

Marketing and Sustainable Economic Development of the Energy Complex: A Case Study of the Administrative And Legal Planning of a Public-Private Partnership

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Abstract

The main purpose of the article is to present a modern methodological approach to choosing the most optimal model of administrative and legal planning of public-private partnership in the context of sustainable development of the energy complex, taking into account various aspects, including issues of security and rational resource use. The object of the study is a system of administrative and legal planning public-private partnership models in the context of sustainable development and security of the energy complex. The research methodology involves the use of the method of strategizing of administrative and legal planning for the sustainable development of public-private partnerships, the method of the vector of efficiency of public-private partnerships, as well as the method of game-theoretic modeling. As a result, a methodological approach was formed to strategies of administrative and legal planning for the sustainable development of public-private partnerships in the energy sector. The optimal interaction model between the state and the private sector in this context was selected.

Keywords: Public-Private Partnerships, Administrative and Legal Planning, Renewable Energy, Sustainable Development, Energy Projects, Private Sector, Security, Economical Aspects, Management, Strategy

INTRODUCTION

The modern paradigm of sustainable development is inextricably linked with the development of public-private partnership projects in the energy sector in the European Union. This model of cooperation makes it possible to make the most optimal use of public sector resources and stimulate the environmental vector of the private sector in the context of achieving energy security in the country. The key aspects of modern public-private partnership in the energy sector are the development of renewable energy, modernization of existing outdated energy infrastructure, as well as the active attraction of innovative technologies. In all countries of the European Union, much attention is paid to the development of stimulating legal support, which not only forms the framework for the activities of state legal partnerships, but also makes all processes transparent and democratic. Thus, today a distinctive feature of the European regulatory framework in this area is the existence of uniform standards for planning government regulations for all members of the European Union.

Thus, the key advantage of implementing public-private partnership projects in the European Union is the ability to scale successful projects to the energy systems of other countries. This practice has made it possible to radically reduce dependence on imports of non-renewable energy sources, as well as the development of trans-European energy networks. Such activities have become a powerful factor in promoting sustainable development in the European Union. However, it should be noted that the development of public and private partnerships largely depends on the stability and transparency of the public sector in the countries of the European Union. Thus, those countries in which distrust in government is often a phenomenon, fundamental political changes, economic changes and there is an imperfect regulatory framework for these processes often

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have problems with the implementation and effectiveness of long-term public-private partnership projects in the energy sector.

Administrative and legal planning within the framework of public-private partnership plays a key role in ensuring sustainable development of the energy complex. By virtue of its structure and regulatory power, such planning can implement strategic development directions, coordinate interactions between the public and private sectors, and ensure compliance with legal and environmental regulations. This becomes especially relevant in the context of energy security, where proper administrative and legal regulation within the framework of public-private partnerships can contribute not only to efficiency and innovation, but also to reducing risks associated with energy supply and the protection of critical infrastructure. Thus, administrative and legal planning in the field of public-private partnership is the foundation for strengthening energy security and supporting long-term sustainable development goals in the energy sector.

As for Poland, public-private partnerships, especially in the energy sector, play a key role both in the issue of sustainable development and in ensuring its energy independence. Effective strategic planning by the Polish government in recent years has made it possible to develop public-private partnership projects in the field of renewable energy sources and innovative technologies in the energy sector. Thus, Poland is becoming less and less dependent on non-renewable energy sources every year, ensuring its energy security.

The Polish government actively cooperates with the private sector, especially in the construction of new energy facilities and the modernization of old ones. Most modern public-private partnerships are focused on the development of renewable energy sources and the formation of a correspondingly updated energy complex. This aims to reduce our carbon footprint and improve energy efficiency, as well as align with global climate agreements and national sustainability strategies. Bringing private capital and technology into government initiatives allows projects such as solar farms, wind parks and other renewable energy projects to be implemented more quickly and efficiently. These measures not only help reduce dependence on traditional energy resources, but increase environmental sustainability and the socio-economic well-being of the population (Fig.1).

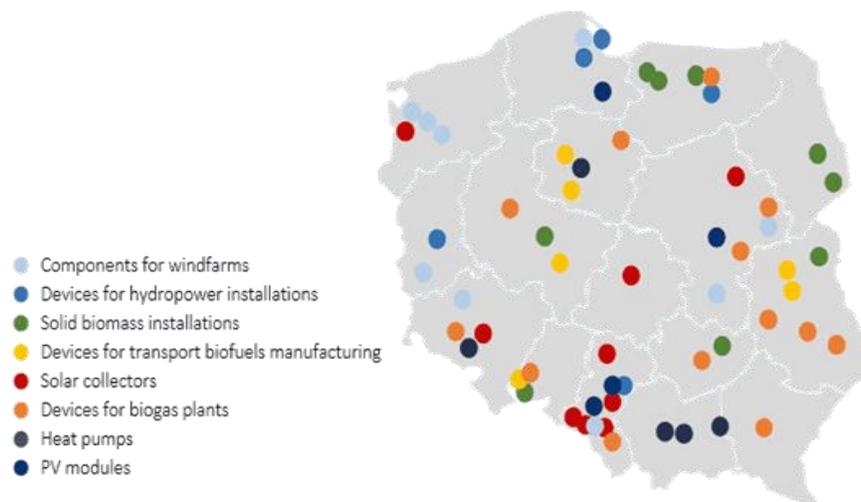


Figure 1. Main types of renewable energy products which were produced through public-private partnerships

Attracting foreign investment through public-private partnerships allows Poland to integrate its energy systems into European networks, thereby increasing energy security and stability. This also helps to increase the competitiveness of national energy at the international level.

However, challenges remain, especially in the context of the need to balance environmental goals with economic benefits. Poland continues to grapple with questions surrounding the social acceptability of some projects, requiring deeper consideration of the impact of local communities and the environment.

Despite these challenges, the prospects for public-private partnerships in Poland's energy sector remain optimistic. Active collaboration between the public and private sectors is key to achieving long-term goals for sustainable development and energy independence.

The main goal of the article is to present a modern methodological approach to choosing the most optimal model of public-private partnership in the context of sustainable development of the energy complex, taking into account various aspects, including issues of safety and rational resource use. The object of the study is public-private partnership models in the context of sustainable development of the energy complex.

LITERATURE REVIEW

The sphere of sustainable development of the energy complex in the context of the development of public-private partnerships is an important issue in the scientific community. Studying modern scientific works in this area will only allow one to become familiar with current trends in this area, but also to identify gaps and shortcomings of the theoretical framework. At the same time, Ahmad and Raza's research (2020) focuses on the role of public-private partnerships in investment in energy and technology innovation in Brazil and EU countries, highlighting their contribution to combating climate change. This source is important for understanding the relationship between energy innovation and the resilience of energy systems to climate change.

In the context of research into contemporary forms of public-private partnerships, an interesting study by Araquistain Portela (2020) explores private sector opportunities in local energy services in Switzerland, showing how urbanized utilities can be integrated into public-private partnerships to improve efficiency and sustainability. A study by Ruiz Serrano et al. (2024) examines sustainability and use of natural resources in EU countries through a psychobiological conceptual model for sustainable development, providing a new approach to understanding the interaction between human behavior and natural resources.

You et al. (2023) analyze design-driven transformation and upgrading of regional industries from a sustainability perspective, demonstrating how innovation strategies can impact the energy industry. While Vo (2022) examines the overall and independent effects of financial development and renewable energy on energy consumption in Trans-Pacific Partnership countries, providing evidence of the links between financial policies and energy efficiency. In the context of public-private partnerships in EU countries, including Poland, Brogaard's study (2017) is important, assessing the impact of innovation training on successful outcomes in public-private partnerships, emphasizing the importance of developing skills and knowledge to improve partnership effectiveness.

Broto and Baker's (2018) study analyzes the spatial dimension of public-private partnerships in the energy sector, focusing on the interaction of social and energy systems. They explore how geographic factors influence the development and integration of energy projects, which is important for understanding local patterns of energy resource management. Zeraibi et al. (2021) examine the impact of renewable electricity generation, technological innovation, financial development and economic growth on environmental footprints in ASEAN-5 countries. Their findings highlight the importance of integrated approaches to reducing environmental impacts, providing valuable context for analyzing the interactions between the economic and environmental aspects of sustainable development.

Carbonara and Pellegrino (2018) are exploring public-private partnerships for energy efficiency projects, particularly through Energy Performance Contracting. They argue that such partnerships can be a win-win for both parties, as they help streamline project designs to improve efficiency. To objectify the processes under study, it is interesting to study Chen et al. (2019), who propose an index of project continuity to assess sustainable development in transnational public-private partnership projects. Their approach allows for a systematic assessment of the sustainability of projects, providing a better understanding of the balance between economic, social and environmental aspects.

Cruz and Sarmiento (2017) explore how traditional models of public-private partnerships can be reformed to address the challenges of smart cities. They focus on the importance of adapting public-private partnership approaches to support innovation and sustainable development in urban environments.

These sources together form a solid basis for understanding a wide range of aspects related to public-private partnerships in energy, from geographic and environmental challenges to innovative strategies and performance models. (Table 1).

Table 1. The main gaps and shortcomings

№	Gaps and shortcomings	Characteristics
1	Long-term impact on sustainable development	The literature often lacks a detailed analysis of how public-private partnerships affect the sustainable development of energy systems in the long term, especially in relation to the integration of low-carbon technologies.
2	Social Considerations	Modern research pays little attention to the social aspects and consequences of public-private partnerships, in particular their impact on the standard of living of the population and other factors.
3	Risk and Safety Management	Modern literature pays insufficient attention to risks and their management in the field of public-private partnerships. This is an important drawback, since it is risks that can act as a destabilizing factor for the success of a public-private partnership project in the energy sector.

Based on the above analysis, we can conclude that the key gap in modern literature is the lack of a theoretically grounded and practically effective methodology for selecting the most optimal public-private partnership strategies in the context of sustainable development of the energy complex. This forms a scientific task in finding approaches to solving this problem.

METHODOLOGY

The research methodology uses several innovative methods to study and evaluate public-private partnership models in the context of sustainable development of the energy sector. Each of these methods allows you to analyze different aspects of interaction between the state and the private sector, providing an integrated approach to choosing the optimal partnership model. These methods form the basis for developing and evaluating a strategy for the sustainable development of public-private partnerships, which allows to select the optimal partnership model, taking into account the safety and rational use of resources in a particular energy complex.

To illustrate the application of the above methods in real conditions, we chose the field of public-private partnerships in the energy sector in Poland. The choice of Poland as a research object is due to several reasons. First of all, Poland is actively developing projects in the field of renewable energy and is looking for ways to optimize the use of its energy resources in the context of sustainable development. In addition, our research group has well-established research communications with experts in the field of sustainable development, the energy complex and public authorities in Poland. These communications provide access to up-to-date data and analysis, which significantly improves the quality and relevance of our research. Over the past five years (2019–2023), Poland has seen a significant increase in the number of public-private partnership projects in the energy sector (Fig.2) impact.

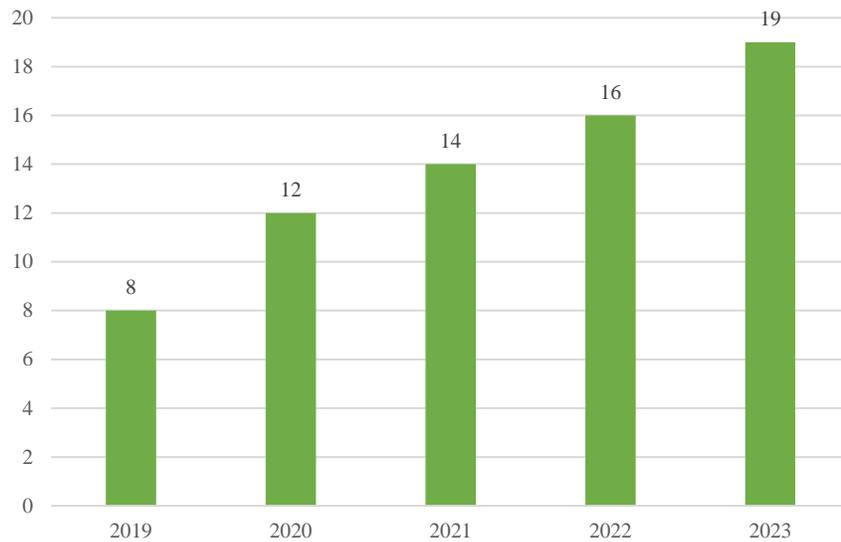


Figure 2. Dynamics of development of public-private partnership projects in the field of energy in Poland

This trend is an important driver for the country's sustainable development, as such partnerships promote the integration of renewable energy sources, increased energy efficiency and the modernization of existing energy infrastructure. The introduction of innovative technologies and practices in this area through public-private initiatives demonstrates mutual benefit for the state and investors, creating the conditions for a more sustainable and resource-efficient energy future.

The method of strategic sustainable development of public-private partnerships is central to our analysis. This method allows for the integration of sustainable development into the strategic planning of public-private partnerships. The essence of the method is to determine long-term goals for the energy sector that meet the environmental, economic and social requirements of sustainable development. A special feature of this method is its ability to adapt to changing external conditions, which allows it to take into account different risks and opportunities. The main advantage is a comprehensive view of the potential for sustainable development, but the disadvantage can be the difficulty of reconciling the interests of different parties and the need for in-depth data analysis. The efficiency vector method of public-private partnerships focuses on assessing the effectiveness of various partnership models in terms of resource use, achieving planned goals and ensuring energy security. This method analyzes how resources are used throughout the project's life cycle. The peculiarity of the method is the ability to determine priority areas for optimizing the use of resources. Its main advantage is to provide a clear understanding of the resource efficiency of projects, but the disadvantage may be its high dependence on the availability and quality of input data.

The game-theoretic modeling method is used to analyze interactions between participants in public-private partnerships. It allows you to model the behavior of participants, taking into account different strategies and their potential consequences for the project. The method uses mathematical modeling to predict the results of various actions and their impact on the success of the project. Its main feature is the ability to identify optimal strategies in conditions of uncertainty and competition. The advantage is a detailed understanding of the dynamics of interactions, but the disadvantage may be the difficulty in interpreting and applying the results in real-world settings.

RESULTS AND DISCUSSIONS

Strategizing the development of public-private partnerships is a process of planning and implementation of cooperation between public authorities and private companies for the joint implementation of projects of great social importance. This process includes the identification of priority areas, the development of long-term plans

and strategies, as well as the creation of a regulatory and legal framework that regulates such partnerships. The purpose of strategizing is to effectively use the resources of both parties to achieve social, economic or technological benefits, while minimizing risks and ensuring the stability and transparency of processes. Strategizing the development of public-private partnerships also includes the selection of various optimal strategies that allow choosing the best way of interaction between the state and private companies. This involves analyzing different scenarios and models of cooperation, assessing potential risks and benefits, and adapting to changing economic, technological and social conditions. The choice of strategy is based on a detailed study of the needs and capabilities of both parties, with the aim of creating the most effective and sustainable partnership model. This approach helps ensure that projects are implemented through public-private partnerships, meet strategic goals and bring maximum benefit to society.

We implement a “game with nature” when making decisions on public-private partnerships. In accordance with the classification of public-private partnerships in the energy sector. As elements of a matrix model of interaction between subjects of public-private partnership in the context of sustainable development, we present:

A1 – interaction between the state and business structures - subjects of the energy sector in Poland and foreign subjects of the energy sector.

A2 – interaction of the state and business structures - subjects of the energy sector of Poland with foreign countries in Europe.

A3 – interaction between the state and business structures – only subjects of the energy sector in Poland.

In each of the interaction options (elements of the matrix model A1-A3), basic models of public-private partnership in the context of administrative and legal planning of sustainable development can be implemented: S1 – management agreements; S2 – leasing (rent); S3 – concession; S4 – agreements on the creation or reconstruction of facilities; S5 – sale of assets.

We will also mark them in the matrix of interaction of subjects of public-private partnership in the energy sector (Table 2). The net present value (NPV) indicator was selected as the resulting indicator for evaluating public-private partnership according to the methodology.

Table 2. Matrix of interaction of public-private partnership subjects in the context of sustainable development of the energy sector in Poland

	S1	S2	S3	S4	S5
A1	NPV ₁₁	NPV ₂₁	NPV ₃₁	NPV ₄₁	NPV ₅₁
A2	NPV ₁₂	NPV ₂₂	NPV ₃₂	NPV ₄₂	NPV ₅₂
A3	NPV ₁₃	NPV ₂₃	NPV ₃₃	NPV ₄₃	NPV ₅₃

The information reliability coefficient (C_{irc}) can be calculated using formula (1):

$$C_{irc} = \sum_{i=1}^n P_i * C_d \quad (1)$$

For sources containing 100% reliable information, the reliability weight is equal to 1; 50% reliable information - 0.5; and unreliable (0%) information - 0. Selection of the optimal interaction of subjects of public-private partnership in the energy sector in the context of sustainable development according to the criteria of Bayes, Laplace, Wald's maximin criterion, Hurwitz's pessimism-optimism criterion, Hodge-Lehman criterion, minimax criterion Savage risk.

According to the Bayes criterion (BA), the calculation should be carried out as follows (2):

$$W_i = \sum_{j=1}^5 A_{ij} * P_j \quad (2)$$

The criterion of insufficient Laplace basis (LA) involves finding the average value of the elements of each row according to formula (3):

$$W_i = \sum_{j=1}^5 A_{ij} \quad (3)$$

To calculate the maximum Wald criterion (WA), we find the minimum element (4) in each row:

$$W_i = \min A_{ij} \quad (1 > j < 5) \quad (4)$$

Hurwitz pessimism-optimism criterion (GA). For each line, we calculate the value of the criterion according to formula (5):

$$W_i = C * \min A_{ij} (1 > j < 5) + (1-C) * \max A_{ij} (1 > j < 5) \quad (5)$$

The Hodge-Lehman criterion (HL) involves the calculation for each row according to the formula (6):

$$W_i = U * A_{ij} + (1 - U) * \min A_{ij} (1 > j < 5) \quad (6)$$

Savage's minimax risk criterion involves calculating a risk matrix for sustainable development. It is better to fill it out in columns (MRS). In each column we find the maximum element, subtract from it all other elements of the column, write the results in the appropriate places using formula (7):

$$R_i = \max A_{ij} - A_{ij} \quad (7)$$

As a result of the work of the expert group, the following matrix of interaction of subjects of public-private partnership in the energy sector was obtained (Table 3.3), U = 0.8, C = 0.6.

Table 3. Results of interaction of public-private partnership subjects in the context of sustainable development of the energy sector in Poland

	S1	S2	S3	S4	S5
A1	2555300	17200	62780	18920	7920
A2	272080	21650	58630	23650	7250
A3	189600	8340	49260	24520	14300
P	0.3	0.3	0.1	0.12	0.18

Let us select the optimal strategy for sustainable development through public-private partnerships in the energy sector by calculating the criteria described above (Table 4).

	BA	LA	WA	GA	HL	MRS
A1	91724	72424	7920	106872	74963	247380
A2	98125	76652	7250	113182	79950	264830
A3	69824	57204	8340	80844	57528	181260

To calculate the MRS criterion, we created a matrix of risks of the sustainable development project (Table 5).

Table 5. Project risk matrix

	S1	S2	S3	S4	S5	Wt
R1	0	238100	192520	236380	247380	247380
R2	0	250430	213450	248430	264830	264830
R3	0	181260	140340	165080	175300	181260

Based on the obtained assessment results for most criteria, the optimal strategy for public-private partnerships in the energy sector is A2. It involves the interaction of the state and structures - subjects of the energy sector with foreign states (Fig.3).

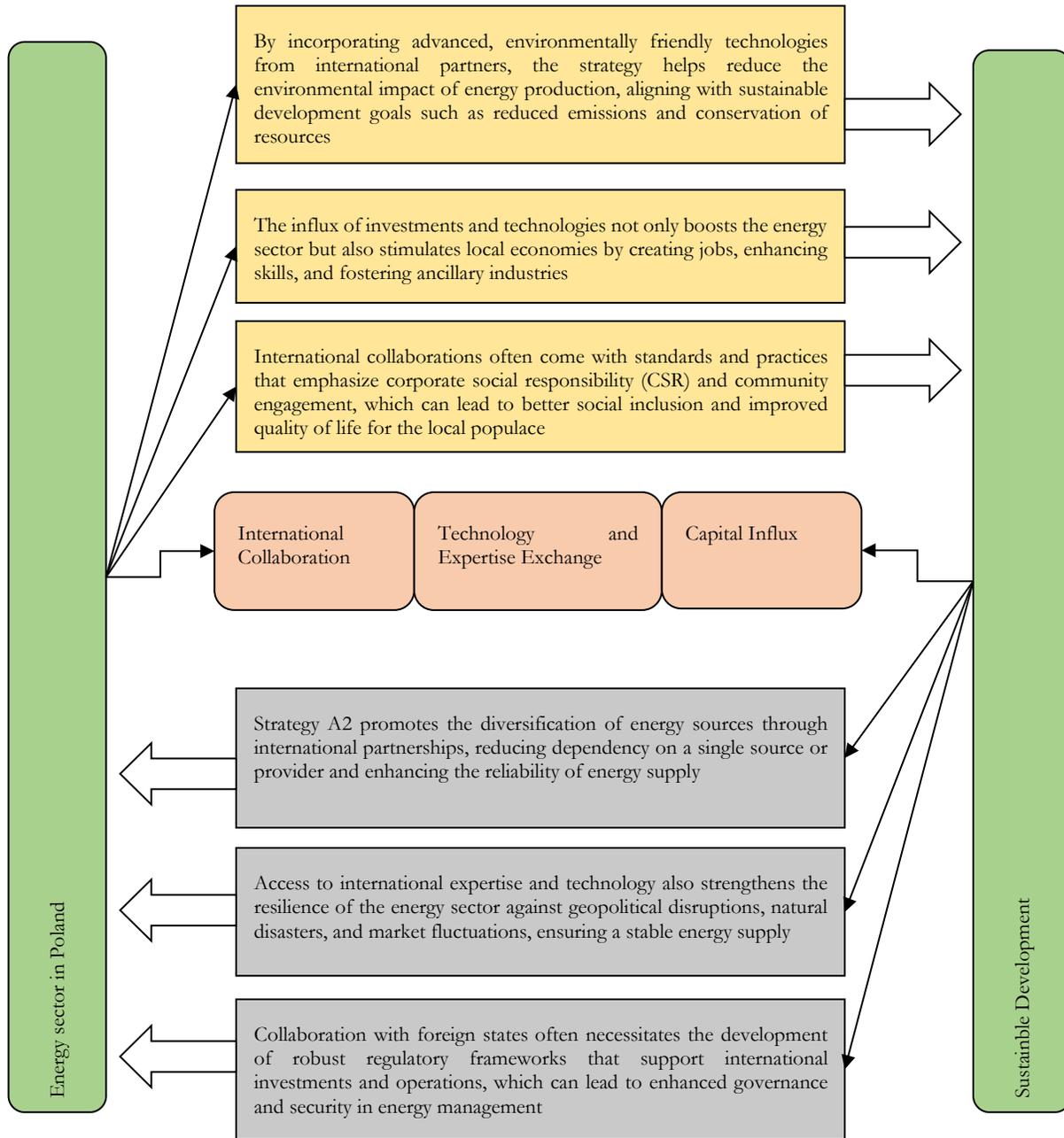


Figure 3. A2 Strategy to ensure sustainable development

Furthermore, the choice of Strategy A2 as optimal suggests that it effectively addresses key challenges and leverages opportunities in the energy sector better than other evaluated strategies. The involvement of foreign states and international entities often means access to a broader market and more robust regulatory frameworks, which can lead to better project scalability and risk management. Additionally, such international partnerships might provide the necessary push to overcome local barriers to innovation and financing, thereby ensuring that large-scale energy projects not only start off well but are sustainable in the long run. Hence, when assessment criteria prioritize global collaboration, technology improvement, and financial stability, Strategy A2 stands out as the superior choice for fostering robust public-private partnerships in the energy sector.

Our research found that the chosen strategy for public-private partnerships in the energy sector largely focuses on administrative-legal planning and security aspects. Ensuring clear regulation of such partnerships through administrative and legal mechanisms allows creating an effective and sustainable basis for cooperation between the state and private investors, which is critically important for the stability and reliability of the energy complex. This, in turn, contributes not only to the achievement of economic goals, but also to the strengthening of energy security, which is crucial for national stability and progress. This approach demonstrates the importance of a systematic and responsible approach to the regulation of public-private interactions, which play a key role in shaping the future of the energy industry.

In order to properly confirm the relevance and scientific novelty of the results obtained in our study, it is important to conduct a comparative analysis with existing research in this area. This involves assessing the extent to which our results correspond to, extend, or contrast with generally accepted concepts. Such a comparison will not only highlight the contribution of our work to public-private partnerships and sustainable development, but will help identify possible directions for future research.

A study by Cui et al. (2019) focused on identifying the critical risk factors affecting waste-to-energy public-private partnership projects in China. It examines in detail the specifics of risk management, which is important for the success of such projects. Our research extends this analysis to include strategic sustainability and game-theoretic modeling methods, allowing for a deeper understanding of the interactions between sustainability, security, and resource efficiency in the context of public-private partnerships. Vassileva's research (2022) focuses on the use of green public-private partnerships as a tool for sustainable development. This provides a valuable overview of the potential of public-private partnerships in supporting environmental initiatives. Our study complements this work by emphasizing a methodological approach to selecting partnership models that optimally meet the requirements of sustainable energy development, providing greater specificity in the context of energy systems.

Acheampong et al. (2019) carry out a comprehensive assessment of the renewable energy potential in Ghana and the ability to achieve sustainable development goals. This study is important for understanding local challenges in renewable energy adoption. Our research is distinguished by taking an integrated approach to analyzing public-private partnerships on a larger scale, focusing on identifying optimal models for promoting sustainable development. In a study by Strasser, et al. (2021) examines the impact of public-private partnerships on sustainability using qualitative analysis. The authors focus on assessing the collective impacts of such partnerships and their ability to promote sustainable development. In contrast to our study, which focuses on administrative planning in the energy sector, the work of Strasser et al. highlights broader issues of sustainability and impacts across a wider range of industries. Our work fleshes out security and resilience strategies specifically in the energy context, thereby providing specific recommendations for public-private partnerships in this important area. Al Qattan et al. (2018) assess the potential of waste-to-energy technologies to achieve sustainable development goals. Their research points to the key role of such technologies in supporting energy sustainability and urbanization. Our research extends this debate by including an analysis of public-private partnerships as a mechanism for effectively deploying and scaling such technologies in the context of the energy complex.

In our study, we focus on the sustainable economic development of the energy complex through administrative and legal planning of public-private partnerships, especially focusing on security aspects. This differs from Cieślak's study (2022), which examines the concept of public-private partnerships in a more general context, without a specific focus on the energy sector or administrative aspects. In our analysis, we focus on the selection of strategies that best meet the needs of sustainable development, while Cieślak engages in a more general review of the implementation and effectiveness of public-private partnerships using the case of Poland. A study by Wen et al. (2022) assesses the impact of investments through public-private partnerships, financial development, and renewable energy consumption on environmental impact in South Asia and the Pacific. It shows the importance of built-in money strategies. Our research adds to this analysis an assessment of partnership models in terms of their contribution to sustainable energy development, showing ways to improve the performance of energy projects. Alam and Murad (2020) examine the impact of economic growth, trade

openness and technological progress on the use of renewable energy in OECD countries. They discover key drivers for increasing the use of renewable sources. A distinctive feature of our research is its focus on methodically selecting public-private partnership models that not only promote the use of renewable energy, but also ensure its sustainability and safety in the broader environmental and social context.

Having compared the results of our study with other relevant studies, we can claim that our research is relevant and brings significant scientific novelty to the field of public-private partnerships and sustainable development of the energy complex. Our findings not only confirm some existing theoretical positions, but also expand understanding of key aspects of the effectiveness and impact of public-private partnerships on the sustainability of energy systems. This study provides new perspectives on the complex challenges facing the energy sector and highlights the need for further research to develop and implement effective strategies in this important area.

The practical application of the results of our research in the field of administrative and legal planning of public-private partnerships in the energy complex has significant potential for increasing efficiency and strengthening safety. The developed strategies and recommendations can serve as reliable tools for policy decisions aimed at optimizing cooperation between the public and private sectors, with the aim of introducing the latest technologies and practices in the energy sector. Focusing on the administrative, legal and security aspects not only ensures compliance with established rules and regulations, but also addresses the challenges associated with risks and vulnerabilities in the energy infrastructure. This ensures the relevance of the research and their importance for the development of national sustainable development strategies, taking into account global challenges and national security needs.

CONCLUSIONS

The modern area of public-private partnership in the energy sector in the context of sustainable development has a number of problems, the solution of which is a decisive factor in the success of this industry and ensuring energy security. These problems relate to the complexity of integrating various types of renewable energy sources into the country's energy infrastructure, the need for significant initial financial investments, as well as the need for the existence and effective implementation of regulatory support in this area. In this context, the search for approaches and methods for selecting the most optimal models of public-private partnership in this area is of particular importance. One of the key tasks in this matter is to find the optimal balance between the development of energy infrastructure and the preservation of the environment and natural resources. This task requires the public sector to find a compromise that ensures parallel economic development, while directing it towards the vector of sustainable development.

In this regard, as a result of our research, a specific approach was developed that allows us to select the most optimal model of public-private partnership in the energy sector that meets the needs of energy security and the principles of sustainable development and rational use of resources. The implementation of this approach is based on the use of methods for strategizing the sustainable development of public-private partnerships, the efficiency vector method and game-theoretic modeling. The analysis showed that public-private partnership can become the key to ensuring sustainable development of the energy complex, taking into account the basic principles of consistency at all stages of planning and implementation of projects. The results of the study also noted the importance of in-depth analysis of the interaction of partners in a partnership to achieve mutually beneficial results.

One of the main limitations of the study is its focus on the energy sector of only one country, which may completely reflect the potential and challenges that exist in other countries with different energy, environmental and economic conditions. In the future, the study is planned to be expanded to include analysis of the environmental and safety sectors. This will allow the formation of more universal and adaptive models of public-private partnerships that can be used in various geographical and economic contexts.

Further research will also be aimed at a more in-depth analysis of the existing interactions and features of various public-private partnership models from the point of view of the possibility of their scaling, as well as

the formation of forecasts for the success and possible impact of projects on the sustainable development system.

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