

OPINION
published: 01 June 2022
doi: 10.3389/fenrg.2022.923739

Problems of EnergyTech Financing in the Context of the COVID-19 Crisis and the Post-Pandemic Period and the Prospects for Their Solution

Vladimir S. Osipov[1,2]*, *Alexander N. Alekseev*[3], *Nelia A. Deberdeeva*[4] and *Antonina A. Seregina*[5]

[1]*Moscow State Institute of International Relations, Moscow, Russia,* [2]*Lomonosov Moscow State University, Moscow, Russia,* [3]*Financial University Under the Government of the Russian Federation, Moscow, Russia,* [4]*Plekhanov Russian University of Economics, Moscow, Russia,* [5]*Diplomatic Academy of the Ministry of Foreign Affairs of the Russian Federation, Moscow, Russia*

Keywords: financing, investment in the energy sector, EnergyTech, energy economy, "green" energy, COVID-19 crisis, post-pandemic period

OPEN ACCESS

Edited by:
Bruno Sergi,
Harvard University, United States

Reviewed by:
Sadriddin Khudaykulov,
Tashkent State Economic University, Uzbekistan
Konstantin V. Vodenko,
Platov South-Russian State Polytechnic University, Russia

***Correspondence:**
Vladimir S. Osipov
*vs.ossipov@gmail.com *

Specialty section:
This article was submitted to Sustainable Energy Systems and Policies, a section of the journal Frontiers in Energy Research

Received: *19 April 2022*
Accepted: *09 May 2022*
Published: *01 June 2022*

Citation:
Osipov VS, Alekseev AN, Deberdeeva NA and Seregina AA (2022) Problems of EnergyTech Financing in the Context of the COVID-19 Crisis and the Post-Pandemic Period and the Prospects for Their Solution.
Front. Energy Res. 10:923739.
doi: 10.3389/fenrg.2022.923739

INTRODUCTION

EnergyTech is a promising investment project for three reasons. The first reason is the overall high investment attractiveness of energy projects due to high global energy demand and broad prospects for return on investment (Ayub et al., 2022; Verba et al., 2022). The second reason is that EnergyTech is not just "smart" technologies in the energy sector but a transition to clean energy (Ratner et al., 2022; Štreimikienė et al., 2022). The implementation of projects on the creation of "smart" infrastructure in the field of clean (renewable) energy allows the operation of infrastructure facilities for a longer period compared to projects for the extraction and use of non-renewable energy (for example, fossil fuels) (Gallo et al., 2020; Sisodia et al., 2020; Ratner et al., 2021).

The third reason is the strategic importance of the projects under consideration for the state, combined with their high social significance, providing support for the state and society (Knayer and Kryvinska, 2022; Kamruzzaman and Alruwaili, 2022). The focus of this article is the problem related to the fact that, despite the prospects, investment projects in the field of EnergyTech in 2020–2021 faced the problem of a shortage of financial resources due to the COVID-19 crisis.

In the existing literature, much attention is paid to the issues of energy financing. Chien et al. (2021), Gong et al. (2021), Li et al. (2022), Popkova et al. (2019) in their works point to the key role of financing in the development of the energy economy, and also note that this role is to ensure the lack of energy resources for economic systems. The cited works emphasize the infrastructure formative function of the energy sector in the system of entrepreneurship, as well as the need for energy availability to maintain a high quality of life of the population, ensure uninterrupted industrial production and continuous economic growth.

Taking into account the general economic downturn, the worsening investment climate, acute government budget deficits and the increase in public debt in many countries, Iqbal and Bilal (2021), Taghizadeh-Hesary et al. (2022), Tran (2021) note that in the context of the COVID-19 crisis, the amount of financing for EnergyTech decreased and progress in its development has slowed down. The works of Lean and Lee (2022), Popkova et al. (2021), Zhao et al. (2022), Zhou and Liu (2022) also indicate that the pandemic and the COVID-19 crisis had a contradictory impact on EnergyTech, on the one hand, causing a shortage of its financing and increased risks of practical implementation of SDG 7, but, on the other hand, by creating common financing conditions for the countries of the world, thereby ensuring equal opportunities for the development of EnergyTech in developed and developing countries.

A review of the literature showed that the issues of financing EnergyTech in the context of the COVID-19 crisis are widely studied in available publications. However, the causal relationships of changes in the amount of financing of EnergyTech in the context of the COVID-19 crisis remain poorly understood and uncertain, which is a research gap. In addition, existing publications are characterized by a generalized consideration of the fuel and energy complex with insufficient attention to its complicated internal structure. Uncertainty regarding the specifics of changes in financing and the pace of development of individual EnergyTech markets in the context of the COVID-19 crisis is another research gap.

Both identified gaps are filled in this article through an in-depth study and clarification of the cause-and-effect relationships of changes in financing and progress in the development of EnergyTech in the context of the COVID-19 crisis with a combination of quantitative and qualitative research methods. The purpose of this article is to identify the problems of financing EnergyTech during the COVID-19 crisis and in the post-pandemic period, as well as to determine the prospects for their solution.

REVIEW AND COMPARISON OF INTERNATIONAL EXPERIENCE IN FINANCING AND DEVELOPMENT OF ENERGYTECH BEFORE THE PANDEMIC AND IN THE CONTEXT OF THE COVID-19 CRISIS

Using the structural analysis method, a quantitative and qualitative assessment of the dynamics of statistical data was carried out for the most accurate and reliable identification of changes in the financing of EnergyTech in the conditions of the COVID-19 crisis. As a result, based on the materials of the International Energy Agency (2022), it was found that energy investments have changed unevenly among energy markets and have two features.

The first feature: the decline in investment in the development of the main energy markets. The downturn in upstream investments (compared to 2019) was 35% in 2020, in mid/downstream investments - 31% in 2020, in coal supply - 5% in 2020, and in fossil fuel power - 15% in 2020. In all these markets, in 2021, there was a significant lag from the pre-pandemic level (2019). The second feature is the independence of alternative and electric energy financing from the impact of the COVID-19 crisis. Thus, in the nuclear market, the volume of financing practically did not change in 2020, and in 2021 it even increased by 3%. In the electricity networks and battery storage market, the amount of financing also remained virtually unchanged in 2020, and increased by 10% in 2021.

The third feature: increasing investments in “green” (“clean”) energy. Thus, the volume of financing for low carbon fuels remained unchanged in 2020, and increased by 3% in 2021. The volume of financing of renewable power in the context of the COVID-19 pandemic and crisis increased by 9% in 2020, and then by another 4% in 2021. It was also found that the total volume of global energy investments in the context of the COVID-19 pandemic and crisis decreased by 8%, while the share of investments in “green” energy in their overall structure increased from 20% in 2019 to 25% in 2021.

In order to determine the consequences of the above-described changes in the volume and structure of its financing, the international experience of EnergyTech development was analyzed. The study was conducted on the example of the top three developed countries (Finland ranks first; Denmark—second; Sweden - third) and top three developing countries (China ranks 25th; Brazil - 27th; Mexico - 29th) in the 2021 Global Energy Innovation Index Rankings (ITIF, 2022a). As a result, using the trend analysis method, three global trends in the development of EnergyTech in the conditions of the COVID-19 crisis (compared to the pre-pandemic period) were identified, based on ITIF (2022a), ITIF (2022b) statistics.

The first trend: progress in knowledge development and diffusion (option generation). In Denmark, this indicator increased by 54.42% from 9.5 points in 2019 to 14.67 points in 2021; in Sweden - by 33.59% from 9.2 points in 2019 to 12.29 points in 2021. In developing countries, the trend under consideration is more moderate. So, in China, this indicator increased by 29.88% from 8.7 points in 2019 to 11.30 points in 2021; in Brazil - by 3.42% from 7.3 points in 2019 to 7.55 points in 2021.

The second trend is an increase in the level of entrepreneurial experimentation and market formation (scale-up). In Finland, this indicator increased by 59.56% from 9.2 points in 2019 to 14.68 points in 2021; in Sweden - by 22.89% from 11.4 points in 2019 to 14.01 points in 2021. In developing countries, this trend is less pronounced. So, in Brazil, this indicator increased by 2.44% from 8.6 points in 2019 to 8.81 points in 2021; in Mexico - by 11.64% from 7.3 points in 2019 to 8.15 points in 2021.

The third trend is a decrease in social legalization and international collaboration. In developed countries, this trend is poorly expressed. In Finland, the indicator in question increased by 9.07% from 12.9 points in 2019 to 11.73 points in 2021. In Sweden, it increased by 25.69% from 14.4 points in 2019 to 10.70 points in 2021. This trend is much stronger in developing countries. In China, the indicator in question increased by 62.43% from 7.8 points in 2019 to 2.93 points in 2021. In Brazil, by 53.17% from 8.2 points in 2019 to 3.84 points in 2021.

From the above results of trend analysis, it is noticeable that all three trends are most clearly manifested in developed countries. Consequently, in the context of the COVID-19 crisis, the decline in the availability of financing for EnergyTech has exacerbated the imbalances in its development and increased the inequality of countries in the practical implementation of SDG 7.

SWOT ANALYSIS OF ENERGYTECH FINANCING DURING THE COVID-19 CRISIS AND IN THE POST-PANDEMIC PERIOD

The obtained results of quantitative and qualitative research are summarized in **Table 1**. Based on them, a SWOT analysis of

TABLE 1 | SWOT analysis of EnergyTech financing problems during the COVID-19 crisis and in the post-pandemic period.

Positive Trends in EnergyTech Financing in the Context of the COVID-19(S) Crisis	Problems of Financing EnergyTech in the Context of the COVID-19 (W) Crisis
– Independence of alternative and electric energy financing from the impact of the crisis	– Decline in investment in the development of major energy markets
– Increasing investments in "green" ("clean") energy	– Reduction of the total volume of global energy investments
– The growth of the share of investments in "green" energy in their overall structure	– Decrease of social legitimation and international collaboration
– Progress in the knowledge development, diffusion and entrepreneurial experimentation and market formation	– Worsening inequality of investments in EnergyTech between developed and developing countries
Opportunities for improving EnergyTech financing in the post-pandemic period (O)	**Threats to EnergyTech financing in the post-pandemic period (T)**
– Acceleration of post-crisis recovery of the economies of developing countries and the growth of investment attractiveness of their EnergyTech	– Slow recovery of developing countries and continued underfunding of their EnergyTech
– Development of public-private partnership in EnergyTech	– Limited opportunities for return on investment in EnergyTech s due to distortions in competition in global energy markets
– Credit and investment support of EnergyTech by international financial organizations	– Uneven demand for energy resources among the EnergyTech markets, causing imbalances in its financing

Developed by the authors.

current problems and prospects for their solution was carried out to clarify the cause-and-effect relationships of EnergyTech financing in the conditions of the COVID-19 crisis and in the post-pandemic period.

As shown in **Table 1**, there are a number of threats to EnergyTech financing in the post-pandemic period. One of the threats is the slow recovery of developing countries and the continued underfunding of their EnergyTech. In this case, the gap in energy investments between developed and developing countries will remain. Another threat is the limited opportunities for the return on investment in EnergyTech due to distortions in competition in global energy markets.

Disruptions in global value chains and energy shocks, including the increase in world prices for fuel and energy resources observed in the first half of 2022, may provide a disincentive for energy companies to develop, as well as reduce the investment attractiveness of "green" energy development projects. Another threat is the uneven demand for energy resources among the EnergyTech markets, which causes imbalances in its financing.

The possibilities of improving EnergyTech financing in the post-pandemic period are connected, firstly, with the accelerated post-crisis recovery of the economies of developing countries and the growth of the investment attractiveness of their EnergyTech. Secondly, they are also related to the development of public-private partnerships, which should be given increased attention in EnergyTech. Thirdly, they are linked to the credit and investment support of EnergyTech from international financial organizations, especially in relation to developing countries.

DISCUSSION

The contribution of the article to the literature is to clarify the cause-effect relationships of changes in financing and progress in the development of EnergyTech in the context of the COVID-19 crisis, as well as prospects in the post-pandemic period. In opposition to the viewpoints by Chien et al. (2021), Gong et al. (2021), Li et al. (2022), Popkova et al. (2019), Sheng et al. (2021) it has been proven that financing of "green" energy is a priority in EnergyTech, which in the conditions of the COVID-19 pandemic and crisis turned out to be the most investment-attractive (compared to the main/traditional energy markets (compared to the main/traditional energy markets (upstream, mid/downstream, coal supply, fossil fuel power).

In contrast to Iqbal and Bilal (2021), Taghizadeh-Hesary et al. (2022), Tran (2021), it is proved that in the conditions of the COVID-19 crisis, the amount of financing for EnergyTech has changed unevenly and, despite its general reduction, the amount of financing for "green" ("clean") energy (low carbon fuels, renewable power) has increased, as well as the amount of financing for alternative and electric energy (nuclear and electricity networks) has been preserved. Thanks to this, progress in the development of EnergyTech has not slowed down, but even accelerated. For example, in Denmark, knowledge development and diffusion increased by 54.42%, and in Finland, entrepreneurial experimentation and market formation increased by 59.56%.

Unlike Popkova et al. (2021), Zhao et al. (2022), Zhou and Liu (2022), it has been proven that the pandemic and the COVID-19 crisis have not reduced, but increased the inequality between developed and developing countries in the field of financing EnergyTech, which is a serious problem that needs to be addressed as a priority in the post-pandemic period. The theoretical value of the results obtained is that they make it possible to see SDG seven in a new perspective, i.e. they show that "clean" energy comes to the fore. This means that the financing of EnergyTech is not aimed at supporting industrial economic growth, but at decarbonization. The resource role of energy gives way to resource efficiency: the conservation of energy resources and their environmental friendliness.

CONCLUSION

Thus, the actual problems of financing EnergyTech in the context of the COVID-19 crisis have been identified, including a reduction of investments in the development of major energy markets, a decrease in the total volume of global investments in energy, a decline in social legitimation and international collaboration, as well as an increase in the inequality of investment in energy technologies between developed and developing countries.

The prospects for solutions in the post-pandemic period related to the growth of investment attractiveness of EnergyTech in developing countries, with the development of public-private partnerships and with credit and investment support of EnergyTech from international financial organizations, especially in relation to developing countries, are also identified.

The contribution of the article to the literature is to substantiate that the COVID-19 pandemic and crisis not only created challenges and threats, but also provided prerequisites and revealed positive trends in EnergyTech financing, among which the priority of investment support for green energy plays a key role. This can be explained by the popularity of the environmental version of EnergyTech, and as a result, the growing attention to the environmental agenda. In the context of the pandemic, serious progress has been made in decarbonizing the economy, achieved by increasing the financing of "clean" energy and requiring support in the post-pandemic period.

The practical significance of the research results is that the identified prospects and the proposed authors' recommendations will be useful for improving the financing of EnergyTech in the post-pandemic period. The conducted research is limited to considering only the experience of leaders in the development of EnergyTech, while the problem of financing of the energy economy in other countries remains outside the scope of this article–it is proposed to devote further scientific research to its study. Another interesting issue is the consideration of regional differences in the financing of EnergyTech, which is also proposed to focus on in future research.

AUTHOR CONTRIBUTIONS

Conceptualization, VO, ND, AA, and AS; Formal analysis, AA; Methodology, VO; Project administration, AS and AA; Resources, AA and ND; Writing—review and editing, ND and VO.

REFERENCES

Ayub, S., Ayob, S. M., Tan, C. W., Taimoor, M., Ayub, L., Bukar, A. L., et al. (2022). Analysis of Energy Management Schemes for Renewable-Energy-Based Smart Homes against the Backdrop of COVID-19. *Sustain. Energy Technol. Assessments* 52, 102136. doi:10.1016/j.seta.2022.102136

Chien, F., Zhang, Y., and Hsu, C.-C. (2021). Assessing the Nexus between Financial Development and Energy Finance through Demand- and Supply-Oriented Physical Disruption in Crude Oil. *Environ. Sci. Pollut. Res.* 28 (46), 66086–66100. doi:10.1007/s11356-021-15535-5

Gallo, E., Wu, Z., and Sergi, B. S. (2020). China's Power in its Strategic Energy Partnership with the Eurasian Economic Union. *Communist Post-Communist Stud.* 53 (4), 200–219. doi:10.1525/j.postcomstud.2020.53.4.200

Gong, X., Ji, Q., and Lin, B. (2021). Literature Review and Frontier Direction Exploration of Energy Finance. *Xit. Gongcheng Lilun yu Shijian/System Eng. Theory Pract.* 41 (12), 3349–3365. doi:10.12011/SETP2020-0163

Information Technology and Innovation Foundation (ITIF) (2022a). Global Energy Innovation Index. National Contributions to the Global Clean Energy Innovation System. Availble at: https://www2.itif.org/2019-global-energy-innovation-index.pdf (data accessed: 06.04.2022).

Information Technology and Innovation Foundation (ITIF) (2022b). The 2021 Global Energy Innovation Index: National Contributions to the Global Clean Energy Innovation System. Availble at: https://itif.org/publications/2021/10/18/2021-global-energy-innovation-index-national-contributions-global-clean (data accessed: 06.04.2022).

International Energy Agency (2022). World Energy Investment 2021. Availble at: https://iea.blob.core.windows.net/assets/5e6b3821-bb8f-4df4-a88b-e891cd8251e3/WorldEnergyInvestment2021.pdf (data accessed: 06.04.2022).

Iqbal, S., and Bilal, A. R. (2021). Energy Financing in COVID-19: How Public Supports Can Benefit? *Cfri* 12, 219–240. doi:10.1108/CFRI-02-2021-0046

Kamruzzaman, M. M., and Alruwaili, O. (2022). Energy Efficient Sustainable Wireless Body Area Network Design Using Network Optimization with Smart Grid and Renewable Energy Systems. *Energy Rep.* 8, 3780–3788. doi:10.1016/j.egyr.2022.03.006

Knayer, T., and Kryvinska, N. (2022). An Analysis of Smart Meter Technologies for Efficient Energy Management in Households and Organizations. *Energy Rep.* 8, 4022–4040. doi:10.1016/j.egyr.2022.03.041

Lean, H. H., and Lee, C.-C. (2022). Editorial: Energy Economics and Energy Finance in Developing and Emerging Countries. *Front. Energy Res.* 10, 814273. doi:10.3389/fenrg.2022.814273

Li, Z., Gallagher, K., Chen, X., Yuan, J., and Mauzerall, D. L. (2022). Pushing Out or Pulling in? the Determinants of Chinese Energy Finance in Developing Countries. *Energy Res. Soc. Sci.* 86, 102441. doi:10.1016/j.erss.2021.102441

Popkova, E. G., Inshakov, O. V., and Bogoviz, A. V. (2019). Regulatory Mechanisms of Energy Conservation in Sustainable Economic Development. *Lect. Notes Netw. Syst.* 44, 107–118. doi:10.1007/978-3-319-90966-0_8

Popkova, E. G., Inshakova, A. O., Bogoviz, A. V., and Lobova, S. V. (2021). Energy Efficiency and Pollution Control through ICTs for Sustainable Development. *Front. Energy Res.* 9, 735551. doi:10.3389/fenrg.2021.735551

Ratner, S., Berezin, A., Gomonov, K., Serletis, A., and Sergi, B. S. (2022). What Is Stopping Energy Efficiency in Russia? Exploring the Confluence of Knowledge, Negligence, and Other Social Barriers in the Krasnodar Region. *Energy Res. Soc. Sci.* 85, 102412. doi:10.1016/j.erss.2021.102412

Ratner, S., Berezin, A., and Sergi, B. S. (2021). Energy Efficiency Improvements under Conditions of Low Energy Prices: The Evidence from Russian Regions. *Energy Sources, Part B Econ. Plan. Policy*, 1–20. doi:10.1080/15567249.2021.1966134

Sheng, Z., Yuan, G., Xiru, D., Minglong, Z., Yi, W., and Yu, H. (2021). Research on High Quality Evaluation and Influencing Factors of China Energy Finance: Evidence from A-Share New Energy Companies. *Front. Environ. Sci.* 9, 662424. doi:10.3389/fenvs.2021.662424

Sisodia, G. S., Awad, E., Alkhoja, H., and Sergi, B. S. (2020). Strategic Business Risk Evaluation for Sustainable Energy Investment and Stakeholder Engagement: A Proposal for Energy Policy Development in the Middle East through Khalifa Funding and Land Subsidies. *Bus. Strat. Env.* 29 (6), 2789–2802. doi:10.1002/bse.2543

Štreimikienė, D., Samusevych, Y., Bilan, Y., Vysochyna, A., and Sergi, B. S. (2022). Multiplexing Efficiency of Environmental Taxes in Ensuring Environmental, Energy, and Economic Security. *Environ. Sci. Pollut. Res.* 29 (5), 7917–7935. doi:10.1007/s11356-021-16239-6

Taghizadeh-Hesary, F., Zakari, A., Alvarado, R., and Tawiah, V. (2022). The Green Bond Market and its Use for Energy Efficiency Finance in Africa. *Cfri* 12, 241–260. doi:10.1108/CFRI-12-2021-0225

Tran, Q. H. (2021). The Impact of Green Finance, Economic Growth and Energy Usage on CO2 Emission in Vietnam - a Multivariate Time Series Analysis. *Cfri* 12, 280–296. doi:10.1108/CFRI-03-2021-0049

Verba, N., Nixon, J. D., Gaura, E., Dias, L. A., and Halford, A. (2022). A Community Energy Management System for Smart Microgrids. *Electr. Power Syst. Res.* 209, 107959. doi:10.1016/j.epsr.2022.107959

Zhao, W., Liu, X., Wu, Y., Zhang, T., and Zhang, L. (2022). A Learning-To-Rank-Based Investment Portfolio Optimization Framework for Smart Grid Planning. *Front. Energy Res.* 10, 852520. doi:10.3389/fenrg.2022.852520

Zhou, M., and Liu, X. (2022). Overnight-Intraday Mispricing of Chinese Energy Stocks: A View from Financial Anomalies. *Front. Energy Res.* 9, 807881. doi:10.3389/fenrg.2021.807881

Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's Note: All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

frontiers | Frontiers in Energy Research

OPINION
published: 06 June 2022
doi: 10.3389/fenrg.2022.928553

An Institutional Approach to the Decarbonization of the Economy and the Transition to Clean Energy Based on EnergyTech

Yuliya V. Chutcheva[1†], Alexander V. Semenov[2†], Galina N. Semenova[3,4†] and Suzana L. Balova[5†]*

[1]Department of Economics, Moscow Timiryazev Agricultural Academy, Moscow, Russia, [2]Rector, Moscow Witte University, Moscow, Russia, [3]Department of Taxes and Taxation, Plekhanov Russian University of Economics, Moscow, Russia, [4]Department of Economics, Moscow State Regional University, Moscow, Russia, [5]Department of Management, Financial University Under the Government of the Russian Federation, Moscow, Russia

Keywords: institutional approach, decarbonization, clean energy, EnergyTech, economy

OPEN ACCESS

Edited by:
Bruno Sergi,
Harvard University, United States

Reviewed by:
Ladislav Zak,
Independent Researcher, Switzerland
Konstantin V. Vodenko,
Platov South-Russian State Polytechnic University, Russia

***Correspondence:**
Galina N. Semenova
Sg6457@mail.ru

[†]These authors have contributed equally to this work

Specialty section:
This article was submitted to Sustainable Energy Systems and Policies, a section of the journal Frontiers in Energy Research

Received: *25 April 2022*
Accepted: *10 May 2022*
Published: *06 June 2022*

Citation:
Chutcheva YV, Semenov AV, Semenova GN and Balova SL (2022) An Institutional Approach to the Decarbonization of the Economy and the Transition to Clean Energy Based on EnergyTech. Front. Energy Res. 10:928553. doi: 10.3389/fenrg.2022.928553

INTRODUCTION

Decarbonization of the economy is an important step towards the practical implementation of SDG 7, that is, the transition to clean energy. Among the large-scale national programs for decarbonization of the economy in international practice, we can single out the initiative of the European Union (representing developed countries), Russia and China as developing countries (Popkova, 2022). In the mentioned successful examples, firstly, the state plays a key role in the decarbonization of the economy and the transition to clean energy. Secondly, this transition is carried out based on progressive digital economies and developed Industry 4.0. Therefore, the tool for monitoring, control, and practical implementation of programs for the decarbonization of the economy is high technology in the energy sector—EnergyTech.

This article intends to systematize, analyze and present the successful international experience of the decarbonization of the economy and the transition to clean energy and identify the contribution of the institutions of state regulation and EnergyTech to this transition. To achieve this goal, this article consistently solves a set of the following tasks:

- The patterns of “Market failure” on the way of decarbonization of the economy and transition to clean energy are revealed;
- The international experience of decarbonization of the economy and the transition to clean energy, as well as the contribution of state regulatory institutions to this process, is studied;
- Recommendations are being developed to overcome the “market failure” of decarbonization of the economy and transition to clean energy through an institutional approach to managing the development of EnergyTech.

The work is completed by a combined discussion and conclusion section, where the contribution of the article to the literature is noted, the results of the study are summarized, its limitations are indicated and prospects for further scientific research are outlined.

“Market failure” on the Way to Decarbonization of the Economy and Transition to Clean Energy

This article is based on the Theory of Sustainable Energy, the fundamental provisions of which are the following:

- -Sustainable energy is the energy that ensures the practical implementation of SDG 7 (Klemm and Wiese, 2022; Saheb et al., 2022; Wang et al., 2022).
- -Decarbonization of the economy is carried out on the basis of the development of sustainable energy (Balaras, 2022; Kany et al., 2022).

The existing literature Awawdeh et al. (2021), Latapí et al. (2021), Ngo et al. (2021), Ren et al. (2022), Taghizadeh-Hesary et al. (2022), Yang et al. (2022) notes that sustainable energy is developing on the basis of corporate social responsibility. The argument put forward is that private business actively supports the UN initiative and consolidates support for the implementation of SDG 7 in its corporate strategies, makes ESG investments in energy. In this regard, in the available literature, sustainable energy is also often called responsible energy (Rehman et al., 2021; Skjølsvold and Coenen, 2021; Adamik et al., 2022; Lu et al., 2022).

Since the basis of corporate social responsibility is market freedom, today there is a market approach to the decarbonization of the economy. In accordance with this approach, for the implementation of SDG 7, it is assumed to reduce the energy intensity of production and consumption in the economy, as well as the transition to "clean" (wind, solar) energy (Carbajo and Cabeza, 2022; Huang et al., 2022; Li et al., 2022; Liu et al., 2022; Safarianzengir et al., 2022; Zhang et al., 2022).

The problem is that corporate social responsibility is unstable, difficult to control, predict and manage at the macroeconomic level. Its contribution to the decarbonization of the economy is insufficiently studied at the empirical level of science. There is a gap in the literature due to insufficient elaboration of the causal relationships of decarbonization of the economy.

Practical experience shows that a high level of market freedom does not guarantee sustainable energy development. For example, Qatar is classified by The Heritage Foundation (2022) as a mostly free economy and is ranked 44th in the world in terms of economic freedom, but its carbon emissions in 2020 increased by 16.52 million tons/18.31% compared to 2015 (Our World in Data, 2022). Similarly, Albania is classified by The Heritage Foundation (2022) as a mostly free economy and is ranked 50th in the world in terms of economic freedom, but its carbon emissions increased by 38.945 million tons/0.66% in 2020 compared to 2015 (Our World in Data, 2022). The Philippines is classified by The Heritage Foundation (2022) as a mostly free economy and is ranked 80th in the world in terms of economic freedom, but their carbon emissions in 2020 increased by 23.88 million tons/21.29% compared to 2015 (Our World in Data, 2022).

In contrast, Venezuela is classified by The Heritage Foundation (2022) as a repressed economy and is ranked 176th in the world in terms of economic freedom, but its carbon emissions in 2020 decreased by 95.51 million tons/ 53.02% compared to 2015 (Our World in Data, 2022). These examples demonstrated the "failure of the market" on the path of decarbonization of the economy and the transition to clean energy. This raises a research question (RQ) about how to overcome the identified "market failure" on the way to decarbonization of the economy. In this article, the hypothesis is put forward that the institutions of state regulation and EnergyTech can solve the problem posed and ensure the decarbonization of the modern economy.

International Experience of Decarbonization of the Economy and Transition to Clean Energy and the Contribution of State Regulatory Institutions To it

To test the hypothesis and determine the role of state regulatory institutions in the decarbonization of the economy, it is necessary to consider the available statistics and analyze it. One of the most reliable and relevant indicators of the level of development of institutions of state regulation of the economy, determined by The Heritage Foundation (2022), is to ensure public institutions embed strong governance principles, build a long-term vision and establish trust by serving their citizens.

Based on the rating for 2020, a sample of the top 10 developed and top 10 developing countries was formed by the level of development of institutions of state regulation of the economy. For this sample, data were collected on annual CO_2 emissions in 2015 (the period of the adoption of the SDGs under the auspices of the UN) and in 2020 (the beginning of the "Decade of Action") on the assessment of (Our World in Data, 2022). These data are summarized in **Table 1**, where their system analysis is also performed.

Using the variation analysis method, the homogeneity of the sample is estimated. The trend analysis method is used to determine the increase in annual carbon emissions in 2020 compared to 2015. The correlation analysis method is used to determine the relationship of institutions with carbon emissions. Using the method of comparative analysis, the results in developed countries are compared with the results in developing countries.

The results obtained in **Table 1** indicate that the level of development of institutions in developed countries is very high (on average it is estimated at 72.50 points in 2020) and homogeneous (variation is 5%). The decarbonization rate is very high: Annual CO_2 emissions decreased by an average of 13.57% in 2020 compared to 2015. Institutions play an important role in achieving decarbonization—their correlation with carbon emissions in 2015–2020 is estimated at 56.23% (the negative value of the correlation coefficient indicates that the higher the level of development of institutions, the lower the amount of carbon emissions).

In developing countries, the level of development of institutions is lower (on average, it is estimated at 53.03 points in 2020) but also homogeneous (the variation is 15%). Due to large differences in the amount of carbon emissions (their variation in 2015 was 119.99%, and in 2020—116.86%), despite the achievements of individual countries (for example, in Argentina decarbonization was 18.41%, in Chile—0.79%, in Russia—2.47%), the amount of carbon emissions in 2020 increased by an average of 0.54% compared to 2015. Institutions play a slightly less important role (compared to

TABLE 1 | State regulatory institutions in 2020 and decarbonization of the economy in 2015–2020 in developed and developing countries.

Category of countries by the development of institutions	Country	Ensure public institutions embed strong governance principles, build a long-term vision and establish trust by serving their citizens, score 1–100	Annual CO_2 emissions, million tonnes		
		2020	2015	2020	Growth, %
Developed countries	Finland	78.5	44.13	39.29	−10.97
	Switzerland	76.8	38.73	32.30	−16.60
	New Zealand	73.0	36.07	33.48	−7.18
	Denmark	72.0	35.20	26.19	−25.60
	Netherlands	72.0	164.20	138.10	−15.90
	Sweden	70.3	43.60	38.63	−11.40
	Austria	69.9	66.35	60.63	−8.62
	United States	67.5	5,370.00	4,710.00	−12.29
	Arithmetic mean	72.50	724.79	634.83	−13.57
	Variation, %	5.00	259.04	259.44	−42.94
	Correlation with institutions, %	-	−56.23	−56.23	—
Developing countries	China	64.3	9.85	10.67	8.32
	Chile	61.9	81.82	81.17	−0.79
	Indonesia	58.8	551.48	589.50	6.89
	South Africa	53.9	450.57	451.96	0.31
	India	49.4	2,270.00	2,440.00	7.49
	Turkey	47.7	381.33	392.79	3.01
	Argentina	45.4	192.41	156.98	−18.41
	Russia	42.8	1,620.00	1,580.00	−2.47
	Arithmetic mean	53.03	694.68	712.88	0.54
	Variation, %	15.02	116.86	119.99	1,595.46
	Correlation with institutions, %	-	−52.74	−49.58	—

Source: Calculated and compiled by the authors on the basis of materials.

developed countries) in achieving decarbonization—their correlation with carbon emissions in 2015 was estimated at 49.58%, and in 2020—at 52.74% (negative values of correlation coefficients indicate that the higher the level of development of institutions, the lower the amount of carbon emissions).

Overcoming the "Market Failure" of Decarbonization of the Economy and the Transition to Clean Energy Through an Institutional Approach to Managing the Development of EnergyTech

The obtained results revealed a significant potential of the institutions of state regulation of the economy in ensuring decarbonization. In this regard, to overcome the "market failure" of decarbonization of the economy and the transition to clean energy, this article suggests an alternative—an institutional approach to managing the development of EnergyTech. The essence of the proposed new approach is to develop institutions and tighten state regulation of EnergyTech. To determine the prospects for the practical implementation of the proposed approach, it is necessary to refer to the best practices of modern countries implementing decarbonization strategies.

The countries of the European Union have adopted the Global Climate Action: 2050 long-term strategy (European Commission, 2022). According to the calculations of the International Renewable Energy Agency (2022) in Denmark (as one of the leading countries in decarbonization in the EU) in 2020, onshore wind energy prevails (46.9%). The share of solid biofuels (18.7%), offshore wind energy (17.6%) and solar photovoltaic (13.4%) is also high.

Russia is implementing the Strategy of socio-economic development of Russia with a low level of emissions of greenhouse gases until 2050, approved by the decree of the Government of the Russian Federation (2022) dated 29 October 2021, No. 3052-R. According to the calculations of the International Renewable Energy Agency (2022) in Russia in 2020, the basis of renewable energy was renewable hydropower (90.8%). China has a strategy to achieve carbon neutrality by 2060 (UN, 2022). According to the calculations of the International Renewable Energy Agency (2022) in China in 2020, despite the predominance of renewable hydropower (36.7%), onshore wind energy (29.5%) and solar photovoltaic (27.4%) are highly developed.

The cited experience of Russia and China shows the wide possibilities of renewable hydropower, the advantage of which in comparison with wind and solar energy is high and stable performance. This makes it possible to move from saving energy to improving energy efficiency in energy production, that is, to manage sustainable energy not from the demand side, but from the supply side.

DISCUSSION AND CONCLUSION

Thus, the hypothesis is proved that the institutions of state regulation and EnergyTech can solve the problem and ensure the decarbonization of the modern economy. Unlike Awawdeh et al. (2021); Adamik et al. (2022); Latapí et al. (2021); Lu et al. (2022); Ngo et al. (2021); Rehman et al. (2021); Ren et al. (2022); Skjølsvold and Coenen (2021); Taghizadeh-Hesary et al. (2022); Yang et al. (2022) found that state intervention in market processes does not create barriers, but on the contrary, stimulates and accelerates sustainable energy development. The theoretical significance of this conclusion is that it allows the development of institutions of state regulation of the economy in support of sustainable energy.

In contrast to Carbajo and Cabeza (2022); Huang et al. (2022); Li et al. (2022), Liu et al. (20 2), Safarianzengir et al. (2022); Zhang et al. (2022), it was revealed that the "clean" energy sector does not necessarily have to be unstable and unproductive. The analysis of case studies on Russia and China shown that sustainable energy can be based on reliable and highly efficient hydroelectricity. The conclusions obtained in this study allow us to recommend an institutional approach to the decarbonization of the economy and the transition to clean energy based on EnergyTech, which is the contribution of the article to the literature. The practical significance of the article is that the proposed new approach improves the practice of SDG 7 implementation.

However, the results of the study are limited by the recommendation to develop institutions in support of EnergyTech and SDG 7, while the process of evolution and increasing the effectiveness of institutions remained outside the scope of the study. Thus, the reduced effectiveness of institutions in supporting decarbonization in developing countries deserves closer study. In further research, it is also advisable to develop concrete and applied measures for the development of EnergyTech institutions in support of decarbonization, taking into account the characteristics of developing countries.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

REFERENCES

Adamik, A., Liczmańska-Kopcewicz, K., Pypłacz, P., and Wiśniewska, A. (2022). Involvement in Renewable Energy in the Organization of the Ir 4.0 Era Based on the Maturity of Socially Responsible Strategic Partnership with Customers—An Example of the Food Industry. *Energies* 15 (1), 180. doi:10.3390/en15010180

Awawdeh, A. E., Ananzeh, M., El-khateeb, A. I., and Aljumah, A. (2021). Role of Green Financing and Corporate Social Responsibility (CSR) in Technological Innovation and Corporate Environmental Performance: a COVID-19 Perspective. *Cfri* 12, 297–316. doi:10.1108/CFRI-03-2021-0048

Balaras, C. A. (2022). Building Energy Audits-Diagnosis and Retrofitting towards Decarbonization and Sustainable Cities. *Energies* 15 (6), 2039. doi:10.3390/en15062039

Carbajo, R., and Cabeza, L. F. (2022). Researchers' Perspective within Responsible Implementation with Socio-Technical Approaches. An Example from Solar Energy Research Centre in Chile. *Renew. Sustain. Energy Rev.* 158, 112132. doi:10.1016/j.rser.2022.112132

European Commission (2022). Climate Action: 2050 Long-Term Strategy. Available at: https://ec.europa.eu/clima/eu-action/climate-strategies-targets/2050-long-term-strategy_en (Accessed on 09 04, 2022).

Huang, W., Dai, J., and Xiong, L. (2022). Towards a Sustainable Energy Future: Factors Affecting Solar-Hydrogen Energy Production in China. *Sustain. Energy Technol. Assessments* 52, 102059. doi:10.1016/j.seta.2022.102059

International Renewable Energy Agency (2022). Renewable Energy Technologies.Available at: https://www.irena.org/Statistics/View-Data-by-Topic/Capacity-and-Generation/Technologies (Accessed on 09 04, 2022).

Kany, M. S., Mathiesen, B. V., Skov, I. R., Korberg, A. D., Thellufsen, J. Z., Lund, H., et al. (2022). Energy Efficient Decarbonisation Strategy for the Danish Transport Sector by 2045. *Smart Energy* 5, 100063. doi:10.1016/j.segy.2022.100063

Klemm, C., and Wiese, F. (2022). Indicators for the Optimization of Sustainable Urban Energy Systems Based on Energy System Modeling. *Energ Sustain Soc.* 12 (1), 3. doi:10.1186/s13705-021-00323-3

Latapí, M., Jóhannsdóttir, L., and Davíðsdóttir, B. (2021). The Energy Company of the Future: Drivers and Characteristics for a Responsible Business Framework. *J. Clean. Prod.* 288, 125634. doi:10.1016/j.jclepro.2020.125634

Li, N., Wang, Y., Ma, W., Xiao, Z., and An, Z. (2022). A Wind Power Prediction Method Based on DE-BP Neural Network. *Front. Energy Res.* 10, 844111. doi:10.3389/fenrg.2022.844111

Liu, C., Li, Q., Tian, X., Wei, L., Chi, Y., and Li, C. (2022). Multi-Objective Mayfly Optimization-Based Frequency Regulation for Power Grid with Wind Energy Penetration. *Front. Energy Res.* 10, 848966. doi:10.3389/fenrg.2022.848966

Lu, X., Xia, S., Gu, W., and Chan, K. W. (2022). A Model for Balance Responsible Distribution Systems with Energy Storage to Achieve Coordinated Load Shifting and Uncertainty Mitigation. *Energy* 249, 123749. doi:10.1016/j.energy.2022.123749

Ngo, Q.-T., Tran, H. A., and Tran, H. T. T. (2021). The Impact of Green Finance and Covid-19 on Economic Development: Capital Formation and Educational Expenditure of ASEAN Economies. *Cfri* 12, 261–279. doi:10.1108/CFRI-05-2021-0087

Our World and Data (2022). CO_2 Emissions. Available at: https://ourworldindata.org/co2-emissions (Accessed on 09 04, 2022).

Popkova, E. G. (2022). *Advanced Issues in the Green Economy and Sustainable Development in Emerging Market Economies (Elements in the Economics of Emerging Markets)*. Cambridge: Cambridge University Press. doi:10.1017/9781009093408

Rehman, M. U., Kashif, M., Naifar, N., and Shahzad, S. J. H. (2021). Socially Responsible Funds and Traditional Energy Commodities: A Diversification Perspective for Investments. *Front. Environ. Sci.* 9, 709990. doi:10.3389/fenvs.2021.709990

Ren, C., Ting, I. W. K., Lu, W. M., and Kweh, Q. L. (2022). Nonlinear Effects of ESG on Energy-adjusted Firm Efficiency: Evidence from the Stakeholder Engagement of Apple Incorporated. *Corp. Soc. Responsib. Env.* doi:10.1002/csr.2266

Safarianzengir, V., Fatahi, A., and Amiri Doumari, S. (2022). Feasibility and Zoning of Establishing Solar Power Stations to Produce Sustainable Energy from the Environment in Northwestern Iran. *Front. Energy Res.* 10, 819577. doi:10.3389/fenrg.2022.819577

Saheb, T., Dehghani, M., and Saheb, T. (2022). Artificial Intelligence for Sustainable Energy: A Contextual Topic Modeling and Content Analysis. *Sustain. Comput. Inf. Syst.* 35, 100699. doi:10.1016/j.suscom.2022.100699

Skjølsvold, T. M., and Coenen, L. (2021). Are Rapid and Inclusive Energy and Climate Transitions Oxymorons? towards Principles of Responsible Acceleration. *Energy Res. Soc. Sci.* 79, 102164. doi:10.1016/j.erss.2021.102164

Taghizadeh-Hesary, F., Zakari, A., Alvarado, R., and Tawiah, V. (2022). The Green Bond Market and its Use for Energy Efficiency Finance in Africa. *China Finance Rev. Int.* doi:10.1108/CFRI-12-2021-0225

The Government of the Russian Federation (2022). The Strategy of Socio-Economic Development of Russia with Low Greenhouse Gas Emissions until 2050. approved by Order No. 3052-p of October 29, 2021. Available at: http://static.government.ru/media/files/. ADKkCzp3fWO32e2yA0BhtIpyzWfHaiUa.pdf (Accessed on 09 04, 2022).

The Heritage Foundation (2022). Index of Economic Freedom 2022. Available at: https://www.heritage.org/index/ranking (Accessed on 09 04, 2022).

UN (2022). President Xi Jinping: China Will Achieve Carbon Neutrality by 2060. Available at: https://news.un.org/en/story/2021/09/1100642 (Accessed on 09 04, 2022).

Wang, G., Chao, Y., Cao, Y., Jiang, T., Han, W., and Chen, Z. (2022). A Comprehensive Review of Research Works Based on Evolutionary Game Theory for Sustainable Energy Development. *Energy Rep.* 8, 114–136. doi:10.1016/j.egyr.2021.11.231

World Economic Forum (2022). Global Competitiveness Report Special Edition 2020: How Countries Are Performing on the Road to Recovery. Available at: https://www.weforum.org/reports/the-global-competitiveness-report-2020 (Accessed on 09 04, 2022).

Yang, Q., Du, Q., Razzaq, A., and Shang, Y. (2022). How Volatility in Green Financing, Clean Energy, and Green Economic Practices Derive Sustainable Performance through ESG Indicators? A Sectoral Study of G7 Countries. *Resour. Policy* 75, 102526. doi:10.1016/j.resourpol.2021.102526

Zhang, X., Qin, Q., Liu, X., and Wang, W. (2022). Effects of Stepwise Microwave Synergistic Process Water Recirculation during Hydrothermal Carbonization on Properties of Wheat Straw. *Front. Energy Res.* 10, 846752. doi:10.3389/fenrg.2022.846752

Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's Note: All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

frontiers | Frontiers in Energy Research

OPINION
published: 21 June 2022
doi: 10.3389/fenrg.2022.931891

Marketing Mix of Energy Companies of EnergyTech From the Positions of Their Contribution to Sustainable and Environmental Development of Energy Economics

Lyudmila V. Borisova[1]*, Yuliya G. Tyurina*[2]**, Irina A. Morozova*[3] *and Oksana N. Momotova*[4]

[1]Department of Innovative Business and Management, Don State Technical University, Rostov-on-Don, Russia, [2]Financial University under the Government of the Russian Federation, Moscow, Russia, [3]Department of Economics and Management, Volgograd State Technical University, Volgograd, Russia, [4]Institute of Economics and Management, North Caucasus Federal University, Stavropol, Russia

Keywords: marketing mix, energy companies, oil and gas companies, EnergyTech, sustainable development, environmental development, energy economics

OPEN ACCESS

Edited by:
Elena G. Popkova, Moscow State Institute of International Relations, Russia

Reviewed by:
Nursultan Shurenov, Al-Farabi Kazakh National University, Kazakhstan

****Correspondence:***
Yuliya G. Tyurina
u_turina@mail.ru

Specialty section:
This article was submitted to Sustainable Energy Systems and Policies, a section of the journal Frontiers in Energy Research

Received: *29 April 2022*
Accepted: *11 May 2022*
Published: *21 June 2022*

Citation:
Borisova LV, Tyurina YG, Morozova IA and Momotova ON (2022) Marketing Mix of Energy Companies of EnergyTech From the Positions of Their Contribution to Sustainable and Environmental Development of Energy Economics. Front. Energy Res. 10:931891. doi: 10.3389/fenrg.2022.931891

INTRODUCTION

If natural monopolies dominated the world energy markets in the past century, in recent years, due to the emergence and mass availability of alternative and clean energy, competition has been increasing in these markets. Global competitiveness requires energy companies to actively use the marketing tools of business management. Marketing support for the corporate environmental responsibility of energy companies also plays an important role.

Marketing penetrates from the outside into the activities of traditional players in the energy markets—oil and gas companies—with the artificial creation of competition in natural monopolies (Li et al., 2022; Wei et al., 2022). Against their background, new players that have entered the energy markets, in connection with the development of sustainable territories and responsible communities, are clearly distinguished—“clean” energy companies (EnergyTech). Marketing is deeply integrated into their activities (rooted in their nature) (Dai et al., 2022).

According to the calculations of the International Energy Agency (2022), the share of “clean” (renewable) energy in the world energy markets was 29% in 2020, which is an increase compared to 2019, when it was 27%. In 2021, its growth continued, which was estimated to be 8%. The largest producers of “clean” energy are China (almost 300 TW), the United States (100 TW), and the European Union (70 TW), where wind energy prevails. They are followed by India (40 TW), where solar energy prevails. In the rest of the world, hydropower is the dominant source of energy, and the share of bioenergy is quite large.

Taking into account the domination in the global energy markets by oil and gas companies, the existing literature reports by Nuseir and El Refae (2021) and Shukla et al. (2021) focus on the marketization of these companies. The growing level of environmental awareness and responsibility of energy consumers, as well as the launch and implementation of economic decarbonization strategies in countries around the world, contributes to rethinking the activities of energy companies from the standpoint of their contribution to sustainable and environmental development of energy economics.

The problem is that the activities of oil and gas companies make a small contribution, while the activities of clean energy companies (EnergyTech), which make the greatest contribution to sustainable and environmental development of energy economics, have not been properly considered in the existing literature. Their marketing mix is poorly understood, while this article hypothesizes that it is marketing that helps to achieve this contribution. This article is aimed at researching the marketing mix of clean energy companies (EnergyTech) in terms of their contribution to the sustainable and ecological development of the energy economy.

NOOSPHERIC APPROACH TO MARKETING OF ENERGYTECH COMPANIES

This article is based on the noospheric approach to the study of economic activity in the unity of its economic (profitability and effectiveness of "green" investment projects of energy companies), social (benefits to society in the form of corporate environmental responsibility), and environmental (contribution of energy companies to the conservation of natural resources for future generations and the fight against climate change) components.

In the existing literature, much attention is paid to the contribution of energy companies to sustainable and environmental development of energy economics. A whole layer of scientific research is devoted to the best practices of the European Union (EU), which enables us to note that this contribution is achieved mainly through regulatory measures. For example, EU legislation is actively fighting against natural monopolies.

The requirement of securing competition contributes to the marketization of the activities of oil and gas companies (Menegaki, 2012), but obviously, this is not enough since it has already been announced that a carbon tax will be introduced in the near future (Jiménez-Marín et al., 2021). Consequently, the contribution of energy companies to sustainable and environmental development of energy economics is determined by government regulation of their operations (Kagiannas et al., 2003). The marketing of oil and gas companies is described in detail in the works of Cheah and Low (2022) and Krishnan and Butt (2022), which note the insignificant role of marketing in ensuring the contribution of these companies to the sustainable and environmental development of energy economics.

At the same time, the marketing of "clean" energy companies (EnergyTech) is poorly studied, and its role in ensuring their contribution to sustainable and environmental development of energy economics is unknown, which is a research gap. Some issues in the marketing of "clean" energy companies are considered in the works of Kratschmann and Dütschke (2021), Wei et al. (2021), and Das et al. (2022). This article is designed to fill this gap, i.e., to identify the features of the marketing mix of EnergyTech companies, as well as to determine the role of marketing in their contribution to achieving sustainable and environmental development of energy economics.

CRITICAL ANALYSIS OF THE MARKETING MIX EXPERIENCE OF THE WORLD'S LARGEST ENERGY COMPANIES SPECIALIZING IN "CLEAN" ENERGY IN 2021

To clarify the causal relationships of the contribution of EnergyTech companies to sustainable and environmental development of energy economics, their marketing activities are being investigated. The research methodology is based on the 7P marketing mix model. Using this method, we will conduct a review and critical analysis of the marketing mix experience of the world's largest energy companies specializing in "clean" energy in 2021, in accordance with the materials of "New Energy Giants Are Renewable Companies" Bloomberg (2022). The study was conducted on the example of the so-called "clean supermajors" Enel, Iberdrola, NextEra, and Orsted, which have overtaken oil and gas companies by market capitalization (in particular, Exxon, Eni, Repsol, and BP). Next, we will consider these results through the prism of the elements of the marketing mix.

P1: product. The range of directions of product quality management of EnergyTech companies is very wide. For example, Iberdrola (based in Spain and operating in the United States, Great Britain, Mexico, Brazil, and Australia) invests in new technologies such as "green" hydrogen and ammonia, as well as in electric vehicle charging stations in order to improve environmental friendliness (as a key quality factor). The volume of investments in the "green" innovations of this company in the period from 2020 to 2025 is estimated to be $ 89 billion.

P2: price. Owing to the large volume of financial resources, EnergyTech companies charge a price premium to the price for the environmental friendliness of their products. According to Bloomberg (2022), in order to avoid an environmental crisis in the period up to 2050, $11 trillion of investments in EnergyTech will be required. This will inevitably lead to an increased cost of "clean" energy compared to oil and gas analogs.

P3: place of sale. EnergyTech companies are strongly dependent on the infrastructure. For example, NextEra (the world's largest investor–producer of solar and wind energy) operates in the United States and Canada, where it invested $60 billion in pipelines from 2019 to 2022 and plans to create another 30 million new solar panels by 2030.

P4: promotion. EnergyTech companies pay great attention to loyalty management programs toward their activities not only on the part of state regulatory authorities but also representatives of businesses and local communities. For example, the company Orsted (based in Denmark and operates in Denmark, Great Britain, Germany, United States, Netherlands, and Taiwan) divested fossil fuels and expanded its clean energy business to develop projects around the world.

P5: people. Human resources are critically important for EnergyTech companies, and they are more human-capital-intensive industries than those of oil and gas companies. For example, the number of employees of the oil and gas company Eni is 31 thousand people, and the company EnergyTech Iberdrola is 67 thousand people. Similarly, the number of employees of the oil and gas company Repsol is 24 thousand people, and the number of staff of the company EnergyTech Orsted is 36 thousand people. At the same time, the capitalization of all these companies is the same.

P6: process. All processes of EnergyTech companies are flexible—they are constantly being transformed in accordance with changes in demand, the environment, and many other factors. As noted in the materials of Bloomberg (2022),

TABLE 1 | Comparative analysis of the marketing mix of "clean" energy companies and oil and gas companies.

Element of marketing mix	Oil and gas companies	"Clean" energy companies (EnergyTech)
P1: product	Environmental risks and environmental damage as criteria that reduce the quality	Ecodesign of the energy infrastructure, unique eco-friendly properties as components of the quality of energy resources, and wide opportunities for quality improvement
P2: price	Price formation based on world prices for energy resources	A price premium to the price for environmental friendliness and lack of binding to world prices
P3: place of sale	World energy markets	High degree of attachment to the target local energy market
P4: promotion	Promotion in government circles and making deals at the state level	Systematic promotion at the level of the state, business, and society
P5: people	Staff interchangeability, low knowledge intensity of production, and low market power of consumers	Importance and indispensability of personnel, high knowledge intensity of production, and large market power of consumers
P6: process	Linear business processes, continuous energy supply, no dependence on the environment, and processes are focused on high productivity	Cyclical business processes, dependence of energy supply on the environment, and processes focused on sustainability and stability
P7: physical evidence	Energy infrastructure	Natural landscape and favorable environment

Source: developed and compiled by the authors.

"clean" energy cannot yet completely replace fossil fuels. As an example, the experience of another EnergyTech company is noteworthy, Tesla Inc., which provides solar energy for about half of the energy in the grid during the day in South Australia.

P7: physical evidence. EnergyTech companies consider the environment as their physical evidence. For example, Enel (based in Italy) conducts business in more than 30 countries and presents itself as an EnergyTech company seeking to support countries around the world to switch to "clean" energy. To achieve this, the company plans to invest $190 billion in "clean" energy by 2030.

DISCUSSION

The article contributes to the development of the theory of sustainable energy through the justification of the key role of marketing in achieving the contribution of EnergyTech companies to sustainable and environmental development of energy economics. A comparative analysis of the marketing mix of "clean" energy companies and oil and gas companies is presented in **Table 1**.

As can be seen from **Table 1**, the difference between oil and gas companies and EnergyTech companies is observed at the marketing level, and the difference is manifested in each element of the marketing mix. P1: product. For oil and gas companies, product marketing is aimed at reducing environmental risks and environmental damage as criteria (preventing quality degradation). The product marketing of EnergyTech companies is aimed at improving quality through eco-design of energy infrastructure and unique environmental properties as components of the quality of energy resources.

P2: price. The pricing of oil and gas companies is based on world prices for energy resources. EnergyTech companies have a premium on the price for environmental friendliness, but they do not have a link to world prices.

P3: place of sale. Oil and gas companies ensure their presence in the global energy markets. EnergyTech companies, due to the peculiarities of the "clean" energy infrastructure, are strictly tied to the target local energy market.

P4: promotion. Oil and gas companies promote their activities in government circles as deals for the supply of their products are concluded at the state level. EnergyTech companies carry out the systematic promotion of their activities and their products in the state, business, and society as the approval of local communities is important for them.

P5: people. Oil and gas companies have interchangeable personnel, low knowledge intensity of production, and low market power of consumers. EnergyTech companies are characterized by the valuable and indispensable personnel, high knowledge intensity of production, and large market power of consumers.

P6: process. Oil and gas companies have linear business processes, and they are focused on high productivity; the energy supply is continuous and does not depend on the environment. EnergyTech companies have circular business processes, and they are focused on sustainability and stability; energy supply depends on the environment.

P7: physical evidence. The physical evidence for oil and gas companies is their energy infrastructure, and it is a natural landscape or a favorable environment in the case of EnergyTech companies.

Thus, in contrast to Kagiannas et al. (2003), Cheah and Low (2022), and Krishnan and Butt (2022), it has been found that the contribution to the sustainable and environmental development of energy economics is provided not through government regulation, but through the marketing of EnergyTech companies. Rethinking the activities of energy companies from the standpoint of the Noospheric approach revealed that the economic component prevails in the activities of oil and gas companies. In contrast, marketing contributes to the fact that the economic, social, and environmental components in the activities of EnergyTech companies are balanced, which contributes much more (compared to oil and gas companies) to the sustainable and environmental development of energy economics.

CONCLUSION

As a result of the conducted research, it can be concluded that the hypothesis put forward has been confirmed; the significant contribution of clean energy companies (EnergyTech) to the sustainable and environmentally friendly development of the energy economy is based on the features of their marketing mix, which is fundamentally different from the marketing mix of oil and gas companies. The theoretical significance of the results obtained lies in revealing the causal relationships of the contribution of EnergyTech companies to the sustainable and ecological development of energy economics, as well as the fact that marketing is the basis of this contribution.

The fundamental difference between oil and gas companies and EnergyTech companies in the field of marketing demonstrated in the article has formed a new wide field for further study of these types of companies separately, taking into account their marketing features. Management implications are related to the fact that the marketing mix of EnergyTech companies revealed in the article may be subject to further improvement by these companies to maximize their contribution to sustainable and environmental development of energy economics.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

REFERENCES

Bloomberg (2022). New Energy Giants Are Renewable Companies. Available at: https://www.bloomberg.com/graphics/2020-renewable-energy-supermajors/ (Accessed 04 25, 2022).

Cheah, S. K. A., and Low, B. (2022). The Impact of Public Policy Marketing, Institutional Narratives and Discourses on Renewable Energy Consumption in a Developing Economy. *Asia Pac. J. Mark. Logist.* 34 (5), 944–962. doi:10.1108/APJML-11-2020-0835

Dai, S., Ye, Z., Wei, W., Wang, Y., and Jiang, F. (2022). Economic Analysis of Transactions in the Energy Storage Power Market: A Life-Cycle Cost Approach. *Front. Energy Res.* 10, 845916. doi:10.3389/fenrg.2022.845916

Das, S., Nayak, J., Mishra, M., and Naik, B. (2022). Solar Photo Voltaic Renewal Energy: Analyzing the Effectiveness of Marketing Mix Strategies. *Lect. Notes Electr. Eng.* 814, 527–540. doi:10.1007/978-981-16-7076-3_45

International Energy Agency (2022). Global Energy Review 2021: Renewables. Available at: https://www.iea.org/reports/global-energy-review-2021/renewables (Accessed 04 25, 2022).

Jiménez-Marín, G., Zambrano, R. E., Galiano-Coronil, A., and Ravina-Ripoll, R. (2021). Business and Energy Efficiency in the Age of Industry 4.0: The Hulten, Broweus and Van Dijk Sensory Marketing Model Applied to Spanish Textile Stores during the COVID-19 Crisis. *Energies* 14 (7), 1966. doi:10.3390/en14071966

Kagiannas, A. G., Patlitzianas, K. D., Askounis, D. T., and Psarras, J. (2003). Enhancing Energy Policy Cooperation between EU and GCC: A Marketing Strategy for Oil and Gas Technologies. *Int. J. Glob. Energy Issues* 19 (4), 310–332. doi:10.1504/IJGEI.2003.003198

Kratschmann, M., and Dütschke, E. (2021). Selling the Sun: A Critical Review of the Sustainability of Solar Energy Marketing and Advertising in Germany. *Energy Res. Soc. Sci.* 73, 101919. doi:10.1016/j.erss.2021.101919

Krishnan, R., and Butt, B. (2022). "The Gasoline of the Future:" Points of Continuity, Energy Materiality, and Corporate Marketing of Electric Vehicles Among Automakers and Utilities. *Energy Res. Soc. Sci.* 83, 102349. doi:10.1016/j.erss.2021.102349

Li, G., Li, G., and Zhou, M. (2022). Market Transaction Model Design Applicable for Both Plan and Market Environment of China's Renewable Energy. *Front. Energy Res.* 10, 862653. doi:10.3389/fenrg.2022.862653

Menegaki, A. N. (2012). A Social Marketing Mix for Renewable Energy in Europe Based on Consumer Stated Preference Surveys. *Renew. Energy* 39 (1), 30–39. doi:10.1016/j.renene.2011.08.042

Nuseir, M. T., and El Refae, G. A. (2021). Marketing Efficiency of Energy-Efficient Electrical Home Appliances in the Gulf Cooperation Council (GCC) Region. *Int. J. Trade Glob. Mark.* 14 (6), 603–619. doi:10.1504/IJTGM.2021.118909

Shukla, P., Paul, D., Malik, S., and Mishra, D. K. (2021). The Role of Green Marketing in Energy Conservation in the Domestic Sector. *Int. J. Energy Econ. Policy* 11 (1), 263–269. doi:10.32479/ijeep.10567

Wei, C., Li-Feng, Z., and Hong-Yan, D. (2021). Impact of Cap-And-Trade Mechanisms on Investments in Renewable Energy and Marketing Effort. *Sustain. Prod. Consum.* 28, 1333–1342. doi:10.1016/j.spc.2021.08.010

Wei, R., Ayub, B., and Dagar, V. (2022). Environmental Benefits from Carbon Tax in the Chinese Carbon Market: A Roadmap to Energy Efficiency in the Post-COVID-19 Era. *Front. Energy Res.* 10, 832578. doi:10.3389/fenrg.2022.832578

Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's Note: All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors, and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

frontiers | Frontiers in Energy Research

DATA REPORT
published: 21 June 2022
doi: 10.3389/fenrg.2022.869588

Eco-Friendly Energy Production: The Influence of Price Factors in the Regions of Russia

Natalia Roslyakova[1]* and Elena Vechkinzova[2]

[1]Laboratory of Economic Dynamics and Innovation Management, V.A. Trapeznikov Institute of Control Sciences Russian Academy of Sciences, Moscow, Russia, [2]Academic Department of Management and Business Technologies, Plekhanov Russian University of Economic, Moscow, Russia

Our review focuses on statistical data on the relationship between electricity prices and emissions, energy availability, and energy consumption in 2017–2020. We used the nonparametric method of data envelopment analysis (DEA) as a methodological basis for analyzing the impact of the "green policy" on electricity consumption in the regions of Russia and regression analysis to quantify dependencies between the parameter. The results of the DEA allowed us to check the effectiveness of the ratio of costs (emissions) and results (electricity consumption by the population and industry). The results of the regression analysis allowed us to find the equation of the relationship between the amount of electricity generated by a renewable energy source (RES), the amount of consumption, and average electricity prices. The obtained equations proved the strong influence of an increase in the amount of energy generated from renewable energy sources on the average electricity price increase and a decrease in energy consumption. In the conclusion, we talk about the low elasticity of the demand for electricity from the Russian population and the significant impact of electricity generated by the RES on increasing the average prices of energy producers and reducing energy consumption.

Keywords: electricity consumption, energy availability, emissions, regression analysis, Russia, renewable energy sources, data envelopment analysis

OPEN ACCESS

Edited by:
Elena G. Popkova,
Moscow State Institute of International Relations, Russia

Reviewed by:
Maria Harja,
Gheorghe Asachi Technical University of Iași, Romania
Dhavamani Doss Sakthidoss,
Annamalai University, India

***Correspondence:**
Natalia Roslyakova
na@roslyakova24.ru

Specialty section:
This article was submitted to Sustainable Energy Systems and Policies, a section of the journal Frontiers in Energy Research

Received: *04 February 2022*
Accepted: *11 May 2022*
Published: *21 June 2022*

Citation:
Roslyakova N and Vechkinzova E (2022) Eco-Friendly Energy Production: The Influence of Price Factors in the Regions of Russia. Front. Energy Res. 10:869588. doi: 10.3389/fenrg.2022.869588

INTRODUCTION

One of the modern development manifestations is the transition to smart technologies in various fields of activity. The most impressive success of this process has been achieved in the industry, where modern production using automation and robotization does almost without labor. To penetrate this trend into all spheres of life, not only high-tech innovations but also a resilience supply of electricity is needed. Thus, it can be predicted that the demand for electricity in all countries of the world will steadily grow. However, energy production causes significant harm to the environment. This is because of the fact that now the main source of energy production in the world is hydrocarbon raw materials and coal. The speed of green technologies and penetration and reduction of waste emissions is incomparable to the speed of production and consumption of electricity.

The collected information allows us to formulate a number of hypotheses about the structure of data and the nature of relationships. The most obvious of them is that one can expect a direct relationship of price dynamics with the amount of electricity production (hypothesis 1) and a reverse relationship with the amount of consumption (hypothesis 2). Furthermore, since the increase in electricity production in the region contributes to an increase in the level of energy supply, we can also expect a direct relationship between price and energy supply (hypothesis 3). In our opinion, the most multidirectional links exist between electricity prices and emissions of pollutants. Hence, there may be a co-directional change in the price of electricity and emissions (hypothesis 4). This is possible if the business does not have internal reserves for efficiency growth and the growth of energy tariffs will lead to an even greater drop in capital efficiency. Consequently, opportunities to invest in environmental projects and activities will be reduced. In conditions when regional authorities do not pay due attention to environmental policy and emissions control, and environmental innovations are too expensive, emissions may increase. Such behavior of enterprises is a way to increase production using cheaper and energy-intensive technologies, internalizing external negative effects in the form of environmental pollution at an accelerated pace. On the other hand, there may be a situation where an increase in electricity tariffs will stimulate a more economical use of this resource. This situation is more typical for regions where pollution charges and tariff increases cover the cost of environmental modernization measures, which will reduce electricity consumption and reduce emissions (hypothesis 5).

METHODS

We have summarized data of 2017–2020 on electricity prices, pollution emissions, energy availability, and energy production and consumption in the regions of Russia. The data were collected on the basis of open statistical information (Rosstat, 2022). In addition, information from the Unified Interdepartmental Statistical Information System was used to estimate the amount of electricity consumption by the manufacturing sector and the population (Fedstat, 2022), and information from specialized analytical agencies (the dynamics of electricity prices) (Energo, 2021). The data were collected on sheet Data_regions in the data file (Supplementary material). First of all, it is possible to make a correlation analysis, it will allow us to identify the presence of linear relationships between the parameters and assess their strength. The matrix is given in sheet Corr in the data file (Supplementary material).

It is obvious that the process of distribution of green technologies in the space of Russian regions is uneven. Regions where larger enterprises operating in the energy sector (including the extraction of hydrocarbon resources) are concentrated can concentrate significant resources for the implementation of complex environmental measures. Here, the parameters of emissions and electricity consumption by the industry and the population are more effective. In other regions, there may be significant deviations from the performance parameters of the leaders. Therefore, it is of great interest to study the parameters of the optimal combination of costs-inputs (emissions) and results-outputs (electricity consumption by the industry and the population) across the regions of Russia using DEA tools. Models with a variable return of scale (VRS) are considered because in the practice of power supply and power consumption, the scale effect is limited by the available energy generation production capacity (for energy supply) and the available capacity of the transportation power grids (for energy consumption). A model with a constant return of scale (CRS) and the assumption of “limitless” possibilities for reducing costs or increasing results in this case does not correspond to reality. Also, calculations are carried out in one input (emissions) and two outputs (electricity consumption by the industry and the population), which makes it possible to visually present the results of the analysis. Calculations were carried out for 2017 and 2020 to assess the initial and final states of the considered system of regions and changes over the period on the basis of normalized data (sheet Data_regions_norn in the data file; Supplementary material). **Figure 1** reflects the distribution of real data, and estimates of optimal parameters obtained from input-oriented models VRS.

The correlation analysis allows us to make conclusions only about the presence or absence of a linear relationship between the parameters. However, it can be assumed that there are other forms of relationship. Therefore, an additional analysis using the STUDIO software is carried out to clarify the type of finite functions. We tested stepwise regression, multiple linear regression, and 23 models of a one-factor model (parabola, polynomial, logarithmic, power, exponents, hyperbola, optimal, logistic, and sinusoidal).

ANALYSIS

Correlation Analysis

A deeper analysis of the data will confirm or refute the hypotheses put forward. The data of the correlation analysis refute hypothesis 1, that is, there is a very non-standard situation when, with an increase in the price of electricity, its production decreases (for all considered periods a correlation coefficient (K) is in the range from −0.29 to −0.22).

Hypothesis 2 is confirmed, since there is a negative dependence of consumption and prices (K varies from −0.25 to −0.23). At the same time, if we divide the demand for electricity into production and consumption, then we can see differences in the degree of intensity of the link. Electricity consumption on the part of the population has a small elasticity, that is, people are very limited in their ability to refuse electricity. Accordingly, we see a weak relationship between the amount of electricity consumed by the population and price dynamics (the correlation coefficient varies from −0.07 to −0.03). On the other hand, electricity consumption by the industry has much greater elasticity and with rising electricity prices, enterprises receive an additional stimulus for the active implementation of energy-saving and energy-efficient technologies, which can cause significant fluctuations in demand from production. Accordingly, in this segment, we see a significantly greater degree of mutual change (K varies from −0.33 to −0.30).

Hypothesis 3 tests give ambiguous results. So, in 2017–2018 there is a positive relationship with prices (K varies from 0.01 to 0.04), whereas in 2019–2020 this relationship becomes negative (K varies from −0.06 to −0.04). This is happening against the background of the fact that in 2017–2020, the correlation between

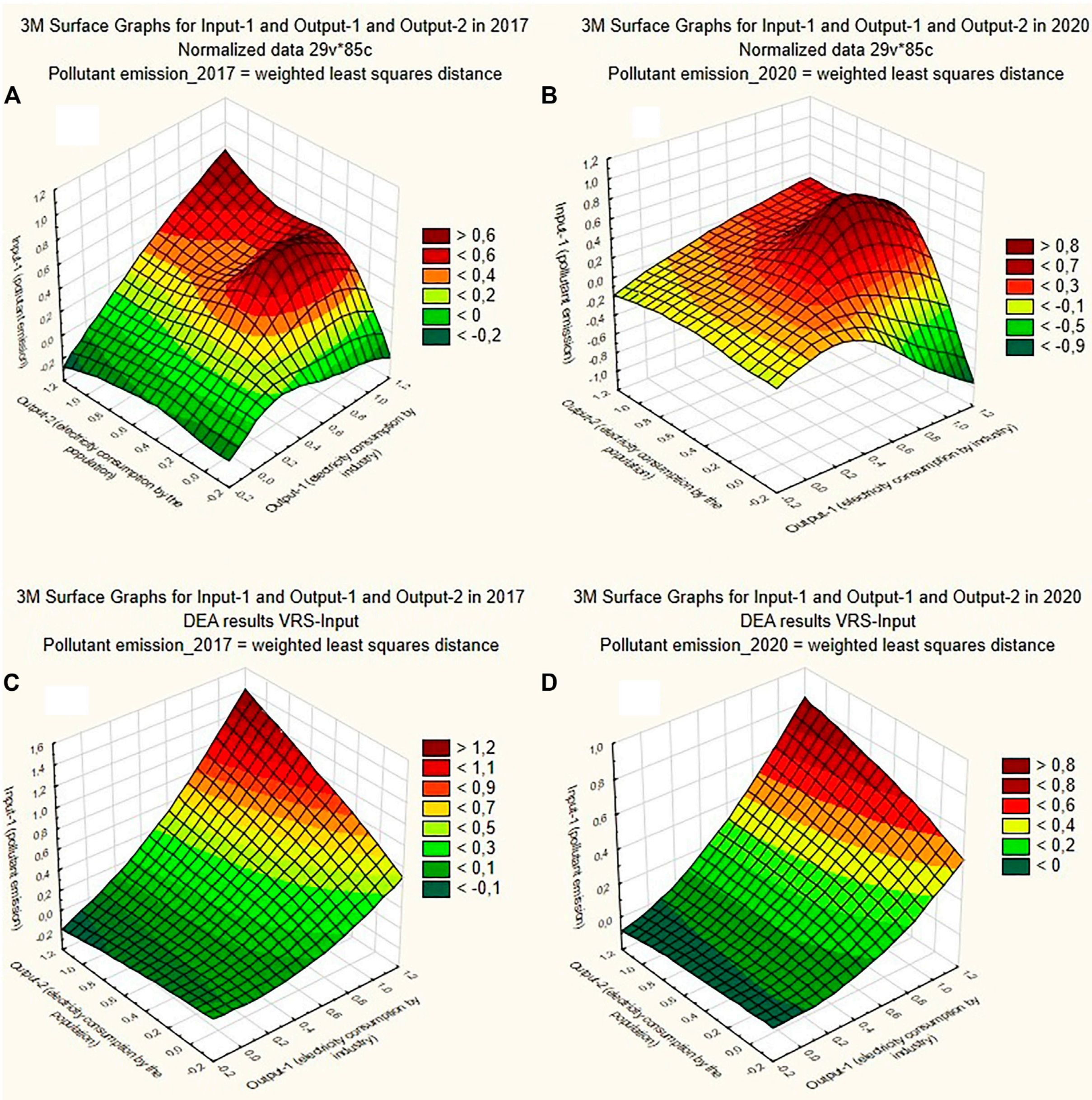


FIGURE 1 | Surface graphs for real data in 2017 **(A)** and 2020 **(B)** and results of VRS models with one input and two outputs in 2017 **(C)** and 2020 **(D)**.

electricity production and energy supply is steadily increasing from 0.48 to 0.62.

With respect to hypotheses 4 and 5, the results are in favor of hypothesis 5, when price increases contribute to reducing emissions (the correlation coefficient varies from −0.30 to −0.27). This situation characterizes positive trends in electricity consumption by the population and industry. Here, a more detailed consideration of consumption by economic spheres is of great interest. The analysis of the correlation matrix allows us to see that the main source of pollution is industrial production (K varies from 0.76 to 0.83), while emissions from the population are of a secondary nature (K varies from 0.32 to 0.37).

The successful implementation of energy-saving technologies in industry is supported by the fact that the correlation between electricity production and industrial consumption is reduced. In 2017–2018, it is 0.82, and in 2019–2020–0.53–0.55. Also, the environmental policy is confirmed by the systematic reduction of the correlation coefficient between the parameters of electricity production and emissions from 0.67 to 0.54, that is, in 2017–2020, electricity production occupies an increasingly smaller share in the dynamics of emissions.

Data Envelopment Analysis Results

If we compare a) and b) **Figure 1**, which describe real data, we can see that, on the one hand, the spread of the controlled parameter (pollution emission) has increased. On the other hand, it is obvious that for most of the units, the emission parameters have approached each other, and strong deviations, which form the scope of variation, are characteristic of single units. That is, there is a decrease in the number of regions with excessively large emissions. Accordingly, the solutions proposed in c) and d) **Figure 1** also reduced the range from 1.4 to 0.9. At the same time, the constancy of the shape and degree of curvature of the surface indicates that the main proportions of efficiency and the spatial distribution of parameters in the period 2017–2020 have been fixed.

It is also noteworthy in the DEA estimates that in 2017, with higher pollution levels, the absolute majority of regions demonstrate effective parameters of the links between inputs and outputs. In the model, this is shown in the fact that the regions can come to the optimum due to a proportional movement in emissions. Slack movement assumes a change in the parameters of the internal efficiency of outputs, in our case, this is electricity consumption by the industry and the population. Such technological gaps and efficiency improvements are required for the industry of Dagestan, Kalmykia, the Chechen Republic, and Sevastopol (see slack movement in electricity consumption by the industry at sheet VRS_2017 in the data file; Supplementary material). These regions are located in desert and mountainous areas and cannot use the advantages of grid distribution of electricity, which gives objective reasons for their low efficiency and increased emissions. Technological gaps and efficiency improvements are required for electricity consumption by the population of the Republics of Altai, Tyva, Kalmykia, Komi and Yamalo-Nenets, Nenets and Chukotka Autonomous Okrugs, and Magadan Region.

The results of DEA modeling in 2020 give slightly different results (sheet VRS_2020 in the data file; Supplementary material). Because of the decrease in the average level of emissions by the leading regions and the lag in the pace of energy-efficient technology implementation in the regions of Russia, the possibility of achieving the optimum only through the proportional movement of emissions is reduced. The number of slack movements is increasing significantly, and they are concentrated in the sphere of electricity consumption by the population. For the industry, a technological gap is required by the same regions (the Republics of Altai, Kalmykia, Dagestan, Chechnya, and Sevastopol). On the hand, for the population, the number of inefficient regions requiring technology changes increases from 8 to 67. In 2020, there are only 18 efficient regions in the sphere of electricity consumption by the population—Moscow, Sverdlovsk, Chelyabinsk, Irkutsk, Kemerovo regions, the cities of Moscow and Sevastopol, the Republics of Dagestan, Ingushetia, Kabardino-Balkaria, North Ossetia, Chechnya, Bashkortostan, Tatarstan, Khakassia, Perm and Krasnoyarsk Territories, and Khanty-Mansi Autonomous Okrug.

The main question in this regard is to what extent the "green policy" is an important ideological factor for Russian consumers (population) does it make them save and consume less energy or is the price still the main factor in the amount of consumption. Because of the lack of data on sources of electricity production in the context of Russian regions, we analyzed the data for the whole country from 1990–2000, and average producer prices for electric energy from 1998–2020 (sheet Data_Russia in the data file; Supplementary material).

Regression Modeling

The results of the correlation analysis show a significant link between the amount of electricity generated by an RES and the amount of consumption: the correlation coefficient is 0.592. However, the correlation coefficient between the amount of electricity generated by classical sources and the amount of consumption is 0.988, and the correlation coefficient between the total amount of electricity generated and the amount of consumption is 0.995. That is, despite the significant correlation between the amount of electricity generated by the RES and the amount of consumption, it is almost twice as low as the link between classical energy sources and consumption. We offer the hypothesis that the link between the amount of electricity generated by the RES and the amount of consumption is weaker because of the fact that the price of electricity generated by the RES is almost two times higher than the price of electricity generated by classical sources. The correlation coefficient between the amount of electricity generated by the RES and the average producer prices for electricity for 1998–2020 is 0.793, which shows a strong link between these factors. To understand the form of the influence of the amount of energy produced by the RES (X_{32}) on the formation of the price (X_{33}), a linear regression model was evaluated as follows:

$$\boldsymbol{X_{33} = -9989 + 0.06672 * X_{32}}. \tag{1}$$

As you can see, the correlation coefficient of the linear model is high (see table on sheet Regression in the **Supplementary Material**) and the STADIA software confirms the hypothesis about the adequacy of the linear model to the real data. To find the best type of regression dependence, we considered 23 types of models. The best results are presented as follows:

$$\boldsymbol{X_{33} = EXP(-86.34) * X_{32}^{7.746}}, \tag{2}$$

$$\boldsymbol{X_{33} = EXP\left(15.34 - \frac{1.427E6}{X_{32}}\right)}. \tag{3}$$

The obtained equations (see table on sheet Regression in the **Supplementary Material**) once again proved the strong influence of the growth of the amount of energy generated by the RES on the growth of average prices. The forecast errors according to retro data are different: according to model 1—36.25%, according to model 2—18.3%, and according to model 3—16.69%. The graphs of the evaluated regression models and the actual price dynamics are shown in a) **Figure 2**.

To answer the research question—how does the "green policy" affect energy consumption prices in Russia—we will evaluate a multiple linear regression. The model reflects the influence of the amount of electricity generation by the RES (X32) and the price of electricity (X33) on the amount of consumption (X34) and has the following specification:

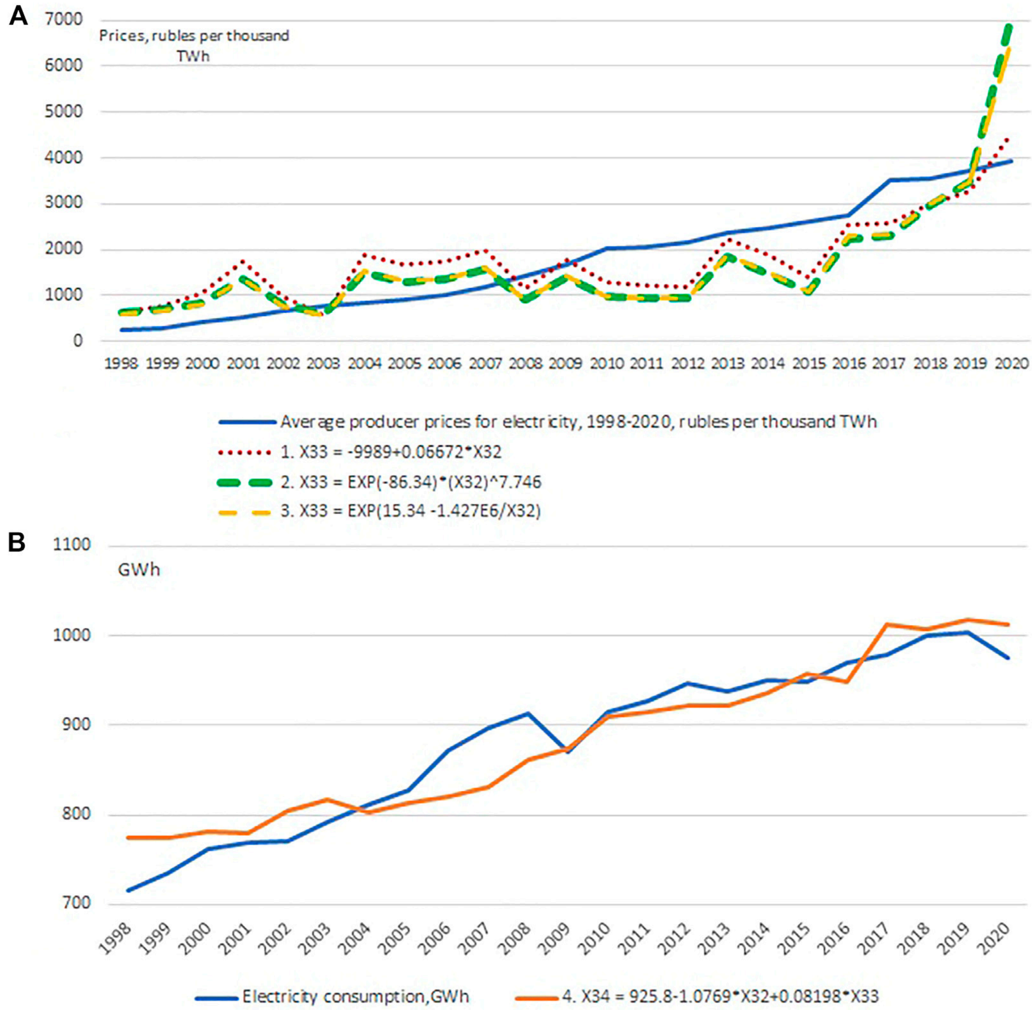


FIGURE 2 | Regression modeling results and real data for electricity price **(A)** and electricity consumption **(B)**.

$$X_{34} = 925.8 - 1.0769 * X_3 + 0.08198 * X_{33}. \quad (4)$$

The average forecast error of the evaluated model is only 0.15%. Graphically, this model and the actual dynamics of electricity consumption are shown in b) **Figure 2**. The regression shows that the growth of electricity generated by the RES almost proportionally reduces the amount of electricity consumption; price growth slightly increases the amount of electricity consumption (which may be due to inflationary price changes). Thus, we can state the significant impact of electricity generated by renewable energy sources on the increase in average electricity prices and a decrease in energy consumption.

DISCUSSION

The rejection of hypothesis 1 by the correlation analysis underscores the monopolistic nature of the Russian energy market. That is, a single operator of the Russian power grid implements a policy of regulating the amount of supply to maximize profits. This is exactly what leads to a drop in supply with an increase in electricity prices. At the same time, market segmentation shows that households bear the brunt of such an increase since they have the lowest elasticity of demand.

Changing the relationship between electricity supply and prices from positive to negative indicates the development of trends of drop in the market efficiency of capital, when favorable external conditions cannot be realized in positive economic effects. These results are confirmed by the example of capital investment in the construction of renewable energy sources. The efficiency of such investments is extremely low because the price of renewable energy is higher than the energy prices of classical sources. That is, green energy is more expensive for Russian consumers. Because of the excessively high cost of construction and maintenance of renewable energy storage, the market is balanced by classical energy sources. With an increase in the supply of renewable energy to the grid, the export of cheaper energy from classical sources increases. This creates conditions for the growth of the average price of electricity in Russia.

Confirmation of the issue about ecology measures stimulated by the price increase indicates the consistency of environmental policy, successful implementation of energy-saving solutions, and technologies to reduce harmful effects on the environment in practice. The successful implementation of energy-saving technologies in the industry is shown by the fact that the correlation between electricity production and industrial consumption is reduced.

It is also noteworthy that in the DEA in 2017, with higher pollution levels, the absolute majority of regions demonstrate effective parameters of the links between inputs and outputs. In the model, this is shown in the fact that the regions can come to the optimum due to a proportional movement in emissions. Only 12 regions of Russia were identified as inefficient (they are located in mountainous, desert, and remote areas). These regions are characterized by increased emissions from electricity production and low involvement in the Russian energy system, a large share of the use of inefficient and non-ecological fuel sources, which creates an objective basis for their low efficiency. The results of the DEA in 2020 show almost the opposite result, when only 18 regions are effective in terms of electricity consumption by the population.

Such results determine the transformations that took place in the field of energy consumption in 2017–2020. They allow us to make recommendations aimed at finding and implementing energy-efficient technologies as quickly as possible, first of all for the population (not for the industry). Green energy is an actual trend for the whole world, including Russia. The main question in this regard is to what extent the "green policy" is an important ideological factor for Russian consumers (population) does it make them save and consume less energy, or is the price still the main factor in the amount of consumption.

The total amount of energy produced in 1990 was 1,082,152 GWh, including classical non-renewable energy source (NRES) generation—916,207 GWh (84.67%) and renewable energy source (RES)—165,945 GWh (15.33%). In 2020, in general, the amount of energy production increased slightly to 1,085,418 GWh, including classical sources—867,757 GWh (79.95%) and RES—217,661 GWh (20.05%). With an overall increase in energy production by only 0.3%, the data show a decrease in energy production from classical sources by 5.29%, mainly due to a significant decrease in energy production from oil by 93.64% and natural gas by 9.23%. The amount of electricity generation from renewable energy sources increased by 31% mainly due to an increase in the use of hydropower and the construction and commissioning of a significant number of solar and wind energy facilities since 2014. Electricity consumption in the same period decreased slightly from 989,580 GWh in 1990 to975,600 GWh in 2020, or by 1.41%, while the increase in producer prices for the period increased 16 times. This confirms the idea expressed previously, the low elasticity of demand for electricity from the population.

CONCLUSION

We have tested many hypotheses regarding the relationship between the parameters of the energy market of Russia. Thus, a high level of market monopolization was proved, which consists in regulating the amount of supply for the purpose of maximizing profits in the industry. Using the correlation matrix, it was proved that a large share of losses from price increases falls on the population since their electricity demand function is much less elastic compared to the demand function of industrial organizations.

Also, using the DEA tools, we showed that the regions of Russia in 2017–2020 underwent a serious change in the parameters of efficiency. If in 2017 the majority of regions were in the zone of effective ratios, by 2020, the number of effective regions has decreased to 18. This is because of the fact that during the reviewed period, the country's industrial organizations, with a consistent policy of supporting the implementation of environmental innovations, completed the process of optimizing emissions and insufficiently efficient electricity consumption by the population came to the fore. Therefore, further movement toward optimum emissions for most regions of Russia is now associated with the search and implementation of energy-saving technologies for the population.

The regression analysis allowed us to quantify the relationship between electricity prices, the amount of renewable energy generation, and electricity consumption. The reverse dependence of renewable energy generation and price growth (correlation coefficient 0.79344) is proved, which indicates a high explanatory power of the evaluated equations. The same conclusions are confirmed by the evaluated model of multiple linear regression (correlation coefficient of 0.93701): the growth in the volume of renewable energy generation proportionally reduces the volume of electricity consumption and slightly increases its prices. Thus, the "green policy" produces a small increase in prices and significant savings in energy resources in Russia.

DATA AVAILABILITY STATEMENT

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found at: http://roslyakova24.ru/load/6-1-0-94.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fenrg.2022.869588/full#supplementary-material

REFERENCES

Data and statistics (2022). *Data from: Data and Statistics*. Moscow: International Energy Agency Digital Repository. Available at: https://www.iea.org/data-and-statistics/data-products.

EES EAEC (2022). *Data from: Energy Complex of Russia*. Moscow: EES EAEC Digital Repository. Available at: https://www.eeseaec.org/elektroenergeticeskij-kompleks-rossi.

Energo (2021). *Data from: Rating of Electricity Tariffs in Russia from January 1, 2021*. Ufa: Energo-24 Digital Repository. Available at: https://energo-24.ru/news/13582.html.

Fedstat (2022). *Data from: Electricity Consumption by Industrial Organizations*. Moscow: Unified Interdepartmental Information and Statistical System (UIISS) Digital Repository. Available at: https://www.fedstat.ru/indicator/58653.

Rosstat (2022). *Data from: Regions of Russia. Main Characteristics of the Subjects of the Russian Federation*. Moscow: Rosstat Digital Repository. Available at: https://rosstat.gov.ru/folder/210/document/13205.

Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's Note: All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors, and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

frontiers | Frontiers in Energy Research

OPINION
published: 07 July 2022
doi: 10.3389/fenrg.2022.943270

Check for updates

Sustainable and Environmental Development of Energy Economy in Smart Regions of Russia

Sergey V. Muzalev[1*†], *Sergey N. Kukushkin*[2†], *Olga A. Grazhdankina*[3†] and *Anastasia V. Nikolaenko*[4†]

[1]*Financial University under the Government of the Russian Federation, Moscow, Russia,* [2]*Department of Economics and Organisation of Production, Plekhanov Russian University of Economics, Moscow, Russia,* [3]*Department of Finances and Credit, Altai State University, Barnaul, Russia,* [4]*North-West Institute of Management—Branch of the Russian Presidential Academy of National Economy and Public Administration, St. Petersburg, Russia*

Keywords: sustainable and environmental development, energy economy, "smart" regions, regional economy of Russia, smart grid, energytech

OPEN ACCESS

Edited by:
Elena G. Popkova,
Moscow State Institute of International Relations, Russia

Reviewed by:
Alina Steblyanskaya,
Harbin Engineering University, China

Correspondence:
Sergey V. Muzalev
msv.com@mail.ru

[†]*These authors have contributed equally to this work*

Specialty section:
This article was submitted to Sustainable Energy Systems and Policies, a section of the journal Frontiers in Energy Research

Received: *13 May 2022*
Accepted: *15 June 2022*
Published: *07 July 2022*

Citation:
Muzalev SV, Kukushkin SN, Grazhdankina OA and Nikolaenko AV (2022) Sustainable and Environmental Development of Energy Economy in Smart Regions of Russia. Front. Energy Res. 10:943270. doi: 10.3389/fenrg.2022.943270

INTRODUCTION

The energy economy is undergoing a digital transformation, which contributes to its sustainable and environmental development. This process has been studied in sufficient detail at the level of the national economy in the existing literature (Ram et al., 2022; Zhao et al., 2022). The problem is that the regional level includes specific characteristics of territories that become less noticeable and are not taken into account at the macroeconomics level (Cortese et al., 2022; Li, 2022; Xu, 2022; Zaidan et al., 2022). This is especially true for countries with a large territory.

In this regard, Russia can serve as an example, since it not only has a territory with a diverse geography, but is also a major energy power. Its exports in the field of energy have been studied in sufficient detail and have been the subject of active scientific discussion in recent years (Popkova et al., 2021; Popkova, 2022). At the same time, Russia's internal energy policy related to the energy supply and energy consumption in the Russian regional economy has been studied and developed to a lesser extent, which is a research gap.

The purpose of this article is to study the experience of sustainable and environmental development of the energy economy in the regions of Russia and the role of "smart" technologies in this process. The originality of this article lies in the fact that it reveals a new–mesoeconomic perspective of studying the sustainable and environmental development of the energy economy based on "smart" technologies, and also highlights the best practices of "smart" regions of Russia.

SUSTAINABLE AND ENVIRONMENTAL DEVELOPMENT OF THE ENERGY ECONOMY BASED ON "SMART" TECHNOLOGIES: LITERATURE REVIEW

The research in this paper is based on the Theory of sustainable and environmental ("green") development of the energy economy, which foundations are set in the works of Ajiboye et al. (2022), Ali et al. (2022), Mahmoud et al. (2022), Matsunaga et al. (2022), Qu et al. (2022) and Sharma et al. (2022). In the existing literature, the issues of sustainable and environmental development of the energy economy based on smart technologies are thoroughly elaborated. The scientific concept of the energy economy of a smart region is formed in the works of Bellocchi et al. (2020), Dominković et al. (2018), Guo et al. (2022), Kleineidam et al. (2016), Li (2022) and Ortiz Cebolla and Navas (2019).

In the works of Chen et al. (2022), Elnour et al. (2022), Kabeyi and Olanrewaju (2022), Kamruzzaman and Alruwaili (2022), Nasir et al. (2022), it is noted that "smart" technologies

TABLE 1 | Environmental profile of the "smart" regions of Russia from the standpoint of the energy economy according to data for the winter of 2021–2022.

Region	Industrial and environmental index (PMI), Scores 1-100	The Share of Organizations Implementing Innovations that Provide		Percentage of Organizations Using		
		Reduction of Energy Intensity of Production (Enp), %	Reduction of Carbon Dioxide (CO_2) (Crb) Emissions into the Atmosphere, %	ERP-System (Erps), %	Electronic sales (Ecmc), %	RFID technologies (rfid), %
Yaroslavl region	71	63.6	54.5	17.9	13.0	6.5
Tambov region	69	25.0	25.0	13.2	8.8	5.6
Chukotka Autonomous Okrug	67	100.0	100.0	7.3	4.6	7.1
Vologda region	66	80.0	40.0	13.2	11.6	6.3
Belgorod region	66	75.0	50.0	17.1	14.9	6.6
Perm Region	65	29.4	11.8	23.1	11.1	6.3
Tyumen region	64	22.2	16.7	19.1	14.1	8.1
Republic of Karelia	63	50.0	50.0	13.0	8.9	5.3
Yamalo-Nenets Autonomous Okrug	63	20.0	50.0	17.0	11.6	7.5
Tomsk region	63	80.0	20.0	15.0	12.8	7.4

Source: compiled by the authors based on the materials of the Green Patrol (2022), the Ministry of Statistics of Russia, Rosstat, HSE (2022), Rosstat (2022).

contribute to the sustainable and environmental development of the energy economy. Environmental benefits are also highlighted, which mainly include combating climate change (SDG 13) and protecting ecosystems (SDGs 14-15).

However, uncertainty remains regarding the social and economic benefits. Studies by Ahmad et al. (2022), Rezaei et al. (2022) indicate that responsible corporate management of "smart" technologies allows them to be introduced as environmental ("green") innovations in the activities of energy companies, creating benefits for the environment. The examination of the characteristics of the region as an economic system in which the sustainable and environmentally friendly development of the energy economy on the basis of "smart" eco-innovations occurs is a gap in the literature. To fill the identified gap, a comprehensive quantitative and qualitative study is conducted in this article.

THE ROLE OF "SMART" TECHNOLOGIES IN THE SUSTAINABLE AND ENVIRONMENTAL DEVELOPMENT OF THE ENERGY ECONOMY IN THE REGIONS OF RUSSIA

In this paper, energy efficiency is considered in three aspects: 1) reduction of energy intensity; 2) decarbonization; 3) environmental friendliness of industry as the most energy-intensive sphere of economy. This allows for the most correct research of energy efficiency as the indicator of the sustainable and environmental development of the energy economy.

In a quantitative aspect, this article presents and analyzes the rate of use of "smart" technologies in organizations (based on statistics from the Ministry of Finance of Russia, Rosstat, HSE, 2022), which allows identifying "smart" regions of Russia. Regional statistics of Rosstat (2022) characterizing the introduction of "green" energy innovations in Russia are also being studied. The study is conducted on the example of the top 10 regions of Russia, which are the leaders of the environmental rating of the NGO "Green Patrol" (2022) for the winter of 2021–2022. Statistical characteristics of the sample regions are presented in **Table 1**.

Using the data from **Table 1**, regression analysis for one year—2021—is performed; it reflects the most up-to-date statistics. The data are not studied in dynamics in this paper, for statistics on the previous period (2020) largely reflects the impact of the COVID-19 pandemic and crisis (the study of which goes beyond this paper), and so its consideration might have distorted the treatment of the results of this research.

Using the methods of regression and correlation analysis, it is established that "smart" technologies play an important role in the sustainable and environmental development of the energy economy in the regions of Russia. Firstly, it has been revealed that "smart" technologies contribute to improving the energy efficiency of the regional economy of Russia. This conclusion is based on the determined regularity of the reduction of energy efficiency in the course of dissemination of smart technologies (demonstrated by the example of online sales). Though the proof is given by the example of ten regions in this paper's sample, the conclusion would be correct for all regions of Russia, because the sample is representative of all of them (it includes regions from all federal districts). This is evidenced by the obtained regression model (**Eq. 1**):

$$\text{enp} = 102.41 - 6.07\text{erps} + 3.95\text{ecmc} + 0.41\text{rfid} \tag{1}$$

Eq. 1 indicates that with an increase in the share of organizations engaged in electronic sales by 1%, the share of organizations implementing innovations that reduce the energy intensity of production increases by 3.95%. And with an increase in the share of organizations using RFID technologies by 1%, the share of organizations implementing innovations that reduce the energy intensity of production increases by 0.41%. The correlation of energy efficiency with "smart" technologies was 66.27% (high).

Secondly, it was revealed that "smart" technologies contribute to the decarbonization of the regional economy of Russia. This is evidenced by the obtained regression model (**Eq. 2**):

$$crp = 86.37 - 3.49erps - 1.86ecmc + 4.57rfid \quad (2)$$

Eq. 2 shows that with an increase in the share of organizations using RFID technologies by 1%, the share of organizations implementing innovations that reduce carbon dioxide (CO_2) emissions into the atmosphere increases by 4.57%. The correlation of decarbonization with "smart" technologies was 72.87% (high). Decarbonization here is treated as a component of energy efficiency in the aspect of an increase in the environmental friendliness of the energy economy.

Thirdly, it is determined that "green" energy innovations contribute to the growth of environmental friendliness of industry in the regions of Russia. This is evidenced by the obtained regression model (**Eq. 3**):

$$PEI = 64.43 + 0.004enp + 0.02crb \quad (3)$$

Eq. 3 indicates that with an increase in the share of organizations implementing innovations that reduce the energy intensity of production by 1%, the industrial and environmental index increases by 0.004%. And with an increase in the share of organizations implementing innovations that reduce the energy intensity of production, reducing carbon dioxide (CO_2) emissions into the atmosphere by 1%, the industrial and environmental index increases by 0.02%. The correlation of the environmental friendliness of industry with the sustainability of the energy economy was 26.77% (moderate).

The reliability of all three obtained regression models (**Equations 1–3**) is confirmed by high values of correlation coefficients, which prove the close connection between the studied indicators. Based on the obtained models, it was revealed that with an increase in the share of organizations engaged in electronic sales by 87.72% (from 11.14% in 2021 to 20.91%), as well as an increase in the share of organizations using RFID technologies by 250.59% (from 6.67% in 2021 to 23.38%), the following advantages will be achieved for the sustainability of the energy economy in the regions of Russia:

→ Increase in the share of organizations implementing innovations that reduce the energy intensity of production by 83.42% (from 54.52% in 2021 to 100%);
→ Increase in the share of organizations implementing innovations that reduce carbon dioxide (CO_2) emissions into the atmosphere by 139.23% (from 41.80% in 2021 to 100%).

Together, this will ensure an increase in the environmental friendliness of industry in the regions of Russia by 2.50% (from 65.70 points in 2021 to 67.34 points).

Case experience of sustainable and environmental development of the energy economy in the "smart" regions of Russia based on EnergyTech and Smart Grid.

In the qualitative aspect, the practical experience of sustainable and environmental development of the energy sector in the "smart" regions of Russia is studied, while special attention is paid to the best practices of Moscow. Successful examples of improving the energy efficiency of the regional economy of Russia involve the use of the following "smart" technologies.

1) Internet of Things (IoT). Moscow United Energy Company (MUEC), in partnership with the mobile operator MTS, has been implementing a project for monitoring energy consumption for more than 10 years (since 2009), within which a unified automated system for monitoring and accounting for the transmission of thermal energy and hot water has been created. The intelligent energy efficiency monitoring system is based on digital sensors (UC)—47 thousand metering devices in municipal houses and social facilities equipped with MTS SIM cards, which continuously transmit data to the server of the Central Electricity Metering System of the MUEC. The consumption indices of thermal energy in residential buildings in Moscow are taken remotely via the Internet (RBC, 2022).
2) Ubiquitous Computing (UC). JSC "Rusnano" is implementing a project for the development of innovative energy storage systems for testing on the railway network in partnership with JSC "Russian Railways" and LLC "Rusenergosbyt". A pilot sample of an energy storage device for testing on the railway has been designed and is being tested. At the same time, PJSC "Rosseti" pays considerable attention to the development of accumulation systems, regulatory systems, distributed generation systems, as well as the development of electric transport (Russian Union of Industrialists and Entrepreneurs, 2022).
3) Blockchain. In a number of "smart" regions of Russia, an experiment is being conducted to test the technology of distributed ledger (blockchain) based on the collection and processing of data on energy consumption in retail electricity markets on the terms of public-private partnership. The experiment is aimed at improving the reliability and quality of power supply to consumers through the introduction of new technologies and optimization of the activities of network organizations (CNews, 2022).
4) Artificial Intelligence (AI). JSC "IDGC Holding" has created a smart distribution grid based on AI. "Smart" electricity metering devices have been introduced, network management centers have been created, and the observability of substations in the Smart Grid network has been increased. The primary task in the "intellectualization" of the distribution network is smart accounting. A unified information landscape of the accounting system using of open-source, flexible multifunctional components (in particular, of metering devices) operating on the "plug and play" principle is being created (Systems and Technologies, 2022).

The described technologies are used in smart regions of Russia. Thus, in "smart Ulyanovsk" (Ulyanovsk Region, Povolzhye of Russia), there is one system of consumption records, which allows reducing expenses for energy consumption, and a modernised system of street lighting helps control the state of networks (Com News, 2022). Moscow's (Moscow Region, Central Russia) strategy "Smart city 2030" already provides the following (Moscow City Government, 2022):

– Increase in energy efficiency, environmental friendliness and effectiveness of real estate objects management;
– Implementation of the principles of "green construction" through using energy-effective technologies and reduction of waste and emissions during the construction and exploitation of buildings;
– Information modelling will be used during the planning and design of energy effective buildings and city transport infrastructure, reconstruction and capital repair;
– Construction of the pilot road infrastructure with the use of technologies of solar generation of energy, which allows providing electric energy to the objects of road infrastructure (lighting, control systems) and charging electric vehicles.
– Use of photoelectrical covering for electric energy production through collecting solar power.

In the Sverdlovsk Region (North of Russia), a regional information system of energy-saving is functioning successfully; it consolidates data on the municipal systems of the region, which allows forming the ranking of municipalities' energy efficiency, performing heat and hydraulic calculations online and creating an interactive regional scheme of heat and water supply (All Events, 2022).

DISCUSSION

The contribution of the article to the literature consists in clarifying the features of Smart Grid and EnergyTech in the sustainable development of the energy economy in "smart" regions and increasing their environmental friendliness. Unlike Chen et al. (2022), Elnour et al. (2022), Kabeyi and Olanrewaju (2022), Kamruzzaman and Alruwaili (2022), Nasir et al. (2022), it has been proven that "smart" technologies contribute much more to the sustainable and environmental development of the energy economy (than previously supposed in the literature), providing not only environmental but also socio-economic benefits. Owing to "green" energy, the "smart" region becomes a favorable socio-economic environment for responsible production and consumption (implementation of SDG 12), as well as sustainable human settlement (implementation of SDG 11). The scientific value of the conclusion is that it has expanded the relationship of SDG 7 with other SDGs.

Unlike Ahmad et al. (2022), Li et al. (2022), Rezaei et al. (2022), it is justified that the management of "smart" technologies for sustainable and environmentally friendly development of the energy economy should be carried out at the regional level. Public management in the "smart" region harmoniously complements the corporate management of energy companies, and public-private partnership also demonstrates high efficiency. The scientific value of the conclusion is that he expanded the idea of the boundaries of EnergyTech and Smart Grid management, transferring them from the micro level to the meso level.

CONCLUSION

Thus, the results of the study on the example of the "smart" regions of Russia demonstrated that the EnergyTech and Smart Grid markets have not only technological but also territorial boundaries. The theoretical significance of the results obtained in the course of the study is in the fact that they revealed the features of the region as an economic system in which there is a sustainable and environmentally friendly development of the energy economy on the basis of "smart" eco-innovations. If "smart" technologies provide advantages at the level of energy companies, this does not mean advantages on the scale of the region's economy.

For example, in the "smart" regions of Russia, RFID has proven to be the most universal technology for sustainable and environmentally friendly development of the energy economy. The advantages of electronic sales have proven to be reduced, and ERP systems have been contradictory. This requires more flexible management of "smart" technologies in the energy sector at the regional level compared to the level of energy companies. The practical significance of the results obtained is that the applied case experience of the "smart" regions of Russia, considered in the article, can be useful for the rest of the Russian regions and regions of other countries of the world in terms of sustainable and environmental development of the energy economy.

Research limitations are connected to the fact that despite this paper's substantiating the expedience and providing successful examples from Russia's leading experience, it does not cover the perspectives of the full-scale transition to a smart regional economy. As the performed case study showed, even in such progressive digital economy with the developed oil and energy complex, the sustainable and environmental development of the energy economy has been achieved only in separate smart regions. Future studied should form the scientific and methodological framework for the systemic sustainable and environmental development of the energy economy in smart regions at the scale of the regional economy on the whole.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

REFERENCES

Ahmad, T., Madonski, R., Zhang, D., Huang, C., and Mujeeb, A. (2022). Data-driven Probabilistic Machine Learning in Sustainable Smart Energy/smart Energy Systems: Key Developments, Challenges, and Future Research Opportunities in the Context of Smart Grid Paradigm. *Renew. Sustain. Energy Rev.* 160, 112128. doi:10.1016/j.rser.2022.112128

Ajiboye, A. A., Popoola, S. I., Adewuyi, O. B., Atayero, A. A., and Adebisi, B. (2022). Data-driven Optimal Planning for Hybrid Renewable Energy System

Management in Smart Campus: A Case Study. *Sustain. Energy Technol. Assessments* 52, 102189. doi:10.1016/j.seta.2022.102189

Ali, S., Ullah, K., Hafeez, G., Khan, I., Albogamy, F. R., and Haider, S. I. (2022). Solving Day-Ahead Scheduling Problem with Multi-Objective Energy Optimization for Demand Side Management in Smart Grid. *Eng. Sci. Technol. Int. J.* 36, 101135. doi:10.1016/j.jestch.2022.101135

All Events (2022). Smart City & Region: Digital Technologies on a Path to "Smart Country". Ekaterinburg. Available at: https://all-events.ru/events/smart-city-region-tsifrovye-tekhnologii-na-puti-k-umnoy-strane-ekaterinburg/(Access date: 21.05.2022).

Bellocchi, S., De Iulio, R., Guidi, G., Manno, M., Nastasi, B., Noussan, M., et al. (2020). Analysis of Smart Energy System Approach in Local Alpine Regions - A Case Study in Northern Italy. *Energy* 202, 117748. doi:10.1016/j.energy.2020.117748

Chen, J., Su, F., Jain, V., Salman, A., Tabash, M. I., Haddad, A. M., et al. (2022). Does Renewable Energy Matter to Achieve Sustainable Development Goals? the Impact of Renewable Energy Strategies on Sustainable Economic Growth. *Front. Energy Res.* 10, 829252. doi:10.3389/fenrg.2022.829252

CNews (2022). Smart Energetics" with Blockchain Computing in Russia. Available at: https://www.cnews.ru/news/top/2019-03-20_vlasti_stroyat_v_rossiyu_umnuyu_energetiku_s_raschetami (Access date: 01.05.2022).

Com News (2022). How Smart Our Smart Cities Are. Available at: https://www.comnews.ru/digital-economy/content/113663/2018-06-25/naskolko-umny-nashi-umnye-goroda (Access date: 21.05.2022).

Cortese, T. T. P., Almeida, J. F. S. d., Batista, G. Q., Storopoli, J. E., Liu, A., and Yigitcanlar, T. (2022). Understanding Sustainable Energy in the Context of Smart Cities: A Prisma Review. *Energies* 15 (7), 2382. doi:10.3390/en15072382

Dominković, D. F., Dobravec, V., Jiang, Y., Nielsen, P. S., and Krajačić, G. (2018). Modelling Smart Energy Systems in Tropical Regions. *Energy* 155, 592–609. doi:10.1016/j.energy.2018.05.007

Elnour, M., Fadli, F., Himeur, Y., Petri, I., Rezgui, Y., Meskin, N., et al. (2022). Performance and Energy Optimization of Building Automation and Management Systems: Towards Smart Sustainable Carbon-Neutral Sports Facilities. *Renew. Sustain. Energy Rev.* 162, 112401. doi:10.1016/j.rser.2022.112401

Green Patrol (2022). National Environmental Rating of Russia by Region – Deputy 2021-2022. Available at: https://greenpatrol.ru/ru/stranica-dlya-obshchego-reytinga/ekologicheskiy-reyting-subektov-rf?tid=449&order=field_prom&sort=desc (Access date: 01.05.2022).

Guo, M., Xia, M., and Chen, Q. (2022). A Review of Regional Energy Internet in Smart City from the Perspective of Energy Community. *Energy Rep.* 8, 161–182. doi:10.1016/j.egyr.2021.11.286

Kabeyi, M. J. B., and Olanrewaju, O. A. (2022). Sustainable Energy Transition for Renewable and Low Carbon Grid Electricity Generation and Supply. *Front. Energy Res.* 9, 743114. doi:10.3389/fenrg.2021.743114

Kamruzzaman, M. M., and Alruwaili, O. (2022). Energy Efficient Sustainable Wireless Body Area Network Design Using Network Optimization with Smart Grid and Renewable Energy Systems. *Energy Rep.* 8, 3780–3788. doi:10.1016/j.egyr.2022.03.006

Kleineidam, G., Krasser, M., and Reischböck, M. (2016). The Cellular Approach: Smart Energy Region Wunsiedel. Testbed for Smart Grid, Smart Metering and Smart Home Solutions. *Electr. Eng.* 98, 335–340. doi:10.1007/s00202-016-0417-y

Li, B. (2022). Effective Energy Utilization through Economic Development for Sustainable Management in Smart Cities. *Energy Rep.* 8, 4975–4987. doi:10.1016/j.egyr.2022.02.303

Li, Q., Liu, Z., Xiao, Y., Zhao, P., Zhao, Y., Yang, T., et al. (2022). An Intelligent Optimization Method for Preliminary Design of Lead-Bismuth Reactor Core Based on Kriging Surrogate Model. *Front. Energy Res.* 10, 849229. doi:10.3389/fenrg.2022.849229

Mahmoud, F. S., Diab, A. A. Z., Ali, Z. M., El-Sayed, A.-H. M., Alquthami, T., Ahmed, M., et al. (2022). Optimal Sizing of Smart Hybrid Renewable Energy System Using Different Optimization Algorithms. *Energy Rep.* 8, 4935–4956. doi:10.1016/j.egyr.2022.03.197

Matsunaga, F., Zytkowski, V., Valle, P., and Deschamps, F. (2022). Optimization of Energy Efficiency in Smart Manufacturing through the Application of Cyber-Physical Systems and Industry 4.0 Technologies. *J. Energy Resour. Technol. Trans. ASME* 144 (10), 102104. doi:10.1115/1.4053868

Ministry of Finance of Russia, Rosstat, HSE (2022). Indicators of the digital economy 2021: a statistical collection. The main indicators of the development of the digital economy in the subjects of the Russian Federation. Available at: https://publications.hse.ru/pubs/share/direct/491154070.pdf (Access date: 01.05.2022).

Moscow City Government (2022). Strategy" Moscow – "smart city – 2030". Available at: https://www.mos.ru/upload/alerts/files/3_Tekststrategii.pdf (Access date: 21.05.2022).

Nasir, M. H., Wen, J., Nassani, A. A., Haffar, M., Igharo, A. E., Musibau, H. O., et al. (2022). Energy Security and Energy Poverty in Emerging Economies: A Step Towards Sustainable Energy Efficiency. *Front. Energy Res.* 10, 834614. doi:10.3389/fenrg.2022.834614

Ortiz Cebolla, R., and Navas, C. (2019). Supporting hydrogen technologies deployment in EU regions and Member States: The Smart Specialisation Platform on Energy (S3PEnergy). *Int. J. Hydrogen Energy* 44, 19067–19079. doi:10.1016/j.ijhydene.2018.05.041

Popkova, E., Bogoviz, A. V., and Sergi, B. S. (20212021). Towards digital society management and 'capitalism 4.0' in contemporary Russia. *Humanit Soc. Sci. Commun.* 8 (1), 77. doi:10.1057/s41599-021-00743-8

Popkova, E. G. (2022). International trade in the era of neo-globalization: disintegration vs digital partnership. *Res. Econ. Anthropol.* 42, 7–13. doi:10.1108/S0190-128120220000042001

Qu, D., Li, J., and Yong, M. (2022). Real-time pricing for smart grid considering energy complementarity of a microgrid interacting with the large grid. *Int. J. Electr. Power & Energy Syst.* 141, 108217. doi:10.1016/j.ijepes.2022.108217

Ram, M., Bogdanov, D., Aghahosseini, A., Gulagi, A., Oyewo, A. S., Mensah, T. N. O., et al. (2022). Global energy transition to 100% renewables by 2050: Not fiction, but much needed impetus for developing economies to leapfrog into a sustainable future. *Energy* 246, 123419. doi:10.1016/j.energy.2022.123419

RBC (2022). Smart technologies in energetics based on the IoT World Summit Russia. Available at: https://rt.rbc.ru/tatarstan/freenews/5b9f49e69a794786292f71bb (Access date: 01.05.2022).

Rezaei, N., Tarimoradi, H., and Deihimi, M. (2022). A coordinated management scheme for power quality and load consumption improvement in smart grids based on sustainable energy exchange based model. *Sustain. Energy Technol. Assessments* 51, 101903. doi:10.1016/j.seta.2021.101903

Rosstat (2022). Regions of Russia. Socio-economic indicators - 2020. Available at: https://gks.ru/bgd/regl/b20_14p/Main.htm (Access date: 01.05.2022).

Russian Union of Industrialists and Entrepreneurs (2022). Session "Digitalization of Modern Energy: from local solutions to industry transformation. Available at: https://rspp.ru/events/news/sostoyalas-sessiya-tsifrovizatsiya-sovremennoy-energetiki-ot-lokalnykh-resheniy-k-transformatsiii-ot/(Access date: 01.05.2022).

Sharma, P., Reddy Salkuti, S., and Kim, S.-C. (2022). Advancements in energy storage technologies for smart grid development. *Ijece* 12 (4), 3421–3429. doi:10.11591/ijece.v12i4.pp3421-3429

Systems and Technologies (2022). Smart Grid smart grids are the future of Russian energy. Available at: http://www.sicon.ru/about/articles/?base=&news=16 (Access date: 01.05.2022).

Xu, C. (2022). Designing and planning of energy efficient sustainable cities and societies: A smart energy. *Trans. Emerg. Tel Tech.* 33 (2), e4460. doi:10.1002/ett.4460

Zaidan, E., Ghofrani, A., Abulibdeh, A., and Jafari, M. (2022). Accelerating the Change to Smart Societies- a Strategic Knowledge-Based Framework for Smart Energy Transition of Urban Communities. *Front. Energy Res.* 10, 852092. doi:10.3389/fenrg.2022.852092

Zhao, J., Sinha, A., Inuwa, N., Wang, Y., Murshed, M., and Abbasi, K. R. (2022). Does structural transformation in economy impact inequality in renewable energy productivity? Implications for sustainable development. *Renew. Energy* 189, 853–864. doi:10.1016/j.renene.2022.03.050

Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's Note: All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

frontiers | Frontiers in Energy Research

OPINION
published: 22 July 2022
doi: 10.3389/fenrg.2022.944798

Smart Grid: Leading International Experience of Marketing and its Contribution to Sustainable and Environmental Development of Energy Economy

Timur A. Mustafin[1†], Lyudmila M. Kuprianova[2†], Anastasiya Yu Ladogina[3†] and Oksana N. Pyatkova[4†]*

[1]Diplomatic Academy of the Ministry of Foreign Affairs of the Russian Federation, Moscow, Russia, [2]Department of Accounting, Analysis and Audit, Financial University Under the Government of the Russian Federation, Moscow, Russian, [3]Department of Advertising, PR and Design, Plekhanov Russian University of Economics, Moscow, Russia, [4]Department of Management, Organisation of Business and Innovations, Altai State University, Barnaul, Russia

OPEN ACCESS

Edited by:
Elena G. Popkova,
Moscow State Institute of International Relations, Russia

Reviewed by:
Gaurav Dhiman,
Government Bikram College of Commerce Patiala, India

***Correspondence:**
Anastasiya Yu Ladogina
a.ladogina@gmail.com

†ORCID:
Timur A. Mustafin
0000-0002-5411-6493
Lyudmila M. Kuprianova
0000-0002-9453-6425
Anastasiya Yu Ladogina
0000-0003-2890-6739
Oksana N. Pyatkova
0000-0002-5630-1772

Specialty section:
This article was submitted to Sustainable Energy Systems and Policies,
a section of the journal Frontiers in Energy Research

Received: 15 May 2022
Accepted: 24 June 2022
Published: 22 July 2022

Citation:
Mustafin TA, Kuprianova LM, Ladogina AY and Pyatkova ON (2022) Smart Grid: Leading International Experience of Marketing and its Contribution to Sustainable and Environmental Development of Energy Economy.
Front. Energy Res. 10:944798.
doi: 10.3389/fenrg.2022.944798

Keywords: smart grid, advanced international experience, sustainable and environmental development, energy economy, strategic perspective

INTRODUCTION

This article is devoted to the study of the contribution of Smart Grid to the sustainable and environmental development of energy. The central category in the article is Smart Grid, which refers to the "smart" technologies used for automation and enhanced environmental monitoring and control of energy production, distribution and consumption. Smart Grid includes, firstly, an extensive telecommunications infrastructure that provides high-precision and continuous measurement of energy efficiency and other energy characteristics. Secondly, the "smart" technologies used by energy companies themselves.

Initially, Smart Grid was created to increase the efficiency of the energy economy and optimize its flows to ensure the availability of energy resources for all economic entities. At the current stage, the advanced energy economies that were the first to create Smart Grid have fully implemented the initial tasks and achieved outstanding success, including energy conservation and mass electricity supply with full coverage of business structures and households. This raises two research questions.

RQ1: What are the future prospects for the development of Smart Grid? Numerous evidences of its benefits for the environment in the studies of Amir et al. (2022), Gajić et al. (2022), Sudhakar and Kumar (2022), Tabar et al. (2022) allow us to hypothesize that Smart Grid can contribute to the development of "clean" (renewable) energy. RQ2: How to realize these prospects and extend the successful experience of Smart Grid to other countries? To answer this question, it is necessary to systematize and analyze the factors of Smart Grid development, as well as to form a scientific basis for managing these factors. The purpose of the article is to study the contribution of Smart Grid to the sustainable and ecological development of the energy economy, as well as the prospects for increasing this contribution with the help of management mechanisms.

The contribution of the article to the literature consists in the formation of a new scientific take on Smart Grid, revealing its contribution to the sustainable and environmentally friendly development of the energy economy. Thus, the article establishes a methodological framework for the consistent achievement of not only energy efficiency, sufficiency and continuity of energy through the development of Smart Grid, but also the sustainability and environmental friendliness of the energy economy. This extends the current concept of Smart Grid and allows using it more flexibly in practical terms of environmental economics and management.

Smart Grid as a Vector of Energy Economy Development

The topic of Smart Grid is widely discussed in existing scientific publications, which indicates its high relevance. The works of Ali A. O. et al. (2022), Dehalwar et al. (2022), Hua et al. (2022), Ibrahim et al. (2022), Kamruzzaman and Alruwaili (2022), Omidvar Tehrani et al. (2022) note numerous advantages of Smart Grid, among which the optimization of production and distribution processes in the energy economy, reduction of losses and accidents in the production, storage and distribution of electricity.

Thus, first of all, Smart Grid has economic and social priorities. Some environmental aspects of Smart Grid are revealed in the available works of Ali S. et al. (2022), Kamruzzaman and Alruwaili (2022), Lamnatou et al. (2022), Popkova et al. (2021), Popkova and Sergei (2021), but in general, the ecological profile of Smart Grid has not been formed, which gives a partial picture of it from the standpoint of sustainable development.

The publications of Albogamy et al. (2022), Almutairi et al. (2022), Liu et al. (2022), Saxena et al. (2022), Zaidan et al. (2022) suggest the functioning and development of Smart Grid based on corporate governance with a secondary role of the state. Smart Grid is interpreted as a high-tech innovation of energy companies. The problem is that Smart Grid has largely revealed its potential as a vector for the development of the energy economy in the most progressive countries that were the first to create "smart" power supply networks. For example, in China, as one of the developing countries leading in the global SmartGrid SP Group development ranking (2022), noticeable progress has been made in increasing the share of the population with access to electricity from 96.907% in 2000 to 99.7% in 2010 and to 100% in 2013 (UNDP, 2022).

In India, progress is even more significant: the share of population with access to electricity increased from 59.125% in 2000 to 76.3% in 2010 and to 95.236% in 2018 (UNDP, 2022), and although data for later periods are still being calculated, we can expect that this share will tend to 100%. The future prospects of Smart Grid are uncertain, which is a gap in the literature. The ambiguity of the strategic vision of the future of Smart Grid hinders its development. To fill the gap formulated in this article, a factor analysis of the development of Smart Grid is carried out, and its contribution to the sustainability and environmental friendliness of the energy economy is determined based on the best international experience.

Smart Grid in the Energy Economy: Modeling and Policy Implications

Verification of the proposed hypothesis is carried out in this article using econometric modeling of Smart Grid as part of the energy economy. To study and highlight international best practices, the countries with the highest results in the field of Smart Grid (sg) development, whose companies/markets are leading in the SP Group (2022) rating for 2021, are included in the sample of countries for research. The justification for choosing Smart Grid Index as the resulting indicator is that this index way reveals the level of Smart Grid development in the most direct (straightforward), full and all-round (comprehensive) way.

The regression analysis method is used for obtaining the most accurate and reliable data, as this method makes it possible to perform both the stochastic factor analysis (to determine relationships between indicators) and the prospective factor analysis (use determined relationships as the basis for examining/predicting changes in factor and resulting variables over the longer term).

The advantage of the chosen method compared to the alternative method of deterministic factor analysis which is characterized by the functional relationship between factor variables and the resulting variable, is that it allows determining more flexible–probabilistic (correlation) and therefore the most reliable relationships of indicators. The benefit of regression analysis compared to its alternative in the form of dynamic factor analysis is the reduced risk of errors due to differences in approaches to calculating indicators, resulting in the data inconsistency.

To obtain the most accurate and reliable data, regression curves are constructed showing the consequences, firstly, the advantages of Smart Grid for the sustainable and ecological development of the energy economy through the prism of SDG 7 indicators: Population with access to clean fuels and technology for cooking (E1), CO_2 emissions from fuel combustion for electricity and heating per total electricity output (E2) and Share of renewable energy in total primary energy supply (E3) based on the materials of UNDP (2022). The justification for choosing these indicators is that it is the implementation of SDG7 that is the most important evidence of the sustainable and environmentally friendly development of the energy economy, while the UNDP is a reputable organization and a generally recognized provider of reliable statistics.

Secondly, the impact of the Smart Grid development factors allocated by the IMD World Competitiveness Center (2022): corporate governance factors–economic performance (f_1), business efficiency (f_2)—and government governance factors–government efficiency (f_3), infrastructure (f_4). The justification for choosing these indicators is that the IMD World Competitiveness Center is one of the most reputable providers of statistics on smart technologies that are fundamental for Smart Grid. The choice of these particular indicators is attributable to the fact that they allow taking into account both the corporate governance factors and the Smart Grid governance factors provided that these factors are comparable (the same units of measurement and the general methods for calculating their statistical values, since they are derived from the same report).

Based on the results of the analysis, Smart Grid governance factors that make the greatest contribution to the sustainable and environmental development of the energy economy are selected and qualitatively rethought, and energy policy implications are proposed. The statistical basis of the study is formed in **Table 1**.

Based on statistics from **Table 1**, the following econometric model (a system of linear regression equations) is obtained, which mathematically characterizes the Smart Grid as part of the energy economy:

$E_1 = -100{,}22 + 2{,}15sg;$

$E_2 = 3{,}55\text{-}0{,}03sg;$

$E_3 = -37{,}78 + 0{,}55sg;$

$sg = 92{,}02 + 0{,}12f_1\text{-}0{,}10f_2+0{,}03f_3\text{-}0{,}26\ f_4.$

The resulting model suggests that with an increase in the level of development of Smart Grid by 1 point, the share of the population with access to environmentally friendly fuels and technologies for cooking increases by 2.15% (correlation: 64.47%), CO_2, emissions from burning fuel for electricity generation and heating for the entire

TABLE 1 | Smart grid in the energy economy 2021.

Country	Utility	Smart Grid index, Score 0-100	Economic Performance, Place	Government Efficiency, Place	Business Efficiency, Place	Infrastructure, Place	Population with Access to Clean Fuels and Technology for Cooking (%)	CO_2 Emissions from Fuel Combustion for Electricity and Heating per Total Electricity Output ($MtCO_2/TWh$)	Share of Renewable Energy in Total Primary Energy Supply (%)
France	Enedis	96.4	28	39	36	15	100	0.537	10.682
United States	ConEd	96.4	5	28	10	6	100	1.145	7.915
Austria	CitiPower	92.9	20	29	18	12	100	0.936	30.187
Great Britain	UKPN	94.6	26	19	19	13	100	1.104	12.493
UAE	DEWA	89.3	9	3	8	28	98.51	1.505	no data
Denmark	Radius	85.7	17	7	4	3	100	0.990	36.931
Netherlands	Stedin	85.7	2	12	4	7	100	1.245	7.177
Japan	TEPCO	82.1	12	41	48	22	100	1.123	6.248
China	State Grid Beijing	80.4	4	27	17	18	59.26	1.407	no data
India	Tata power-DDL	80.4	37	46	32	19	41.04	1.462	no data

Source: IMD, World Competitiveness Center (2022), SP, Group (2022), UNDP (2022).

production of electricity decrease by 0.03 $MtCO_2/TWh$ (correlation of 60.60%), the share of renewable energy sources in the total volume of primary energy supplies increases by 0.55% (correlation of 27.94%).

The contribution to the development of Smart Grid was demonstrated only by government governance factors (multiple correlation with all governance factors 36.15%). Thus, with the improvement of government efficiency to 1 place in the international rating, the level of Smart Grid development increases by 0.10 points. With the improvement of infrastructure to 1 place in the international ranking, the level of Smart Grid development increases by 0.26 points.

Based on the obtained econometric model, a strategic forecast of the development of Smart Grid in the leading countries (included in the sample) based on management optimization is compiled. The obtained forecast assumes maximizing the government efficiency (improvement from 25.10th place for the sample mean to 1st place: –96.02%) and infrastructure (improvement from 14.30th place for the sample mean to 1 place: –93.01%). Thanks to this, the level of development of Smart Grid will increase by 6.56% (from 88.39 points to 94.19 points), which will contribute to:

– The share of the population with access to environmentally friendly fuels and technologies for cooking increased by 13.87% (from 89.88 to 100%);
– Reduction of CO_2 emissions from fuel combustion for electricity and heating per total electricity output by 13.80% (from 1.15 $MtCO_2/TWh$ to 0.99 $MtCO_2/TWh$);
– The share of renewable energy in total primary energy supply increased by 28.75% (from 11.16 to 14.37%).

The presented prospect for further development of Smart Grid is stochastic (probabilistic), since it is based on data on a sample of countries (rather than a single specific country) and projected (rather than actual, observed) indicator values. With the development of Smart Grid and the accumulation of statistical information, experimental evidence of the identified prospect would be expedient, which shall be understood to mean substituting the actual data into the formulated regression models for their refinement, as well as for the correction of forecast. The data for each regression model will be derived from subsequent official statistics (for 2022, 2023 and beyond) from the IMD World Competitiveness Center, SP Group, and UNDP.

These recommendations determined the algorithm for the sustainable and environmentally friendly development of the energy economy based on Smart Grid. At the first stage of the algorithm, government efficiency and infrastructure are maximized. At the second stage, the development of Smart Grid is achieved. At the third stage, the benefits for the sustainable and environmentally friendly development of the energy economy are derived through an increase in population with access to clean fuels and technology for cooking, a decrease in CO_2 emissions from fuel combustion for electricity and heating per total electricity output, and an increase in the share of renewable energy in total primary energy supply.

Other applications of the proposed algorithm include the decarbonization of the economy, the transition to renewable energy and the circular economy, and the development of responsible communities and sustainable territories. For real-time applications, consideration must be given to the performance of the technique–power-generation facilities used in Smart Grid. In addition, it would be expedient to rely upon state-of-the art solutions in the field of engineering and technical algorithms (Dhiman and Kumar, 2017; Dhiman and Kumar, 2018; Dehghani et al., 2019; Dhiman and Kaur, 2019; Dhiman and Kumar, 2019; Dehghani et al., 2020a; Dehghani et al., 2020b; Kaur et al., 2020; Dhiman et al., 2021a; Dhiman et al., 2021b; Chatterjee, 2021; Dhiman, 2021; Kumar and Dhiman, 2021; Vaishnav et al., 2021; Gupta et al., 2022; Sharma et al., 2022; Shukla et al., 2022), since this will allow for the most efficient government and corporate governance.

DISCUSSION

The contribution of the article to the literature consists in revealing the prospects for further development of Smart Grid and clarifying its organizational and managerial model. Unlike Ali A. O. et al. (2022), Dehalwar et al. (2022), Hua et al. (2022), Ibrahim et al. (2022), Kamruzzaman and Alruwaili (2022), Omidvar Tehrani et al. (2022), it was proved that the advantages of Smart Grid are not only support for mass accessibility, efficiency and security of the energy economy, but also an increase in its environmental friendliness (by an average of 14% compared to the level of 2021).

In contrast to Albogamy et al. (2022), Almutairi et al. (2022), Liu et al. (2022), Saxena et al. (2022), Zaidan et al. (2022), it was found that Smart Grid mainly depends on government governance, which includes both infrastructure support, and regulation of the energy economy. The role of corporate governance is secondary. This gives a new perspective on Smart Grid, transferring it from the category of high–tech innovations of energy companies (at the micro level–individual enterprises) to the state program for the development of the energy economy as a whole (at the meso-regional and macronational levels).

This allows us to offer a promising strategic vision of the future of Smart Grid, associated with the systematic modernization of the territorial economy and the integration of "smart" power supply networks into urban planning. In the authors' vision of Smart Grid, it is transformed from separate (isolated, disparate and small-scale) sections of high-tech power supply networks into a new format of electricity supply organization and a new technological structure of the energy economy.

Smart Grid's environmental priorities include: increasing access to environmentally friendly fuels and technologies for cooking, reducing CO_2 emissions from fuel combustion for electricity and heating per total electricity output, as well as increasing the share of share of renewable energy in total primary energy supply.

CONCLUSION

The result of the conducted research is the proof of the hypothesis put forward by the authors. Based on the best international experience, the article demonstrates that Smart Grid can contribute to the development of "clean" (renewable) energy. This new authors' vision is fundamentally different from some of the environmental benefits of Smart Grid noted in the literature, bringing it to the level of a vector of sustainable and environmentally friendly development of the energy economy.

The resulting factor models revealed the causal relationships of Smart Grid development, while the proposed recommendations determined the algorithm for sustainable and environmentally friendly development of the energy economy based on Smart Grid. At the first stage of the algorithm, government efficiency and infrastructure are maximized. At the second stage, the development of Smart Grid is achieved. At the third stage, the benefits for the sustainable and environmentally friendly development of the energy economy are derived through an increase in population with access to clean fuels and technology for cooking, a decrease in CO_2 emissions from fuel combustion for electricity and heating per total electricity output, and an increase in the share of renewable energy in total primary energy supply.

A stochastic forecast for the implementation of the proposed algorithm has been made. This forecast yielded the following benefits for the sustainable and environmentally friendly development of the energy economy: an increase in population with access to clean fuels and technology for cooking by 13.87% (from 89.88 to 100%); a decrease in CO_2 emissions from fuel combustion for electricity and heating per total electricity output by 13.80% (from 1.15 $MtCO_2$/TWh to 0.99 $MtCO_2$/TWh); an increase in the share of renewable energy in total primary energy supply by 28.75% (from 11.16 to 14.37%).

The scientific novelty of the article is to substantiate the serious contribution of Smart Grid to the sustainable and environmentally friendly development of the energy economy. Based on this contribution, a long-term strategic vision of the future of Smart Grid is proposed, supplemented by environmental priorities. The theoretical significance of the obtained results consists in the systematization and formation of the scientific basis for managing the factors of Smart Grid development. The practical significance of the authors' conclusions is related to the fact that they provided a scientific and methodological basis for improving the effectiveness of Smart Grid development management based not only on corporate, but also on government governance, which, as shown in the article, is even more significant.

The limitation and drawback of the proposed algorithm is its stochasticity–the flexibility of results and their dependence on the context, although the probability of the forecast is fairly high in general (more than 60%) and guarantees the benefits from the development of EnergyTech for the sustainable and environmentally friendly development of the energy economy. In future studies, in proportion to the accumulation of experimental (corporate–at the level of enterprises) and statistical data, it would be expedient to re-evaluate and refine the derived models, recheck the determined dependencies of indicators, and correct the proposed algorithm.

AUTHOR CONTRIBUTIONS

TM, LK, and AL contributed to conception and design of the study. AL and OP performed the statistical analysis. OP wrote the first draft of the manuscript. TM, LK, AL, and OP wrote sections of the manuscript. All authors contributed to manuscript revision, read, and approved the submitted version.

REFERENCES

Albogamy, F. R., Khan, S. A., Hafeez, G., Murawwat, A., Khan, K.-D., Haider, S. I., et al. (2022). Real-Time Energy Management and Load Scheduling with Renewable Energy Integration in Smart Grid. *Sustainability* 14 (3), 1792. doi:10.3390/su14031792

Ali, A. O., Elmarghany, M. R., Abdelsalam, M. M., Sabry, M. N., and Hamed, A. M. (2022a). Closed-loop Home Energy Management System with Renewable Energy Sources in a Smart Grid: A Comprehensive Review. *J. Energy Storage* 50, 104609. doi:10.1016/j.est.2022.104609

Ali, S., Ullah, K., Hafeez, G., Khan, F. R., Albogamy, S. I., and Haider, S. I. (2022b). Solving Day-Ahead Scheduling Problem with Multi-Objective Energy

Optimization for Demand Side Management in Smart Grid. *Eng. Sci. Technol. Int. J.* 36, 101135. doi:10.1016/j.jestch.2022.101135

Almutairi, K., Almutairi, M., Harb, K., and Marey, O. (2022). Optimal Sizing Grid-Connected Hybrid PV/Generator/Battery Systems Following the Prediction of CO2 Emission and Electricity Consumption by Machine Learning Methods (MLP and SVR): Aseer, Tabuk, and Eastern Region, Saudi Arabia. *Front. Energy Res.* 10, 879373. doi:10.3389/fenrg.2022.879373

Amir, M., Prajapati, A. K., and Refaat, S. S. (2022). Dynamic Performance Evaluation of Grid-Connected Hybrid Renewable Energy-Based Power Generation for Stability and Power Quality Enhancement in Smart Grid. *Front. Energy Res.* 10, 861282. doi:10.3389/fenrg.2022.861282

Chatterjee, I. (2021). Artificial Intelligence and Patentability: Review and Discussions. *Int. J. Mod. Res.* 1, 15–21.

Dehalwar, V., Kolhe, M. L., Deoli, S., and Jhariya, M. K. (2022). Blockchain-based Trust Management and Authentication of Devices in Smart Grid. *Clean. Eng. Technol.* 8, 100481. doi:10.1016/j.clet.2022.100481

Dehghani, M., Montazeri, Z., Dhiman, G., Malik, J. M., Morales-Menendez, L., Ramirez-Mendoza, R. A., et al. (2020a). A Spring Search Algorithm Applied to Engineering Optimization Problems. *Appl. Sci.* 10 (18), 6173. doi:10.3390/APP10186173

Dehghani, M., Montazeri, Z., Malik, O. P., Dhiman, G., and Kumar, V. (2019). BOSA: Binary Orientation Search Algorithm. *Ijitee* 9 (1), 5306–5310. doi:10.35940/ijitee.A4215.119119

Dehghani, M., Montazeri, Z., Montazeri, H., Givi, J. M., Guerrero, G., and Dhiman, G. (2020b). Darts Game Optimizer: A New Optimization Technique Based on Darts Game. *Ijies* 13 (5), 286–294. doi:10.22266/ijies2020.1031.26

Dhiman, G. (2021). ESA: a Hybrid Bio-Inspired Metaheuristic Optimization Approach for Engineering Problems. *Eng. Comput.* 37 (1), 323–353. doi:10.1007/s00366-019-00826-w

Dhiman, G., Garg, M., Nagar, A., Kumar, V., and Dehghani, M. (2021a). A Novel Algorithm for Global Optimization: Rat Swarm Optimizer. *J. Ambient. Intell. Hum. Comput.* 12 (8), 8457–8482. doi:10.1007/s12652-020-02580-0

Dhiman, G., and Kaur, A. (2019). STOA: a Bio-Inspired Based Optimization Algorithm for Industrial Engineering Problems. *Eng. Appl. Artif. Intell.* 82, 148–174. doi:10.1016/j.engappai.2019.03.021

Dhiman, G., and Kumar, V. (2018). Emperor Penguin Optimizer: A Bio-Inspired Algorithm for Engineering Problems. *Knowledge-Based Syst.* 159, 20–50. doi:10.1016/j.knosys.2018.06.001

Dhiman, G., and Kumar, V. (2019). Seagull Optimization Algorithm: Theory and its Applications for Large-Scale Industrial Engineering Problems. *Knowledge-Based Syst.* 165, 169–196. doi:10.1016/j.knosys.2018.11.024

Dhiman, G., and Kumar, V. (2017). Spotted Hyena Optimizer: a Novel Bio-Inspired Based Metaheuristic Technique for Engineering Applications. *Adv. Eng. Softw.* 114, 48–70. doi:10.1016/j.advengsoft.2017.05.014

Dhiman, G., Oliva, D., Kaur, A., Singh, A., Vimal, K., Sharma, A., et al. (2021b). BEPO: A Novel Binary Emperor Penguin Optimizer for Automatic Feature Selection. *Knowledge-Based Syst.* 211, 106560. doi:10.1016/j.knosys.2020.106560

Gajić, D. B., Petrović, V. B., Horvat, N., Dragan, V., Stanisavljević, J., Katić, V., et al. (2022). A Distributed Ledger-Based Automated Marketplace for the Decentralized Trading of Renewable Energy in Smart Grids. *Energies* 15 (6), 2121. doi:10.3390/en15062121

Gupta, V. K., Shukla, S. K., and Rawat, R. S. (2022). Crime Tracking System and People's Safety in India Using Machine Learning Approaches. *Int. J. Mod. Res.* 2 (1), 1–7.

Hua, W., Chen, Y., Qadrdan, M., Jiang, H., Sun, J., and Wu, J. (2022). Applications of Blockchain and Artificial Intelligence Technologies for Enabling Prosumers in Smart Grids: A Review. *Renew. Sustain. Energy Rev.* 161, 112308. doi:10.1016/j.rser.2022.112308

Ibrahim, C., Mougharbel, I., Kanaan, H. Y., Daher, S., Georges, M., and Saad, M. (2022). A Review on the Deployment of Demand Response Programs with Multiple Aspects Coexistence over Smart Grid Platform. *Renew. Sustain. Energy Rev.* 162, 112446. doi:10.1016/j.rser.2022.112446

IMD World Competitiveness Center (2022). World Competitiveness Ranking: Overall and Factor Rankings - 5 Years. Available at: https://www.imd.org/centers/world-competitiveness-center/rankings/world-competitiveness/ [data accessed 30 04 2022].

Kamruzzaman, M. M., and Alruwaili, O. (2022). Energy Efficient Sustainable Wireless Body Area Network Design Using Network Optimization with Smart Grid and Renewable Energy Systems. *Energy Rep.* 8, 3780–3788. doi:10.1016/j.egyr.2022.03.006

Kaur, S., Awasthi, L. K., Sangal, A. L., and Dhiman, G. (2020). Tunicate Swarm Algorithm: A New Bio-Inspired Based Metaheuristic Paradigm for Global Optimization. *Eng. Appl. Artif. Intell.* 90, 103541. doi:10.1016/j.engappai.2020.103541

Kumar, R., and Dhiman, G. (2021). A Comparative Study of Fuzzy Optimization through Fuzzy Number. *Int. J. Mod. Res.* 1, 1–14.

Lamnatou, C., Chemisana, D., and Cristofari, C. (2022). Smart Grids and Smart Technologies in Relation to Photovoltaics, Storage Systems, Buildings and the Environment. *Renew. Energy* 185, 1376–1391. doi:10.1016/j.renene.2021.11.019

Liu, X., Zhong, W., Hou, M., and Luo, Y. (2022). Two-Stage Optimal Operation Management of a Microgrid Considering Electricity-Hydrogen Coupling Dynamic Characteristics. *Front. Energy Res.* 10, 856304. doi:10.3389/fenrg.2022.856304

Omidvar Tehrani, S., Shahrestani, A., and Yaghmaee, M. H. (2022). Online Electricity Theft Detection Framework for Large-Scale Smart Grid Data. *Electr. Power Syst. Res.* 208, 107895. doi:10.1016/j.epsr.2022.107895

Popkova, E. G., Inshakova, A. O., Bogoviz, A. V., and Lobova, S. V. (2021). Energy Efficiency and Pollution Control through ICTs for Sustainable Development. *Front. Energy Res.* 9, 735551. doi:10.3389/fenrg.2021.735551

Popkova, E. G., and Sergi, B. S. (2021). Energy Efficiency in Leading Emerging and Developed Countries. *Energy* 221, 119730. doi:10.1016/j.energy.2020.119730

Saxena, A., Shankar, R., Parida, S., and Kumar, R. (2022). Demand Response Based Optimally Enhanced Linear Active Disturbance Rejection Controller for Frequency Regulation in Smart Grid Environment. *IEEE Trans. Ind. Appl.*, 1. doi:10.1109/TIA.2022.3166711

Sharma, T., Nair, R., and Gomathi, S. (2022). Breast Cancer Image Classification Using Transfer Learning and Convolutional Neural Network. *Int. J. Mod. Res.* 2 (1), 8–16.

Shukla, S. K., Gupta, V. K., Joshi, K., Gupta, A., and Singh, M. K. (2022). Self-aware Execution Environment Model (SAE2) for the Performance Improvement of Multicore Systems. *Int. J. Mod. Res.* 2 (1), 17–27.

SP Group (2022). Smart Grid Index: 2021 Benchmarking Results. Available at: https://www.spgroup.com.sg/sp-powergrid/overview/smart-grid-index [accessed 30 04 2022).

Sudhakar, A., and Kumar, B. M. (2022). Maximum Exploitation of Electric Vehicle Storage in Smart Micro Grids with Stochastic Renewable Sources. *J. Energy Storage* 48, 104029. doi:10.1016/j.est.2022.104029

Tabar, V. S., Ghassemzadeh, S., Tohidi, S., and Siano, P. (2022). Enhancing Information Security of Renewable Smart Grids by Utilizing an Integrated Online-Offline Framework. *Int. J. Electr. Power & Energy Syst.* 138, 107954. doi:10.1016/j.ijepes.2022.107954

UNDP (2022). Sustainable Development Report 2021. Available at: https://dashboards.sdgindex.org/accessed 30 04 2022].

Vaishnav, P. K., Sharma, S., and Sharma, P. (2021). Analytical Review Analysis for Screening COVID-19. *Int. J. Mod. Res.* 1, 22–29.

Zaidan, E., Ghofrani, A., Abulibdeh, A., and Jafari, M. (2022). Accelerating the Change to Smart Societies- a Strategic Knowledge-Based Framework for Smart Energy Transition of Urban Communities. *Front. Energy Res.* 10, 852092. doi:10.3389/fenrg.2022.852092

Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's Note: All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

frontiers | Frontiers in Energy Research

OPINION
published: 26 July 2022
doi: 10.3389/fenrg.2022.932229

Global Monitoring of the Development of Digital Energetics Based on the Technologies of Industry 4.0: IoT, Blockchain, Robots, and Artificial Intelligence

Valery I. Khoruzhy[1], Vladimir V. Lebedev[2], Natalya Farkova[3] and Elena L. Pozharskaya[4]*

[1]Institute of Online Education, Financial University Under the Government of the Russian Federation, Moscow, Russia, [2]Independent Researcher, Tula, Russia, [3]Diplomatic Academy of the Russian Foreign Ministry, Moscow, Russia, [4]Department of Psychology, Plekhanov Russian University of Economics, Moscow, Russia

Keywords: global monitoring, digital energy, Industry 4.0 technologies, Internet of Things, Blockchain, robots, Artificial Intelligence

OPEN ACCESS

Edited by:
Aleksei V. Bogoviz, Independent researcher, Moscow, Russia

Reviewed by:
Konstantinos G. Arvanitis, Agricultural University of Athens, Greece
Ivan Milenkovic, University of Novi Sad, Serbia

****Correspondence:***
Valery I. Khoruzhy
vkhoruzhiy@yandex.ru

Specialty section:
This article was submitted to Sustainable Energy Systems and Policies, a section of the journal Frontiers in Energy Research

Received: *29 April 2022*
Accepted: *15 June 2022*
Published: *26 July 2022*

Citation:
Khoruzhy VI, Lebedev VV, Farkova N and Pozharskaya EL (2022) Global Monitoring of the Development of Digital Energetics Based on the Technologies of Industry 4.0: IoT, Blockchain, Robots, and Artificial Intelligence. Front. Energy Res. 10:932229. doi: 10.3389/fenrg.2022.932229

INTRODUCTION

The transition to Industry 4.0 contributed to the formation of digital energy, which is characterized by the active use of high technologies in various economic processes of the energy economy. Industry 4.0 technologies are defined in different ways in the national programs and strategies of the same name. For example, in Germany, which was the first to adopt a national strategy referred to as "Industrie 4.0," Industry 4.0 technologies shall be understood to mean the entirety of technologies that form cyber-physical systems and make Germany a leader in terms of technology (European Commission, 2022).

In the United Kingdom, Industry 4.0 technologies shall be understood to mean "eight great technologies" (Government of UK, 2022). The most general (universal, international) list of Industry 4.0 technologies can be found in UNCTAD records (2022), where they are referred to as "Frontier technologies" and include Artificial Intelligence (AI), Internet of Things (IoT), Big Data, Blockchain, 5G, 3D printing, robots, drones, Gene Editing, nanotechnologies, and Solar Photovoltaic (Solar PV).

The studies by Haddouche and Ilinca (2022), Kanoun et al. (2021), Maggiore et al. (2021), Matsunaga et al. (2022), Morelli et al. (2022), Otoum et al. (2022), Wachnik et al. (2022) refer to IoT, Blockchain, robots, and AI as the most advanced and most common technologies of Industry 4.0 in the energy economy. The problem lies in the fact that despite the advantages of digital energetics disclosed in detail in the existing literature (Popkova, 2022), there is still much uncertainty as to whether these advantages are achieved in practice and how to maximize them.

Due to this problem, the development of digital energetics occurs spontaneously. The lack of scientific and methodological support prevents achieving full growth potential to increase the effectiveness of advanced technologies of Industry 4.0 in the energy economy. In the context of global competition in the field of high technologies, energy economies aim to strengthen their digital competitive advantages.

The disadvantage of the current approach to the development of the energy economy based on Industry 4.0 technologies is that its digital competitiveness is an objective in itself. This approach does not guarantee benefits in the form of energy sustainability, providing only its innovation and high-tech. This causes the low effectiveness of this approach due to limited results at high costs (investments in high technologies) and risks (relating to innovations). The hypothesis of this article is that, with the current approach, there is a weak connection between digitalization and energy sustainability.

TABLE 1 | Global monitoring of the development of digital energy based on Industry 4.0 technologies in 2021.

Country category	Country	Energy Trilemma index, scores 0–100	The readiness for frontier technologies index		Government AI readiness index, scores 0–100	Digital Competitiveness, scores 0–100	Efficiency of digital energy
			Scores 0–1	Scores 0–100			
		ETI	-	RFT	AIR	DCEE	DEEF
Top countries by GDP per unit of energy use	Irish	76.8	0.92	92.0	72.80	80.53	0.93
	Switzerland	83.8	0.97	97.0	68.56	83.12	1.01
	Colombia	69.0	0.44	44.0	58.91	57.30	1.34
	Denmark	83.0	0.92	92.0	76.96	83.99	0.98
Top countries by energy imports, net	Singapore	69.3	0.95	95.0	82.46	82.25	0.78
	South Korea	70.1	0.93	93.0	76.55	79.88	0.83
	Belgium	76.3	0.90	90.0	60.07	75.46	1.02
	Portugal	75.6	0.71	71.0	64.31	70.30	1.12
Top countries by fuel exports (merchandise exports)	Qatar	70.3	0.46	46.0	67.18	61.16	1.24
	UAE	69.5	0.63	63.0	71.60	68.03	1.03
	Saudi Arabia	67.5	0.57	57.0	63.42	62.64	1.12
	Kazakhstan	67.7	0.50	50.0	48.43	55.38	1.38

Source: compiled and calculated by the authors on the basis of the materials from Oxford Insights (2022), UNCTAD (2022), and World Energy Council (2022).

Thus, to accelerate the development of digital energetics based on the technologies of Industry 4.0 aimed at achieving the Sustainable Development Goal 7 (SDG 7), a new (alternative) approach and scientific and methodological support for its implementation are required. The significance of SDG 7 is that it goes beyond the interests of particular categories of beneficiaries of the energy economy (e.g., affordability of energy for society, reduction in expenses for the development of the energy economy for the state, and increase in profits for energy companies) and forms a consistent idea of how to simultaneously and comprehensively maximize the benefits of the energy economy for all stakeholders (He et al., 2022; Yu et al., 2022).

In this regard, SDG 7 sets such priorities as sustainability (deficit-free energy, balance of global energy markets, stability of global and local energy prices to ensure its wide affordability, reliable and flawless operation of value chains in the energy economy), and environmental friendliness (mitigation of environmental risks of energy production and transportation, reduction/prevention of the depletion of natural resources for their conservation for succeeding generations, and the transition to "clean" energy) of the energy economy (Che et al., 2021; Firoiu et al., 2021; Madurai Elavarasan et al., 2021).

The purpose of this article is to conduct global monitoring of the development of digital energetics based on the technologies of Industry 4.0 and propose a new (alternative) approach to managing this development with a focus on supporting the practical implementation of SDG 7. The novelty of this study and its contribution to knowledge consist in forming a consistent scientific concept of the benefits of using Industry 4.0 technologies for the sustainable and environmentally friendly development of the energy economy.

DIGITAL ENERGETICS BASED ON THE TECHNOLOGIES OF INDUSTRY 4.0: IOT, BLOCKCHAIN, ROBOTS, AND AI

This article is based on the theory of digital energetics. In the available literature, numerous benefits from advanced technologies of Industry 4.0 in the energy economy are noted as follows:

→ The Internet of Things (IoT) makes it possible to integrate production and distribution networks and processes into a single cyber-physical system of Industry 4.0 in digital energetics (Krishnan and Jacob, 2022; Zhao et al., 2022).
→ Blockchain increases the transparency and control of value chains in the energy economy (Gawusu et al., 2022; Mahmoudian Esfahani, 2022).
→ Robots increase the productivity of energy companies (Huang et al., 2022).
→ Artificial Intelligence (AI) increases the flexibility and efficiency (through intelligent management decision support) of value chains in the energy economy (Bezbakh and Frolova, 2022).

In the works of Amir et al. (2022), Chen et al. (2022), Favi et al. (2022), and Vlasov et al. (2019), the use of advanced Industry 4.0 technologies in the energy economy provides advantages in both production and distribution processes. Maggiore et al. (2021), Morelli et al. (2022), Wachnik et al. (2022), and Zaidan et al. (2022) indicated that, in order to fully take benefit of the advanced technologies of Industry 4.0 in the energy economy, it is advisable to actively use them by representatives of all interested parties: energy companies, state regulators of the energy economy, and energy consumers. Baxter (2012), Inshakov et al. (2019), Kabeyi and Olanrewaju (2022), Kapitonov et al. (2019), Kluczek et al. (2021), and Ratner et al. (2022) stated that the digitalization of the energy economy based on advanced technologies of Industry 4.0 is universal—it is suitable for all countries, regardless of their energy efficiency, role, and position in global energy markets.

Based on the above publications, it can be concluded that the existing approach to the development of the energy economy based on Industry 4.0 technologies recognizes digitalization as a priority of this development with the secondary sustainability of energy (it is assumed that digitalization provides it). However, the relationship between digitalization and energy sustainability is poorly studied and not confirmed, which is a research gap. The identified gap is filled in this study by clarifying the relationship between the use of advanced Industry 4.0 technologies and energy sustainability.

DIGITAL COMPETITIVENESS OF ENERGY ECONOMIES AND ANALYSIS OF ITS DIFFERENCES AMONG CATEGORIES OF COUNTRIES

In order to achieve this goal and verify the hypothesis put forward, this article conducts global monitoring of the development of digital energetics based on the technologies of Industry 4.0. Monitoring is aimed at accurately quantifying the level of development of digital energetics as a vector of growth and sustainable development of the energy economy.

The study is based on the experience of the top four countries with the highest energy efficiency of the economy (according to the criterion of GDP per unit of energy use, constant 2017 PPP $ per kg of oil equivalent), the top four countries with the largest energy imports, net (% of energy use), and the top four countries with the largest fuel exports (% of merchandise exports) according to the materials of the World Bank (2022). The sample of countries formed for this study made it possible to comprehensively highlight the modern experience of digital energy development, which is considered from the standpoint of two groups of indicators.

The first group: Industry 4.0 technology development indicators: 1) “AI Readiness Index 2020” Oxford Insights (2022), designated AIR; 2) Readiness for Frontier Technologies Index 2021, presented in the UNCTAD report (2022) and designated RFT. The second group: the “World Energy Trilemma Index 2020 Report” World Energy Council (2022) as an indicator of sustainability and environmental friendliness of the energy economy, designated by ETI.

Based on the systematization of the data of both groups, the digital competitiveness of the energy economy [DCEE = (ETI, RFT, and AIR) is estimated/3] and its efficiency [DEEF = ETI/(RFT + AIR)/2]. The classical concepts of economic efficiency as the ratio of results (in our case: sustainability and environmental friendliness of the energy economy) to costs (in our case: technologies of Industry 4.0) (Akram et al., 2022; Gorus and Karagol, 2022) and competitiveness in terms of achieved results compared to other competing countries (in our case, identified by means of rankings) (Nagel et al., 2022; Shuai et al., 2022) served as the prerequisites and the basis for the calculation methods. The study is conducted according to data for 2021. The initial data and the results of their analysis are presented in **Table 1**.

The global monitoring of the development of digital energetics based on the technologies of Industry 4.0 in 2021, presented in **Table 1**, led to the following results:

→ The digital competitiveness of the energy economy as a whole is high in all the categories of countries considered. It is highest in the top countries by energy imports (76.97 points) and in the top countries by GDP per unit of energy use (76.24 points), and in the top countries by fuel exports, it is estimated at 61.80 points.
→ The efficiency of digitalization of the energy economy is low in all categories of countries (it has not reached 1.5). The digital energy economy is inefficient in the top countries by energy imports (0.94—costs exceed benefits, less than 1) and low-efficient (benefits slightly exceed costs) in the top countries by GDP per unit of energy use (1.07) and in the top countries by fuel exports (1.19).
→ This leads us to the conclusion that the introduction, expansion, and use of technologies of Industry 4.0 (i.e., the transition to the digital energy economy) guarantees an increase in the digital competitiveness of the energy economy but does not indicate an increase in its efficiency (from the perspective of contribution to the sustainability and environmental friendliness of the energy economy).
→ Hence, this calls for more complex management of the development of the digital energy economy, which will ensure not only an increase in the level of its high technologies (the use of Industry 4.0 technologies—IoT, blockchain, robots, and AI) but also improved results from the perspective of increasing the sustainability and environmental friendliness of the energy economy. The contribution of the suggested methodology to the more intensive acquisition of new knowledge is that the methodological guidelines of the authors allow improving the accuracy and reliability of the quantitative measurement of the efficiency and competitiveness of the digital energy economy.
→ The authors’ methodology allows obtaining highly detailed evaluation results and, thus, identifying the cause-and-effect relationship between changes in the efficiency and competitiveness of the digital energy economy and their weaknesses and strengths. As a result, it is possible and recommended to develop a national economic policy to manage the development of the digital energy economy, aimed at increasing the efficiency and competitiveness of the digital energy economy.

THE LEVEL OF THE DEVELOPMENT OF DIGITAL ENERGETICS AS A VECTOR OF GROWTH AND SUSTAINABLE DEVELOPMENT OF THE ENERGY ECONOMY: A NEW MANAGEMENT APPROACH

In order to determine the contribution of digital energy to the sustainable development of the energy economy based on empirical data from **Table 1**, the following regression model was obtained by regression analysis:

$$ETI = 67.9697 + 0.2240*RFT - 0.1678*AIR. \quad (1)$$

According to model (1), energy sustainability increases by 0.2240 points when the readiness for Frontier technologies index increases by one point but does not demonstrate a positive dependence on the government AI Readiness Index. The significance of F for model (1) was 0.0628. The multiple R in model (1) was 0.6778. The advantage of the regression analysis method that has been chosen for the pursuance of the research in this study is its high accuracy—this is one of the most reliable methods of statistical economics (econometrics).

The existing concepts of the potential relationship between these indicators (Ghobakhloo and Fathi, 2021; Kluczek et al., 2021) and the successful identification of individual manifestations of this relationship in previous works by Hidayatno et al. (2019), Knez et al. (2022), and Koyuncu et al. (2021) served as the prerequisites and the basis for the calculation methods for obtaining the regression model that is presented to determine the contribution of the digital energy economy to the sustainable development of the energy economy. Also, by the method of correlation analysis, the following was found:

→ Readiness for Frontier Technologies Index is positively associated with energy sustainability only in the top countries by GDP per unit of energy use (correlation 0.91), in the top countries by energy imports (−0.65), and in the top countries by fuel exports (−0.17%); the relationship of these indicators is negative.

→ The Government AI Readiness Index is positively associated with energy sustainability only in the top countries by GDP per unit of energy use (correlation 0.78), in the top countries by energy imports (0.67), and in the top countries by fuel exports (−0.99%); the relationship of these indicators is negative.

This brings us to the conclusion that Industry 4.0 technologies make a considerable and significant contribution to ensuring the sustainability and environmental friendliness of the energy economy. In this regard, a new (alternative) approach to the development of digital energetics based on the technologies of Industry 4.0 is proposed, which supports the implementation of SDG 7 and assumes a focus on the digitalization of energy companies, the flexibility necessary to consider the characteristics of each category of countries, and the priority of the efficiency of the digital energy economy.

Based on model (1), the new approach is expected to increase energy sustainability by 6.20% (73.24–77.78 points) while maximizing the readiness for advanced technologies of the index (+33.83%, 74.17–100 points). The established approach to the development of digital energetics based on the technologies of Industry 4.0 is versatile—it can be implemented around the world (by large energy suppliers and exporters and by large energy consumers and importers, as well as by other countries). This approach will ensure the accelerated digitalization of the energy economy and increase its efficiency; as a result, it will support the global implementation of SDG 7.

DISCUSSION

The article contributed to the development of the theory of digital energetics by clarifying the relationship between digitalization and energy sustainability. In contrast to Amir et al. (2022), Chen et al. (2022), Favi et al. (2022), and Vlasov et al. (2019), the use of advanced Industry 4.0 technologies in the energy economy provides advantages only in the production (but not in distribution) processes. The argumentation of this conclusion is based on the fact that the relationship of energy sustainability with the readiness for Frontier Technologies Index and with the government AI Readiness Index among countries of different categories is much stronger in the top countries by GDP per unit of energy use compared to other categories of countries. Consequently, advanced technologies of Industry 4.0 contribute to the growth of energy efficiency of the economy, but only to a small extent improve distribution processes.

In contrast to Maggiore et al. (2021), Morelli et al. (2022), Wachnik et al. (2022), and Zaidan et al. (2022), it was justified that, in order to take advantage of the use of advanced technologies of Industry 4.0 in the energy economy, it is advisable to actively use them only in entrepreneurship, while their use in society and the state does not provide advantages with the current approach to the development of the energy economy based on Industry 4.0 technologies. The reasoning of this conclusion is based on the revealed absence of a positive contribution of the government AI Readiness Index to the sustainability of energy.

Unlike Baxter (2012), Inshakov et al. (2019), Kabeyi and Olanrewaju (2022), Kapitonov et al. (2019), Kluczek et al. (2021), and Ratner et al. (2022), it was proved that digitalization of the energy economy based on advanced technologies of Industry 4.0 is not universal—it should be based on a unique organizational model for each category of countries, considering its peculiarities. The reasoning of this conclusion is based on the fundamental differences in the connection of energy sustainability with the readiness for the Frontier Technologies Index and with the government AI Readiness Index among countries of different categories.

Furthermore, this study contributes to the development of the methodology for monitoring the development of digital energetics based on the technologies of Industry 4.0. The methodological guidelines proposed in this study allow for the highly accurate quantification of the competitiveness (through the arithmetic mean of Industry 4.0 technologies, sustainability, and environmental friendliness of the energy economy) and efficiency (through the ratio of sustainability and environmental friendliness of the energy economy to Industry 4.0 technologies) of the digital energy economy.

This is of particular assistance in the "decade of action"—in the modern global context, where the implementation of SDG

7 is the priority of the development of the digital energy economy. Authors' guidelines have established a methodological basis for the measurement (evaluation formulas, regression model) and management (a new approach to the development of digital energetics based on the technologies of Industry 4.0) of the development of the digital energy economy to support the implementation of SDG 7.

CONCLUSION

Therefore, the global monitoring of the development of digital energetics based on the technologies of Industry 4.0 has shown that, with the current approach, the connection between digitalization and energy sustainability is weak. Although Industry 4.0 technologies generally determine the sustainability and environmental friendliness of the global energy economy by 67.78%, their relationship is contradictory at the level of certain categories of countries. In the top countries in terms of GDP per unit of energy use, Industry 4.0 technologies determine the sustainability and environmental friendliness of the energy economy by 78%–91%. In the top countries in terms of energy imports, this contribution is lower and amounts to 65%–67%, whereas in the top countries in terms of fuel exports, no positive contribution has been identified. This indicates significant differences in the development of digital energetics based on the technologies of Industry 4.0 (IoT, blockchain, robots, and AI) across the world.

In order to solve this problem, a new (alternative) approach to the development of digital energetics based on the technologies of Industry 4.0 is proposed, supporting the implementation of SDG 7 and assuming a focus on the digitalization of energy companies, the flexibility necessary to consider the characteristics of each category of countries, and the priority of the efficiency of the digital energy economy.

The theoretical significance of the study is to substantiate the primacy of energy sustainability over its digitalization. This fundamental conclusion allowed us to more accurately determine the order of development of digital energetics based on the technologies of Industry 4.0. The practical significance of the article is explained by the fact that the proposed new approach to the development of digital energetics based on the technologies of Industry 4.0 allows accelerating this development and increasing its efficiency, considering the peculiarities of countries of different categories.

AUTHOR CONTRIBUTIONS

VK, VL, NF, and EP contributed to the conception and design of the study. VK, VL, NF, and EP wrote sections of the manuscript. All authors contributed to manuscript revision and read and approved the submitted version.

REFERENCES

Akram, R., Umar, M., Xiaoli, G., and Chen, F. (2022). Dynamic linkages between energy efficiency, renewable energy along with economic growth and carbon emission. A case of MINT countries an asymmetric analysis. *Energy Rep.* 8, 2119–2130. doi:10.1016/j.egyr.2022.01.153

Amir, M., Prajapati, A. K., and Refaat, S. S. (2022). Dynamic Performance Evaluation of Grid-Connected Hybrid Renewable Energy-Based Power Generation for Stability and Power Quality Enhancement in Smart Grid. *Front. Energy Res.* 10, 861282. doi:10.3389/fenrg.2022.861282

Baxter, R. (2012). Energy storage & the digital economy: Enabling innovative change. *Oil Gas J.* 110 (12), 8–12.

Bezbakh, V. V., and Frolova, E. E. (2022). Artificial intelligence in the regulatory context of Industry 4.0 and epistemological optimism. *Adv. Res. Russ. Bus. Manag.* 2022, 289–307.

Che, X., Jiang, M., and Fan, C. (2021). Multidimensional Assessment and Alleviation of Global Energy Poverty Aligned With UN SDG 7. *Front. Energy Res.* 9, 777244. doi:10.3389/fenrg.2021.777244

Chen, G., Gao, H., Ma, G., Liu, J., and Yin, W. (2022). The Evolution Trend of "Digital Economy" and Its Enlightenment to Energy Enterprises. *Lect. Notes Data Eng. Commun. Technol.* 85, 858–863. doi:10.1007/978-981-16-5854-9_114

European Comission (2022). Digital Transformation Monitor Germany: Industrie 4.0, January 2017. Available at: https://ati.ec.europa.eu/sites/default/files/2020-06/DTM_Industrie%204.0_DE.pdf (accessed date: 05.06.2022).

Favi, C., Marconi, M., Mandolini, M., and Germani, M. (2022). Sustainable life cycle and energy management of discrete manufacturing plants in the Industry 4.0 framework. *Appl. Energy* 312, 118671. doi:10.1016/j.apenergy.2022.118671

Firoiu, D., Ionescu, G. H., Pîrvu, R., Cismaș, L. M., Tudor, S., and Patrichi, I. C. (2021). Dynamics of implementation of sdg 7 targets in eu member states 5 years after the adoption of the paris agreement. *Sustainability* 13 (15), 8284. doi:10.3390/su13158284

Gawusu, S., Zhang, X., Ahmed, A., Jamatutu, S. A., Miensah, E. D., Amadu, A. A., et al. (2022). Renewable energy sources from the perspective of blockchain integration: From theory to application. *Sustain. Energy Technol. Assessments* 52, 102108. doi:10.1016/j.seta.2022.102108

Ghobakhloo, M., and Fathi, M. (2021). Industry 4.0 and opportunities for energy sustainability. *J. Clean. Prod.* 295, 126427. doi:10.1016/j.jclepro.2021.126427

Gorus, M. S., and Karagol, E. T. (2022). Reactions of energy intensity, energy efficiency, and activity indexes to income and energy price changes: The panel data evidence from OECD countries. *Energy* 254, 124281. doi:10.1016/j.energy.2022.124281

Government of Uk (2022). Eight great technologies. Available at: https://www.gov.uk/government/speeches/eight-great-technologies (accessed date: 05.06.2022).

Haddouche, M., and Ilinca, A. (2022). Energy Efficiency and Industry 4.0 in Wood Industry: A Review and Comparison to Other Industries. *Energies* 15 (7), 2384. doi:10.3390/en15072384

He, J., Yang, Y., Liao, Z., Xu, A., and Fang, K. (2022). Linking SDG 7 to assess the renewable energy footprint of nations by 2030. *Appl. Energy* 317, 119167. doi:10.1016/j.apenergy.2022.119167

Hidayatno, A., Destyanto, A. R., and Hulu, C. A. (2019). Industry 4.0 technology implementation impact to industrial sustainable energy in Indonesia: A model conceptualization. *Energy Procedia* 156, 227–233. doi:10.1016/j.egypro.2018.11.133

Huang, G., He, L.-Y., and Lin, X. (2022). Robot adoption and energy performance: Evidence from Chinese industrial firms. *Energy Econ.* 107, 105837. doi:10.1016/j.eneco.2022.105837

Inshakov, O. V., Bogachkova, L. Y., and Popkova, E. G. (2019). Energy efficiency as a driver of global competitiveness, the priority of the state economic policy and the international collaboration of the Russian Federation. *Lect. Notes Netw. Syst.* 44, 119–134. doi:10.1007/978-3-319-90966-0_9

Kabeyi, M. J. B., and Olanrewaju, O. A. (2022). Sustainable Energy Transition for Renewable and Low Carbon Grid Electricity Generation and Supply. *Front. Energy Res.* 9, 743114. doi:10.3389/fenrg.2021.743114

Kanoun, O., Khriji, S., Naifar, S., Bradai, S., Bouattour, G., Bouhamed, A., et al. (2021). Prospects of wireless energy-aware sensors for smart factories in the industry 4.0 era. *Electronics* 10 (23), 2929. doi:10.3390/electronics10232929

Kapitonov, I. A., Filosofova, T. G., and Korolev, V. G. (2019). Development of digital economy in the energy industry-specific modernization. *Ijeep* 9 (4), 273–282. doi:10.32479/ijeep.8013

Kluczek, A., Żegleń, P., and Matušíková, D. (2021). The use of prospect theory for energy sustainable Industry 4.0. *Energies* 14 (22), 7694. doi:10.3390/en14227694

Knez, S., Šimić, G., Milovanović, A., Starikova, S., and Županič, F. Ž. (2022). Prices of conventional and renewable energy as determinants of sustainable and secure energy development: regression model analysis. *Energ Sustain Soc.* 12 (1), 6. doi:10.1186/s13705-022-00333-9

Koyuncu, T., Beşer, M. K., and Alola, A. A. (2021). Environmental sustainability statement of economic regimes with energy intensity and urbanization in Turkey: a threshold regression approach. *Environ. Sci. Pollut. Res.* 28 (31), 42533–42546. doi:10.1007/s11356-021-13686-z

Krishnan, P. R., and Jacob, J. (2022). An IOT based efficient energy management in smart grid using DHOCSA technique. *Sustain. Cities Soc.* 79, 103727. doi:10.1016/j.scs.2022.103727

Madurai Elavarasan, R., Pugazhendhi, R., Jamal, T., Dyduch, J., Arif, M. T., Manoj Kumar, N., et al. (2021). Envisioning the UN Sustainable Development Goals (SDGs) through the lens of energy sustainability (SDG 7) in the post-COVID-19 world. *Appl. Energy* 292, 116665. doi:10.1016/j.apenergy.2021.116665

Maggiore, S., Realini, A., Zagano, C., Bazzocchi, F., Gobbi, E., and Borgarello, M. (2021). Energy efficiency in Industry 4.0: assessing the potential of Industry 4.0 to achieve 2030 decarbonisation targets. *Int. J. EQ* 6 (4), 371–381. doi:10.2495/EQ-V6-N4-371-381

Mahmoudian Esfahani, M. (2022). A hierarchical blockchain-based electricity market framework for energy transactions in a security-constrained cluster of microgrids. *Int. J. Electr. Power & Energy Syst.* 139, 108011. doi:10.1016/j.ijepes.2022.108011

Matsunaga, F., Zytkowski, V., Valle, P., and Deschamps, F. (2022). Optimization of Energy Efficiency in Smart Manufacturing Through the Application of Cyber-Physical Systems and Industry 4.0 Technologies. *J. Energy Resour. Technol. Trans. ASME* 144 (10), 102104. doi:10.1115/1.4053868

Morelli, G., Magazzino, C., Gurrieri, A. R., Pozzi, C., and Mele, M. (2022). Designing Smart Energy Systems in an Industry 4.0 Paradigm towards Sustainable Environment. *Sustainability* 14 (6), 3315. doi:10.3390/su14063315

Nagel, N. O., Kirkerud, J. G., and Bolkesjø, T. F. (2022). The economic competitiveness of flexibility options: A model study of the European energy transition. *J. Clean. Prod.* 350, 131534. doi:10.1016/j.jclepro.2022.131534

Otoum, S., Ridhawi, I. A., and Mouftah, H. (2022). A Federated Learning and Blockchain-enabled Sustainable Energy-Trade at the Edge: A Framework for Industry 4.0. *IEEE Internet Things J.*, 1. doi:10.1109/JIOT.2022.3140430

Oxford Insights (2022). Government AI Readiness Index 2021. Available at: https://static1.squarespace.com/static/58b2e92c1e5b6c828058484e/t/61ead0752e7529590e98d35f/1642778757117/Government_AI_Readiness_21.pdf.

Popkova, E. G. (2022). *Advanced Issues in the Green Economy and Sustainable Development in Emerging Market Economies (Elements in the Economics of Emerging Markets)*. Cambridge: Cambridge University Press. doi:10.1017/9781009093408 Advanced Issues in the Green Economy and Sustainable Development in Emerging Market Economies.

Ratner, S., Berezin, A., Gomonov, K., Serletis, A., and Sergi, B. S. (2022). What is stopping energy efficiency in Russia? Exploring the confluence of knowledge, negligence, and other social barriers in the Krasnodar Region. *Energy Res. Soc. Sci.* 85, 102412. doi:10.1016/j.erss.2021.102412

Shuai, J., Zhao, Y., Wang, Y., and Cheng, J. (2022). Renewable energy product competitiveness: Evidence from the United States, China and India. *Energy* 249, 123614. doi:10.1016/j.energy.2022.123614

UNCTAD (2022). Technology And Innovation Report 2021 Catching technological waves Innovation with equity. Available at: https://unctad.org/system/files/official-document/tir2020_en.pdf (Accessed April 20, 2022).

Vlasov, A. I., Shakhnov, V. A., Filin, S. S., and Krivoshein, A. I. (2019). Sustainable energy systems in the digital economy: Concept of smart machines. *Jesi* 6 (4), 1975–1986. doi:10.9770/jesi.2019.6.4(3010.9770/jesi.2019.6.4(30)

Wachnik, B., Kłodawski, M., and Kardas-Cinal, E. (2022). Reduction of the Information Gap Problem in Industry 4.0 Projects as a Way to Reduce Energy Consumption by the Industrial Sector. *Energies* 15 (3), 1108. doi:10.3390/en15031108

World Bank (2022). Indicators: Energy and Mining. Available at: https://data.worldbank.org/indicator (Accessed April 20, 2022).

World Energy Council (2022). Energy Trilemma Index. Available at: https://trilemma.worldenergy.org/ (Accessed April 20, 2022).

Yu, M., Kubiczek, J., Ding, K., Jahanzeb, A., and Iqbal, N. (2022). Revisiting SDG-7 under energy efficiency vision 2050: the role of new economic models and mass digitalization in OECD. *Energy Effic.* 15 (1), 2. doi:10.1007/s12053-021-10010-z

Zaidan, E., Ghofrani, A., Abulibdeh, A., and Jafari, M. (2022). Accelerating the Change to Smart Societies- a Strategic Knowledge-Based Framework for Smart Energy Transition of Urban Communities. *Front. Energy Res.* 10, 852092. doi:10.3389/fenrg.2022.852092

Zhao, W., Chen, J., Hai, T., Mohammed, M. N., Yaseen, Z. M., Yang, X., et al. (2022). Design of low-energy buildings in densely populated urban areas based on IoT. *Energy Rep.* 8, 4822–4833. doi:10.1016/j.egyr.2022.03.139

Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

frontiers | Frontiers in Energy Research

TYPE Opinion
PUBLISHED 04 August 2022
DOI 10.3389/fenrg.2022.943447

Check for updates

OPEN ACCESS

EDITED BY
Bruno Sergi,
Harvard University, United States

REVIEWED BY
Qaisar Mahmood,
COMSATS University, Islamabad Campus, Pakistan

*CORRESPONDENCE
Anastasia Andreevna Sozinova,
1982nastya1982@mail.ru

SPECIALTY SECTION
This article was submitted to Sustainable Energy Systems and Policies, a section of the journal Frontiers in Energy Research

RECEIVED 13 May 2022
ACCEPTED 30 June 2022
PUBLISHED 04 August 2022

CITATION
Fokina OV, Sozinova AA, Glebova AG and Nikonova NV (2022), Improving the quality of project management at energytech through marketing in support of sustainable and environmental development of energy economics.
Front. Energy Res. 10:943447.
doi: 10.3389/fenrg.2022.943447

Improving the quality of project management at energytech through marketing in support of sustainable and environmental development of energy economics

Olga Vasilyevna Fokina[1], Anastasia Andreevna Sozinova[1]*, Anna Gennadyevna Glebova[2] and Natalia Valeryevna Nikonova[3]

[1]Department of Management and Marketing, Vyatka State University, Kirov, Russia, [2]Financial University under the Government of the Russian Federation, Moscow, Russia, [3]Department of Accounting and Finance, Vyatka Agrotechnological University, Kirov, Russia

KEYWORDS

quality improvement, project management, EnergyTech, marketing, sustainable and environmental development, energy economics

Introduction

EnergyTech is a promising mechanism through which entrepreneurship can and actively supports the environmental development of the energy economy (Azam et al., 2022; Javed et al., 2022; Li et al., 2022; Tang, 2022). EnergyTech refers to advanced technologies in the energy sector introduced by both energy producers (energy companies) and consumers (urban power supply networks, businesses, and households) (Popkova et al., 2019; Popkova and Sergi, 2021). If urban power supply networks and households are guided by state energy norms, standards, and regulatory measures (and therefore are least subject to change), business is the most flexible subject of the energy economy and a driver of the development of EnergyTech.

The introduction of energy innovations into business activities takes place through project management, which from the standpoint of EnergyTech means the implementation of high-tech investment and innovation projects through production management, personnel management, and quality management (Sozinova and Lysova, 2021; Sozinova et al., 2021). An integrated view of project management in EnergyTech from the standpoint of Stakeholder Theory reveals its contradiction. On the one hand, energy companies are introducing advanced technologies to improve the efficiency of their activities, which may be and often is accompanied by an increase in the environmental costs of the energy economy. On the other hand, the state and society are interested in advanced technologies in the energy sector as sources of sustainable and environmental development of the energy economy.

Such contradictions in Stakeholder Theory are successfully overcome, in many cases, with the help of marketing. In this regard, based on the works of Daifen (2022), Jiménez-Marín et al. (2021), Krishnan and Butt (2022), and Wei et al. (2021), which highlight the advantages of marketing in EnergyTech, this article hypothesizes that marketing allows to improve the practice of project management in EnergyTech and provide support for sustainable and environmental development of energy economics. The purpose of this article is to explore the prospects for improving project management in EnergyTech through marketing in support of sustainable and environmental development of energy economics.

The role of project management quality in EnergyTech in ensuring sustainable and environmental development of energy economics

The fundamental basis of the research carried out in this article was laid by the scientific concept of EnergyTech as a field of high technologies in the energy economy. Project management at EnergyTech focuses on internal business priorities (Goyal et al., 2014; Sisodia et al., 2020; Štreimikienė et al., 2022; Teichmann et al., 2020), and therefore, this type of management is usually quantified in terms of costs and benefits, as well as their ratio (financial efficiency) (Buah et al., 2020; Martinez and Komendantova, 2020; Onubi et al., 2022).

From a qualitative point of view, the issues of project management in EnergyTech are insufficiently developed, which is a gap in the literature. In the works of Lotfi et al. (2022) and Mora-Villagómez and Reyes-López (2022), it is noted that, during the "Decade of Action," the quality of project management in EnergyTech should be evaluated from the standpoint of sustainable and environmental development of energy economics, but the issues of formation and improvement of the quality of this type of management need scientific study.

The established approach to project management belongs to the field of internal management (Anastasi et al., 2021; Khan et al., 2022; Qi et al., 2021; Rezaei et al., 2022; Sahoo et al., 2021). This approach ensures that the interests of the business are sufficiently fully respected when managing projects at EnergyTech (Hadini et al., 2021; Ji et al., 2021; Karthick et al., 2021; Vinjamuri and Burthi, 2022). At the same time, the interests of the external environment (society and the state) remain outside project management with the current approach, which is its disadvantage (Garcia-Bernabeu et al., 2019; Storch de Gracia et al., 2019; Hosseini et al., 2020; Izquierdo et al., 2020). The uncertainty of prospects for achieving a balance of internal and external interests (with their equivalence from the standpoint of Stakeholder Theory) in project management in EnergyTech is another gap in the literature. It seems that marketing can open up prospects for achieving the desired balance, but this requires scientific justification.

Both identified gaps are filled in this article through the study of project management in EnergyTech from the standpoint of quality (in support of sustainable and environmental development of energy economics), as well as the identification of prospects for improving the quality of this management through marketing. The essence of the hypothesis put forward and tested in this article is that quality plays a key role in project management in EnergyTech with a focus on ensuring sustainable and environmental development of energy economics.

Research methodology

The set purpose is achieved and the advanced hypothesis is tested in this paper based on empirical data of 2021 in two successive stages. At the first research stage, the method of correlation analysis is used to determine the significance of marketing for the quality of project management at EnergyTech. The following quantifiable parameters of project management at EnergyTech have been identified and used in the course of research. Firstly, project management results from the standpoint of quality (ISO 9001 quality certificates), production (high-tech manufacturing), and personnel (labor productivity growth) based on the World Bank statistics (2022).

Secondly, the manifestations of sustainable and environmental development of energy economics: GDP/unit of energy use and ISO 14001 environmental certificates, based on the World Bank statistics (2022) as well. Thirdly, the market potential of the economy as a basis for project management at EnergyTech through marketing based on the Global EDGE statistics (2022). The countries of the world are classified according to this criterion, and a separate study was conducted for each category of countries (countries with large and moderate market potentials) to take into account their marketing features when managing projects at EnergyTech.

At the second research stage, the case study method is used for the review and analysis of the empirical experience of project management at EnergyTech through marketing of energy companies in support of sustainable and environmental development of energy economics in Russia. Furthermore, the materials of a survey of CEOs in the energy sector in Russia "CEO Outlook Pulse Survey 2021," held by KPMG (2022) in 2021, are presented and rethought from the perspective of the quality of project management at EnergyTech.

TABLE 1 Quality of project management in EnergyTech from the standpoint of supporting sustainable and environmental development of the energy economy in countries with different market potentials in 2021. Score: 0–100.

Country category by marketing criterion	Country	ISO 9001 quality certificates/bn PPP$ GDP	High-tech manufacturing (%)	Labor productivity growth (%)	GDP/ unit of energy use	ISO 14001 environmental certificates/bn PPP$ GDP
Countries with a large (more than 35) market potential	China	31.3	63.1	87.5	17.0	35.5
	India	9.2	43.9	73.9	28.0	5.3
	Singapore	14.0	100.0	56.0	39.9	10.9
	Canada	5.9	48.5	58.9	10.8	2.5
	Japan	15.8	71.8	46.1	34.4	20.3
	South Korea	16.0	77.1	64.0	17.5	16.1
	Germany	28.6	74.6	49.3	38.2	11.5
	Vietnam	9.7	38.2	91.3	18.8	9.3
	Russia	2.8	32.6	63.7	7.9	1.2
	Australia	14.6	31.1	50.9	22.9	11.3
Countries with a moderate (less than 35) market potential	Malaysia	27.8	57.6	55.6	25.8	15.0
	Mexico	7.6	63.5	41.7	35.3	3.9
	UAE	14.5	33.4	52.8	25.7	16.8
	Chile	17.5	30.2	65.6	28.4	12.0
	Italy	94.5	52.9	43.8	44.8	40.1
	Lithuania	40.0	26.1	71.2	33.9	58.7
	Austria	16.7	59.0	50.1	39.3	12.1
	Poland	23.0	41.8	70.8	30.9	17.6
	Brazil	14.4	46.8	65.1	29.1	5.5
	South Africa	11.6	25.7	59.2	10.4	7.5

Source: compiled by the authors based on the materials of the World Bank (2022).

The importance of marketing for the quality of project management in EnergyTech: A view from the perspective of sustainable and environmental development of energy economics

To determine the importance of marketing for the quality of project management, EnergyTech uses the method of correlation analysis. Using this method, the quality of project management is determined as the relationship of project management results from the standpoint of quality (ISO 9001 quality certificates), production (high-tech manufacturing), and personnel (labor productivity growth) with the manifestations of sustainable and environmental development of the energy economy: GDP/unit of energy use and ISO 14001 environmental certificates.

Based on the Global EDGE (2022) statistics, the countries of the world are classified according to the marketing criterion (the value of the market potential index (MPI)), and countries with a large (MPI more than 35) market potential and countries with a moderate (MPI less than 35) market potential are highlighted. In each category, 10 countries with different levels and rates of socio-economic development, as well as from different geographical regions of the world, were selected from the Global EDGE rating (2022), which made it possible to provide a representative picture of the world economy. To determine the importance of marketing for the quality of project management in EnergyTech, the results of correlation analysis are compared between two categories of countries. The statistical basis of the study is given in Table 1.

Based on the data in Table 1, it was found that the quality of project management in EnergyTech in countries with a large market potential is higher. Thus, the correlation of GDP/unit of energy use in countries with a large market potential was 65.23% compared to 56.27% in countries with a moderate market potential. The correlation of ISO 9001 quality certificates with high-tech manufacturing was 80.71 vs. 69.26%, that with labor productivity growth was 38.55% vs. negative value, and that with

ISO 14001 environmental certificates was 24.23 vs. 22.19%—that is, in all cases, it was higher in countries with a large market potential.

On average, the correlation of project management with sustainable and environmental development of the energy economy in countries with a large market potential was 34.35%, which is significantly higher than that in countries with a smaller market potential (23.18%). Therefore, marketing is important for improving the quality of project management in EnergyTech from the standpoint of supporting sustainable and environmental development of the energy economy.

Practical experience in project management at EnergyTech through marketing of energy companies in support of sustainable and environmental development of the energy economy in Russia

Conducting an in-depth qualitative study of the modern Russian project management experience in the field of EnergyTech of energy companies using the case study method allowed us to identify advanced marketing practices in each component of project management. Environmental marketing is actively developing in production management in Russian energy companies. Thus, according to the KPMG survey (2022) of energy sector managers, these companies consider the environmental risk/risk of climate change to be the most serious (43%).

For example, PJSC "Rosseti" develops solar energy (it has already prepared the infrastructure and power transmission lines to put into operation the Torey solar station). PJSC "RusHydro" develops hydropower (invests in the modernization and development of the Primorye Energy System). JSC "Concern Rosenergoatom" supports employment and develops alternative energy in the regions of Russia (commissioned the sixth unit of the Leningrad NPP) (Energy and industry of Russia, 2022).

In the personnel management system in Russia, personnel marketing aimed at automation for the growth of productivity and labor safety of employees of energy companies is actively used. The most common technologies are production automation (robotics), artificial intelligence, digital communication tools, customer-oriented technologies (chatbots), and data security technologies (cybersecurity) (KPMG, 2022). With the introduction of advanced technologies (that is, the development of EnergyTech), energy companies support work adaptation, training, and retraining of employees with the help of personnel marketing.

In quality management, Russian energy companies implement relationship marketing in corporate environmental responsibility. For example, LLC "Rusatom Infrastructure Solutions" (part of the State Atomic Energy Corporation "Rosatom") conducts marketing research and PR of its contribution to the development of EnergyTech with the help of digital marketing, which consists in reducing the level of accidents in power plants, reducing heat losses and improved AI analytics of their causes, improving the quality of operational-dispatching management, increasing the level of energy efficiency, remote data collection and management of heat supply systems, ensuring transparency and efficiency of collection of funds from management companies and the public, and containment of growth of tariffs (Tadviser (2022)).

Discussion

This article contributed to the development of the EnergyTech concept by clarifying the specifics of project management in support of sustainable and environmental development of energy economics. Unlike Buah et al. (2020), Martinez and Komendantova (2020), and Onubi et al. (2022), the authors proposed to evaluate project management in EnergyTech using qualitative rather than quantitative criteria. The essence of qualitative criteria is to determine the degree of compliance of project management with the goals of sustainable and environmental development of energy economics. The relationship of ISO 9001 quality certificates, high-tech manufacturing, and labor productivity growth with GDP/unit of energy use and ISO 14001 environmental certificates is proposed as an indicator for assessing the quality of EnergyTech project management.

In contrast to Garcia-Bernabeu et al. (2019), Hosseini et al. (2020), Izquierdo et al. (2020), and Storch de Gracia et al. (2019), this article suggests a transition from quality management to quality marketing in the management of EnergyTech projects. The advantage of the recommended marketing management is the balance of internal and external interests in project management. This brought project management in EnergyTech in line with Stakeholder Theory. The marketing approach to project management in EnergyTech provides the greatest support for sustainable and environmental development of energy economics.

Thus, the contribution of this paper to the literature consists in the statement of need and the formation of a scientific and methodological basis for improving the quality of project management at EnergyTech in support of sustainable and environmental development of energy economics. The key conclusion of this research is that the improved quality of project management at EnergyTech in support of sustainable and environmental development of energy economics must be based on the marketing methodology. The review and analysis of best international practices, as well as the case experience of Russia in 2021, has shown that the way to improving the quality of project management at EnergyTech lies through the development and fulfillment of the market potential of the economy.

This paper has provided an integrated perspective on project management at EnergyTech from the standpoint of Stakeholder Theory. A new approach—the marketing approach that has been put forward in this paper—to improving the quality of project management at EnergyTech allows overcoming the contradiction of this management that exists with the current approach (assuming quality management) and achieving a balance of interests of stakeholders and energy markets.

Conclusion

In conclusion, it should be noted that the hypothesis put forward in this study has been confirmed. It is proved that marketing makes it possible to improve the practice of project management in EnergyTech and provide support for sustainable and environmental development of energy economics. This is evidenced by the fact that, in countries with a large market potential, the quality of project management in EnergyTech is 1.5 times higher (through marketing). This is also confirmed by the case experience related to project management in EnergyTech through marketing of energy companies in support of sustainable and environmental development of the energy economy in Russia, which is discussed in this article.

The theoretical significance of the findings made in this study is that they clarified the essence of project management in EnergyTech from the standpoint of quality and also identified prospects for improving the quality of this management through marketing. The practical significance of the results obtained and the recommendations formulated is related to the fact that they formed the scientific and methodological basis for the transition to the marketing approach of quality management in EnergyTech, which provides the greatest support for sustainable and environmental development of energy economics.

Author contributions

AS and OF contributed to conception and design of the study. AG organized the database. AS wrote the first draft of the manuscript. OF, AG, and NN performed the statistical analysis and wrote sections of the manuscript. All authors contributed to manuscript revision and read and approved the submitted version.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

References

Anastasi, G., Bartoli, C., Conti, P., Franco, A., Saponara, S., Thomopulos, D., et al. (2021). Optimized energy and air quality management of shared smart buildings in the Covid-19 scenario. *Energies* 14 (8), 2124. doi:10.3390/en14082124

Azam, A., Rafiq, M., Shafique, M., and Yuan, J. (2022). Towards achieving environmental sustainability: the role of nuclear energy, renewable energy, and ICT in the top-five carbon emitting countries. *Front. Energy Res.* 9, 804706. doi:10.3389/fenrg.2021.804706

Buah, E., Linnanen, L., Wu, H., and Kesse, M. A. (2020). Can artificial intelligence assist project developers in long-term management of energy projects? the case of CO_2 capture and storage. *Energies* 13 (23), 6259. doi:10.3390/en13236259

Daifen, T. (2022). Evaluate the sustainable marketing strategy to optimal online leasing of new energy vehicles under the background big data economy. *J. Enterp. Inf. Manag.* 35, 1409–1424. doi:10.1108/JEIM-02-2021-0087

Energy and industry of Russia (2022). Rating of energy companies for the first quarter of 2021. Available at: https://www.eprussia.ru/epr/417-418/4900829.htm (data accessed: 08.05.2022).

Garcia-Bernabeu, A., Mayor-Vitoria, F., Bravo, M., and Pla-Santamaria, D. (2019). Financial risk management in renewable energy projects: a multicriteria approach. *J. Manag. Inf. Decis. Sci.* 22 (4), 360–371.

Global EDGE (2022). Market potential index (MPI) – 2021. Available at: https://globaledge.msu.edu/mpi/data/2021 (accessed: 08.05.2022).

Goyal, S., Esposito, M., Kapoor, A., Jaiswal, M. P., and Sergi, B. S. (2014). Linking up: inclusive business models for access to energy solutions at base of the pyramid in India. *Int. J. Bus. Glob.* 12 (4), 413–438. doi:10.1504/IJBG.2014.062843

Hadini, M., Ali, M. B., Rifai, S., Bouksour, O., and Adri, A. (2021). Proposal of a causal model to measure the impact of quality management system on industrial performance: a case study of a multinational energy company located in casablanca, kingdom of morocco. *Int. J. Qual. Eng. Technol.* 8 (2), 173–200. doi:10.1504/IJQET.2021.113720

Hosseini, S. H., Shakouri, H. G., Kazemi, A., Zareayan, R., and Mousavian, M. H. (2020). A system dynamics investigation of project portfolio management evolution in the energy sector: case study: an iranian independent power producer. *Kybernetes* 49 (2), 505–525. doi:10.1108/K-12-2018-0688

Izquierdo, J., Márquez, A. C., Uribetxebarria, J., and Erguido, A. (2020). On the importance of assessing the operational context impact on maintenance management for life cycle cost of wind energy projects. *Renew. Energy* 153, 1100–1110. doi:10.1016/j.renene.2020.02.048

Javed, H., Irfan, M., Shehzad, M., Akhter, J., Dagar, V., Guerrero, J. M., et al. (2022). Recent trends, challenges, and future aspects of P2P energy trading platforms in electrical-based networks considering blockchain technology: a roadmap toward environmental sustainability. *Front. Energy Res.* 10, 810395. doi:10.3389/fenrg.2022.810395

Ji, X., Wang, H., and He, L. (2021). New energy grid-connected power quality management system based on internet of things. *Sustain. Comput. Inf. Syst.* 30, 100460. doi:10.1016/j.suscom.2020.100460

Jiménez-Marín, G., Zambrano, R. E., Galiano-Coronil, A., and Ravina-Ripoll, R. (2021). Business and energy efficiency in the age of industry 4.0: the hulten, broweus and van dijk sensory marketing model applied to spanish textile stores during the COVID-19 crisis. *Energies* 14 (7), 1966. doi:10.3390/en14071966

Karthick, T., Charles Raja, S., Jeslin Drusila Nesamalar, J., and Chandrasekaran, K. (2021). Design of IoT based smart compact energy meter for monitoring and controlling the usage of energy and power quality issues with demand side management for a commercial building. *Sustain. Energy, Grids Netw.* 26, 100454. doi:10.1016/j.segan.2021.100454

Khan, I., Lei, H., Shah, A. A., Baz, K., Koondhar, M. A., Hatab, A. A., et al. (2022). Environmental quality and the asymmetrical nonlinear consequences of energy consumption, trade openness and economic development: prospects for environmental management and carbon neutrality. *Environ. Sci. Pollut. Res.* 29 (10), 14654–14664. doi:10.1007/s11356-021-16612-5

KPMG (2022). CEO outlook pulse survey 2021 – the results of an express survey of the heads of companies in the energy sector. Available at: https://assets.kpmg/content/dam/kpmg/ru/pdf/2021/07/ru-ru-energy-industry-insights.pdf (accessed: 08.05.2022).

Krishnan, R., and Butt, B. (2022). The gasoline of the future:" points of continuity, energy materiality, and corporate marketing of electric vehicles among automakers and utilities. *Energy Res. Soc. Sci.* 83, 102349. doi:10.1016/j.erss.2021.102349

Li, G., Li, G., and Zhou, M. (2022). Market transaction model design applicable for both plan and market environment of China's renewable energy. *Front. Energy Res.* 10, 862653. doi:10.3389/fenrg.2022.862653

Lotfi, R., Yadegari, Z., Hosseini, S. H., Tirkolaee, E. B., and Weber, G.-W. (2022). A robust time-cost-quality-energy-environment trade-off with resource-constrained in project management: a case study for a bridge construction project. *J. Industrial Manag. Optim.* 13 (5), 1–22. doi:10.3934/jimo.2020158

Martinez, N., and Komendantova, N. (2020). The effectiveness of the social impact assessment (SIA) in energy transition management:stakeholders' insights from renewable energy projects in Mexico. *Energy Policy* 145, 111744. doi:10.1016/j.enpol.2020.111744

Mora-Villagómez, E., and Reyes-López, C. (2022). Sustainable management model of rural electrification project isolated by renewable photovoltaic energy. *Smart Innovation, Syst. Technol.* 252, 455–465. doi:10.1007/978-981-16-4126-8_41

Onubi, H. O., Yusof, N., Hassan, A. S., and Bahdad, A. A. S. (2022). Effect of energy management and waste management on schedule performance: role of technological complexity and project size. *Environ. Sci. Pollut. Res.* 29 (19), 29075–29090. doi:10.1007/s11356-021-18376-4

Popkova, E. G., Inshakov, O. V., and Bogoviz, A. V. (2019). Regulatory mechanisms of energy conservation in sustainable economic development. *Lect. Notes Netw. Syst.* 44, 107–118. doi:10.1007/978-3-319-90966-0_8

Popkova, E. G., and Sergi, B. S. (2021). Energy efficiency in leading emerging and developed countries. *Energy* 221, 119730. doi:10.1016/j.energy.2020.119730

Qi, Y., Qian, Q. K., Meijer, F. M., and Visscher, H. J. (2021). Unravelling causes of quality failures in building energy renovation projects of northern china: quality management perspective. *J. Manage. Eng.* 37 (3), 04021017. doi:10.1061/(ASCE)ME.1943-5479.0000888

Rezaei, N., Tarimoradi, H., and Deihimi, M. (2022). A coordinated management scheme for power quality and load consumption improvement in smart grids based on sustainable energy exchange based model. *Sustain. Energy Technol. Assessments* 51, 101903. doi:10.1016/j.seta.2021.101903

Sahoo, B., Routray, S. K., and Rout, P. K. (2021). A novel centralized energy management approach for power quality improvement. *Int. Trans. Electr. Energy Syst.* 31 (10), e12582. doi:10.1002/2050-7038.12582

Sisodia, G. S., Awad, E., Alkhoja, H., and Sergi, B. S. (2020). Strategic business risk evaluation for sustainable energy investment and stakeholder engagement: a proposal for energy policy development in the middle east through khalifa funding and land subsidies. *Bus. Strategy Environ.* 29 (6), 2789–2802. doi:10.1002/bse.2543

Sozinova, A. A., and Lysova, E. A. (2021). The marketing approach to managing the quality of company's products based on industrial and manufacturing engineering in the conditions of transnational capital transformation. *Int. J. Qual. Res.* 15 (4), 1091–1110. doi:10.24874/IJQR15.04-05

Sozinova, A. A., Sofiina, E. V., Safargaliyev, M. F., and Varlamov, A. V. (2021). Pandemic as a new factor in sustainable economic development in 2020: scientific analytics and management prospects. *Lect. Notes Netw. Syst.* 198, 756–763. doi:10.1007/978-3-030-69415-9_86

Storch de Gracia, M. D., Moya Perrino, D., and Llamas, B. (2019). Multicriteria methodology and hierarchical innovation in the energy sector: the project management institute approach. *Manag. Decis.* 57 (5), 1286–1303. doi:10.1108/MD-07-2017-0676

Štreimikienė, D., Samusevych, Y., Bilan, Y., Vysochyna, A., and Sergi, B. S. (2022). Multiplexing efficiency of environmental taxes in ensuring environmental, energy, and economic security. *Environ. Sci. Pollut. Res.* 29 (5), 7917–7935. doi:10.1007/s11356-021-16239-6

Tadviser (2022). The Russian energy automation market. Available at: https://www.tadviser.ru/index.php/Статья:Russia_market of Automatisation_energy (data accessed: 08.05.2022).

Tang, J. (2022). Combing effects of economic development and globalization towards energy efficiency and environmental degradation: fresh analysis from energy efficient resources. *Front. Energy Res.* 10, 847235. doi:10.3389/fenrg.2022.847235

Teichmann, F., Falker, M.-C., and Sergi, B. S. (2020). Gaming environmental governance? bribery, abuse of subsidies, and corruption in European union programs. *Energy Res. Soc. Sci.* 66, 101481. doi:10.1016/j.erss.2020.101481

Vinjamuri, U. R., and Burthi, L. R. (2022). Internet of things platform for energy management in multi-microgrid system to enhance power quality: ARBFNOCS technique. *Int. J. Numer. Model.* 35 (1), e2926. doi:10.1002/jnm.2926

Wei, C., Li-Feng, Z., and Hong-Yan, D. (2021). Impact of cap-and-trade mechanisms on investments in renewable energy and marketing effort. *Sustain. Prod. Consum.* 28, 1333–1342. doi:10.1016/j.spc.2021.08.010

World Bank (2022). Explore the interactive database of the WIPO global innovation index 2021 indicators. Available at: https://www.globalinnovationindex.org/analysis-indicator (data accessed: 08.05.2022).

OPINION
published: 26 August 2022
doi: 10.3389/fenrg.2022.945109

Corporate Social Responsibility of Energy Companies: International Experience and Polycriterial Evaluation of Technological Innovations' Effectiveness

Sergei G. Vagin[1,2]*, *Bogdan Vasyakin*[3], *Mikhail Y. Zakharov*[4] *and Irina E. Shaker*[5]

[1]National Research University Higher School of Economics, Moscow, Russia, [2]Department of Modern Technologies of Management, Institute of Management Technologies, MIREA—Russian Technological University, Moscow, Russia, [3]Plekhanov Russian University of Economics, Moscow, Russia, [4]Institute of Personnel Management and Social and Business Communications, State University of Management, Moscow, Russia, [5]Financial University Under the Government of the Russian Federation, Moscow, Russia

Keywords: EnergyTech, corporate social responsibility, energy companies, international experience, polycriterial evaluation, technological innovations, effectiveness

OPEN ACCESS

Edited by:
Elena G. Popkova,
Moscow State Institute of International Relations, Russia

Reviewed by:
Pietro Stilo,
Mediterranea University of Reggio Calabria, Italy

Correspondence:
Sergei G. Vagin
vsg63@hotmail.com

Specialty section:
This article was submitted to Sustainable Energy Systems and Policies,
a section of the journal Frontiers in Energy Research

Received: *16 May 2022*
Accepted: *20 June 2022*
Published: *26 August 2022*

Citation:
Vagin SG, Vasyakin B, Zakharov MY and Shaker IE (2022) Corporate Social Responsibility of Energy Companies: International Experience and Polycriterial Evaluation of Technological Innovations' Effectiveness. Front. Energy Res. 10:945109. doi: 10.3389/fenrg.2022.945109

INTRODUCTION

The fuel and energy complex is a system-forming element of the modern economy, determining both the opportunities for economic growth and the prospects for sustainable development (Cui et al., 2022; Li et al., 2022; Padmanabhan et al., 2022; Wen and Jia, 2022). This strategic role of energy companies covers two types of activities. First, the implementation of initiatives in the field of corporate social responsibility aimed at increasing the sustainability (universal accessibility and environmental safety/purity) of energy (Ahmed et al., 2022; Ates, 2022; Madaleno et al., 2022; Shukla and Geetika, 2022; Wang and Sun, 2022).

Second, the introduction of technological innovations that allow optimizing the business processes of energy companies. In the existing literature, authors such as Brizhak and Tolstobokov (2022), Dudukalov et al. (2021), Guo et al. (2022), Popkova et al. (2022), Qu et al. (2022), Shi et al. (2022), and Vanchukhina et al. (2016) consider technological innovations as a promising tool for corporate social responsibility of energy companies, as they have the potential to increase productivity and environmental safety of their activities. However, the extent to which this potential can be used in practice is insufficiently studied and unclear. This is a research gap that is being filled in this article.

This article is intended to demonstrate the contradictory impact of technological innovations on the corporate social responsibility of energy companies. The originality of the study lies in the fact that it goes beyond the usual framework of modernization of energy companies, taking into account the impact of the digital economy on their corporate social responsibility. The traditional focus on internal factors forms the idea of corporate social responsibility as a manifestation of the altruism of energy companies.

The article presents a new view on the corporate social responsibility of energy companies since it is heavily influenced by market pressure. In this vein, the article is aimed at studying international experience and conducting a polycriterial evaluation of the effectiveness of technological innovations of energy companies from the standpoint of corporate social responsibility.

The contribution of the article to the improvement of scientific knowledge consists in the development of a new scientific-methodological approach to assessing the compliance of energy companies with EnergyTech criteria. The novelty, peculiarity, and advantage of the new approach are that it involves determining the compliance of EnergyTech energy companies from the perspective of efficiency rather than from the perspective of costs (digital competitiveness)—for the first time, it takes into account the contribution of these costs to results—energy intensity level of primary energy, investment in energy with private participation, and renewable electricity output.

Place of Technological Innovations in the System of Corporate Social Responsibility of Energy Companies

The theoretical basis of the research conducted in this article is formed by the concept of EnergyTech, in which the system combination of high technologies and sustainability is defined as a priority of energy companies (Baur et al., 2022; Haoyang et al., 2022; Matsunaga et al., 2022; Wang and Hasani, 2022). In accordance with this concept, the corporate social responsibility of energy companies is interpreted as an activity carried out on their own initiative (going beyond meeting the requirements of the state) in support of the implementation of SDG 7: sustainable energy development (Ajagekar and You, 2022; Gebreslassie et al., 2022; Son Le et al., 2022; Tang et al., 2022).

In the works of Kurowski and Huk (2021), Madaleno et al. (2022), and Nguyen (2022), the corporate social responsibility of energy companies is identified with altruism—their non-profit support for sustainable energy development. The clearest and generally recognized indicators of corporate social responsibility of energy companies are offered and calculated annually by the World Bank (2022). Among these, indicators are the energy intensity level of primary energy (we will introduce the notation e_1, its reduction is assumed), renewable electricity output (we will introduce the notation e_2, its increase is necessary), and investment in energy with private participation (we will introduce the notation e_3; its increase is required).

Technological innovations of energy companies are interpreted as the use of advanced capabilities of scientific and technological progress (in support of the implementation of SDG 9). In the works of Asakereh et al. (2022), Buonomano et al. (2022), and Zhang and Fu (2022), breakthrough technologies such as robots, artificial intelligence, and Big Data are cited as key technological innovations at the present stage of the Fourth Industrial Revolution. In accordance with this, it is also indicated that technological innovations of energy companies are determined by internal factors—the successful introduction and active practical application of the aforementioned breakthrough technologies.

The existing scientific and methodological approach to assessing the degree of compliance of energy companies with the EnergyTech criteria involves the analysis of their technological innovations from the standpoint of digital competitiveness. This approach is described in the works of Cibinskiene et al. (2021), Li and Kimura (2021), Nagel et al. (2022), and Shuai et al. (2022). The problem lies in the fact that the current approach takes into account only high technological intensity, the relationship of which with the sustainability of energy is still poorly understood and not clearly defined, which is a gap in the literature. Because of this, the boundaries of EnergyTech remain blurred, and its scientific study is hampered by the uncertainty of the subject area to study. The identified gap is filled in this article through the study of the interdependence of corporate social responsibility and technological innovations of energy companies.

Polycriterial Evaluation of the Effectiveness of Technological Innovations of Energy Companies From the Standpoint of Corporate Social Responsibility

To determine the interdependence of corporate social responsibility and technological innovations of energy companies, this article provides a polycriterial evaluation of the effectiveness of technological innovations of energy companies from the standpoint of corporate social responsibility. The study is conducted on the example of a sample of countries representative of the global economy, covering both developed and developing countries from different parts of the world with the highest digital competitiveness in 2021 (included in the IMD World Competitiveness Center rating, 2022).

Using the hierarchical procedure of T.L. Saati (the Saati method), the contribution of various technological innovations available in the digital economy to the corporate environmental responsibility of energy companies is determined. The internal factors of technological modernization (the use of robots, AI, and Big Data) and external (market) factors of the digital economy (the level of development of the information society, e-government) are considered simultaneously according to the materials of the IMD World Competitiveness Center (2022). The basic statistics and evaluation results are given in **Table 1**.

It is essential to consider the calculations made in **Table 1** and their results in more detail using the example of Russia. In accordance with the Saati method, the values of indicators of technological innovation are transferred from places to percentages of the maximum possible values (the best value: 1^{st} place and the worst: 64^{th} place). For example, the value for world robots distribution is obtained as follows: ((64–51.56)/64) *100% = 51.56%.

Then, the correlation of indicators of technological innovation with each of the indicators of corporate social responsibility (for the entire sample) is calculated. For example, the correlation of world robots distribution with an energy intensity level of primary energy (e_1) was −0.02, with renewable electricity output (e_2): −0.13, and with investment in energy with private participation (e_3): −0.49. The arithmetic mean of the correlation coefficients was −0.22. A negative correlation value indicates the antagonism of technological innovations and corporate social responsibility.

The average correlation of corporate social responsibility indicators with the use of Big Data and analytics was 0.54, with e-participation: 0.06, and with e-government: 0.32. Next, weighted amounts are calculated, reflecting the contribution of each technological innovation to the corporate social responsibility of energy companies. For example, in Russia:

TABLE 1 | Polycriterial evaluation of the effectiveness of technological innovations of energy companies from the standpoint of corporate social responsibility in 2021.

Country	Energy intensity level of primary energy, megajoules per constant 2017 PPP GDP	Renewable electricity output, % of total electricity output	Investment in energy with private participation, thousand US$	World robot distribution		Use of Big Data and analytics		E-participation		E-government		Integral synthesis
				Place 1–64	%	Place 1–64	%	Place 1–64	%	Place 1–64	%	
United States	5	13.23	n/a	4	93.75	5	92.19	1	98.44	9	85.94	63.00
China	6	23.93	838.180	1	98.44	11	82.81	9	85.94	40	37.50	40.49
Australia	4	13.64	n/a	30	53.13	35	45.31	9	85.94	5	92.19	47.88
Spain	3	34.95	n/a	10	84.38	55	14.06	34	46.88	17	73.44	15.99
Kazakhstan	6	8.87	265.480	No data	0.00	6	90.63	25	60.94	27	57.81	71.01
Russia	8	15.86	486.950	31	51.56	31	51.56	26	59.38	33	48.44	35.80
Argentina	3	28.14	160.000	37	42.19	46	28.13	28	56.25	29	54.69	27.08
Brazil	4	73.97	6,242.530	18	71.88	56	12.50	18	71.88	47	26.56	4.08
Colombia	3	38.24	205.230	50	21.88	51	20.31	26	59.38	52	18.75	15.77
India	4	15.34	3,389.000	12	81.25	15	76.56	28	56.25	59	7.81	29.45
Correlation	c e_1	—	—	—	–0.02[a]	0.58[a]	0.24[a]	0.05[a]	—	—	—	—
	c e_2	—	—	—	–0.13	0.73	0.15	0.39	—	—	—	—
	c e_3	—	—	—	–0.49	0.30	–0.22	0.53	—	—	—	—
	On average	—	—	—	–0.22	0.54	0.06	0.32	35.05	—	—	—

[a]*Values with the opposite sign are indicated since CSR is indicated by a negative correlation with e_1.*

Source: calculated and compiled by the authors based on the materials of the IMD World Competitiveness Center (2022) and World Bank (2022).

– world robots distribution: 51.56%*(−0.22) = −11.10%;
– use of Big Data and analytics: 51.56%*0.54 = 27.68%;
– e-participation: 59.38%*0.06 = 3.48%;
– e-government: 48.44%*0.32 = 15.74%.

Integral synthesis is determined by summing weighted sums. For example, in Russia: −11.10 + 27.68 + 3.48 + 15.74 = 35.80 (moderate efficiency). The results obtained mean that in Russia, technological innovations of energy companies make a moderate contribution to their corporate social responsibility in 2021—energy companies correspond to EnergyTech by 35.80%. The largest compliance of EnergyTech energy companies was found in the United States (63%), China (40%), Australia (47.88%), and Kazakhstan (71.01%). In the whole sample (taking into account the representativeness, this can be extended to the global economy as a whole), the degree of compliance of EnergyTech energy companies is estimated at 35.05%.

DISCUSSION

The article contributed to the literature by clarifying the scientific provisions of the EnergyTech concept through the disclosure of the essence of the interdependence of corporate social responsibility and technological innovations of energy companies. Unlike Kurowski and Huck (2021), Madaleno et al. (2022), and Nguyen (2022), it was revealed that the corporate social responsibility of energy companies is not a "pure" manifestation of altruism but is carried out under significant market pressure—demand from society (consumers) and government incentives.

Unlike Asakereh et al. (2022), Buonomano et al. (2022), and Zhang and Fu (2022), it is proved that not only internal factors but also external market factors play an important role in the implementation of technological innovations by energy companies. Moreover, one of the internal factors—robotization—does not make a significant contribution to the corporate social responsibility of energy companies. The most significant was the internal factor of using Big Data and artificial intelligence for their analysis (0.54%). Among the external factors, the most significant is the development of the e-government system (0.32). The information society turned out to be a less significant external factor (0.06), but it also needs to be taken into account.

Unlike Cibinskiene et al. (2021), Li and Kimura (2021), Nagel et al. (2022), and Shuai et al. (2022), the article shows, on the basis of a review of international experience, that a high level of digital competitiveness does not guarantee that energy companies meet the criteria of EnergyTech. For example, India ((12 + 15 + 28 + 59)/4 = 29) and Spain ((10 + 55 + 34 + 17)/4 = 29) have a similar level of digital competitiveness from the positions of the considered indicators of the IMD World Competitiveness Center (2022). But in India (29.45%), the compliance of energy companies with the EnergyTech criteria turned out to be higher than in Spain (15.99%) since technological innovations are used to varying degrees in the implementation of corporate social responsibility in these countries. Based on the obtained conclusion, the article demonstrates a new scientific and methodological approach to assessing the degree of compliance of energy companies with the EnergyTech criteria, which involves analyzing their technological innovations from the standpoint of efficiency.

CONCLUSION

So, technological innovations occupy an important place in the system of corporate social responsibility of energy companies. But the impact of technological innovations on this responsibility is contradictory, which requires flexible management of energy companies. The scientific novelty of the research and its contribution to the literature are involved in the development of a new scientific-methodological approach to assessing the compliance of energy companies with EnergyTech criteria.

The novelty of the authors' approach is that it provides a transition from the single-criteria assessment of competitiveness prevailing in the existing literature to the multicriteria assessment of the efficiency of technological innovations of energy companies. This allows for the first time to take into account not only costs (digital competitiveness) but also results (energy intensity level of primary energy, investment in energy with private participation, and renewable electricity output), as well as the ratio of results and costs (efficiency). As a result, the suggested approach allows making the most accurate and reliable assessment of the contribution of corporate social responsibility of energy companies to EnergyTech.

The theoretical significance of the results obtained in this study is that they formed a systemic vision of the practical implementation of SDG 7 and SDG 9 in the activities of energy companies, clarified the conceptual boundaries of EnergyTech, and offered scientific and methodological recommendations to accurately quantify the degree of compliance of energy companies with the requirements of EnergyTech.

The practical significance of the obtained results lies in the fact that the application of the progressive Saati method allowed not only to systematize but also to rank the criteria according to the degree of significance. Based on the ranks assigned to the indicators, energy companies will be able to prioritize the development of technological innovations when managing them in their activities. This will improve the efficiency of technological innovation management from the standpoint of increasing their contribution to the corporate social responsibility of energy companies, as well as accelerate their transition to EnergyTech.

AUTHOR CONTRIBUTIONS

All authors contributed to the manuscript contributed to the conception and design of the study revision, read, and approved the submitted version.

REFERENCES

Ahmed, R. I., Zhao, G., Ahmad, N., and Habiba, U. (2022). A Nexus between Corporate Social Responsibility Disclosure and its Determinants in Energy Enterprises. *Jbim* 37 (6), 1255–1268. doi:10.1108/JBIM-07-2020-0359

Ajagekar, A., and You, F. (2022). Quantum Computing and Quantum Artificial Intelligence for Renewable and Sustainable Energy: A Emerging Prospect towards Climate Neutrality. *Renew. Sustain. Energy Rev.* 165, 112493. doi:10.1016/j.rser.2022.112493

Asakereh, A., Soleymani, M., and Safieddin Ardebili, S. M. (2022). Multi-criteria Evaluation of Renewable Energy Technologies for Electricity Generation: A Case Study in Khuzestan Province, Iran. *Sustain. Energy Technol. Assessments* 52, 102220. doi:10.1016/j.seta.2022.102220

Ates, S. (2022). The Credibility of Corporate Social Responsibility Reports: Evidence from the Energy Sector in Emerging Markets. *Srj*. doi:10.1108/SRJ-04-2021-0149

Baur, D., Emmerich, P., Baumann, M. J., and Weil, M. (2022). Assessing the Social Acceptance of Key Technologies for the German Energy Transition. *Energ Sustain Soc.* 12 (1), 4. doi:10.1186/s13705-021-00329-x

Brizhak, O. V., and Tolstobokov, O. N. (2022). Forming the New Industrial Core of Russian Industry: Problems and Perspectives. *Curr. Problems World Econ. Int. Trade* 42. Emerald Publishing Limited. doi:10.1108/s0190-128120220000042015

Buonomano, A., Barone, G., and Forzano, C. (2022). Advanced Energy Technologies, Methods, and Policies to Support the Sustainable Development of Energy, Water and Environment Systems. *Energy Rep.* 8, 4844–4853. doi:10.1016/j.egyr.2022.03.171

Cibinskiene, A., Dumciuviene, D., Bobinaite, V., and Dragašius, E. (2021). Competitiveness of Industrial Companies Forming the Value Chain of Wind Energy Components: The Case of Lithuania. *Sustainability* 13 (16), 9255. doi:10.3390/su13169255

Cui, L., Mu, Y., Shen, Z., and Wang, W. (2022). Energy Transition, Trade and Green Productivity in Advanced Economies. *J. Clean. Prod.* 361, 132288. doi:10.1016/j.jclepro.2022.132288

Dudukalov, E. V., Munister, V. D., Zolkin, A. L., Losev, A. N., and Knishov, A. V. (2021). The Use of Artificial Intelligence and Information Technology for Measurements in Mechanical Engineering and in Process Automation Systems in Industry 4.0. *J. Phys. Conf. Ser.* 1889 (5), 052011. doi:10.1088/1742-6596/1889/5/052011

Gebreslassie, M. G., Cuvilas, C., Zalengera, C., To, L. S., Baptista, I., Robin, E., et al. (2022). Delivering an Off-Grid Transition to Sustainable Energy in Ethiopia and Mozambique. *Energ Sustain Soc.* 12 (1), 23. doi:10.1186/s13705-022-00348-2

Guo, Z., Peng, Y., and Chen, Y. (2022). How Digital Finance Affects the Continuous Technological Innovation of Chinese Energy Companies? *Front. Energy Res.* 10, 833436. doi:10.3389/fenrg.2022.833436

Haoyang, W., Lei, G., and Ying, J. (2022). The Predicament of Clean Energy Technology Promotion in China in the Carbon Neutrality Context: Lessons from China's Environmental Regulation Policies from the Perspective of the Evolutionary Game Theory. *Energy Rep.* 8, 4706–4723. doi:10.1016/j.egyr.2022.03.142

IMD World Competitiveness Center (2022). World Digital Competitiveness Ranking 2021. Available at: https://www.imd.org/centers/world-competitiveness-center/rankings/world-digital-competitiveness/[data accessed 04 29 2022].

Kurowski, M., and Huk, K. (2021). Selected Aspects of Corporate Social Responsibility in the Industry Related to the Production and Supply of Energy. *Energies* 14 (23), 7965. doi:10.3390/en14237965

Li, R., Xu, L., Hui, J., Cai, W., and Zhang, S. (2022). China's Investments in Renewable Energy through the Belt and Road Initiative Stimulated Local Economy and Employment: A Case Study of Pakistan. *Sci. Total Environ.* 835, 155308. doi:10.1016/j.scitotenv.2022.155308

Li, Y., and Kimura, S. (2021). Economic Competitiveness and Environmental Implications of Hydrogen Energy and Fuel Cell Electric Vehicles in ASEAN Countries: The Current and Future Scenarios. *Energy Policy* 148, 111980. doi:10.1016/j.enpol.2020.111980

Madaleno, M., Dogan, E., and Taskin, D. (2022). A Step Forward on Sustainability: The Nexus of Environmental Responsibility, Green Technology, Clean Energy and Green Finance. *Energy Econ.* 109, 105945. doi:10.1016/j.eneco.2022.105945

Matsunaga, F., Zytkowski, V., Valle, P., and Deschamps, F. (2022). Optimization of Energy Efficiency in Smart Manufacturing through the Application of Cyber-Physical Systems and Industry 4.0 Technologies. *J. Energy Resour. Technol. Trans. ASME* 144 (10), 102104. doi:10.1115/1.4053868

Nagel, N. O., Kirkerud, J. G., and Bolkesjø, T. F. (2022). The Economic Competitiveness of Flexibility Options: A Model Study of the European Energy Transition. *J. Clean. Prod.* 350, 131534. doi:10.1016/j.jclepro.2022.131534

Nguyen, C. P. (2022). The "Karma" of Impact on the Earth: Will Humans Take Responsibility? Evidence of Energy Consumption and CO2 Emissions. *Environ. Sci. Pollut. Res.* doi:10.1007/s11356-022-19461-y

Padmanabhan, S., Giridharan, K., Stalin, B., Kumaran, S., Kavimani, V., Nagaprasad, N., et al. (2022). Energy Recovery of Waste Plastics into Diesel Fuel with Ethanol and Ethoxy Ethyl Acetate Additives on Circular Economy Strategy. *Sci. Rep.* 12 (1), 5330. doi:10.1038/s41598-022-09148-2

Popkova, E. G., De Bernardi, P., Tyurina, Y. G., and Sergi, B. S. (2022). A Theory of Digital Technology Advancement to Address the Grand Challenges of Sustainable Development. *Technol. Soc.* 68, 101831. doi:10.1016/j.techsoc.2021.101831

Qu, F., Xu, L., and Zheng, B. (2022). Directed Technical Change and Pollution Emission: Evidence from Fossil and Renewable Energy Technologies in China. *Front. Energy Res.* 10, 794104. doi:10.3389/fenrg.2022.794104

Shi, G., Fei, F., Qin, J., Gao, Y., Li, Y., and Xu, D. (2022). Application, Prospect, and Challenge of Small-Spacing Stereo-Staggered Well Pattern Deployment Technology in the Shale Oil Reservoir. *Front. Energy Res.* 10, 859348. doi:10.3389/fenrg.2022.859348

Shuai, J., Zhao, Y., Wang, Y., and Cheng, J. (2022). Renewable Energy Product Competitiveness: Evidence from the United States, China and India. *Energy* 249, 123614. doi:10.1016/j.energy.2022.123614

Shukla, A., and Geetika, N. A. (2022). Impact of Corporate Social Responsibility on Financial Performance of Energy Firms in India. *Ijbge* 16 (1), 88–105. doi:10.1504/IJBGE.2022.119356

Son Le, H., Said, Z., Tuan Pham, M., Hieu Le, T., Veza, I., Nhanh Nguyen, V., et al. (2022). Production of HMF and DMF Biofuel from Carbohydrates through Catalytic Pathways as a Sustainable Strategy for the Future Energy Sector. *Fuel* 324, 124474. doi:10.1016/j.fuel.2022.124474

Tang, J., Zhao, Y., Wang, M., Wang, D., Yang, X., Hao, R., et al. (2022). Circadian Humidity Fluctuation Induced Capillary Flow for Sustainable Mobile Energy. *Nat. Commun.* 13 (1), 1291. doi:10.1038/s41467-022-28998-y

Vanchukhina, L. I., Leybert, T. B., and Khalikova, E. A. (2016). Methodological Approaches to Evaluation and Analysis of Labor Efficiency in the Spheres of Fuel and Energy Complex. *J. Environ. Manag. Tour.* 7 (4), 585–593.

Wang, J., and Sun, J. (2022). The Role of Audit Committees in Social Responsibility and Environmental Disclosures: Evidence from Chinese Energy Sector. *Int. J. Discl. Gov.* 19 (1), 113–128. doi:10.1057/s41310-021-00131-3

Wang, Y., and Hasani, J. (2022). Energy Generation from a System Based on Solar Energy and Fuel Cell Technology with the Option of Storing Electrical Energy. *Energy Rep.* 8, 4988–5004. doi:10.1016/j.egyr.2022.03.199

Wen, S., and Jia, Z. (2022). The Energy, Environment and Economy Impact of Coal Resource Tax, Renewable Investment, and Total Factor Productivity Growth. *Resour. Policy* 77, 102742. doi:10.1016/j.resourpol.2022.102742

World Bank (2022). Data – Energy & Mining. Available at: https://data.worldbank.org/topic/energy-and-mining?view=chart [data accessed 29 04 2022].

Zhang, R., and Fu, Y. (2022). Technological Progress Effects on Energy Efficiency from the Perspective of Technological Innovation and Technology Introduction: An Empirical Study of Guangdong, China. *Energy Rep.* 8, 425–437. doi:10.1016/j.egyr.2021.11.282

Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's Note: All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors, and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

frontiers | Frontiers in Energy Research

TYPE Opinion
PUBLISHED 20 September 2022
DOI 10.3389/fenrg.2022.923784

OPEN ACCESS

EDITED BY
Muyiwa S. Adaramola,
Norwegian University of Life Sciences,
Norway

REVIEWED BY
Marek Dvořák,
Czech University of Life Sciences
Prague, Czechia
Galina Chebotareva,
Ural Federal University, Russia

*CORRESPONDENCE
Tatiana M. Vorozheykina,
vorozheykina@gmail.com

SPECIALTY SECTION
This article was submitted to Sustainable Energy Systems and Policies,
a section of the journal
Frontiers in Energy Research

RECEIVED 19 April 2022
ACCEPTED 15 August 2022
PUBLISHED 20 September 2022

CITATION
Vorozheykina TM, Averin AV, Semenova EI and Semenov AV (2022), Scenarios of the alternative energetics development in the age of the fourth industrial revolution: Clean energy prospects and policy implications.
Front. Energy Res. 10:923784.
doi: 10.3389/fenrg.2022.923784

Scenarios of the alternative energetics development in the age of the fourth industrial revolution: Clean energy prospects and policy implications

Tatiana M. Vorozheykina [1]*, Aleksandr V. Averin[2], Elena I. Semenova [3] and Aleksandr V. Semenov [4]

[1]Russian State Agrarian University - Moscow Timiryazev Agricultural Academy, Moscow, Russia, [2]Russian Presidential Academy of National Economy and Public Administration, Moscow, Russia, [3]Federal State Budgetary Scientific Institution "Federal Research Center of Agrarian Economy and Social Development of Rural Areas – All Russian Research Institute of Agricultural Economics", Moscow, Russia, [4]Russian State Agrarian Correspondence University, Balashiha, Russia

KEYWORDS

alternative energy, clean energy, energytech, the fourth industrial revolution, industry 4.0, high technology

Introduction

The Fourth Industrial Revolution is a global challenge of the modern times for sustainable and environmental development of energy economics. On the one hand, the leading technologies of the fourth technological mode (Industry 4.0) are often characterized by large energy efficiency, which allows reducing the specific energy consumption (energy efficiency of production and consumption).

On the other hand, ubiquitous automation raises the total need of economy for energy, since economic functions, which were earlier based on manual (or conventionally manual) labor (which energy intensity is minimal) now become automated, and, therefore, require more energy. Thus, for example, quick growth of energy consumption in the world economy was observed in 2014, when electric power consumption reached 3,131.68 kWh per capita (as compared to 2,274.94 kWh per capita in 2009) (World Bank, 2022).

In the existing literature, much attention is paid to the energy efficiency of advanced technologies in industry 4.0, in particular, industrial robots. In the works of Aubin et al. (2022), Huang et al. (2022), Luan et al. (2022), Nonoyama et al. (2022), Ntsiyin et al. (2022), Wang et al. (2022) note the cost-effectiveness of energy efficiency of industrial robots. In this regard, the robotization of the economy is considered as an energy-neutral process.

In the available works of Anthopoulos and Kazantzi (2022), Dreher et al. (2022), Fang et al. (2022), Xuan and Ocone (2022), another key technology of Industry 4.0–artificial intelligence (AI) received a positive assessment from the standpoint of energy efficiency. In particular, it was noted that AI has a great potential for use in the energy sector, contributing to its optimization.

In their research, Cui et al. (2022), Ng et al. (2021), Popkova et al. (2021), Popkova and Sergi (2021), Tabor et al. (2018), Taghizadeh-Hesary et al. (2022), Zaidan et al. (2022) point out that Industry 4.0 technologies, which are widely used in the context of the Fourth Industrial Revolution, support the transition to "clean" energy.

Accordingly, the state regulation of sustainable energy development in the publications of Chen et al. (2022), Deng et al. (2022), Inshakova et al. (2022), Iqbal and Bilal (2021), Liu et al. (2022), Nyenno et al. (2021) is recommended to be implemented through promoting the use of advanced technologies of industry 4.0 in the context of the Fourth Industrial Revolution.

Nevertheless, the existing publications are limited to the current situation and do not disclose in sufficient detail the future prospects for the development of alternative and clean energy in the era of the Fourth Industrial Revolution, which is a research gap. This article is intended to fill the identified gap. The main purpose of the research is to identify scenarios for the development of alternative and clean energy in the age of the Fourth Industrial Revolution and to elaborate recommendations for economic policy.

This purpose is achieved by coping with the following tasks: 1) to review international practices and to carry out the mathematical economic modeling of the impact of the Fourth Industrial Revolution on the energy economy; 2) To compile, describe and compare forecast scenarios for the development of the energy economy in the age of the Fourth Industrial Revolution; 3) To elaborate recommendations for economic policy on the development of clean and alternative energy in the age of the Fourth Industrial Revolution.

The object of research is the driving force of the Fourth Industrial Revolution–the world's top 10 countries in terms of the degree of automation, according to the International Federation of Robotics. (2022). For these countries, the analysis is carried out, scenarios are developed and their practical relevance is assessed. The main results obtained consist, firstly, in the compilation of an econometric model (in the form of a simultaneous-equation system) of the impact of the Fourth Industrial Revolution on the energy economy, which mathematically describes the consistent patterns of development of clean energy with the development of automation. Secondly, in the identification of prospects and making recommendations for the development of alternative (clean) energy in the age of the Fourth Industrial Revolution.

The significance of the results for science is that the article has clearly substantiated and dramatically illustrated, through the example of international practices, the conflict between the interests and practices of development of alternative (clean) energy and the interests and practices of automation. The significance of this new input is that, given the absolute consistency, acute importance for humanity, and the equivalence of all 17 UN SDGs, the article has demonstrated the high complexity of the simultaneous implementation of SDG7 and SDG9 due to the contradiction between the essence of sustainable energy (a reduction of energy consumption and the transition to clean energy) and the Fourth Industrial Revolution (an increase in the energy intensity of the economy and the consumption of fossil fuels with the development of automation).

The practical applicability of the results is attributable to the fact that the identified scenarios allow for the most complete, accurate, and reliable assessment of the implications of managerial decision-making and state regulation of the energy economy for the period until 2030 (which is the focus of the SDGs). The practical relevance of the authors' conclusions and recommendations is that for the first time they have justified the need for joint development and consistent implementation of the energy and innovative technology policy of the state. This will offer an advantage in the form of the balanced development of clean energy and automation–using the possibilities of the Fourth Industrial Revolution.

A literature review is singled out in the structure of the article after this Introduction. It is followed by a review of international practices and modeling of the impact of the Fourth Industrial Revolution on the energy sector (the first stage of research). Further, scenarios for the development of the energy sector in the age of the Fourth Industrial Revolution are compiled (the second stage of research). Subsequently, recommendations are made for economic policy on the development of clean and alternative energy in the age of the Fourth Industrial Revolution (the third stage of research). The work ends with the discussion followed by the conclusion.

Literature review

The issues of the Fourth Industrial Revolution have become particularly relevant since the middle of the last decade. In their works, Bragança et al. (2019), Contreras (2020), Hayhoe et al. (2019), and Jin (2019) point to automation based on Robotics and Artificial Intelligence (AI) as the main features of Industry 4.0.

The history of industrial revolutions is inextricably connected with the evolution of the energy economy. Thus, the First Industrial Revolution was accompanied by the advent of the steam engine (steam-powered engine), the wide-scale installation of gas lamps, more efficient mining, and improved coal handling (McNeill, 2019; Tainter and Taylor, 2019). The Second Industrial Revolution was crowned by the advent of the internal combustion engine Peter and Mbohwa. (2018). The Third Industrial Revolution was marked by the development of the power-generating industry (Matizamhuka, 2018).

The fundamental distinction between the Fourth Industrial Revolution and them is that it is implemented against the background of the global sustainability initiative which is expressed in the 17 UN SDGs and has designated the development of clean energy as a priority (Alimhan et al., 2019). Like all industrial revolutions, the fourth revolution increased the energy intensity of the economy, but it has been interpreted negatively for the first time (Ignatov and Korolev, 2019). In this regard, the process of the development of Industry 4.0 is a way to achieving a balance between the interests of automation and the interests of the sustainable development of the energy economy (Tijani et al., 2018).

The relationship between Industry 4.0 and alternative energy has been pointed out in numerous literature sources. The critical analysis has made it possible to identify several main emerging issues in this relationship. These issues include, firstly, low power and unstable volume of production of clean (wind, solar) energy. Hence, the transition to clean energy implies a reduction in energy consumption and dictates the strict framework for energy consumption in the economy, which contradicts the idea of economic growth in general and automation in particular (Mangla et al., 2020; Mascarenhas et al., 2020).

Secondly, the total automation that is taking place in the context of Industry 4.0 significantly increases the energy intensity of each economic process, causing an exponential increase in energy consumption (Matsunaga et al., 2022; Seixas et al., 2018). Thirdly, the fundamental idea of creation and the advantage of smart enterprises consists in continuous production and distribution. This calls for a continuous supply of a large amount of energy, which is impossible using clean energy alone (Ang et al., 2017; Huang et al., 2017; Junker and Domann, 2017).

Nonetheless, Li. (2022), Matsunaga et al. (2022), and Saikia et al. (2020) write in their works that the mentioned contradiction can be overcome since high technologies of Industry 4.0 are not only high-performance but also energy-saving. Hargreaves et al. (2022), Kang and Reiner (2022) cite the relevant experience of particular countries that are leading in terms of the development of Industry 4.0 - the United Kingdom and China respectively - as evidence of this effect.

According to the results of the literature review, it can be concluded that the existing publications have recognized the close relationship between Industry 4.0 and clean energy, but the nature of this relationship is interpreted in the available literature in different ways. The lack of a clear idea of the consistent patterns of progress in clean energy and automation, as well as prospects for the development of the energy economy in the age of the Fourth Industrial Revolution, is a gap in the literature.

To fill in the identified gap, this article contains a comprehensive study of the international best practices of the world's top 10 countries in terms of the degree of automation, constituting the driving force of the Fourth Industrial Revolution, and these practices are used as the basis for modeling a consistent pattern and compiling forecast scenarios for the development of alternative energy in the age of the Fourth Industrial Revolution.

Methodology

In this article, the study is carried out in three successive stages. In the first stage, international practices are examined and the impact of the Fourth Industrial Revolution on energy is modeled. The method of regression analysis is used to carry out the mathematical economic modeling of the consistent patterns of development of clean energy (Alternative and nuclear energy, Renewable electricity output, Renewable energy consumption, and Fossil fuel energy consumption based on statistics from the World Bank. (2022) in the age of the Fourth Industrial Revolution (under the influence of factors of Robot Density in the manufacturing industry based on statistics from the International Federation of Robotics. (2022) and The global AI index based on statistics from Tortois (2022).

In the second stage of research, scenarios for the development of the energy economy in the age of the Fourth Industrial Revolution are compiled. To this end, arithmetic means and standard deviations have been used as the basis for making the forecasts of changes in each of the above variables using the Monte Carlo technique. Previously obtained economic and mathematical (regression) dependencies are used as the basis for determining the probable (forecast) combinations of achievements in the field of clean energy and the field of automation based on Robotics and AI. Two alternative scenarios are considered within this framework.

The first scenario involves further unrestricted automation in the context of the freedom of proliferation of technologies of Industry 4.0 in the age of the Fourth Industrial Revolution. The best possible values of automation indicators are substituted into the regression models for its quantification. The second scenario is associated with the preservation of the current trend of the development of alternative and clean energy. To quantify it in regression models, the least-squares method is used for determining the values of automation indicators with the best possible values of clean energy indicators.

In the third stage of research, recommendations are made for economic policy on the development of clean and alternative energy in the age of the Fourth Industrial Revolution. Framework recommendations are provided for the balanced implementation of the energy and innovative technology policy of the state. In addition, specific recommendations are made for the adaptation of relevant policy papers to modern requirements in the world's top 10 countries in terms of the degree of automation through the example of South Korea as a developed country and China as a fast-growing country.

Review of international experience and modeling of the influence of the fourth industrial revolution on energy

To conduct the research, this article has formed a sample of the top 10 countries in the world in terms of automation

TABLE 1 The world experience in implementation of robots and AI and energy development.

Country	Robot density in the manufacturing industry, robots installed per 10.000 employees	The global AI index, score 0–100	Alternative and nuclear energy (% of total energy use)	Renewable electricity output (% of total electricity output)	Renewable energy consumption (% of total final energy consumption)	Fossil fuel energy consumption (% of total)
	rb	Ai	ANE	REO	REC	FFE
Republic of Korea	932	38.60	15.96	1.89	3.18	81.03
Singapore	605	38.67	0.19	1.82	0.73	90.58
Japan	390	30.53	3.09	15.98	7.39	93.03
Germany	371	36.04	12.86	29.23	15.80	78.86
Sweden	289	29.85	43.24	63.26	52.48	25.12
United States	255	100.00	11.87	13.23	10.11	82.43
China	246	62.92	5.11	23.93	13.12	87.67
Denmark	246	30.87	11.75	65.51	35.33	64.93
Italy	224	24.45	6.33	38.68	17.07	79.95
Netherlands	209	36.35	3.37	12.44	7.38	93.46
Arithmetic mean	376.70	42.83	11.38	26.60	16.26	77.71
Standard deviation	228.23	22.60	12.30	22.94	15.96	20.32

Compiled by the authors based on the materials of International Federation of Robotics (2022), Tortois (2022), World Bank. (2022).

according to the International Federation of Robotics. (2022), which are the leaders of the Fourth Industrial Revolution. Statistics on robotics (International Federation of Robotics, 2022), AI development (Tortois, 2022), and energy (World Bank, 2022) have been collected for these countries. The study is based on the most relevant data for 2020–2021. The energy data dates from 2015 to 2019 (the most up-to-date available data have been collected), but given the relative stability of energy development, they generally reliably/acceptably reflect the situation for 2020–2021. The factual basis of the study is given in Table 1.

Based on the international experience given in Table 1, the following system of equations describing the patterns of energy development in the conditions of the Fourth Industrial Revolution was obtained using the regression analysis method:

$$\begin{cases} ANE = 14.15 - 0.0010rb - 0.06ai \\ REO = 67.34 - 0.06rb - 0.42ai \\ REC = 38.53 - 0.03rb - 0.23ai \\ FRE = 62.07 + 0.02rb + 0.22ai \end{cases} \quad (1)$$

According to formula (1), the spread of advanced technologies of Industry 4.0 (robots and AI) under the influence of the Fourth Industrial Revolution leads to a decrease in the share of alternative and clean energy, as well as an increase in the dependence of the economy on fossil energy. The correlation in all four equations turned out to be quite high and amounted to, respectively 10.24, 67.89, 53.46, 28.55%, which indicates the reliability of the resulting system of equations.

Scenarios of energy development in the era of the fourth industrial revolution

Alternative scenarios have been compiled to determine the prospects for the development of energy in the era of the Fourth Industrial Revolution. For this purpose, the Monte Carlo method has been used to make forecasts of changes in each of the variables in Table 1 based on arithmetic averages and standard deviations. Based on the resulting system of Eq. 1, the relationships of among variables are taken into account.

The first scenario assumes further unlimited automation along with the freedom of dissemination of Industry 4.0 technologies in the context of the Fourth Industrial Revolution. In this case, the most likely values of Industry 4.0 technologies are the following: an increase in robotization to 452.58 per 10 thousand industrial workers (+20.14% with a probability of 20%) and an increase in the activity of using AI to 49.94 points (+16.61% with a probability of 16%). Substitution of the obtained values of factor variables into the system of Eq. 1 showed that this scenario will be associated with the following implications for the energy sector:

→ Reduction of the share of alternative and nuclear energy by 4.17% (to 10.90%);
→ Decrease in the share of renewable electricity output by 28.44% (up to 19.03%);
→ Decline of renewable energy consumption by 25.47% (up to 12.12%);
→ Growth of the share of fossil fuel energy consumption by 3.63% (up to 80.53%).

The fullest possible fulfillment of the potential of automation in Industry 4.0 has been used as a criterion in the development of this scenario. A special thing about the practical implementation of this scenario is the accelerated robotization and the spread of AI, which, unfortunately, occurs at the expense of clean energy and critically increases the energy intensity of the economy, threatening the onset of the energy crisis.

The second scenario is connected with the preservation of the current trend in the development of alternative and clean energy. In this case, the most likely values of energy development indicators turned out to be the following:

→ Increase in the share of alternative and nuclear energy by 49.42% (up to 17% with a 20% probability);
→ Increase in the share of renewable electricity output by 9.03% (up to 29% with a probability of 25%);
→ The growth of renewable energy consumption by 66.75% (up to 27.11% with a probability of 17%);
→ Reduction of the share of fossil fuel energy consumption by 12.74% (to 67.81% with a probability of 14%).

Based on the dependencies from the system of Eq. 1 by the least squares method, it was found that the implementation of this scenario would require a complete abandonment of the use of AI, as well as the limitation of robotics by 8.52% (up to 344.60 robots per 10 thousand industrial workers). The fullest possible fulfillment of the potential of the development of clean energy has been used as a criterion in the development of this scenario. A special thing about the practical implementation of this scenario is the rapid pace of decarbonization. However, unfortunately, decarbonization is contrary to the interests of economic growth and slows down the innovative and technological development of the economy.

The third scenario is the balanced development of clean energy and high technologies in EnergyTech This is an alternative to the two radical scenarios described above, which are based on a clear opposition of clean energy and high technology. EnergyTech is the most optimal scenario, as it allows developing both clean energy and advanced technologies of industry 4.0 at the same time. The current practice of using robots and AI does not allow quantifying the parameters of this scenario. It is the least likely, but it deserves the closest attention.

Recommendations for economic policy on the development of clean and alternative energy in the context of the fourth industrial revolution

To improve economic policy, it is expedient to take into account the impact of the proposed scenarios on political decision-making by state bodies, as well as the possible implications of scenarios. In the first scenario (unrestricted automation), the economic implications are associated with the accelerated rate of economic growth and increased labor productivity. However, the social implications consist in the growth of unemployment and the imbalance of the labor market, while the environmental implications consist in the critical increase in the energy intensity of the economy and the exacerbation of climate change issues.

In the second scenario (development of alternative and clean energy), the social implications consist in stable employment and improvement of the quality of life. In contrast, the environmental implications consist in a decrease in the energy intensity of the economy and decarbonization. However, the economic implications are associated with a slowdown in the rate of economic growth and scientific-technological progress.

In the third scenario (EnergyTech), all the implications are balanced, so this scenario is preferable. The economic implications are associated with moderate economic growth and a gradual increase in labor productivity. The social implications consist in the relative stability of the labor market, while the environmental implications consist in the implementation of the plan for decarbonization of the economy and the gradual reduction of its energy intensity.

To implement the EnergyTech scenario in practice, the following applied recommendations for improving the state economic policy are proposed. Firstly, it is the increase of public financing and the stimulation of private investment in energy saving of high technologies. The revealed quantitative dependencies 1) indicate that by now energy-saving high technologies have not been common due to their high cost. Therefore, high technologies with low energy efficiency prevail. Additional funding will help solve this problem.

Secondly, it is the support for the development of EnergyTech. High technologies should be developed not only in economic sectors, but also in the energy sector itself. This will increase the amount of energy generated, as well as allow for a more flexible combination of clean/alternative energy and fossil fuels. Thirdly, it is necessary to tighten the norms and standards of energy efficiency for high-tech industries and enterprises. High technologies (in particular, robots and AI) should be implemented in practice only if they contribute to the development of clean energy or energy neutrality.

The framework recommendations for the development of clean and alternative energy in the age of the Fourth Industrial Revolution for economic policy allow for the adaptation of specific policy papers to modern requirements in each particular country. To make the authors' recommendations more specific, the consistent implementation of the "pledge to achieve carbon neutrality by 2050" (European Parlament, 2022) and "The Development Strategy of the Smart Robot Industry Under the Framework of South Korea Industry 4.0" (Market Prospects, 2022) is proposed in South Korea.

In China, the consistent implementation of "The new 5-year plan for the robotics industry" (The Robot Report, 2022) and the "roadmap for decarbonization with five guiding principles, dozens of measures, and emission targets for 2025, 2030, and 2060" (Climate Dialogue, 2022) is recommended. The abovementioned examples of South Korea as a developed country and China as a fast-growing country will be useful in the adaptation of relevant policy papers in other countries to up-to-date requirements by analogy with these countries, especially in the world's top 10 countries in terms of the degree of automation included in the sample of this research.

Discussion

The contribution of the article to the literature is to fill the scientific gap by highlighting the future prospects for the development of alternative and clean energy in the era of the Fourth Industrial Revolution. Unlike Aubin et al. (2022), Huang et al. (2022), Luan et al. (2022), Nonoyama et al. (2022), Ntsiyin et al. (2022), Wang et al. (2022), it was found that robotization is characterized by insufficiently high energy efficiency, as it causes an increase in the dependence of the economy on fossil fuels.

In contrast to Anthopoulos and Kazantzi (2022), Dreher et al. (2022), Fang et al. (2022), Xuan and Ocone (2022), it was proven that the use of AI hinders the development of clean and alternative energy. Unlike Cui et al. (2022), Ng et al. (2021), Popkova et al. (2021), Popkova and Sergi (2021), Tabor et al. (2018), Taghizadeh-Hesary et al. (2022), Zaidan et al. (2022), t was justified, that the technologies of industry 4.0, which are becoming widespread in the conditions of the Fourth Industrial Revolution, not only do not support, but also slow down the transition to "clean" energy.

Unlike Chen et al. (2022), Deng et al. (2022), Inshakova et al. (2022), Iqbal and Bilal (2021), Liu et al. (2022), Nyenno et al. (2021), direct state regulation of sustainable energy development is recommended. For the balanced development of clean energy and high technologies, progress in the field of energy technologies was proposed and appropriate recommendations were developed.

The practical significance of the results obtained is that they clearly identified the contradiction between clean energy and high technologies–outlined the problem areas and offered the authors' vision of ways to solve them. In further research, it is necessary to study this problem more deeply, as well as to work out in more detail the prospects and recommendations for the development of EnergyTech for the balanced progress of clean energy and high technologies.

The novel nature of the discovery of the obvious conflict between clean energy and automation in the context of the "decade of action" consists in the evidence of the contradiction (antagonism) and complexity of the simultaneous implementation of SDG7 and SDG9. It promotes existing views on the development of alternative energy in the age of the Fourth Industrial Revolution by justifying the need for the consistent development and joint implementation of the economic policy of decarbonization and automation of the economy.

Conclusion

The main conclusions and results of this research are as follows. The review of international practices and the results of the econometric modeling of the impact of the Fourth Industrial Revolution on the energy economy have shown that the proliferation of high technologies of Industry 4.0 (Robotics and AI) leads to the decreasing share of alternative and clean energy, as well as the growing dependence of the economy on fossil energy. With an independent implementation of energy and innovative technology policies, there are two prospective alternative scenarios for the development of the energy economy in the age of the Fourth Industrial Revolution.

The first scenario involves further unrestricted automation in the context of the freedom of proliferation of technologies of Industry 4.0 in the age of the Fourth Industrial Revolution. This will enable the accelerated rate of economic growth and increased labor productivity but will cause a critical increase in the energy intensity of the economy and exacerbate the climate change issues. The second scenario is associated with the preservation of the current trend of the development of alternative and clean energy. This will reduce the energy intensity of the economy and ensure decarbonization while critically slowing down the rate of economic growth and scientific-technological progress.

Consistent development and joint implementation of the energy and innovative technology policy have been proposed to improve the economic policy. As a result, this will enable a third, more promising scenario of the development of energy in the age of the Fourth Industrial Revolution. This optimal scenario will make it possible to achieve the balanced development of clean energy and high technologies in EnergyTech. The economic implications are associated with moderate economic growth and a gradual increase in labor productivity. The social implications consist in the relative stability of the labor market, while the environmental implications consist in the implementation of the plan for decarbonization of the economy and the gradual reduction of its energy intensity.

Author contributions

Conceptualization, TV; Formal analysis, AS.; Methodology, TV; Project administration, S; Resources, AS and TV.; Writing – review and editing, ES and TV.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

References

Alimhan, A., Makhambayev, A., and Ukaegbu, I. A. (2019). The fourth industrial revolution: Towards energy 4.0 in Kazakhstan. International conference on advanced communication technology. *ICACT* 8701979, 527–532. doi:10.23919/ICACT.2019.8701979

Ang, J. H., Goh, C., Saldivar, A. A. F., and Li, Y. (2017). Energy-efficient through-life smart design, manufacturing and operation of ships in an industry 4.0 environment. *Energies* 10 (5), 610. doi:10.3390/en10050610

Anthopoulos, L., and Kazantzi, V. (2022). Urban energy efficiency assessment models from an AI and big data perspective: Tools for policy makers. *Sustain. Cities Soc.* 76, 103492. doi:10.1016/j.scs.2021.103492

Aubin, C. A., Gorissen, B., Milana, E., Lewis, J. A., Shepherd, R. F., Slipher, G. A., et al. (2022). Towards enduring autonomous robots via embodied energy. *Nature* 602 (7897), 393–402. doi:10.1038/s41586-021-04138-2

Bragança, S., Costa, E., Castellucci, I., and Arezes, P. M. (2019). A brief overview of the use of collaborative robots in industry 4.0: Human role and safety. *Stud. Syst. Decis. Control* 202, 641–650. doi:10.1007/978-3-030-14730-3_68

Chen, F., Liu, A., Lu, X., Tong, J., and Akram, R. (2022). Evaluation of the effects of urbanization on carbon emissions: The transformative role of government effectiveness. *Front. Energy Res.* 10, 848800. doi:10.3389/fenrg.2022.848800

Climate Dialogue (2022). The reforms needed for 'deep decarbonisation' in China. Available at: https://chinadialogue.net/en/climate/the-reforms-needed-for-deep-decarbonisation-in-china/#:~:text=In%20October%202021%2C%20the%20State,near-term%20emission%20reduction%20targets (accessed: 06 27, 2022).

Contreras, J. D. (2020). Industrial robots migration towards industry 4.0 components. *Lect. Notes Netw. Syst.* 112, 1–12. doi:10.1007/978-3-030-40309-6_1

Cui, W., Liu, H., Xu, B., and Zhong, C. (2022). Impact of industry 4.0 on green decoration materials in public architectural engineering for application of energy conservation and environmental protection. *Wirel. Commun. Mob. Comput.* 2022, 1–5. doi:10.1155/2022/1360739

Deng, X., Huang, B., Zheng, Q., and Ren, X. (2022). Can environmental governance and corporate performance be balanced in the context of carbon neutrality? — a quasi-natural experiment of central environmental inspections. *Front. Energy Res.* 10, 852286. doi:10.3389/fenrg.2022.852286

Dreher, A., Bexten, T., Sieker, T., Lehna, M., Schütt, J., Scholz, C., et al. (2022). AI agents envisioning the future: Forecast-based operation of renewable energy storage systems using hydrogen with Deep Reinforcement Learning. *Energy Convers. Manag.* 258, 115401. doi:10.1016/j.enconman.2022.115401

European Parlament (2022). South Korea's pledge to achieve carbon neutrality by 2050. Available at: https://www.europarl.europa.eu/RegData/etudes/BRIE/2021/690693/EPRS_BRI(2021)690693_EN.pdf (accessed 06 27, 2022).

Fang, W., Zhu, C., Richard Yu, F., Wang, K., and Zhang, W. (2022). Towards energy-efficient and secure data transmission in AI-enabled software defined industrial networks. *IEEE Trans. Ind. Inf.* 18 (6), 4265–4274. doi:10.1109/TII.2021.3122370

Hargreaves, N., Hargreaves, T., and Chilvers, J. (2022). Socially smart grids? A multi-criteria mapping of diverse stakeholder perspectives on smart energy futures in the United Kingdom. *Energy Res. Soc. Sci.* 90, 102610. doi:10.1016/j.erss.2022.102610

Hayhoe, T., Podhorska, I., Siekelova, A., and Stehel, V. (2019). Sustainable manufacturing in industry 4.0: Cross-sector networks of multiple supply chains, cyber-physical production systems, and ai-driven decision-making. *J. Self-Governance Manag. Econ.* 7 (2), 31–36. doi:10.22381/JSME7220195

Huang, G., He, L.-Y., and Lin, X. (2022). Robot adoption and energy performance: Evidence from Chinese industrial firms. *Energy Econ.* 107, 105837. doi:10.1016/j.eneco.2022.105837

Huang, Z., Yu, H., Peng, Z., and Feng, Y. (2017). Planning community energy system in the industry 4.0 era: Achievements, challenges and a potential solution. *Renew. Sustain. Energy Rev.* 78, 710–721. doi:10.1016/j.rser.2017.04.004

Ignatov, A., and Korolev, P. (2019). The global energy association and the perspectives of future development of the energy sector within the fourth industrial revolution. *IOP Conf. Ser. Earth Environ. Sci.* 390 (1), 012052. doi:10.1088/1755-1315/390/1/012052

Inshakova, A. O., Deryugina, T. V., and Goncharova, M. V. (2022). The legal matrix of cross-cutting technologies of the national technological initiative (NTI): Methodology of formation. *Adv. Res. Russ. Bus. Manag.* 2022, 117–127.

International Federation of Robotics (2022). The robot report 2021. Available at: https://www.therobotreport.com/10-most-automated-countries-wordlwide-in-2020/(accessed 04 10, 2022).

Iqbal, S., and Bilal, A. R. (2021). Energy financing in COVID-19: How public supports can benefit. *China Finance Rev. Int.* 12, 219–240. doi:10.1108/CFRI-02-2021-0046

Jin, A. (2019). Digital innovations, AI, industrie 4.0. *Control Eng.* 66 (4), 5.

Junker, H., and Domann, C. (2017). Towards industry 4.0 in corporate energy management. *WIT Trans. Ecol. Environ.* 214, 49–56. doi:10.2495/ECO170051

Kang, J., and Reiner, D. M. (2022). Off seasons, holidays and extreme weather events: Using data-mining techniques on smart meter and energy consumption data from China. *Energy Res. Soc. Sci.* 89, 102637. doi:10.1016/j.erss.2022.102637

Li, B. (2022). Effective energy utilization through economic development for sustainable management in smart cities. *Energy Rep.* 8, 4975–4987. doi:10.1016/j.egyr.2022.02.303

Liu, C., Li, Q., Tian, X., Chi, Y., and Li, C. (2022). Multi-objective mayfly optimization-based frequency regulation for power grid with wind energy penetration. *Front. Energy Res.* 10, 848966. doi:10.3389/fenrg.2022.848966

Luan, F., Yang, X., Chen, Y., and Regis, P. J. (2022). Industrial robots and air environment: A moderated mediation model of population density and energy consumption. *Sustain. Prod. Consum.* 30, 870–888. doi:10.1016/j.spc.2022.01.015

Mangla, S. K., Luthra, S., Jakhar, S., Muduli, K., and Kumar, A. (2020). A step to clean energy - sustainability in energy system management in an emerging economy context. *J. Clean. Prod.* 242, 118462. doi:10.1016/j.jclepro.2019.118462

Market Prospects (2022). The development Strategy of the smart robot industry under the framework of South Korea industry 4.0. Available at: https://www.market-prospects.com/articles/smart-robot-industry-of-south-korea (accessed 06 27, 2022).

Mascarenhas, K. L., Peyerl, D., Weber, N., Mouette, D., Meneghini, J. R., Moretto, E. M., et al. (2020). *Sustainable development goals as a tool to evaluate multidimensional clean energy initiatives. World sustainability series*, (Cham: Springer), 645–657. doi:10.1007/978-3-030-26759-9_37

Matizamhuka, W. (2018). The impact of magnetic materials in renewable energy-related technologies in the 21st century industrial revolution: The case of South Africa. *Adv. Mater. Sci. Eng.* 2018, 1–9. doi:10.1155/2018/3149412

Matsunaga, F., Zytkowski, V., Valle, P., and Deschamps, F. (2022). Optimization of energy efficiency in smart manufacturing through the application of cyber-physical systems and industry 4.0 technologies. *J. Energy Resour. Technol.* 144 (10), 102104. doi:10.1115/1.4053868

McNeill, J. R. (2019). Cheap energy and ecological teleconnections of the industrial revolution, 1780-1920. *Environ. Hist.* 24 (3), 492–503.

Ng, A. W., Nathwani, J., Fu, J., and Zhou, H. (2021). Green financing for global energy sustainability: Prospecting transformational adaptation beyond industry 4.0. *Sustain. Sci. Pract. Policy* 17 (1), 377–390. doi:10.1080/15487733.2021.1999079

Nonoyama, K., Liu, Z., Fujiwara, T., Alam, M. M., and Nishi, T. (2022). Energy-efficient robot configuration and motion planning using genetic algorithm and particle swarm optimization. *Energies* 15 (6), 2074. doi:10.3390/en15062074

Ntsiyin, T., Markus, E. D., and Masheane, L. (2022). A survey of energy-efficient electro-hydraulic control system for collaborative humanoid robots. *Smart Innovation, Syst. Technol.* 251, 65–77. doi:10.1007/978-981-16-3945-6_8

Nyenno, I., Truba, V., Lomachynska, I., and Mazur, O. (2021). Digital public goods as a means to support affordable and clean energy. *Polityka Energetyczna –. Energy Policy J.* 24 (4), 139–152. doi:10.33223/epj/144907

Peter, O., and Mbohwa, C. (2018). Correlation between future energy systems and industrial revolutions. *Proc. Int. Conf. Industrial Eng. Operations Manag.* 2018, 1953–1961.

Popkova, E. G., Inshakova, A. O., Bogoviz, A. V., and Lobova, S. V. (2021). Energy efficiency and pollution control through ICTs for sustainable development. *Front. Energy Res.* 9, 735551. doi:10.3389/fenrg.2021.735551

Popkova, E. G., and Sergi, B. S. (2021). Energy efficiency in leading emerging and developed countries. *Energy* 221, 119730. doi:10.1016/j.energy.2020.119730

Saikia, P., Gauravand Rakshit, D. (2020). Designing a clean and efficient air conditioner with AI intervention to optimize energy-exergy interplay. *Energy AI* 2, 100029. doi:10.1016/j.egyai.2020.100029

Seixas, M., Melicio, R., and Mendes, V. (2018). Comparison of offshore and onshore wind systems with MPC five-level converter under energy 4.0. *Electr. Power Components Syst.* 46 (13), 1399–1415. doi:10.1080/15325008.2018.1495277

Tabor, D. P., Roch, L. M., Saikin, S. K., Persson, K. A., Aspuru-Guzik, A., Montoya, J. H., et al. (2018). Accelerating the discovery of materials for clean energy in the era of smart automation. *Nat. Rev. Mat.* 3 (5), 5–20. doi:10.1038/s41578-018-0005-z

Taghizadeh-Hesary, F., Zakari, A., Alvarado, R., and Tawiah, V. (2022). The green bond market and its use for energy efficiency finance in Africa. *China Finance Rev. Int.* 12, 241–260. doi:10.1108/CFRI-12-2021-0225

Tainter, J. A., and Taylor, T. G. (2019). Energy, transport, and consumption in the industrial revolution. *Behav. Brain Sci.* 42, e209. doi:10.1017/S0140525X19000153

The Robot Report (2022). How realistic is China's five-year plan for robotics? Avilable at: https://www.therobotreport.com/how-realistic-is-chinas-five-year-plan-for-robotics/(accessed 06 27, 2022).

Tijani, A. O., Khumbulani, M., and Gamede, G. B. (2018). Energy efficiency in manufacturing in the context of the fourth industrial revolution. *Proc. Int. Conf. Industrial Eng. Operations Manag.* 2018, 526–536.

Tortois (2022). The global AI index. Avilable at: https://www.tortoisemedia.com/intelligence/global-ai/(accessed on 04 10, 2022).

Wang, E.-Z., Lee, C.-C., and Li, Y. (2022). Assessing the impact of industrial robots on manufacturing energy intensity in 38 countries. *Energy Econ.* 105, 105748. doi:10.1016/j.eneco.2021.105748

World Bank (2022). Energy & mining. Avilable at: https://data.worldbank.org/topic/energy-and-mining?view=chart (accessed on 04 10, 2022).

Xuan, J., and Ocone, R. (2022). The equality, diversity and inclusion in energy and AI: Call for actions. *Energy AI* 8, 100152. doi:10.1016/j.egyai.2022.100152

Zaidan, E., Ghofrani, A., Abulibdeh, A., and Jafari, M. (2022). Accelerating the change to smart societies- a strategic knowledge-based framework for smart energy transition of urban communities. *Front. Energy Res.* 10, 852092. doi:10.3389/fenrg.2022.852092

frontiers | Frontiers in Energy Research

TYPE Opinion
PUBLISHED 07 November 2022
DOI 10.3389/fenrg.2022.1021886

Check for updates

OPEN ACCESS

EDITED BY
Chun Sing Lai,
Brunel University London,
United Kingdom

REVIEWED BY
Vera Shumilina,
Don State Technical University, Russia

*CORRESPONDENCE
Svetlana V. Lobova,
barnaulhome@mail.ru

†These authors have contributed equally to this work

SPECIALTY SECTION
This article was submitted to Sustainable Energy Systems and Policies, a section of the journal Frontiers in Energy Research

RECEIVED 17 August 2022
ACCEPTED 26 October 2022
PUBLISHED 07 November 2022

CITATION
Bogoviz AV, Lobova SV and Alekseev AN (2022), Advanced HRM practices and digital personnel for digital energetics based on the technologies of Industry 4.0.
Front. Energy Res. 10:1021886.
doi: 10.3389/fenrg.2022.1021886

Advanced HRM practices and digital personnel for digital energetics based on the technologies of Industry 4.0

Aleksei V. Bogoviz[1†], Svetlana V. Lobova[2*†] and Alexander N. Alekseev[3†]

[1]Independent Researcher, Moscow, Russia, [2]Altai State University, Barnaul, Russia, [3]Financial University Under the Government of the Russian Federation, Moscow, Russia

KEYWORDS

HRM practices, Digital personnel, digital energetics, Industry 4.0, energy economy system

Introduction

Digital energetics is the energy economy in which the digital technological mode dominates, which implies the active use of the leading digital technologies of Industry 4.0 (e.g., robots, big data and AI) and digital personnel (highly qualified employees with skills to use the leading technologies).

The Fourth Industrial Revolution, like all the previous ones, assumes that systemic changes are taking place in economic systems, which are not only technological but also social. It is advisable to consider the latter systematically from the standpoint of Stakeholder Theory. From the perspective of employees (supply in the energy segment of the labor market), deep technological shifts in the energy sector increase the risks of unemployment and cause uncertainty about the prospects for the disclosure of human potential.

In many countries, especially in large energy economies, employment in the energy sector is quite large, which makes the energy sector an important segment of the labor market. For example, according to Rosstat (2022), in 2020 in Russia the number of people employed in mining was 1,160,500 people, and in the field of electricity, gas, steam and air conditioning supply—1,568,100 people. The share of employment in the energy sector (and indicated related fields of activity) was 3.94% of the total number of employed 6,925,190 people.

From the standpoint of energy companies (demand in the energy segment of the labor market), the transition to industry 4.0 technologies is aimed at automating production and distribution processes that pose a threat to the health of workers. Many energy companies note in their corporate social responsibility reports that the introduction of advanced automation tools has allowed them to reduce industrial injuries and improve production safety. At the same time, technological modernization cannot take place without highly qualified personnel introducing "smart" innovations. Therefore, it seems that the demand for human resources and human resources management (HRM) practices is specific to each production process of energy companies, which further increases uncertainty.

In this regard, the study of the social consequences of the transition to digital energetics for people employed in the energy sector demonstrates both high relevance and scientific and practical significance. In the existing literature (Morelli et al., 2022; Zhang et al., 2022; Zhao et al., 2022), much attention is paid to the technological advantages of the transition to digital energetics, including increased productivity and production capacities of energy companies, improved safety (including environmental) of production and distribution processes in the energy sector, expanded opportunities for the development of "clean" energy.

At the same time, the social consequences of the transition to digital energetics have not been sufficiently studied, which is a gap in current scientific knowledge. This article aims to fill this gap and specify the role of digital staff in the development of digital energetics based on the technologies of Industry 4.0, as well as to review the best practices of performing this role.

The contradiction of the social consequences of the transition to digital energetics

In the existing literature, much attention is paid to the prospects of the digital development of the energy sector. Automation covers more and more economic processes and systems of energy companies (Afshari et al., 2022' Buchmayr et al., 2022; Krupnik et al., 2022). The research works (Chadwick et al., 2022; Guglielmi et al., 2022; Shidong et al., 2022) note that the transition to digital energetics based on the technologies of Industry 4.0 increases the risks for workers in this industry (Al-Haidan et al., 2022; Baur et al., 2022; Büscher, 2022).

However, in most cases, industrial robots and other "smart" technologies of industry 4.0 do not displace human resources, but transform the need for them and change the functional component of their work (Matsunaga et al., 2022; Niet et al., 2021; Shinkevich et al., 2021; Udin, 2020). At the same time, not purely cybernetic, but cyber-physical systems are being formed in the energy economy, in which the "smart" technologies of industry 4.0 (technological resources) are flexibly combined with other types of resources (natural, social, *etc.*) (Matsunaga et al., 2022; Morelli et al., 2022; Nathaniel et al., 2021a; Nathaniel et al., 2021b; Trzaska et al., 2021).

This leads, firstly, to the need for digital personnel capable of effectively using the "smart" technologies of industry 4.0 in the activities of energy companies, as well as subsequently developing new digital competencies as technological development proceeds (in accordance with the concept of lifelong learning) (Hoffmann and Thommes, 2020; Rolim and Baptista, 2021; Silamut and Sovajassatakul, 2021; Zaychenko et al., 2019).

Secondly, this results in the need to use advanced HRM practices that allow energy companies to create high-performance and knowledge-intensive jobs, introduce effective labor incentives for the fullest disclosure and development of human potential (Christina et al., 2017; Fatihudin et al., 2020; Lee, 2020; Wang, 2021).

At the same time, the consequences of the transition to digital energetics for human resources are poorly studied and ambiguous, and therefore represent a research gap. In particular, despite a large number of the existing publications, it is still unclear to which extent human resources are required in EnergyTech and what their significance/technological resources (high technologies of Industry 4.0) ratio is. Uncertainty of the social factors of digital energetics leads to incomplete scientific view of it.

Unjustified (due to the absence of the scientific and methodological support) personnel cuts by energy companies, in their striving for digital competitiveness could lead to unpredictable consequences. In particular, contrary to their expectations, this may lead to the loss of their competitive advantages (which are based on corporate knowledge). From the society's point of view, uncertainty of the future employment in the energy economy destabilizes the labor market and aggravates the social tension.

That is why, at the current stage of the development of EnergyTech, it is important to reveal and substantiate scientifically its needs for human resources (including digital personnel) in the long-term. This will be a signal for managing the social risks of EnergyTech for universities (e.g., the change of educational programs) and applicants (e.g., preferring alternative professions instead of energetics) and for the current energy personnel in the labor market (e.g., retraining or advanced training).

This research gap slows down the development of EnergyTech due to the contradiction and obscureness of social consequences (chances for employment, character of labor, possibility of human potential development) of the transition to digital energetics. In this article, the identified research gap is filled through a review of international experience and a case study of Russia's experience in implementing advanced HRM practices, training digital personnel in the education system and their distribution in the labor market in digital energetics based on the technologies of Industry 4.0.

International experience of the contribution of advanced HRM practices and digital personnel to the development of digital energetics based on the technologies of Industry 4.0

To study international best practices, this article provides a sample of the top 10 countries by the value of the Energy Trilemma index prepared by the World Energy Council

TABLE 1 Advanced HRM practices, digital personnel, high technologies of Industry 4.0 and energy sustainability in the top 10 digital energy economies of the world in 2021, score 0–100.

Top 10 digital energy economies of the world	Energy trilemma index	The knowledge index, reflecting the level of training and availability of digital personnel	Knowledge-intensive employment	High-tech manufacturing
Switzerland	84.2	86.929	83.1	89.8
Sweden	83.8	86.485	88.9	62.8
Denmark	83.0	81.415	79.2	63.4
Finland	81.7	77.181	79.2	52.3
Great Britain	81.7	76.031	82.3	58.2
Austria	81.0	77.166	67.4	59.0
France	81.1	68.044	75.0	66.9
Canada	80.6	81.795	70.4	48.5
Germany	80.4	75.854	74.6	74.6
Norway	79.6	73.499	84.3	42.2

(2022) in 2021, which are also the leaders of The IMD World Digital Competitiveness (WDC) rating (2022) in 2021. This makes it possible to characterize the sample countries as developed digital energy economies in terms of the use of high technologies, energy security and sustainability (environmental friendliness) of the energy sector, which makes their experience especially valuable for research.

The selection of the Energy Trilemma Index as an empirical basis of the research is due to the following: first, it is one of the most reliable and authoritative sources of statistics on energetics. Second, the advantage of the Energy Trilemma Index is that it fully (systemically) reflects the achieved progress in the implementation of SDG 7, covering 1) energy security (affordability of energy and absence of its deficit); 2) energy (general equal accessibility of energy); 3) environmental sustainability of energy systems (reduction of production waste, distribution and consumption of energy, and decarbonization of economy).

The choice of such a sample of countries is explained by the following: first, it includes the leading digital economies of the world according to IMD Business School (2022). Thus, the sample precisely characterizes the modern practice of the development of digital energetics based on the technologies of Industry 4.0 (EnergyTech). Second, the sample is optimal for this research, because it allows studying the experience of countries that reached the biggest success in the practical implementation of SDG 7.

Third, countries of the sample are known for their progressive HRM practices, which are based on a high level of corporate social responsibility and knowledge-intensive and highly-efficient jobs. Due to these reasons, the sample fits the research of advanced HRM practices and digital personnel for digital energetics based on the technologies of Industry 4.0. Experience of countries of the sample, which is systematized and reconsidered in this paper, will be useful for other countries, for it will allow world dissemination of advanced HRM practices of digital personnel management in digital energetics based on the technologies of Industry 4.0, thus supporting the development of EnergyTech and the practical implementation of SDG 7 at the scale of the world energy economy.

To determine the role played by digital personnel in the development of digital energy based on the technologies of Industry 4.0, a factor analysis of the Energy Trilemma Index is carried out (let us introduce the notation DE). The Knowledge Index calculated by IMD Business School (2022) (let us introduce the notation Hrm_1) acts as a factor of the level of training and availability of digital personnel (2022) (let us introduce the notation Hrm_2) acts as a factor of advanced HRM practices. For comparison with the noted social factors, a technological factor is also used—High-tech manufacturing according to the World Bank (2022) (let us introduce the notation Hrm_3). The values of the indicators selected for research in the sample of countries are systematized in Table 1.

The data were obtained from references to IMD Business School (2022), the World Bank (2022), the World Energy Council (2022).

Based on the data from Table 1, the following model of multiple linear regression is obtained:

$$DE = 63,27 + 0,13^{*}Hrm_1 + 0,07^{*}Hrm_2 + 0,05\,Hrm_3$$

In the resulting model, F-value was 0.02116 (the model is reliable at the significance level of 0.05 and therefore is characterized by high accuracy and reliability). The R-squared was 0.7804, therefore, the change in energy stability (energy trilemma index) by 78.04% is explained by the influence of the considered factor variables. The factor of the level of training and availability of digital personnel proved to be the most significant: an increase in the Knowledge Index by 1 point leads to an increase in energy sustainability (energy trilemma index) by 0.13 points.

The factor of advanced HRM practices was in second place in significance–an increase in knowledge-intensive employment by one point leads to an increase in energy sustainability (energy trilemma index) by 0.07 points. Technological factor - when increasing high-tech manufacturing by one point, it leads to an increase in energy sustainability (energy trilemma index) by 0.05 points. It was also found that with the maximum (100 points) values of all the factors under consideration, energy sustainability will increase by 7.39% from 81.71 points on average in the sample of countries in 2021 to 87.75 points.

This indicates an important positive role of digital personnel in the development of sustainable digital energy, and also indicates a much greater importance of social factors compared to technological factors (high technologies of Industry 4.0).

Advanced HRM practices: Case experience in training and managing digital personnel for digital energetics based on the technologies of Industry 4.0 in Russia

To clarify the quantitative results obtained, we will supplement them with a qualitative analysis of the case experience of training and managing digital personnel for digital energetics based on the technologies of Industry 4.0 on the example of Russia. Russia's experience is also advanced, as it is among the top 30 countries in the world for energy sustainability (energy trilemma index) and is included in the ranking of the world's leading digital economies (IMD business school, 2022). Consequently, a progressive digital energy economy has been formed in Russia, the practical experience of which is useful for other countries. The advantage of studying Russia's experience in this paper is that this allows covering not only the practice of developed countries (which was considered above) but also the practice of developing countries, expanding the specter of the applied use of the authors' conclusions.

In 2019, the Government of the Russian Federation adopted the national program "Digital economy of the Russian Federation," which is planned until 2024. The goals of the Program are the provision of wide accessibility of the Internet, coverage of all largest cities with 5G, protection of the information of citizens, business and the government, growth of the effectiveness of the main spheres of the economy (including energetics), and training of personnel for the work in the digital environment. Training and management of digital personnel is distinguished as a separate direction of the Program, which emphasizes its high priority.

In Russia, the development of digital energetics based on the technologies of Industry 4.0 takes place in accordance with the departmental project "Digital Energy" of The Ministry of Energy of Russia (2022), developed with the active participation of energy companies. In this regard, the broad involvement of private business in the normative legal regulation (creation of "rules of the game") of digital energetics is a feature and advantage of modern Russian practice.

One of the four objectives of the Project is "to ensure the training of highly qualified personnel for digital energetics," which involves "the development of sectoral educational programs and retraining programs for digital energetics," as well as "the creation and launch of sectoral educational centers based on universities" (Ministry of Energy of Russia, 2022).

In the period up to 2024, it is planned to implement the following sectoral measures of state support for the training and disclosure of the human potential of digital personnel in the digital energy industry of Russia (Digital Energy Association, 2022):

→ Provision of certificates for the development of digital competencies by employees of the energy sector;
→ State approval of the official competence map of digital personnel in the energy sector;
→ Organization of an independent assessment of the competence of digital personnel in the energy sector (personnel audit of energy companies).

One of the first government initiatives was supported by Kazan State Energy University (2022), which organized the work of a unique educational and research laboratory "Digital Switchgear" for training personnel in digital energetics.

The following innovative practices in digital energetics based on the technologies of Industry 4.0 are being implemented in Russia by Russian oil and gas companies (Oil and Gas Vertical, 2022):

– Automation of AI-based equipment maintenance: reduction of the staff of repair crews with their gradual replacement with digital sensors for collecting data on the operation of equipment;
– The transition of consulting analysts to remote work based on the Internet of Things: continuous remote monitoring of complex technological processes in remote fields;
– Development of human potential of employees using AR/VR technologies: training of personnel reserve with the help of simulators that accurately reproduce production processes in the field without the need to travel to remote areas;
– Professional corporate training using 3D printers: young employees improve their skills by practicing on 3D models of equipment that is not available for transportation to training centers;
– Intellectual support for managerial decision-making based on Big Data: risk assessment is partially automated to increase the productivity of managerial personnel;

– Creation of knowledge-intensive jobs in energy logistics using mobile applications: intra-corporate logistics and work with large clients is carried out through linear programming.

Discussion

The results obtained contribute to the literature on the topic of digital energy economy. In contrast to (Chadwick et al., 2022; Guglielmi et al., 2022; Shidong et al., 2022), the authors' conclusions of this article indicate that the transition to digital energetics based on the technologies of Industry 4.0 causes not so much new risks as new opportunities for workers in this industry. A quantitative analysis of the international experience of the contribution of advanced HRM practices and digital personnel to the development of digital energetics revealed the primary role of digital personnel in the sustainable development of energy with the secondary role of high technologies of Industry 4.0.

The qualitative review and analysis of advanced HRM practices of case experience in training and managing digital personnel for digital energetics based on the technologies of Industry 4.0 in Russia showed that digital technologies displace employees only from those few business processes that cannot be effectively performed by people or are unsafe for them. At the same time, most business processes (which are not subject to automation) are accompanied by increased employee participation and support for knowledge-intensive and high-performance employment, which contributing to the full development of human potential.

The practical significance of the findings is that the illustrated best practices are useful for other countries. The article offered a new way of looking at human resource management of energy companies, which should attract digital personnel and improve their management practices in order to support high-tech and sustainable digital energetics. This makes it possible to resolve the contradiction of the social consequences of the transition to digital energetics in favor of digital personnel as its key subjects.

Conclusion

The results obtained allow for the following conclusions. First, the key role of digital personnel and HRM practices in the development of digital energetics based on the technologies of Industry 4.0 is substantiated. This opens a new unique view of the Fourth Industrial Revolution, which is presented for the first time not through the lens of technical progress but the lens of social progress. This essentially new and original view shows the in-depth—social—nature of EnergyTech.

Due to this, the paper contributes to the new body of knowledge in the forming, but perspective, a sphere of human resource management in digital energetics. This conclusion allows bridging the gap between digital personnel and leading technologies, which leads to their systemic and highly-effective use in digital energetics. The substantiated high knowledge intensity of EnergyTech assigns it with previously unknown and leading ability to form cyber-socio-technical systems, facilitating the transition from Industry 4.0 to Industry 5.0.

Second, it is demonstrated that EnergyTech is accessible and develops successfully in developed and developing countries. The authors described a wide range of advanced HRM practices of digital personnel management in digital energetics (increase in labor safety, creation of knowledge-intensive jobs, training of personnel, and stimulation of efficiency growth) based on the technologies of Industry 4.0, which include AI, IoT, AR/VR, 3D printers and 3D models, Big Data, mobile applications, and linear programming. Management implications of this paper consist in the following: systematization and scientific analysis of the empirical and case experience of the implementation of advanced HRM practices of digital personnel management in digital energetics based on the technologies of Industry 4.0 allows energy companies around the world to perform a transition to EnergyTech and improve the results in the sphere of implementing SDG 7, using the practices that are described in this paper.

It should be concluded that a limitation of this research is its focus on the achieved results (implemented practices), while the process of their launch remained outside the scope of this paper. It seems that the process of implementing advanced HRM practices of digital personnel management in digital energetics based on the technologies of Industry 4.0 in the activities of energy companies is complex and rather long and must take into account the specifics of each company (e.g., its corporate culture and organizational structure). In it proposed that further studies pay attention to the scientific elaboration of the issues of implementing the described advanced HRM practices of digital personnel management in digital energetics based on the technologies of Industry 4.0 in the activities of energy companies.

Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

References

Afshari, H., Agnihotri, S., Searcy, C., and Jaber, M. Y. (2022). Social sustainability indicators: A comprehensive review with application in the energy sector. *Sustain. Prod. Consum.* 31, 263–286. doi:10.1016/j.spc.2022.02.018

Al-Haidan, S. A., Azazz, A. M. S., and Elshaer, I. A. (2022). Social disconnectedness and career advancement impact on performance: The role of employees' satisfaction in the energy sector. *Energies* 15 (7), 2599. doi:10.3390/en15072599

Association Digital Energy, (2022). Expert session "Personnel for digital energy – issues, research, trends" 22.05.2020. Available at: https://www.digital-energy.ru/2020/05/22/news/assotsiatsiya-tsifrovaya-energetika-provela-ekspertnuyu-sessiyu-kadry-dlya-tsifrovoy-energetiki-voprosy-issledovaniya-trendy/ (Accessed August 10, 2022).

Baur, D., Emmerich, P., Baumann, M. J., and Weil, M. (2022). Assessing the social acceptance of key technologies for the German energy transition. *Energy sustain. Soc.* 12 (1), 4. doi:10.1186/s13705-021-00329-x

Buchmayr, A., Verhofstadt, E., Van Ootegem, L., Dewulf, J., Taelman, S. E., and Dewulf, J. (2022). Exploring the global and local social sustainability of wind energy technologies: An application of a social impact assessment framework. *Appl. Energy* 312, 118808. doi:10.1016/j.apenergy.2022.118808

Büscher, C. (2022). The problem of observing sociotechnical entities in social science and humanities energy transition research. *Front. Sociol.* 6, 699362. doi:10.3389/fsoc.2021.699362

Chadwick, K., Russell-Bennett, R., and Biddle, N. (2022). The role of human influences on adoption and rejection of energy technology: A systematised critical review of the literature on household energy transitions. *Energy Res. Soc. Sci.* 89, 102528. doi:10.1016/j.erss.2022.102528

Christina, S., Dainty, A., Daniels, K., Tregaskis, O., and Waterson, P. (2017). Shut the fridge door! HRM alignment, job redesign and energy performance. *Hum. Resour. Manag. J.* 27 (3), 382–402. doi:10.1111/1748-8583.12144

Fatihudin, D., Sembiring, M. J., Firmansyah, M. A., and Holisin, I. The role of intellectual human capital, human resource practices and intention to use of energy resources on the company performance. *Int. J. Energy Econ. Policy* 10 (6), 2020,704–712. doi:10.32479/ijeep.10623

Guglielmi, D., Paolucci, A., Cozzani, V., Fraboni, F., Pietrantoni, L., and Fraboni, F. (2022). Integrating human barriers in human reliability analysis: A new model for the energy sector. *Int. J. Environ. Res. Public Health* 19 (5), 2797. doi:10.3390/ijerph19052797

Hoffmann, C., and Thommes, K. (2020). Can digital feedback increase employee performance and energy efficiency in firms? Evidence from a field experiment. *J. Econ. Behav. Organ.* 180, 49–65. doi:10.1016/j.jebo.2020.09.034

Imd Business School (2022). World digital competitiveness ranking 2021. Available at: https://www.imd.org/centers/world-competitiveness-center/rankings/world-digital-competitiveness/ (Accessed August 10, 2022).

Kazan State Energy University (2022). Educational and Research Laboratory "Digital switchgear" for training personnel for digital energetics. Available at: https://kgeu.ru/News/Item/159/9176 (Accessed August 10, 2022).

Krupnik, S., Wagner, A., Koretskaya, O., Wade, R., Misik, M., Zapletalová, V., et al. (2022). Beyond technology: A research agenda for social sciences and humanities research on renewable energy in europe. *Energy Res. Soc. Sci.* 89, 102536. doi:10.1016/j.erss.2022.102536

Lee, H. (2020). The role of environmental uncertainty, green HRM and green SCM in influencing organization's energy efficacy and environmental performance. *Int. J. Energy Econ. Policy* 10 (3), 332–339. doi:10.32479/ijeep.9221

Matsunaga, F., Zytkowski, V., Valle, P., and Deschamps, F. (2022). Optimization of energy efficiency in smart manufacturing through the application of cyber-physical systems and industry 4.0 technologies. *J. Energy Resour. Technol.* 144 (10), 102104. doi:10.1115/1.4053868

Morelli, G., Magazzino, C., Gurrieri, A. R., Pozzi, C., and Mele, M. (2022). Designing smart energy systems in an industry 4.0 paradigm towards sustainable environment. *Sustain. Switz.* 14 (6), 3315. doi:10.3390/su14063315

Nathaniel, S. P., Bekun, F. V., and Faizulayev, A. (2021b). Modelling the impact of energy consumption, natural resources, and urbanization on ecological footprint in South Africa: Assessing the moderating role of human capital. *Int. J. Energy Econ. Policy* 11 (3), 130–139. doi:10.32479/ijeep.11099

Nathaniel, S. P., Yalçiner, K., and Bekun, F. V. (2021a). Assessing the environmental sustainability corridor: Linking natural resources, renewable energy, human capital, and ecological footprint in BRICS. *Resour. Policy* 70, 101924. doi:10.1016/j.resourpol.2020.101924

Niet, I. A., Dekker, R., and van Est, R. (2021). Seeking public values of digital energy platforms. *Sci. Technol. Hum. Values*. 47, doi:10.1177/01622439211054430

Oil and gas vertical (2022). Top 7 digital solutions in the oil and gas industry. Available at: http://www.ngv.ru/magazines/article/top-7-tsifrovykh-resheniy-v-neftegazovoy-otrasli/ (Accessed August 10, 2022).

Rolim, C. C., and Baptista, P. (2021). Sharing lisboa: A digital social market to promote sustainable and energy efficient behaviours. *Climate* 9 (234), 34–28. doi:10.3390/cli9020034

Rosstat (2022). Russia in numbers: 2021 – a short statistical collection. Available at: https://rosstat.gov.ru/folder/210/document/12993 (Accessed August 10, 2022).

Shidong, L., Chupradit, S., Maneengam, A., Nguyen Ngoc, Q., Phan The, C., and Nguyen Ngoc, Q. (2022). The moderating role of human capital and renewable energy in promoting economic development in G10 economies: Evidence from CUP-FM and CUP-BC methods. *Renew. Energy* 189, 180–187. doi:10.1016/j.renene.2022.02.053

Shinkevich, A. I., Shaimieva, E. S., Nurgaliev, R. K., and Gumerova, G. I. (2021). The modeling of operating activities of petrochemical and fuel and energy enterprises in industry 4.0. *Acad. Entrepreneursh. J.* 27 (4), 1–10.

Silamut, A.-A., and Sovajassatakul, T. (2021). Self-directed learning with knowledge management model on academic achievement and digital literacy abilities for employees of a Thai energy organization. *Educ. Inf. Technol. (Dordr).* 26 (5), 5149–5163. doi:10.1007/s10639-021-10484-5

The Ministry of Energy of Russia (2022). Departmental project "digital energy" Available at: https://in.minenergo.gov.ru/energynet/vedomstvennyi-proekt-tsifrovaya-energetika/ (Accessed August 10, 2022).

Trzaska, R., Sulich, A., Organa, M., Niemczyk, J., and Jasiński, B. (2021). Digitalization business strategies in energy sector: Solving problems with uncertainty under industry 4.0 conditions. *Energies* 14 (23), 7997. doi:10.3390/en14237997

Udin, U. (2020). Renewable energy and human resource development: Challenges and opportunities in Indonesia. *Int. J. Energy Econ. Policy* 10 (2), 233–237. doi:10.32479/ijeep.8782

Wang, T. (2021). Research on automation processing of human resource management system in energy enterprises. *IOP Conf. Ser. Earth Environ. Sci.* 692 (2), 022029. doi:10.1088/1755-1315/692/2/022029

World Bank (2022). Explore the interactive database of the WIPO global innovation index 2021 indicators. Available at: https://www.globalinnovationindex.org/analysis-indicator (Accessed August 10, 2022).

World Energy Council (2022). Energy trilemma index 2021. Available at: https://trilemma.worldenergy.org/ (Accessed August 10, 2022).

Zaychenko, I., Smirnova, A., and Kriukova, V. (2019). Application of digital technologies in human resources management at the enterprises of fuel and energy complex in the far north. *Adv. Intelligent Syst. Comput.* 983, 321–328. doi:10.1007/978-3-030-19868-8_33

Zhang, J., Wang, B., Wang, H., Li, Y., Li, Y., Zhang, Y., et al. (2022). Operation state evaluation method of smart distribution network based on free probability theory. *Front. Energy Res.* 9, 803010. doi:10.3389/fenrg.2021.803010

Zhao, W., Liu, X., Wu, Y., Zhang, T., and Zhang, L. (2022). A learning-to-rank-based investment portfolio optimization framework for smart grid planning. *Front. Energy Res.* 10, 852520. doi:10.3389/fenrg.2022.852520

frontiers | Frontiers in Energy Research

TYPE Opinion
PUBLISHED 24 November 2022
DOI 10.3389/fenrg.2022.1025441

Check for updates

OPEN ACCESS

EDITED BY
Bamidele Victor Ayodele,
University of Technology Petronas,
Malaysia

REVIEWED BY
Ivan Milenkovic,
University of Novi Sad, Serbia

*CORRESPONDENCE
Elena G. Popkova,
elenapopkova@yahoo.com

SPECIALTY SECTION
This article was submitted to Sustainable Energy Systems and Policies, a section of the journal Frontiers in Energy Research

RECEIVED 22 August 2022
ACCEPTED 11 November 2022
PUBLISHED 24 November 2022

CITATION
Popkova EG, Karanina EV, Stankevich GV and Shaimardanov TR (2022), The contribution of clean energetics based on energy technology (EnergyTech) to the reduction of production waste and the fight against climate change: Legal regulation issues. *Front. Energy Res.* 10:1025441. doi: 10.3389/fenrg.2022.1025441

The contribution of clean energetics based on energy technology (EnergyTech) to the reduction of production waste and the fight against climate change: Legal regulation issues

Elena G. Popkova[1]*, Elena V. Karanina[2], Galina V. Stankevich[3,4] and Timur R. Shaimardanov[5]

[1]MGIMO University, Moscow, Russia, [2]Vyatka State University, Kirov, Russia, [3]Pyatigorsk State University, Pyatigorsk, Russia, [4]Nevinnomyssk State Humanitarian and Technical Institute, Nevinnomyssk, Russia, [5]Russian Presidential Academy of National Economy and Public Administration, Moscow, Russia

KEYWORDS

clean energetics, EnergyTech, fight against climate change, legal regulation, clean energy

Introduction

Energy technology is high technology in the fuel and energy complex, which are to ensure its sustainable development. Similar to high-tech segments of other sectors of the economy, for example, high-tech finance (FinTech), high-tech education (EdTech), and high-tech medicine (MedTech), it is expedient to use the term “EnergyTech” for high-tech energy.

Clean energy powered by EnergyTech is the way to achieving SDG7. The essence, features, and accumulated experience of passing this way in the global economy are studied in sufficient detail from the standpoint of business and economy, society, and environmental protection. At the same time, clean energy based on EnergyTech remains poorly studied from the standpoint of legal regulation, although it plays an important role in its development since it forms the necessary institutional framework for this. The existing literature (Wei et al., 2019; Qu et al., 2021; Solgi et al., 2022) dwells on the technologies of clean energetics based on EnergyTech. These technologies are widely known and accessible, but the level of high technology does not explain the essence and regularities of the transition to clean energetics based on EnergyTech.

The problem is that high technologies in energetics could be used for various purposes. For example, in countries where the export of fossil fuels largely determines the international production specialization (e.g., countries of OPEC and OPEC+), high technologies could be used to optimize the production and distribution processes for oil and gas energy (Schwalm et al., 2013; Chen et al., 2021; Quan et al., 2022). Unlike them, countries that import energy resources demonstrate a striving toward successful results in the use of high technologies for the development of clean energetics (Yin et al., 2021; Liu et al., 2022).

Therefore, the high-tech character of the economy does not predetermine a quick rate of its transition to clean energetics and does not guarantee its contribution to the reduction of production waste and the fight against climate change. This means that the use of high technologies in the energy economy is a mandatory, but not sufficient, condition for assigning it to EnergyTech. There is a need for more complex criteria, which would allow for a more precise outlining of the sphere of EnergyTech and the determination of a path to it.

EnergyTech is a progressive concept that is based on the philosophy of sustainable development and envisages the systemic character of the advantages of high technologies in energetics for the economy, society, and environment (Jia et al., 2022a; Nasser et al., 2022a; Jamali and Yari, 2022; Khan et al., 2022; Li and Haneklaus, 2022; Ramli et al., 2022).

The existing views on the use of high technologies in energetics (Dinh et al., 2021; Yang et al., 2021) elaborate mainly on the socio-economic advantages, while environmental advantages remain poorly studied and uncertain—this is a research gap. The existing view of the development of energetics from the position of technologies does not describe the causal connections of the transition to clean energetics based on EnergyTech or the advantages for the environmental economy in the form of a decrease in production waste and the fight against climate change. Therefore, it should be replaced by a new—institutional—view, which describes systemic and in-depth causal connections.

This paper strengthens the scientific framework of the hypothesis based on the research materials of Bolgova (2017), Chen et al. (2022), Huang et al. (2022), Inshakova et al. (2020), and Li et al. (2022). The hypothesis is as follows: institutes play an important role in the process of the transition to clean energetics based on EnergyTech and greatly determine its contribution to the reduction of production waste and the fight against climate change. The purpose of this paper is to determine the institutes of transition to clean energetics based on EnergyTech. This paper is aimed at strengthening the scientific and methodological basis for the reduction of production waste and the fight against climate change from the position of legal regulation. For, we support the hypothesis on the institutional nature of the transition to clean energetics based on EnergyTech.

Literature review

The fundamental base of this paper is the theory of clean energetics. The issues of transition to clean energetics based on EnergyTech have been studied in detail in the existing literature. Haoyang et al. (2022) substantiate the predicament of clean energy technology promotion in China in the carbon neutrality context, describing lessons from China's environmental regulation policies from the position of the evolutionary game theory.

Islam et al. (2022) prove the close interconnection between the demand for minerals and clean energy transitions. Naeem et al. (2022) substantiate the differences in the asymmetric efficiency of dirty and clean energy markets pre and during COVID-19. Doblinger et al. (2022) describe the substantial effect of global manufacturing shifts on long-term clean energy innovation (by the example of a study of wind energy suppliers).

Sun and Dong (2022) prove the connection between the decomposition of carbon emission reduction efficiency and the potential for clean energy power (based on the evidence from 58 countries). Martí-Ballester (2022) outlines renewable energy mutual funds as a prospective way toward clean energy-related sustainable development goals. Saleh (2022) sees clean energy and a green environment as global trends in technologies and nanomaterials for the removal of sulfur organic compounds. Nasser et al. (2022b) prove that techno-economic factors are of critical importance for clean hydrogen production and storage using a hybrid renewable energy system of PV/wind under different climatic conditions.

However, the causal connections of the transition to clean energetics remain unclear because the existing literature is limited by the technical issues of clean energetics. In practice, sustainable development of the energy economy based on clean energetics is a complex system, which includes the fuel and energy complex (SDG 7) and EnergyTech (SDG 9), aimed at the fight against climate change (SDG 13) and protection of ecosystems (SDG 14 and SDG 15) (Khoruzhy et al., 2022; Mustafin et al., 2022; Wang et al., 2022; Zhi et al., 2022).

This system is socio-economic and is, thus, based on social institutes—norms of law (SDG 16), sustainable territories (SDG 11), and responsible consumption and production (SDG 12) (Jia et al., 2022b; Fu et al., 2022; Wu et al., 2022). Inadequate elaboration and ambiguity of the specified social nature of clean energetics is a literature gap.

To fill in the revealed gap, this paper strengthens the scientific framework of the hypothesis on the existence of interconnection between social institutes and clean energetics based on EnergyTech. This hypothesis is supported from the position of legal regulation. Thus, this paper helps understand differences in the development of clean energetics based on EnergyTech in developed and developing countries, given the specifics of their institutes.

Materials and methods

This paper describes the strengths and weaknesses of the hypothesis on the existence of the interconnection between social institutes and clean energetics based on EnergyTech. To support the scientific evidence base of this hypothesis, this paper identifies the specific institutes that form the basis of the transition to clean energetics based on EnergyTech for the reduction of production waste and the fight against climate change.

This paper presents the authors' view of the interpretation of recent results in the sphere of study of EnergyTech and demonstrates the strengths of this scientific hypothesis. The hypothesis is supported from the position of legal regulation, through the prism of which the interconnection between the institutes of EnergyTech and the transition to clean energetics is described. Determination of the institutes of transition to clean energetics based on EnergyTech is performed with the help of the methods of classification and systematization.

Results: Determining the institutes of transition to clean energetics based on EnergyTech

From the position of high technologies, the contribution of clean energetics to the reduction of production waste and the fight against climate change is studied and elaborated in the studies by D'Agata et al. (2020), Li et al. (2022), Rahman and Islam (2020), Salman and Ahmed (2020), and Wu et al. (2021). The essence of the scientific hypothesis is as follows: the connection between 1) the development of high technologies and the transition to clean energetics based on EnergyTech, and 2) this transition and its contribution to the reduction of production waste and the fight against climate change is explained and determined by the institutes. As a result of systematization and interpretation of recent results in the sphere of EnergyTech, we determined the following institutes of transition to clean energetics based on EnergyTech:

– Institute of modernization of infrastructure to accelerate the transition to clean energetics based on the expansion of access to electricity and information and communication technologies (EnergyTech). Energy transit requires the implementation of large infrastructural projects in the energy sphere and high-tech sphere, i.e., in EnergyTech;
– Institute of "healthy" competition in EnergyTech. Amid the Fourth Industrial Revolution, it is necessary to reconsider the principles of competition and anti-monopoly law;
– Institute of public–private partnership in EnergyTech as a market of tomorrow. The creation of a market of tomorrow in most cases—especially during the implementation of large infrastructural projects, in particular, in the energy sphere—requires cooperation between the public and private sectors.

Discussion

The results obtained contribute to the development of the theory of clean energetics by specifying the causal connections of the transition to it based on EnergyTech and the achievement of the advantages for the environmental economy in the form of reduction of production waste (pollution) and the fight against climate change.

This paper proves that the transition to clean energetics and its contribution to the reduction of pollution and the fight against climate change is determined not only by technologies (in addition to Qu et al., 2021; Solgi et al., 2022; Wei et al., 2019), corporate social responsibility (in addition to Davoodi et al., 2021; Ghanem and Crosbie, 2021), and state ecological standards (in addition to Jang and Yi, 2022) but also by EnergyTech institutes, the influence of which is undervalued in the existing literature.

The following hypothesis has been proven: the issues of legal regulation play an important role in the transition to clean energetics based on EnergyTech and its contribution to the reduction of production waste and the fight against climate change. Unlike Bolgova (2017), Chen et al. (2022), Huang et al. (2022), Inshakova et al. (2020), and Li et al. (2022), we provided reasoning in favor of the fact that this role is different in developed and developing countries.

Conclusion

The use of the institutional approach allowed revealing the specifics of developed and developing countries, which consists in different effectiveness of the institutes of the energy economy in the aspect of the support of EnergyTech. On the whole, in both categories of countries, an important role of the institutes of transition to clean energetics to production waste reduction and the fight against climate change was established, and the interconnection of these processes from the position of legal regulation was specified.

This paper's contribution to the literature consists in demonstrating the advantage of the institutional approach to studying the transition to clean energetics and its contribution to the reduction of production waste and the fight against climate change, which lies in the possibility of a thorough study of the causal connections between these processes and their results.

The practical significance of the conclusions made is connected to the substantiation of the essential difference of the transition to clean energetics, which is manifested at the level of institutes. The strengthening of the hypothesis on the key results of institutes, which is achieved in this paper, allows improving the practice of legal regulation of EnergyTech through the development of its institutes and overcoming their limitations and ensuring systemic advantages: reduction of production waste and the fight against climate change at the same time. Due to this, the paper allows for a more detailed and effective program-targeted approach to the development of clean energetics based on EnergyTech institutes. The novelty and scientific contribution of this paper lie in its revealing the network effect of the institutes and substantiating their perspective role as a bridge between high technologies and sustainable development of energetics, which supports the complex advantages of production waste reduction and the fight against climate change.

However, the results obtained are limited by the institutes of the energy economy, while the development of EnergyTech can and probably is under the systemic influence of the whole set of institutes of the modern economic systems. New knowledge on the contribution of clean energetics based on EnergyTech to the reduction of production waste and the fight against climate change, which was obtained in this paper, raised a new question—on the presence of potential of this contribution with other institutes. This question remains open. In future studies, it is expedient to expand the list of the studied institutes and strengthen the evidential base of the offered hypothesis.

Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors, and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

References

Bolgova, V. (2017). The legal forms of economic relations and their transformation in the modern economic conditions: Part One: The anti-crisis laws: Problems of financing and development in modern Russia. In *Economic and legal foundations of modern Russian society*. Charlotte, NC, USA, Information Age Publishing.

Chen, J., Wang, Q., and Huang, J. (2021). Motorcycle ban and traffic safety: Evidence from a quasi-experiment at zhejiang, China. Journal of advanced transportation. 2021. doi:10.1155/2021/7552180

Chen, L., Bai, X., Chen, B., and Wang, J. (2022). *Incentives Green Low-Carbon Technol. Innovation Enterp. Under Environ. Regul. Perspective Evol. Game/Front. Energy Res.*, 9, 793667. doi:10.3389/fenrg.2021.793667

D'Agata, C., Diolaiuti, G., Maragno, D., Smiraglia, C., and Pelfini, M. (2020). Climate change effects on landscape and environment in glacierized alpine areas: Retreating glaciers and enlarging forelands in the bernina group (Italy) in the period 1954–2007. Geology, ecology, and landscapes, 4. doi:10.1080/24749508.2019.1585658

Davoodi, A., Reza Abbasi, A., and Nejatian, S. (2021). Multi-objective dynamic generation and transmission expansion planning considering capacitor bank allocation and demand response program constrained to flexible-securable clean energy. *Sustain. Energy Technol. Assessments*, 47, 101469. doi:10.1016/j.seta.2021.101469

Dinh, C. K., Ngo, Q. T., and Nguyen, T. T. (2021). Medium-and high-tech export and renewable energy consumption: Non-linear evidence from the ASEAN countries. *Energies*, 14(15), 4419. doi:10.3390/en14154419

Doblinger, C., Surana, K., Li, D., Hultman, N., and Anadón, L. D. (2022). How do global manufacturing shifts affect long-term clean energy innovation? A study of wind energy suppliers. *Res. Policy*, 51(7), 104558. doi:10.1016/j.respol.2022.104558

Fu, Z., Chen, Z., Sharif, A., and Razi, U. (2022). The role of financial stress, oil, gold and natural gas prices on clean energy stocks: Global evidence from extreme quantile approach. *Resour. Policy*, 78, 102860. doi:10.1016/j.resourpol.2022.102860

Ghanem, D. A., and Crosbie, T. (2021). The transition to clean energy: Are people living in island communities ready for smart grids and demand response? *Energies*, 14(19), 6218. doi:10.3390/en14196218

Haoyang, W., Lei, G., and Ying, J. (2022). The predicament of clean energy technology promotion in China in the carbon neutrality context: Lessons from China's environmental regulation policies from the perspective of the evolutionary game theory. *Energy Rep.*, 8, 4706–4723. doi:10.1016/j.egyr.2022.03.142

Huang, Y., Chen, F., and Wei, H., (...), Xu, Z., akram, R. (2022). the impacts of FDI inflows on carbon emissions: Economic development and regulatory quality as moderators. *Front. Energy Res.*, 9, 820596. doi:10.3389/fenrg.2021.820596

Inshakova, A. O., Bogoviz, A. B., and Popkova, E. G. (2020). Preface. In A. O. Inshakova and A. V. Bogoviz (Ed.) *Alternative methods of judging economic conflicts in the national positive and soft law*. Charlotte, NC, USA, Information Age Publishing.

International Monetary Fund (2022). World economic outlook database: October 2021, by countries. URL: https://www.imf.org/en/Publications/WEO/weo-database/2021/October[Accessed January 19, 2022].

Islam, M. M., Sohag, K., Hammoudeh, S., Mariev, O., and Samargandi, N. (2022). Minerals import demands and clean energy transitions: A disaggregated analysis. *Energy Econ.*, 113, 106205. doi:10.1016/j.eneco.2022.106205

Jamali, S., and Yari, M. (2022). Recovery of liquefied natural gas cold energy in a clean cogeneration system utilizing concentrated photovoltaics. *J. Clean. Prod.*, 350, 131517. doi:10.1016/j.jclepro.2022.131517

Jang, S., and Yi, H. (2022). Organized elite power and clean energy: A study of negative policy experimentations with renewable portfolio standards. *Rev. Policy Res.*, 39(1), 8–31. doi:10.1111/ropr.12449

Jia, W., Jia, X., Wu, L., Wang, E., and Xiao, P. (2022a). Research on regional differences of the impact of clean energy development on carbon dioxide emission and economic growth. *Humanit. Soc. Sci. Commun.*, 9(1), 25. doi:10.1057/s41599-021-01030-2

Jia, W., Jia, X., Wu, L., Wang, E., and Xiao, P. (2022b). Research on regional differences of the impact of clean energy development on carbon dioxide emission and economic growth. *Humanit. Soc. Sci. Commun.*, 9(1), 25. doi:10.1057/s41599-021-01030-2

Khan, I., Zakari, A., Zhang, J., Dagar, V., and Singh, S. (2022). A study of trilemma energy balance, clean energy transitions, and economic expansion in the midst of environmental sustainability: New insights from three trilemma leadership. *Energy*, 248, 123619. doi:10.1016/j.energy.2022.123619

Khoruzhy, V. I., Lebedev, V. V., Farkova, N., and Pozharskaya, E. L. (2022). Global monitoring of the development of digital energetics based on the technologies of industry 4.0: IoT, blockchain, robots, and artificial intelligence. *Front. Energy Res.*, 10, 932229. doi:10.3389/fenrg.2022.932229

Li, B., and Haneklaus, N. (2022). Reducing CO2 emissions in G7 countries: The role of clean energy consumption, trade openness and urbanization. *Energy Rep.*, 8, 704–713. doi:10.1016/j.egyr.2022.01.238

Li, C., Zhang, Y., Pratap, S., Liu, B., and zhou, G. (2022). Regulation effect of smart grid on green transformation of electric power enterprises: Based on the investigation of "leader" trap. *Front. Energy Res.*, 9, 783786. doi:10.3389/fenrg.2021.783786

Li, H., Hou, K., Xu, X., Jia, H., Zhu, L., and Mu, Y. (2022). Probabilistic energy flow calculation for regional integrated energy system considering cross-system failures. Applied Energy, 308. doi:10.1016/j.apenergy.2021.118326

Liu, Y., Tian, J., Zheng, W., and Yin, L. (2022). Spatial and temporal distribution characteristics of haze and pollution particles in China based on spatial statistics. Urban Climate, 41. doi:10.1016/j.uclim.2021.101031

Martí-Ballester, C.-P. (2022). Do renewable energy mutual funds advance towards clean energy-related sustainable development goals? *Renew. Energy*, 195, 1155–1164. doi:10.1016/j.renene.2022.06.111

Mustafin, T. A., Kuprianova, L. M., Ladogina, A. Y., and Pyatkova, O. N. (2022). Smart grid: Leading international experience of marketing and its contribution to sustainable and environmental development of energy economy. *Front. Energy Res.*, 10, 944798. doi:10.3389/fenrg.2022.944798

Naeem, M. A., Karim, S., Farid, S., and Tiwari, A. K. (2022). Comparing the asymmetric efficiency of dirty and clean energy markets pre and during COVID-19. *Econ. Analysis Policy*, 75, 548–562. doi:10.1016/j.eap.2022.06.015

Nasser, M., Megahed, T. F., Ookawara, S., and Hassan, H. (2022a). Techno-economic assessment of clean hydrogen production and storage using hybrid renewable energy system of PV/Wind under different climatic conditions. *Sustain. Energy Technol. Assessments*, 52, 102195. doi:10.1016/j.seta.2022.102195

Nasser, M., Megahed, T. F., Ookawara, S., and Hassan, H. (2022b). Techno-economic assessment of clean hydrogen production and storage using hybrid renewable energy system of PV/Wind under different climatic conditions. *Sustain. Energy Technol. Assessments*, 52, 102195. doi:10.1016/j.seta.2022.102195

Numbeo (2022). Quality of life index by country 2022. URL: https://www.numbeo.com/quality-of-life/rankings_by_country.jsp [Accessed February 5, 2022].

Popkova, E. G., Inshakova, A. O., Bogoviz, A. V., and Lobova, S. V. (2021). Energy efficiency and pollution control through ICTs for sustainable development. *Front. Energy Res.*, 2021, 9. doi:10.3389/fenrg.2021.735551

Popkova, E. G., and Sergi, B. S. (2021). Energy efficiency in leading emerging and developed countries. *Energy*, 2021, 221, 119730. doi:10.1016/j.energy.2020.119730

Qu, F., Chen, Y., and Zheng, B. (2021). Is new energy driven by crude oil, high-tech sector or low-carbon notion? New evidence from high-frequency data. *Energy* 230, 120770. doi:10.1016/j.energy.2021.120770

Quan, Q., Liang, W., Yan, D., and Lei, J. (2022). Influences of joint action of natural and social factors on atmospheric process of hydrological cycle in Inner Mongolia, China. Urban Climate, 41. doi:10.1016/j.uclim.2021.101043

Rahman, M. M., and Islam, I. (2020). Exposure of urban infrastructure because of climate change-induced flood: Lesson from municipal level planning in Bangladesh, *Ecofeminism Clim. Change*, 1(3), 107–125. doi:10.1108/EFCC-05-2020-0011

Ramli, M., Mardlijah, M., Ikhwan, M., and Umam, K. (2022). Fuzzy entropy type II method for optimizing clean and renewable solar energy. *Glob. J. Environ. Sci. Manag.*, 8(3), 389–402. doi:10.22034/GJESM.2022.03.07

Saleh, T. A. (2022). Global trends in technologies and nanomaterials for removal of sulfur organic compounds: Clean energy and green environment. *J. Mol. Liq.*, 359, 119340. doi:10.1016/j.molliq.2022.119340

Salman, M. A., and Ahmed, F. (2020). Climatology in barishal, Bangladesh: A historical analysis of temperature, rainfall, wind speed and relative humidity data. *Malays. J. Geosciences (MJG)*, 4(1), 43–53. doi:10.26480/mjg.01.2020.43.53

Schwalm, C. R., Huntinzger, D. N., Michalak, A. M., Fisher, J. B., Kimball, J. S., Mueller, B., et al. (2013). Sensitivity of inferred climate model skill to evaluation decisions: A case study using CMIP5 evapotranspiration. Environmental research letters, 8(2). doi:10.1088/1748-9326/8/2/024028

Solgi, E., Gitinavard, H., and Tavakkoli-Moghaddam, R. (2022). Sustainable high-tech brick production with energy-oriented consumption: An integrated possibilistic approach based on criteria interdependencies. *Sustain. Switz.* 14(1), 202. doi:10.3390/su14010202

Sun, J., and Dong, F. (2022). Decomposition of carbon emission reduction efficiency and potential for clean energy power: Evidence from 58 countries. *J. Clean. Prod.*, 363, 132312. doi:10.1016/j.jclepro.2022.132312

Wang, X., Li, J., and Ren, X. (2022). Asymmetric causality of economic policy uncertainty and oil volatility index on time-varying nexus of the clean energy, carbon and green bond. *Int. Rev. Financial Analysis*, 83, 102306. doi:10.1016/j.irfa.2022.102306

Wei, Z., Han, B., Han, L., and Shi, Y. (2019). Factor substitution, diversified sources on biased technological progress and decomposition of energy intensity in China's high-tech industry. *J. Clean. Prod.*, 231, 87–97. doi:10.1016/j.jclepro.2019.05.223

World Economic Forum (2022). Global competitiveness report special edition 2020: How countries are performing on the road to recovery. URL: https://www.weforum.org/reports/the-global-competitiveness-report-2020[Accessed February 2, 2022].

Wu, X., Liu, Z., Yin, L., Zheng, W., Song, L., Tian, J., et al. (2021). A haze prediction model in chengdu based on LSTM. Atmosphere, 12(11). doi:10.3390/atmos12111479

Wu, Y., Liao, Y., and Xu, M., (...), Zhou, J., Chen, W. (2022). Barriers identification, analysis and solutions to rural clean energy infrastructures development in China: Government perspective. *Sustain. Cities Soc.*, 86, 104106. doi:10.1016/j.scs.2022.104106

Yang, Y., Zhang, Q., Yu, H., and Feng, X. (2021). Tech-economic and environmental analysis of energy-efficient shale gas and flue gas coupling system for chemicals manufacture and carbon capture storage and utilization. *Energy*, 217, 119348. doi:10.1016/j.energy.2020.119348

Yin, L., Wang, L., Huang, W., Liu, S., Yang, B., and Zheng, W. (2021). Spatiotemporal analysis of haze in beijing based on the multi-convolution model. Atmosphere, 12(11). doi:10.3390/atmos12111408

Zhi, H., Ni, L., and Zhu, D. (2022). The impact of emission trading system on clean energy consumption of enterprises: Evidence from a quasi-natural experiment in China. *J. Environ. Manag.*, 318, 115613. doi:10.1016/j.jenvman.2022.115613

frontiers | Frontiers in Energy Research

TYPE Opinion
PUBLISHED 11 January 2023
DOI 10.3389/fenrg.2022.1032231

The modern capabilities of monitoring of sustainable and environmental development of the energy economy based on big data and datasets

Veronika Yankovskaya[1]*, Svetlana V. Lobova[2], Valentina V. Grigoreva[3] and Alena Y. Fedorova[4]

[1]Plekhanov Russian University of Economics, Moscow, Russia, [2]Altai State University, Barnaul, Russia, [3]Financial University Under the Government of the Russian Federation, Moscow, Russia, [4]Tambov State University Named After G. R. Derzhavin, Tambov, Russia

Check for updates

OPEN ACCESS

EDITED BY
Bruno Sergi,
Harvard University, United States

REVIEWED BY
Sunday Olayinka Oyedepo,
Covenant University, Nigeria

*CORRESPONDENCE
Veronika Yankovskaya,
veronika28-2@mail.ru

SPECIALTY SECTION
This article was submitted to Sustainable Energy Systems and Policies, a section of the journal Frontiers in Energy Research

RECEIVED 30 August 2022
ACCEPTED 22 December 2022
PUBLISHED 11 January 2023

CITATION
Yankovskaya V, Lobova SV, Grigoreva VV and Fedorova AY (2023), The modern capabilities of monitoring of sustainable and environmental development of the energy economy based on big data and datasets.
Front. Energy Res. 10:1032231.
doi: 10.3389/fenrg.2022.1032231

KEYWORDS

monitoring, sustainable development, environmentally friendly development, energy economy, big data, datasets, EAEU

1 Introduction

The relevance of this study is explained by the fact that the environmental friendliness of energy is defined as its key benchmark by the Sustainable Development Goal 7 (SDG 7) (Ceglia et al., 2022; Chang et al., 2022; Pandey and Asif, 2022; Taskin et al., 2022). The problem is that sustainability and environmental friendliness of energy are multifaceted, which makes it difficult to quantify them (Popkova et al., 2021; Popkova and Sergi, 2021; Shabaltina et al., 2021; , 2022). To date, many indices have been calculated that directly or indirectly reflect the sustainability and environmental friendliness of energy (Sisodia et al., 2020; Štreimikienė et al., 2022; Teichmann et al., 2020), as well as many individual statistical indicators, but a systematic understanding of it has not yet been formed (Gallo et al., 2020; Ratner et al., 2021; Ratner et al., 2022).

In the existing literature, authors such as Hao (2022), Kluczek and Gladysz (2022), Romdhane et al. (2022), Xie (2022) proposed many methodological developments to improve the assessment of the energy economy, but no clear idea has been formed on how to implement them in practice. The calculated values of the composite indices on the example of individual countries cannot be used for analysis on the scale of the global energy economy, which does not allow international comparisons (de Oliveira Gabriel et al., 2022; Rink et al., 2022). Therefore, methodological developments should be supplemented with advanced technical solutions for their implementation (Bionaz et al., 2022; Haoyang et al., 2022).

To solve this problem, this paper suggests using Big Data and conducting dataset monitoring of sustainable and environmentally friendly development of the energy economy. The purpose of the article is to identify modern capabilities for monitoring of the sustainable and environmentally friendly development of the energy economy based on Big Data and datasets, as well as to develop recommendations for their implementation in practice. The originality of the article lies in the fact that it offers not only methodological but also complementary technical recommendations for improving the monitoring of sustainable and environmentally friendly development of the energy economy based on Big Data and datasets.

The paper's contribution to the literature consists in the development of a new approach to the monitoring of sustainable and environmental development of the energy economy, the specific features and advantages of which are, first, the use of serious mathematical tools—structural equation modelling—which allows for the transition from onedimensional (as in regular, simple indices) to multi-dimensional evaluation of sustainability and environmental friendliness of the energy economy. Second, the use of the leading technologies—big data and datasets—allows achieving unequalled high speed, precision and correctness (full objectivity) of evaluation.

Due to the above specifics and advantages, the authors' approach allows determining the level of sustainability and environmental friendliness of the energy economy (SDG 7) and determining the causal connections of the achievement of this level: revealing the factors of its achievement [Sustainable cities and communities (SDG 11) and Responsible production and consumption (SDG12)] and consequences (Climate action—SDG 13) and preservation of eco-systems and protection of biodiversity (SDG 14 and SDG 15).

The issues of environmental monitoring of the energy economy have been covered in detail in the existing literature. Kizielewicz (2022) analysed the scientific basis of the monitoring of energy efficiency and the Environmental Ship Index by cruise seaports in Northern Europe. Amerson et al. (2022) proposed recommendations on monitoring of the environment for marine energy development that considers life cycle sustainability.

Mataloto et al. (2021) developed 3D IoT system for the environmental and energy consumption monitoring system. Glinskii et al. (2020) presented their view of the prospects for the development of monitoring of the environment in the vicinity of nuclear energy facilities. Can (2019) discovered the risks that are based on the aerial photography that is used in photogrammetric monitoring maps for environmental wind power energy plant projects.

Cai et al. (2019) analysed wireless sensor network node energy technology for environmental monitoring. Pereira et al. (2022) proposed a promising data model and file format for representing and storing high-frequency energy monitoring and disaggregation datasets. Rahmani et al. (2022) recommended an energy-aware and Q-learning-based area coverage for the systems of monitoring of oil pipeline with the use of sensors and the Internet of Things.

The conducted content analysis of the existing literature revealed three disadvantages of monitoring of the sustainable and environmentally friendly development of the energy economy based on the existing approach to its implementation. The first disadvantage is the compartmentalization and incompatibility of indicators of sustainability and environmental friendliness of the energy economy. In the existing literature, Amir and Khan (2022), Gunnarsdottir et al. (2022), Klemm and Wiese (2022), Reynolds et al. (2022), Schöne et al. (2022) propose methods involving the use of indicators from different empirical databases. These indicators have different units of measurement. Some indicators are statistical (quantitative), while others are obtained by expert means (qualitative) (Çağman et al., 2022; Laing et al., 2022; Maki et al., 2022). The evaluation results based on such methods are not accurate enough and not reliable enough, therefore, there is a high probability of errors and misinterpretations (Magrini et al., 2022; Pereira et al., 2022; Rahmani et al., 2022).

The second disadvantage is the uncertainty of cause-and-effect relationships of sustainable and environmentally friendly development of the energy economy. The methods proposed in the works of Huang et al. (2022), Sarwar (2022), Shah and Longsheng (2022), Yamaka et al. (2022) focused on evaluating only the results (for example, the energy efficiency of economic growth, the share of "clean" energy in the structure of energy consumption). At the same time, the factors for achieving these results remain unclear and break the limits of existing methods. The results of the assessment according to existing methods do not provide the necessary support for the management of sustainable and environmentally friendly development of the energy economy (Kang et al., 2022; Ratner et al., 2022; Vu et al., 2022).

The third disadvantage focuses on low technical efficiency. The methods described in the works of Bilal et al. (2022), Wang et al. (2022), Yang et al. (2022) involved the so-called manual collection and analysis of data from many different sources. In this regard, the process of assessing the sustainability and environmental friendliness of the development of the energy economy is long, time-consuming and greatly affected by the "human factor" (the risks of the subjectivity of the assessment) (Li et al., 2022; Ullah et al., 2022; Zhang et al., 2022). The ambiguity of the prospects for overcoming these disadvantages is a research gap that is being filled in this article through a review of current opportunities for improving the scientific and methodological approach to monitoring of the sustainable and environmentally friendly development of the energy economy based on Big Data and datasets.

2 Materials and methods

To overcome the disadvantages of the existing approach, a new (alternative) system approach is proposed to conduct automated monitoring of sustainable and environmentally friendly development of the energy economy based on Big Data and datasets. The following recommendations are proposed for monitoring based on the authors' approach. Firstly, it is recommended to rely on the statistics of the UNDP (2022), since it most accurately and reliably characterizes the sustainability and environmental friendliness of the development of the energy economy, and also contains comparable indicators (the results of the implementation of various SDGs).

Secondly, it is proposed to take into account not only the result (SDG 7) but also the factors of its achievement and the consequences of sustainable and environmentally friendly development of the energy economy. The factors are the sustainability of cities and populated areas (SDG 11) and the responsibility of production and consumption (SDG 12). The consequences are the fight against climate change (SDG 13), the conservation of ecosystems and the protection of biodiversity (SDG 14 and SDG 15).

Thirdly, it is recommended to use an improved algorithm for monitoring of the sustainable and environmentally friendly development of the energy economy based on Big Data and datasets. At the first stage of the proposed algorithm, data is collected for each of the above SDG—a set of data is generated (for example, on a large sample of countries or a number of periods). The second stage is associated with the analysis of variation (the spread of values of indicators). At the third stage, the relationship of indicators is evaluated and their network structure is formed (based on Big Data technologies). The fourth stage is the calculation of the integral indicator of sustainability and environmental friendliness of the energy economy with a systematic account of the values of indicators and their interrelations.

2.1 The model of sustainable and green development of the energy economy in the EAEU in 2021

In the Eurasian Economic Union (EAEU), a lot of attention is paid to the issues of sustainable and green development of the energy economy. There is a special Energy Department with the Eurasian Economic Commission (2022). The implemented initiatives include the provision of energy security, unification of the legal regulation of energy resources exchange trading and digital development of the energy economy based on Smart Grid and EnergyTech. All participants of the EAEU share the strategic initiatives on the achievement of carbon neutrality of the economy by 2050.

For example, the Kyrgyz Republic started in 2022 the Project on modernisation and sustainability of the energy sector, aimed at improving the financial state and operational effectiveness of the sector of electric energy and strengthening the mechanisms of social protection to assuage the potential influence of reforms on consumers. The project is implemented with financial and coordination support from the World Bank and SECO development of hydropower and solar energy. This project is expected to pave the way to sustainable and affordable use of renewable sources of energy (World Bank, 2022).

Kazakhstan actively develops alternative energetics by the example of successful developed countries. For example, nuclear power in Kazakhstan is developed based on the leading experience of France (Centre for business information Kapital, 2022). The model of sustainable and green development of the energy economy in the EAEU in 2021 implies close cooperation between the EAEU members at all stages of the chain of value-added creation in energetics: from production to consumption. This model is based on the unification of efforts and the development of responsible communities, as well as responsible energy companies.

2.2 Dataset-countries monitoring of sustainable and environmentally friendly development of the energy economy in the EAEU countries in 2021

To demonstrate the possibilities of the proposed approach, we conducted a dataset monitoring of sustainable and environmentally friendly development of the energy economy in 2020 in the Eurasian Economic Union (EAEU) (Regions used for the SDR: E. Europe & C. Asia). At the same time, we rely on the dataset framework “Corporate Social Responsibility, Sustainable Development and Combating Climate Change: Simulation and Neural Network Analysis in the Regions of the World—2020” (Institute of Scientific Communications). There is a shortage of data on SDG 14 in the EAEU countries, so it is not taken into account in the ongoing monitoring. The study is based on the official data set of the UNDP (2022) for 2021, according to which:

→ In Armenia, SDG 7 is estimated at 94.821 points, SDG 11 at 76.445 points, SDG 12 at 88.685 points, SDG 13 at 93.073 points and SDG 15 at 61.792 points;
→ In Belarus, SDG 7 is estimated at 90.59 points, SDG 11 at 76.084 points, SDG 12 at 86.433 points, SDG 13 at 88.838 points and SDG 15 at 78.601 points;
→ In Kazakhstan, SDG 7 is estimated at 86.528 points, SDG 11 at 83.715 points, SDG 12 at 74.854 points, SDG 13 at 74.854 points and SDG 15 at 56.959 points;
→ In Kyrgyzstan, SDG 7 is estimated at 89.752 points, SDG 11 at 88,656 points, SDG 12 at 86.505 points, SDG 13 at 86,505 points and SDG 15 at 71.352 points;
→ In Russia, SDG 7 is estimated at 90.823 points, SDG 11 at 85,867 points, SDG 12 at 76.669 points, SDG 13 at 76.669 points and SDG 15 at 66.183 points.

Based on the authors’ approach, the structural equation modelling (SEM) method provides a case example of monitoring of the sustainable and environmentally friendly development of the energy economy in the EAEU countries (Figure 1).

2.2.1 Source: Authors’ work

Figure 1 shows that in the EAEU countries in 2021, in general, there is a fairly high level of sustainability and environmental friendliness of the energy economy. It is defined through the product of arithmetic averages for the considered SDGs with their correlation coefficients with SDG 7 as follows:

[(82.1532*(−0.5233)) + (82.6291*0.6967) + 90.5029 + (81.7441*0.7298) + (66.9774*0.1497)]/5 = [−42.994 + 57.565 + 90.50 + 59.654+41.182]/5 = 205.91/5 = 41.1820 points (with a maximum value of 100 points).

These results were obtained from the methodological point of view–based on the authors’ methodological developments (the systems approach and an improved algorithm from the second section of this paper); and from the methodical point of view–based on the capabilities of modern digital technologies: big data and datasets. The statistics on the EAEU countries are unified in one dataset, which is used–with the technology of big data processing–to perform automatised calculations. Thus, a SEM model was obtained.

The analysis of cause-and-effect relationships revealed that sustainable cities and settlements make an insufficient contribution to the sustainable and environmentally friendly development of the energy economy in the EAEU countries. The small contribution of this development to the protection of ecosystems and the conservation of biodiversity has also been established. In this regard, to increase the sustainability and environmental friendliness of the energy economy in the EAEU countries, it is recommended to pay increased attention to the practical implementation of SDG 12 and SDG 15.

2.3 Forecast for sustainable and green development of the energy economy in the EAEU for the period until 2024

To specify the connections between the selected indicators, we identify the regression dependencies of sustainable and green development of the energy economy in the EAEU in 2021. As a result, it is determined that affordability and “cleanliness” of energy in the EAEU grow by 0.32 points in the case of the development of responsible production and consumption by one point (SDG 7 = 63.71 + 0.32*SDG 12). It is also determined that the growth of affordability and “cleanliness” of energy in the EAEU by one point lead to the growth of results in the fight against climate change by 3.44 points (SDG 13 = -229.68 + 3.44*SDG 7) and the growth of success in the preservation of land ecosystems and protection of biodiversity by 0.42 points (SDG 15 = 28.57 + 0.42*SDG 7).

Based on the arithmetic mean for the EAEU (82.63 points) and standard deviation (6.37 points), we perform a scenario analysis of responsible production and consumption, using the Monte Carlo method. 100 random numbers are generated, and their histogram

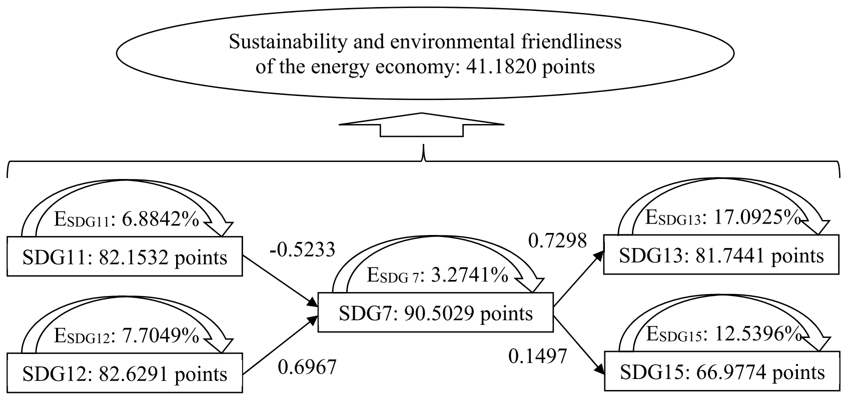


FIGURE 1
A case example of monitoring of the sustainable and environmentally friendly development of the energy economy in the EAEU countries.

is obtained, according to which the most probable forecast value (with the probability of 24%) is 86.70 points, which is 4.96% higher than the 2021 level (realistic scenario).

In the least favourable (pessimistic) scenario (probability: 6%), the level of development of responsible production and consumption will drop down to 78.79 points, which is 4.65% lower than the 2021 level. In the most favourable (optimistic) scenario (probability: 5%), the level of development of responsible production and consumption will grow up to 94.62 points, which is 14.51% higher than the 2021 level.

Based on the revealed regression dependencies of the variables, we compile a forecast for sustainable and green development of the energy economy in the EAEU for the period until 2024. In the realistic scenario, affordability and "cleanliness" of energy in the EAEU until 2024 will grow up to 91.82 points (+1.46%). Due to this, the results in the fight against climate change will grow up to 86.29 points (+5.56%), and success in the preservation of land ecosystems and protection of biodiversity will grow up to 67.54 points (+0.84%).

In the pessimistic scenario, affordability and "cleanliness" of energy in the EAEU until 2024 will reduce to 89.26 points (−1.38%). Due to this, the results in the fight against climate change will reduce to 77.46 points (−5.24%), and success in the preservation of land ecosystems and protection of biodiversity will reduce to 66.45 points (−0.79%). This scenario may be implemented in the case of a global energy crisis, the preconditions for which are observed in 2022.

In the optimistic scenario, affordability and "cleanliness" of energy in the EAEU until 2024 will grow up to 94.39 points (+4.30%). Due to this, the results in the fight against climate change will grow up to 95.129 points (+16.37%), and success in the preservation of land ecosystems and protection of biodiversity will grow up to 68.63 points (+2.46%). This scenario may be implemented in the case of a successful resolution of the international sanction crisis until 2024.

3 Results and discussion

The key results of the performed research are as follows: first, a model of sustainable and green development of the energy economy in the EAEU in 2021 was created–it reflects the organisational and legal foundations of environmental management in this integration union of countries. The model discovered the unification of managing the sustainable and environmental development of the energy economy among the participants of integration unions of countries (by the example of the EAEU). Therefore, monitoring of the results of this management should be performed at the supranational level, since this will allow identifying not only private (achieved in certain participating countries) but also common (achieved by the integration union on the whole) results, as well as the synergetic effect of integration, which consists in the accelerated implementation of the SDGs.

Second, monitoring of sustainable and environmentally friendly development of the energy economy in the EAEU countries in 2021 (based on the dataset countries) was performed. We discovered a high level of sustainable and environmental development of the energy economy, demonstrated by the achieved serious results in the implementation of SDG 7: 94.821 points in Armenia, 90.590 points in Belarus, 86.528 points in Kazakhstan, 89.752 points in Kyrgyzstan and 90.823 points in Russia.

On the whole (on average) for the EAEU, the results in the achievement of SDG 7 equals 90.503 points. Given the fact that the maximum possible value is 100 points, the sustainability and environmental friendliness of the energy economy in the EAEU exceeds 90%. This is just the beginning of the Decade of Action, and the variation among participating countries is very low (3.274%). This is a sign of uniformity of the results of the achievement of SDG 7 among the EAEU members and the reliability of the monitoring results (they could be applied to the entire integration union).

The case example of the monitoring of sustainable and environmental development of the energy economy in the EAEU also demonstrated a synergetic effect: the sustainable and environmental development of the energy economy supports–by 41.182%—the development of the green economy in the EAEU, i.e., the results on SDG 11, SDG 12, SDG 13 and SDG 15. Therefore, the sustainable and environmental development of the energy sphere in the EAEU facilitates the development of sustainable territories, responsible production and consumption, the fight against climate change and the preservation of land ecosystems.

Third, a forecast for sustainable and green development of the energy economy in the EAEU for the period until 2024 was prepared. Due to the comprehensiveness of the monitoring (consideration of the connections between the SDGs of the green economy), the forecast, which is based on it, reflected not only the expected growth of the result of the implementation of SDG 7 (+4.30%—up to 94.39 points–increase in accessibility and cleanliness of energy by 2024) but also the expected advantages for other Sustainable Development Goals. In particular, for the fight against climate change (+16.37% for SDG 13, up to 95.129 points) and for biodiversity protection (+2.46% for SDG 15, up to 68.63 points).

The discovered advantages belong to the synergetic effect of the sustainable and environmental development of the energy economy and will be added to independent initiatives on the implementation of the considered SDGs. Due to the discovered synergetic effect, the totality of SDGs of the green economy, in the case of the optimistic scenario, might be fully achieved even before 2030, i.e., exceeded in the Decade of Action.

Thus, the increased completeness and correctness of the results of the monitoring, as well as the increased precision and consistency of forecasts that are based on them are the advantages (proved in this paper), which point at the preference for the use of big data and datasets during the monitoring of sustainable and environmental development of the energy economy.

The contribution of the article to the literature is the improvement of the scientific and methodological approach to monitoring of the sustainable and environmentally friendly development of the energy economy. Unlike Gunnarsdottir et al. (2022), Klemm and Wiese (2022), Reynolds et al. (2022), Schöne et al. (2022), it is proposed not to collect data from different sources, but to rely on ready-made datasets in which all indicators are comparable, for example, on the UNDP (2022) dataset. This improves the accuracy of the assessment. In contrast to Huang et al. (2022), Sarwar (2022), Shah and Longsheng (2022), Yamaka et al. (2022), it is proved that there is a need in the monitoring process to take into account not only the results achieved but also the factors and consequences of sustainable and environmentally friendly development of the energy economy. At the same time, the interrelated SDGs are considered systematically (SDG 11-12, SDG 7, SDG 13–15). This ensures the completeness of the assessment and the increased practical significance of its results.

Unlike Bilal et al. (2022), Wang et al. (2022), Yang et al. (2022), it is recommended to use the improved algorithm for monitoring of the sustainable and environmentally friendly development of the energy economy based on Big Data and datasets. Reliance on high technologies and advanced automation tools makes it possible to model the relationships of indicators and on their basis to conduct an integrated assessment of the sustainability and environmental friendliness of the energy economy. This ensures the acceleration and simplification of the evaluation procedure, as well as guarantees the reliability of its results (objectivity due to the reduction of dependence on the "human factor").

4 Conclusion

The main contribution of this paper to the literature lies in revealing the prospects for the improvement of monitoring of sustainable and environmental development of the energy economy. As shown in the paper, these prospects are connected with the use of Big Data and datasets, which allow raising the flexibility of monitoring. This ensures more accurate and informative results, which are useful for environmental management.

Based on the results of the study, many disadvantages of monitoring of the sustainable and environmentally friendly development of the energy economy based on the existing approach to its implementation are substantiated: 1) fragmentation and incomparability of the indicators of sustainability and environmental friendliness of the energy economy; 2) uncertainty of the causal connections of the sustainable and environmental development of the energy economy; 3) low technical effectiveness. The authors' vision of modern capabilities of overcoming these disadvantages with the help of improved methods and the use of advanced technical means is presented.

The improved algorithm of monitoring of the sustainable and environmental development of the energy economy based on big data and datasets optimised the methodology for evaluating the results of this development. The advantage of the authors' methodological recommendations is their analysing of the sustainability and environmental friendliness of the energy economy from the position of the SDGs and taking into account the specified results on the SDGs in quantitative terms.

The novelty and originality of the authors' methodological development lies in its taking into account the systemic connection between the SDGs of the green economy. Due to this, the monitoring allows–for the first time–determining not only own results of the energy economy (SDG 7) but also its contribution to the development of sustainable territories (SDG 11), responsible production and consumption (SDG 12), fight against climate change (SDG 13) and preservation of land ecosystems (SDG 15).

From the technical point of view, the authors' methodological development can be implemented with the help of modern digital opportunities–big data and datasets. Their application for the monitoring of sustainable and environmental development of the energy economy simplifies and accelerates the process of monitoring (due to automatization) and ensures consistency, as well as raises the completeness and correctness of its results and precision of forecasts based on them. As a practical implication of this study, applied recommendations and a systematic approach to conducting automated monitoring of sustainable and environmentally friendly development of the energy economy based on Big Data and datasets have been developed.

The advantages of the new approach are the following: it has clarified the list of performance indicators; has improved the monitoring algorithm; it is universal (suitable for different countries of the world). The developed approach allows the most complete and effective use of modern monitoring capabilities for sustainable and environmentally friendly development of the energy economy based on Big Data and datasets. The approbation of the approach by the case example of the EAEU countries made it possible to systematically assess the sustainability and environmental friendliness of the energy economy, as well as to offer recommendations for improving its management (for economic policy).

The theoretical significance and value of the results obtained consist in their demonstrating a successful model of sustainable and green development of the energy economy in the EAEU in 2021 and the case experience of the practical implementation of this model by the example of Kazakhstan and Kyrgyzstan. The practical significance of the research is due to the compiled forecast for sustainable and green development of the energy economy in the EAEU until 2024 demonstrating the prospects for this development.

The forecast outlined the alternative scenarios of sustainable and green development of the energy economy and reduced the uncertainty of the environmental economy and management in the EAEU for the period until 2024. It is recommended that their efforts be focused on the development of responsible production and consumption.

The results of this research will contribute to the ongoing discussions on the topics of environmental monitoring of the energy sphere, as well as management of sustainable and environmental development of the energy economy. This paper revealed the essence and demonstrated the capabilities and advantages of the high-tech approach to this monitoring and management. The limitation of the results obtained during this study is that they identified only scientific and methodological recommendations that should be supported by applied developments for practical implementation, in particular, datasets, the promising frameworks of which are offered by the Institute of Scientific Communications (2022) and UNDP (2022). It is proposed to devote future research to the creation of new datasets with up-to-date data for 2022 and later periods for mass use of the authors' recommendations.

Author contributions

Writing, original draft, writing, review and editing—VY, SL, VG, and AF.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

References

Amerson, A. M., Harris, T. M., Michener, S. R., Gunn, C. M., and Haxel, J. H. (2022). A summary of environmental monitoring recommendations for marine energy development that considers life cycle sustainability. *J. Mar. Sci. Eng.* 10 (5), 586. doi:10.3390/jmse10050586

Amir, M., and Khan, S. Z. (2022). Assessment of renewable energy: Status, challenges, COVID-19 impacts, opportunities, and sustainable energy solutions in Africa. *Energy Built Environ.* 3 (3), 348–362. doi:10.1016/j.enbenv.2021.03.002

Bilal, M., Ali, M. K., Qazi, U., Wasim, A., Jahanzaib, M., and Wasim, A. (2022). A multifaceted evaluation of hybrid energy policies: The case of sustainable alternatives in special Economic Zones of the China Pakistan Economic Corridor (CPEC). *Sustain. Energy Technol. Assessments* 52, 101958. doi:10.1016/j.seta.2022.101958

Bionaz, D., Marocco, P., Ferrero, D., Sundseth, K., and Santarelli, M. (2022). Life cycle environmental analysis of a hydrogen-based energy storage system for remote applications. *Energy Rep.* 8, 5080–5092. doi:10.1016/j.egyr.2022.03.181

Çağman, S., Soylu, E., and Ünver, Ü. (2022). A research on the easy-to-use energy efficiency performance indicators for energy audit and energy monitoring of industrial compressed air systems. *J. Clean. Prod.* 365, 132698. doi:10.1016/j.jclepro.2022.132698

Cai, X., Kassim, S., and Dong, V. H. (2019). Environmental monitoring wireless sensor network node energy technology analysis. *Nat. Environ. Pollut. Technol.* 18 (5), 1667–1673.

Can, E. (2019). Analysis of risks that are based on the aerial photography used in photogrammetric monitoring maps for environmental wind power energy plant projects. *Environ. Monit. Assess.* 191 (12), 746. doi:10.1007/s10661-019-7944-8

Ceglia, F., Marrasso, E., Roselli, C., and Sasso, M. (2022). Time-evolution and forecasting of environmental and energy performance of electricity production system at national and at bidding zone level. *Energy Convers. Manag.* 265, 115772. doi:10.1016/j.enconman.2022.115772

Centre for business information Kapital (2022). Kazakhstan studies the experience of France in the development of nuclear energetics. Available at: https://kapital.kz/economic/107514/kazakhstan-izuchayet-opyt-frantsii-po-razvitiyu-atomnoy-energetiki.html (Accessed 08 20, 2022).

Chang, L., Saydaliev, H. B., Meo, M. S., and Mohsin, M. (2022). How renewable energy matter for environmental sustainability: Evidence from top-10 wind energy consumer countries of European Union. *Sustain. Energy, Grids Netw.* 31, 100716. doi:10.1016/j.segan.2022.100716

de Oliveira Gabriel, R., Leal Braga, S., Pradelle, F., Torres Serra, E., and Coutinho Sobral Vieira, C. L. (2022). Numerical simulation of an on-grid natural gas PEMFC - solar photovoltaic micro CHP unit: Analysis of the energy, economic and environmental impacts for residential and industrial applications. *Technol. Econ. Smart Grids Sustain. Energy* 7 (1), 5. doi:10.1007/s40866-022-00124-3

Eurasian Economic Commission (2022). Important events in the work of the energy department. Available at http://www.eurasiancommission.org/ru/act/energetikaiinfr/energ/Pages/activityy.aspx (Accessed 08 20, 2022).

Gallo, E., Wu, Z., and Sergi, B. S. (2020). China's power in its strategic energy partnership with the Eurasian economic union. *Communist Post-Communist Stud.* 53 (4), 200–219. doi:10.1525/j.postcomstud.2020.53.4.200

Glinskii, M. L., Glagolev, A. V., Speshilov, S. L., Evseenkova, T. A., Plyamina, O. V., and Evseenkova, T. A. (2020). Development of environmental monitoring in the vicinity of nuclear energy facilities. *At. Energy* 127 (3), 166–173. doi:10.1007/s10512-020-00605-7

Gunnarsdottir, I., Davidsdottir, B., Worrell, E., and Sigurgeirsdottir, S. (2022). Indicators for sustainable energy development: An Icelandic case study. *Energy Policy* 164, 112926. doi:10.1016/j.enpol.2022.112926

Hao, Y. (2022). Effect of economic indicators, renewable energy consumption and human development on climate change: An empirical analysis based on panel data of selected countries. *Front. Energy Res.* 10, 841497. doi:10.3389/fenrg.2022.841497

Haoyang, W., Lei, G., and Ying, J. (2022). The predicament of clean energy technology promotion in China in the carbon neutrality context: Lessons from China's environmental regulation policies from the perspective of the evolutionary game theory. *Energy Rep.* 8, 4706–4723. doi:10.1016/j.egyr.2022.03.142

Huang, W., Dai, J., and Xiong, L. (2022). Towards a sustainable energy future: Factors affecting solar-hydrogen energy production in China. *Sustain. Energy Technol. Assessments* 52, 102059. doi:10.1016/j.seta.2022.102059

Institute of Scientific Communications (2022). Dataset "corporate social responsibility, sustainable development and combating climate change: Simulation and neural network analysis in the regions of the World – 2020". Availabel https://iscvolga.ru/dataset-climate-change (Accessed 04 28, 2022).

Kang, L., Shang, Y., Zhang, M., and Liao, L. (2022). Research on monitoring technology of power stealing behavior in bitcoin mining based on analyzing electric energy data. *Energy Rep.* 8, 1183–1189. doi:10.1016/j.egyr.2022.02.054

Kizielewicz, J. (2022). Monitoring energy efficiency and environmental Ship Index by cruise seaports in northern europe. *Energies* 15 (12), 4215. doi:10.3390/en15124215

Klemm, C., and Wiese, F. (2022). Indicators for the optimization of sustainable urban energy systems based on energy system modeling. *Energy, Sustain. Soc.* 12 (1), 3. doi:10.1186/s13705-021-00323-3

Kluczek, A., and Gladysz, B. (2022). Energy sustainability performance Index of biodigester using energy LCA-based indicators. *Front. Energy Res.* 10, 848584. doi:10.3389/fenrg.2022.848584

Laing, H., O'Malley, C., Browne, A., Baines, T., Moore, A., Black, K., et al. (2022). Optimisation of energy usage and carbon emissions monitoring using MILP for an advanced anaerobic digester plant. *Energy* 256, 124577. doi:10.1016/j.energy.2022.124577

Li, M., Zhang, Y., Li, K., Xu, K., Liu, X., Zhong, S., et al. (2022). Self-powered wireless sensor system for water monitoring based on low-frequency electromagnetic-pendulum energy harvester. *Energy* 251, 123883. doi:10.1016/j.energy.2022.123883

Magrini, A., Marenco, L., and Bodrato, A. (2022). Energy smart management and performance monitoring of a NZEB: Analysis of an application. *Energy Rep.* 8, 8896–8906. doi:10.1016/j.egyr.2022.07.010

Maki, S., Fujii, M., Fujita, T., Ashina, S., Gomi, K., Immanuel, G., et al. (2022). A deep reinforced learning spatiotemporal energy demand estimation system using deep learning and electricity demand monitoring data. *Appl. Energy* 324, 119652. doi:10.1016/j.apenergy.2022.119652

Mataloto, B., Calé, D., Carimo, K., Ferreira, J. C., and Resende, R. (2021). 3d iot system for environmental and energy consumption monitoring system. *Sustain. Switz.* 13 (3), 1495. doi:10.3390/su13031495

Pandey, A., and Asif, M. (2022). Assessment of energy and environmental sustainability in south asia in the perspective of the sustainable development goals. *Renew. Sustain. Energy Rev.* 165, 112492. doi:10.1016/j.rser.2022.112492

Pereira, L., Velosa, N., and Pereira, M. (2022). A data model and file format to represent and store high frequency energy monitoring and disaggregation datasets. *Sci. Rep.* 12 (1), 10284. doi:10.1038/s41598-022-14517-y

Popkova, E. (2022). *Advanced issues in the green economy and sustainable development in emerging market economies (elements in the economics of emerging markets).* Cambridge: Cambridge University Press.

Popkova, E. G., Inshakova, A. O., Bogoviz, A. V., and Lobova, S. V. (2021). Energy efficiency and pollution control through ICTs for sustainable development. *Front. Energy Res.* 9, 735551. doi:10.3389/fenrg.2021.735551

Popkova, E. G., and Sergi, B. S. (2021). Energy efficiency in leading emerging and developed countries. *Energy* 221, 119730. doi:10.1016/j.energy.2020.119730

Rahmani, A. M., Ali, S., Malik, M. H., Yousefpoor, M. S., Mousavi, A., khan, F., et al. (2022). An energy-aware and Q-learning-based area coverage for oil pipeline monitoring systems using sensors and Internet of Things. *Sci. Rep.* 12 (1), 9638. doi:10.1038/s41598-022-12181-w

Ratner, S., Berezin, A., Gomonov, K., Serletis, A., and Sergi, B. S. (2022). What is stopping energy efficiency in Russia? Exploring the confluence of knowledge, negligence, and other social barriers in the krasnodar region. *Energy Res. Soc. Sci.* 85, 102412. doi:10.1016/j.erss.2021.102412

Ratner, S., Berezin, A., and Sergi, B. S. (2021). Energy efficiency improvements under conditions of low energy prices: The evidence from Russian regions. *Energy Sources, Part B Econ. Plan. Policy* 17. doi:10.1080/15567249.2021.1966134

Reynolds, J., Kennedy, R., Ichapka, M., Oke, A., Cox, E., Edwards, C., et al. (2022). An evaluation of feedstocks for sustainable energy and circular economy practices in a small island community. *Renew. Sustain. Energy Rev.* 161, 112360. doi:10.1016/j.rser.2022.112360

Rink, K., Şen, Ö. O., Schwanebeck, M., Gasanzade, F., Nordbeck, J., Bauer, S., et al. (2022). An environmental information system for the exploration of energy systems. *Geotherm. Energy* 10 (1), 4. doi:10.1186/s40517-022-00215-5

Romdhane, A., Emmel, B., Zonetti, S., Dupuy, B., Gawel, K., Edvardsen, L., et al. (2022). Screening, monitoring, and remediation of legacy wells to improve reservoir integrity for large-scale CO2 storage—an example from the smeaheia structure in the northern north sea. *Front. Energy Res.* 10, 826100. doi:10.3389/fenrg.2022.826100

Sarwar, S. (2022). Impact of energy intensity, green economy and blue economy to achieve sustainable economic growth in GCC countries: Does Saudi Vision 2030 matters to GCC countries. *Renew. Energy* 191, 30–46. doi:10.1016/j.renene.2022.03.122

Schöne, N., Timofeeva, E., and Heinz, B. (2022). Sustainable development goal indicators as the foundation for a holistic impact assessment of access-to-energy projects. *J. Sustain. Dev. Energy, Water Environ. Syst.* 10 (2), 1–24. doi:10.13044/j.sdewes.d9.0400

Shabaltina, L. V., Karbekova, A. B., Milkina, E., and Pushkarev, I. Y. (2021). The social impact of the downturn in business and the new context of sustainable development in the context of the 2020 economic crisis in developing countries. *Lect. Notes Netw. Syst.* 198, 74–82. doi:10.1007/978-3-030-69415-9_9

Shah, S. A. A., and Longsheng, C. (2022). Evaluating renewable and sustainable energy impeding factors using an integrated fuzzy-grey decision approach. *Sustain. Energy Technol. Assessments* 51, 101905. doi:10.1016/j.seta.2021.101905

Sisodia, G. S., Awad, E., Alkhoja, H., and Sergi, B. S. (2020). Strategic business risk evaluation for sustainable energy investment and stakeholder engagement: A proposal for energy policy development in the Middle East through khalifa funding and land subsidies. *Bus. Strategy Environ.* 29 (6), 2789–2802. doi:10.1002/bse.2543

Štreimikienė, D., Samusevych, Y., Bilan, Y., Vysochyna, A., and Sergi, B. S. (2022). Multiplexing efficiency of environmental taxes in ensuring environmental, energy, and economic security. *Environ. Sci. Pollut. Res.* 29 (5), 7917–7935. doi:10.1007/s11356-021-16239-6

Taskin, D., Dogan, E., and Madaleno, M. (2022). Analyzing the relationship between energy efficiency and environmental and financial variables: A way towards sustainable development. *Energy* 252, 124045. doi:10.1016/j.energy.2022.124045

Teichmann, F., Falker, M.-C., and Sergi, B. S. (2020). Gaming environmental governance? Bribery, abuse of subsidies, and corruption in European union programs. *Energy Res. Soc. Sci.* 66, 101481. doi:10.1016/j.erss.2020.101481

Ullah, Z., Wang, S., Wu, G., Elkadeem, M. R., Lai, J., and Elkadeem, M. R. (2022). Advanced energy management strategy for microgrid using real-time monitoring interface. *J. Energy Storage* 52, 104814. doi:10.1016/j.est.2022.104814

UNDP (2022). Sustainable development report: Dataset 2021. Available at https://dashboards.sdgindex.org/(Accessed 04 28, 2022).

Vu, T. T. H., Delinchant, B., Phan, A. T., Bui, V. C., and Nguyen, D. Q. (2022). A practical approach to launch the low-cost monitoring platforms for nearly net-zero energy buildings in vietnam. *Energies* 15 (13), 4924. doi:10.3390/en15134924

Wang, G., Chao, Y., Cao, Y., Chen, Z., Han, W., and Chen, Z. (2022). A comprehensive review of research works based on evolutionary game theory for sustainable energy development. *Energy Rep.* 8, 114–136. doi:10.1016/j.egyr.2021.11.231

World Bank (2022). Reforms of the energy sector of the Kyrgyz Republic. Forward movement. Available at https://blogs.worldbank.org/ru/europeandcentralasia/energy-sector-reforms-kyrgyz-republic-green-light-ahead (Accessed 08 20, 2022).

Xie, J. (2022). Data-driven traction substations' health condition monitoring via power quality analysis. *Front. Energy Res.* 10, 873602. doi:10.3389/fenrg.2022.873602

Yamaka, W., Chimprang, N., and Klinlumpu, C. (2022). The dynamic linkages among environment, sustainable growth, and energy from waste in the circular economy of EU countries. *Energy Rep.* 8, 192–198. doi:10.1016/j.egyr.2022.02.122

Yang, X., Guo, Y., Liu, Q., and Zhang, D. (2022). Dynamic Co-evolution analysis of low-carbon technology innovation compound system of new energy enterprise based on the perspective of sustainable development. *J. Clean. Prod.* 349, 131330. doi:10.1016/j.jclepro.2022.131330

Zhang, Y., Wang, W., Xie, J., Bowen, C., Oelmann, B., Xu, Y., et al. (2022). Enhanced variable reluctance energy harvesting for self-powered monitoring. *Appl. Energy* 321, 119402. doi:10.1016/j.apenergy.2022.119402

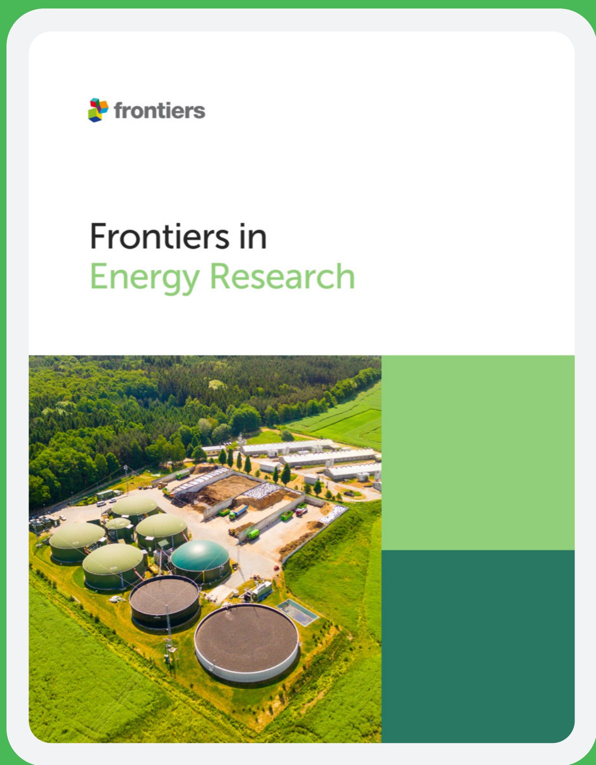
Frontiers in Energy Research

Advances and innovation in sustainable, reliable and affordable energy

Explores sustainable and environmental developments in energy. It focuses on technological advances supporting Sustainable Development Goal 7: access to affordable, reliable, sustainable and modern energy for all.

Discover the latest Research Topics

See more →



Frontiers

Avenue du Tribunal-Fédéral 34
1005 Lausanne, Switzerland
frontiersin.org

Contact us

+41 (0)21 510 17 00
frontiersin.org/about/contact