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IDENTIFYING THE CHARACTERISTICS OF PUBLIC-PRIVATE PARTNERSHIP PROJECTS ON GREEN ENERGY IN DEVELOPING COUNTRIES WITH DIFFERENT INCOMES

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The object of the study is public-private partnership projects in green energy in developing countries. The problematics of the study is based on the intersection of the current problems of improving energy efficiency and environmental friendliness of energy innovations.

The problem of analyzing such projects was solved with the following results:

1. The findings of the study indicate the importance of country income as a factor influencing investment in public-private partnership projects in green energy.

2. The analysis indicates the importance of the country's income as a factor influencing the established technological structure of public-private partnership projects in the green energy sector.

3. It is proved that energy efficiency significantly depends on the technological structure of public-private partnership projects in green energy.

The obtained results are explained by assuming the dependence of public-private partnership projects in green energy on the income level of the economy, based on Wallis one-way analysis of variance and cross-tabulation. Mann-Whitney U test was used to explain the dependence of energy efficiency on the technological structure of such projects.

The particularity of this study is the analysis of the technological structure of public-private partnership projects in green energy, taking into account the specifics of developing countries and the application of their clustering.

This research is of practical significance in the possibility of applying the results obtained by the authorities for the creation and implementation of public-private partnership projects in the field of green energy, as well as by energy companies implementing new technologies using water, wind and solar energy

Keywords: public-private partnership, green energy, economic profitability, developing countries, cluster analysis, technological profile

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1. Introduction

The modern world economy prioritizes the problem of increasing energy efficiency due to the growing demand of mankind for resources, which requires additional energy inputs. The rational use of energy makes it possible to reduce carbon emissions into the atmosphere.

Improving energy efficiency has a strong impact on the energy market, influencing the reduction of energy costs. For example, energy savings in the US over twenty years due to structural changes to improve energy efficiency amounted to 2.3 billion MTOE, in the EU countries over the same period – 1.3 billion MTOE (Fig. 1).

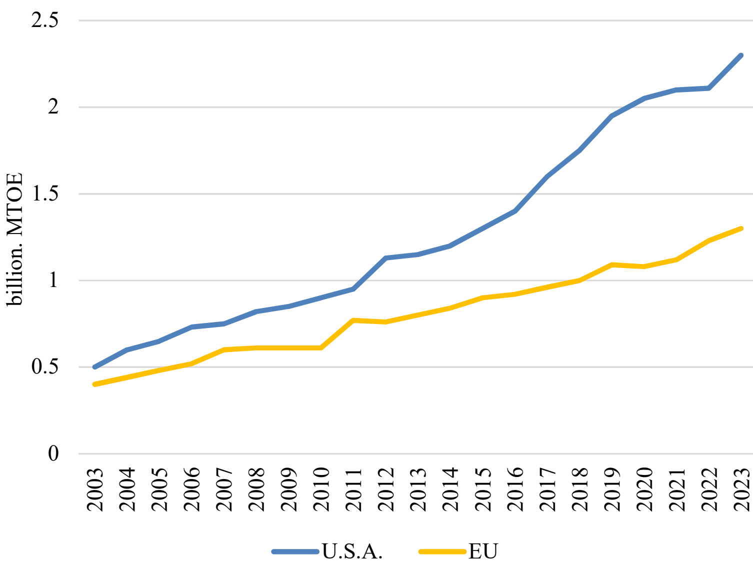

Fig. 1. Amount of energy savings in the US and EU over 2003–2023
Note: MTOE – million tonnes of oil equivalent
Source: Compiled by the author from [1]

At the same time, the problem of energy supply and energy efficiency is particularly acute for developing countries, where, according to the International Energy Agency, 1.6 billion people do not have access to electricity and other modern forms of energy [2]. The energy hunger and low energy efficiency of economies in Africa and other developing countries make it impossible to utilize their rich potential for development. Increasing geopolitical rivalries in various areas, including the energy sector, challenge each state to overcome energy obstacles against the backdrop of rising energy prices [3].

Thanks to the efforts of various countries to improve energy efficiency, public-private partnership projects (hereinafter: 3PE projects) are being implemented, which have a strong impact on the system of global economic linkages, as well as on the economies of individual states.

Over the past few years, the Paris Climate Agreement [4] and decarbonization of the world economy by 2050 [5] have actualized the search for the most effective mechanisms to improve energy efficiency on the basis of public-private partnership. According to the UN statement, such a partnership is a tool that realizes the UN Sustainable Development Goals, including SDG 7.3 – doubling the growth rate of energy efficiency [6].

The International Energy Agency emphasizes the importance of engaging the private sector for energy efficient policies and programs and notes the high productivity of public-private partnerships in developing economies if they introduce co-financing of developments in energy and new green technologies [7].

Projects that integrate innovative energy efficient and green energy technologies are the most relevant object of study for developing countries. Such projects realize more positive externalities than traditional projects, including: improvement of environmental quality; development of science and education; reduction of energy poverty; increase of national security of the country through implementation of energy security, etc.

It is impossible to determine the planning strategy and create long-term priorities for energy development in a country today without knowledge about the structure of public-private partnerships in green energy projects (hereinafter: 3PGE projects). In this regard, the topic of analyzing the structure of such projects in developing countries is relevant for the study.

2. Literature review and problem statement

The theoretical foundations of public-private partnership were laid in [8], when the concept of "X-efficiency" was created, explaining the difference in productivity between public companies and private enterprises by means of intangible "X-factors": organizational structures, labor relations, personnel selection, and labor incentive system. Adapting this position in relation to the present study, we can conclude that public-private partnerships are needed by governments (public companies) in order to minimize the inefficiencies that arise in organizational structures.

The study [9] states that public-private partnerships can increase the amount of investment capital in infrastructure, strengthen the performance of activities by applying the experience gained in the private sector. Continuing this idea, we note that for private companies, participation in such a partnership provides a significant financial effect and the opportunity to use administrative resources that are under the jurisdiction of the state.

Public-private partnership can have a broad and narrow interpretation and includes cooperation between the state and private companies, both in the short and long term. Thus, in [10], the scope of public-private partnership includes even sponsorship and charitable support for developing countries. This approach seems unreasonable, as it does not correspond to the essence of partnership as an agreement to pool resources. Therefore, this study will use the classical interpretation of public-private partnership, which implies the signing of a contract between the state and a private company on joint participation in the financing and implementation of projects significant for society, including the joint distribution of responsibility, possible risks and rewards.

The study [11] states that public-private partnership is a traditional procurement model, i.e. the provision of a certain service by a private company, which is ordered by a public agency, sometimes with the contribution of part of its financial resources. We believe that this approach is not applicable to 3PGE projects, as they have a more complex scheme of interaction. But tenders in the innovative energy sector can have the features of public-private partnerships. Including popular in European countries mechanisms of renewable energy support, such as green tariff and tenders for projects in this area [12]:

– construction and operation of renewable energy facilities by companies;

– state guarantees for the return of invested funds, guarantees for the receipt of profits by companies that meet the requirements;

– conclusion of long-term renewable energy support contracts (up to 20 years).

The question remains open as to who should create the infrastructure that allows the development of green projects, which, in fact, are innovative: the state or business. The study [13] shows that this task should be performed by the state. This statement is controversial, since many countries are inferior to private major corporations in terms of the intensity of implementation and the degree of intellectual property protection. Nevertheless, for developing countries state capabilities are crucial. Here the issue of the impact of state budget revenues on 3PGE projects is actualized.

On the other hand, the main factors for the development of public-private partnership in the field of energy efficiency in the EU are subsidies, tax preferences, grants, tariffs and other instruments developed by the Government, as well as the creation by the state (independently or jointly with private business) of a developed institutional environment and infrastructure of high quality. In [14], a direct correlation between these factors and the performance of public-private partnership in the field of energy efficiency projects was shown using economic and statistical methods. The creation and support of such a state strategy require significant budgetary investments.

In [15], the focus is on the allocation of public subsidies precisely for the initial high transaction costs arising at the stage of development of energy-efficient green technologies by private companies. This reduces the risks of launching innovative processes. However, this approach does not take into account the strategic orientation of the state's interests when participating in public-private partnerships. The state is primarily interested in infrastructure energy projects, where the main goal is to meet current or projected demand. Energy efficiency of such projects is often not the only objective.

The paper [16] puts forward the position that the primary factor for innovative public-private partnership projects in the energy sector is the characteristics of the private partner, since the state invests its resources in it and assumes the economic risk. Disagreeing with this opinion, we note that the state partner in the implementation of such a project supports, first of all, the project itself, and not the private party considered as a recipient. Therefore, the primary factor is the project itself, its content and validity for a particular country in the structure of the national energy sector.

Reference [17] emphasizes that partners do not care about the place of the proposed project in the country's energy mix, as they are primarily guided by the cost/profitability dimension. However, this view is one-sided, as it is necessary to consider the impact of the project throughout its duration. A systemic approach to public-private partnerships realizes the lifecycle performance of projects by governments, rather than a cheap during construction and expensive in operation outcome.

The study [18] shows that the assessment of the impact of energy efficient technologies on society, economy and natural environment is perceived differently by different sectors, and expectations from the introduction of such technologies also differ. Continuing this idea, we specify that the public sector is focused on achieving energy and environmental goals, the most effective implementation of incentive measures to promote renewable energy sources. The attention of the private sector, on the other hand, is primarily focused on making profit, reducing payback periods and mitigating risks. Social responsibility of business in such projects is typical mainly for developed countries.

The paper [19] notes that public-private partnerships in innovative energy projects are based on the pooling of financial resources. Let us complement this position with a broader view. Public-private partnerships can expand administrative and organizational capacity for the implementation of energy efficiency projects, minimize the risks of each party, activate information exchange between economic sectors, thanks to which it becomes possible to jointly create, develop and implement knowledge in the field of energy. This is an important point for developing countries whose economies are complicated by bureaucratic problems.

In [20], the focus of the interaction of the public-private partnership sphere in innovative energy in developing countries is shifted to finance and the state. It is argued that the state should encourage investment in energy efficient industrial equipment and production processes by introducing targeted financial incentives, including tax incentives for energy efficiency investments in various sectors of the economy. Expanding on this position, we would add: promoting financing through public-private partnerships to improve industrial energy efficiency through risk sharing, providing credit guarantees to financial institutions together with private investors, providing conditions for energy service contracts, etc.

With energy efficiency improvements being a priority for governments, public sector awareness of the specific barriers arising from the creation, financing and implementation of energy efficiency projects is developing [21]. Indeed, most of the innovative private energy projects have economic barriers entailing a negative financial flow for the entire duration of their implementation. And if neither the government nor private companies have the ability to invest and channel large amounts of financing into long-term projects, which is usually characteristic of developing countries, the 3P form solves these problems.

The study [22] shows that the partnership between the government (its local financial institutions) and energy organizations makes it possible to structure a public-private partnership that allows the use of market instruments, avoiding direct subsidies from the government. Critically evaluating this approach, we come to the clarification that this scheme ensures that the government achieves its goals of improving energy and environmental efficiency by using only part of the public funding. In this case, the financial capacity of the government and, consequently, the profitability of the state budget are important.

Thus, the issues of 3PGE projects are widely disclosed in economic science, but, despite this, the problem of analyzing their structure is insufficiently investigated. In the conditions of economic and political manipulations in the global energy market from 2020, the problem of 3PGE projects is also poorly represented at the moment. This shortcoming is especially evident in relation to green energy, i.e. in such areas where the greatest potential of energy efficiency for developing countries is contained. All the above aspects contribute to the allocation of 3PGE projects in a separate category, combining the areas of green energy and energy efficient technologies.

3. The aim and objectives of the study

The aim of the study is to identify the characteristics of 3PGE projects in developing countries with different incomes. This will allow identifying the most effective types of 3PGE projects for developing countries.

To achieve this aim, the following objectives are accomplished with respect to developing countries:

– to identify whether the profitability of the national economy affects investment in 3PGE projects;

– to establish whether the technological structure of 3PGE projects depends on the profitability of the national economy with differentiation by clusters;

– to determine whether the technological structure of 3PGE projects affects the energy efficiency of national economies.

4. Materials and methods

The object of the study is public-private partnership projects in green energy in developing countries.

The hypothesis of the study: upper-middle-income developing countries are characterized by high intensity of 3PGE projects in general, but reduce the share of hydro-3PGE projects. The study suggests that there is a relationship between a country's income and the intensity, structure and efficiency of 3PGE projects.

To simplify the work with a large amount of data, only common types of energy for 3PGE projects (water, solar, wind) are selected, while there are other types (bioenergy, hydrogen, etc.) that are insignificantly represented in these countries.

3PGE projects of developing countries are studied, as developed countries are characterized by a special institutional environment and high financial support of the state in infrastructure development. When applying generalized indices, the inclusion of developed countries may lead to the leveling of problems of developing countries, while the latter are mostly in energy poverty.

At the first stage, developing countries were graded by the criterion of per capita income according to the World Bank methodology (in US dollars):

1) low level: up to 1,035;

2) below average: from 1,035 to 4,085;

3) above average: from 4,085 to 12,615.

At the second stage, 3PGE projects were selected. 3PGE projects were selected for the study, i.e. projects that have both attributes: public-private partnership and green energy. Green energy includes projects that utilize energy from the main renewable sources: water, wind and solar.

The information base of the study is provided by the World Bank [23], which gives analytics on public-private projects in developing countries for the period from 2016 to 2023. The information is presented in a convenient breakdown, which allows you to get a report on any sector. Each block also allows grouping projects into separate categories. In total, 137 states are represented on this resource, but 3PGE projects were conducted in 85. This means that the sample for our analysis is 85 countries.

At the third stage, the impact of national economy income on investments in 3PGE projects was analyzed. Due to the lack of normal distribution of quantitative indicators, nonparametric statistics methods were applied at this and subsequent stages. The analysis of the impact of national economy income on investments in 3PGE projects was carried out using the Kruskal-Wallis test method. The technological profile of 3PGE projects implies values within (0;1) characterizing the number of projects on a particular technology in the total sample of projects.

At the fourth stage, cluster analysis based on the k-means method with a hierarchical clustering algorithm was used to identify common and different parameters of countries in terms of the technological profile of projects. Cross-tabulation calculations were performed and Pearson's goodness of fit criterion was applied. Differences between countries were determined using Fisher's criterion. Euclidean distance was used to measure the gap between the study objects.

At the fifth stage, the impact of the structure of 3PGE projects on the energy efficiency of national economies was analyzed using Spearman rank correlation. Assessment of the structure of 3PGE projects with different directions of change in energy efficiency was realized by applying a series of Mann-Whitney tests.

The basis for analyzing the dynamics of energy efficiency of the selected countries was the indicator of GDP per 1 kg TOE according to the World Bank data. In our study, the difference between the initial values and the latest data for 2016–2023 for each country is calculated. The obtained variable ΔE is expressed as a percentage. The analysis of the dynamics of the country's energy efficiency at the qualitative level is reflected through the variable ΔE_{sign} (its value corresponds to the sign of the variable ΔE).

Data processing was performed using "Statistica 12" software (France).

5. Results of research on the structure of 3PGE projects of developing countries

5. 1. Analyzing the impact of national economy income on investments in 3PGE projects

Before analyzing the impact of the national economy's income on investments in 3PGE projects, it is necessary to exclude the factor of foreign participation in the financing of such projects. This will make it possible to conduct the analysis in a pure form. The obtained variable ΔE is expressed as a percentage. The analysis of the dynamics of the country's energy efficiency at the qualitative level is reflected through the variable ΔE_{sign} (its value corresponds to the sign of the variable ΔE).

For this purpose, a non-parametric correlation analysis was conducted to determine the relationship between the amount of foreign financing of 3PGE projects (Q) and the dynamics of energy efficiency in the countries (ΔE). The results are presented in Table 1.

Table 1

Values of non-parametric correlation between the volume of foreign financing of 3PGE projects and the dynamics of energy efficiency in the country using Spearman's coefficient

Variable	Q	ΔE
Q	1.000000	0.120191
ΔE	0.120191	1.000000

The test using Kruskal-Wallis criterion to investigate the intensity of investment in 3PGE projects depending on the income level of the country's population was conducted against non-green 3PE projects for comparison. The results are presented in Table 2.

Table 2

Analysis of the results obtained during the application of a series of Kruskal-Wallis tests

Description of the dependent variable	H-statistic indicator	p-criteria statistics
Investments in 3PE projects to GDP	7.1710	0.0286
Investments in 3PGE projects to GDP	7.0839	0.0289
Investments in non-green 3PE projects to GDP	3.3473	0.1876
Share of 3PGE projects (of the total number of 3PE projects)	4.8987	0.0864
Share of non-green 3PE projects (of the total number of 3PE projects)	12.7958	0.0017
Change in energy efficiency	8.63779	0.0134

Note: The independent grouping variable is the income group of the country.

Obtaining the expected results on the profitability of the national economy and 3PGE projects allows us to proceed to the analysis of this relationship using the clustering method.

5. 2. Clustering of countries according to the structure of 3PGE projects and testing the relationship with the profitability of national economies

Based on the clustering of countries according to the structure of 3PGE projects, all countries were divided into 3 groups (Table 3).

Table 3

Clustering of countries by the structure of 3PGE projects for the period 2016–2023

Cluster	I	II	III
Source	Sun 43	Wind 33	Water 9
Countries	Afghanistan, Algeria, Angola, Armenia, Azerbaijan, Bulgaria, Bangladesh, Bolivia, Botswana, Cambodia, Cuba, Egypt, Gambia, Ghana, Guinea, Haiti, Iran, Jordan, Yemen, Venezuela, Zambia, China, Congo, Chad, El Salvador, Ethiopia, Fiji, Jamaica, Lebanon, Malawi, Malaysia, Mali, Mexico, Mozambique, Namibia, Nigeria, Senegal, South Africa, Thailand, Tanzania, Tunisia, Ukraine, Uzbekistan	Albania, Argentina, Belarus, Bosnia and Herzegovina, Brazil, Costa Rica, Ecuador, Guatemala, Honduras, India, Indonesia, Kazakhstan, Kenya, Kosovo, Madagascar, Malaysia, Mongolia, Montenegro, Morocco, Nepal, Nicaragua, Pakistan, Peru, Philippines, Russia, Rwanda, Serbia, Solomon Islands, Sri Lanka, Turkey, Uganda, Vietnam, Zimbabwe	Bhutan, Cameroon, Colombia, Dominica, Georgia, Iraq, Laos, Lesotho, Tajikistan

Cross-tabulation was used to test for statistically significant differences between the selected clusters of states by income level. The nominal variables were both cluster number and income level. The calculation of Pearson's goodness of fit criterion (χ^2) and maximum likelihood statistics are presented in Table 4.

Differences between countries were determined using the F-test (Table 5).

This breakdown allows you, on the one hand, to use the optimal number of variables for clustering and, on the other hand, to obtain a logical interpretation and identify significant differences between countries.

Table 4

Testing the hypothesis that there is a relationship between the cluster order number and the country's income level

Analyzed indicator	Selected research method	
	Pearson's goodness of fit criterion	Maximum likelihood method
χ^2	17.58978	20.23540
p-level of statistical significance	0.00734	0.00251

Table 5

Calculation of Fisher's criterion for variables characterizing the structure of 3PGE projects

Percentage of projects	General dispersion	Within-group variance	p-level	F-statistic
Water	46502.14	9632.19	0.00000	162.5355
Wind	9435.68	37246.80	0.00004	8.5287
Sun	63239.89	23265.80	0.00000	91.5110

5. 3. Analyzing the impact of the structure of 3PGE projects on the energy efficiency of national economies

Spearman's rank correlation coefficient was used to test the relationship between the structure of 3PGE projects and the dynamics of energy efficiency (Table 6).

Table 6

Values of non-parametric correlation between 3PGE projects by structure and energy efficiency dynamics in countries using Spearman's coefficient

Variable	ΔE	ΔE_{sign}
Wind	0.124922	0.233008
Sun	0.057954	–0.033589
Water	–0.214611	–0.25502

The results obtained from a series of Mann-Whitney tests conducted to analyze the structure of 3PGE projects are presented in Table 7. For convenience, all states are divided into 2 groups according to the sign of change in energy efficiency.

Table 7

Results obtained in a series of Mann-Whitney tests to evaluate the structure of 3PGE projects with different directions of energy efficiency change

Percentage of projects in the category	Z	Z adjusted	p-level Z	p-level Z adjusted
Wind	2.03404	2.18411	0.042060	0.028954
Sun	–0.29819	–0.30328	0.766434	0.754829
Water	–2.44901	–2.49577	0.013962	0.012659

Thus, the application of various economic and statistical methods allows analyzing 3PGE projects as an independent object of research and in the context of the structure by the criterion of the type of renewable energy source used.

6. Discussion of the results of the analysis of 3PGE projects and their structure in developing countries

The non-parametric correlation analysis revealed the existence of a weak positive correlation between the amount of foreign financing of 3PGE projects and energy efficiency improvement (R=0.12, p<0.05) (Table 1). Consequently, this factor in relation to the subject of the study can be disregarded in further analysis.

The results of Kruskal-Wallis criterion tests showed that the intensity of investment in 3PGE projects directly depends on the level of income of the country's population. In the course of calculations, the value of H=7.171 was obtained at the significance level of p=0.0286. This characterizes the statistical significance of differences between the studied groups within p=0.05 (Table 1).

Based on Table 2, the following conclusion can be drawn: the low intensity of investment in 3PGE projects is characteristic of low-income countries. This indicator increases for lower-middle-income countries and decreases again for upper-middle-income countries. It follows that there is a non-linear relationship between a country's income level and the intensity of investment in 3PGE projects.

For comparison, we note that no statistically significant differences between the intensity of investment in non-green 3PE projects and the level of income of the country's population were revealed. The analysis of the influence of income level on the share of 3PGE projects (from the total number of 3PE projects) revealed that the estimated indicator is characterized by a statistically significant influence (p=0.1). Low-income countries are characterized by the minimum share of 3PGE projects. For the states with income above the average level, this indicator increases, and in the countries with high income it takes the maximum value. So, there is a relationship between the level of income of the state and the share of 3PGE projects, which is close to linear.

The application of Kruskal-Wallis criterion showed that energy efficiency differs between countries with different income levels. At the level of criterion statistics H=8.63779 and statistical significance p=0.0134, statistically significant differences between groups of countries at the level of p=0.05 are observed (Table 2). The analysis showed that the greatest dynamics of energy efficiency is characteristic of countries with lower-middle income. Note that in this group there were no states in which the energy efficiency indicator decreased. In the group of countries with above-average income, this indicator is lower, and in the group with the lowest income – the minimum.

Clustering of countries according to the technological component of 3PGE projects resulted in the following grouping (Table 3):

– cluster I: dominated by countries with the highest share of solar projects. The largest cluster by number of countries (43 countries) occupies more than half of the developing country sample;

– cluster II: countries with the highest share of wind energy projects are represented. The cluster occupies more than one-third of the sample, bringing together 33 countries;

– cluster III: countries with the highest share of water energy projects are included. By number of countries (9 countries), it is the smallest cluster, occupying 10.6 % of the sample.

The results of the cross-tabulation analysis (Table 4) show a statistical relationship between cluster and income level in the country. Upper-middle-income countries are characterized by a technology profile of 3PGE projects focused on solar or wind energy. Low-income and lower-middle-income countries have a technology profile focused on hydro and solar power (Table 5). Thus, countries with above-average income are characterized by either cluster I or cluster II. The rest are placed in clusters I and III.

The calculated non-parametric correlation coefficients characterize a statistically significant positive relationship between the growth of energy efficiency and the number of 3PGE projects. The obtained Spearman rank correlation coefficient takes the value of 0.28 at the level of statistical significance p<0.05. The correlation is also present between the technological structure of such projects and the increase in energy efficiency. For example, a weak but positive correlation exists between the growth of energy efficiency and the share of wind projects (obtained values R=0.233 at p<0.05), and the share of hydro projects – a weak negative correlation (Table 6).

However, wind projects do not act as a driver of energy efficiency of the country. At the same time, hydro projects cannot be attributed to the main reason for the decline in energy efficiency of national economies. These indicators are formed under the influence of different sectors of the economy and industry structure, so the identified trends have only a minor impact on the final result. In general, this aspect can be recognized as a shortcoming of this study.

The cause-and-effect relationship in this issue is not quite clear. There is a logical explanation for the positive correlation: countries that are committed to improving energy efficiency have developed clear programs in this area and have chosen certain technologies when implementing 3PGE projects.

This argument is supported by the results obtained from a series of Mann-Whitney tests used to analyze the structure of 3PGE projects (Table 7). With statistical significance taking the value of p=0.05, there are significant differences between countries with a high level of energy efficiency and those with a decrease in this indicator for wind projects.

Countries with a high level of energy efficiency are characterized by an increase in the share of wind projects and a decrease in the share of hydro projects. When considering solar power generation technologies, no statistically significant differences were found between countries with increasing or decreasing energy efficiency, which is also a shortcoming of this study.

It should be noted that there is a similar study [21], in which the problems and key success factors of public-private partnership projects in the field of renewable energy are identified on the basis of a literature review and expert survey. Its advantage is the use of qualitative methods, but its disadvantage is the lack of economic and statistical methods, and most importantly, there is no analysis in terms of the structure of such projects. In addition, unlike [21], where the analysis was conducted only for 5 continents, the present study is based on the processing of a large data set of 85 developing countries with their distribution into clusters.

Another similar paper [16] analyzes the determinants of private investment in public-private partnership (PPP) projects in renewable energy. But compared to the present study, the sample in [16] included a smaller number of developing countries (63 countries) and an irrelevant period of 1997–2016, although the paper was published in 2021. In addition, the conclusions do not contain the factor of project structure, while the present study reveals this problem.

Similar in methodology studies of 3PGE projects using similar economic and statistical methods were not found. But there is a work [24] with a broader subject of study (public-private partnership projects in the field of energy). The analysis of the impact of national economy profitability on investments in energy projects is also conducted using the

Kruskal-Wallis test method. A similar result was obtained: the intensity of investment in public-private partnership energy projects directly depends on the level of income of the country. But the revealed relationship is linear in nature. The latter difference from the present work can be explained by the fact that the subject of the study includes thermal projects (combustion of fuel: gas, oil, etc.), which prevail in the sample, making up the absolute majority (78 %). These projects are financed mainly from the profits generated by the oil and gas industry itself, which provides a significant share of the income of developing countries with commodity economies.

Thus, the peculiarity of this study is the analysis of the technological structure of 3PGE projects with specification by developing countries using clustering. The prospect of the study may be a more disaggregated differentiation of 3PGE projects by structure and/or the study of this object in relation to developed countries.

A limitation of this paper is the study of 3PGE projects only in developing countries; analyzing such projects in developed countries may give a different result. Another limitation is the use of a period of only 8 years and only those countries that provided statistics to the World Bank. A wider range of the study period, a different number of countries, and a more disaggregated clustering of countries may yield more accurate results.

7. Conclusions

1. The results of Kruskal-Wallis criterion tests showed that the intensity of 3PGE projects development directly depends on the level of income of the country's population (H=7.171). There is a non-linear relationship between the level of income of the country and the intensity of investment in 3PGE projects. But the share of 3PGE projects from the total number of 3PE projects demonstrates a direct linear relationship with the state income.

2. The results of the cross-tabulation analysis show a statistical correlation between the cluster and the level of income in the country (χ^2=17.59). Upper-middle-income countries are characterized by a technology profile of 3PGE projects focused on solar or wind power. Low-income and lower-middle-income countries have a technology profile focused on hydro and solar energy.

3. There are significant differences between countries with a high level of energy efficiency and those with a decreasing level of energy efficiency for wind and water 3PGE projects. Countries with high energy efficiency are characterized by an increase in the share of wind projects (Mann-Whitney Z_a=2.18) and a decrease in the share of hydro projects (Z_a=2.49, respectively). When considering solar power generation technologies, no statistically significant differences were found between states with increasing or decreasing energy efficiency.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

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Data availability

Data will be made available on reasonable request.

Use of artificial intelligence

The authors have used artificial intelligence technologies within acceptable limits to provide their own verified data, which is described in the research methodology section.

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