“Effectiveness of reforms to eliminate obstacles in the development of sustainable energy in different countries of the world”

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ARTICLE INFO	Olena Dobrovolska, Knut Schmidtke, Julia Krause, Olena Matukhno and Arne Cierjacks (2024). Effectiveness of reforms to eliminate obstacles in the development of sustainable energy in different countries of the world. *Problems and Perspectives in Management*, *22*(3), 1-13. doi:10.21511/ppm.22(3).2024.01
DOI	http://dx.doi.org/10.21511/ppm.22(3).2024.01
RELEASED ON	Monday, 01 July 2024
RECEIVED ON	Monday, 20 November 2023
ACCEPTED ON	Wednesday, 05 June 2024
LICENSE	This work is licensed under a Creative Commons Attribution 4.0 International License
JOURNAL	"Problems and Perspectives in Management"
ISSN PRINT	1727-7051
ISSN ONLINE	1810-5467
PUBLISHER	LLC “Consulting Publishing Company “Business Perspectives”
FOUNDER	LLC “Consulting Publishing Company “Business Perspectives”

NUMBER OF REFERENCES	NUMBER OF FIGURES	NUMBER OF TABLES
68	3	3

BUSINESS PERSPECTIVES

LLC “CPC “Business Perspectives”
Hryhorii Skovoroda lane, 10,
Sumy, 40022, Ukraine

www.businessperspectives.org

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EFFECTIVENESS OF REFORMS TO ELIMINATE OBSTACLES IN THE DEVELOPMENT OF SUSTAINABLE ENERGY IN DIFFERENT COUNTRIES OF THE WORLD

Received on: 20th of November, 2023
Accepted on: 5th of June, 2024
Published on: 1st of July, 2024

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Conflict of interest statement:
Author(s) reported no conflict of interest

Abstract

The development of strategy and tactics for reforms in the energy industry involves the identification of benchmark countries whose experience can form the basis of a quantitative assessment of the main targets of the reforms. The basis for such decisions can be the results of the integrated assessment of energy reforms in the EU countries for 2010–2021. This study aims to cluster these countries according to the integral indicator and determine specific directions in which the respective country needs to make progress in moving to another cluster. Thus, based on a linear model, the Fishburn formula, and variance analysis, 10 energy development indicators were combined into a single indicator that characterizes the effectiveness of energy reforms (for example, in 2021, it was the highest in Austria (0.612), Germany (0.644), and France (0.620); the lowest – in Latvia (0.383) and Croatia (0.369)). Based on this indicator, countries were clustered using the k-means method. Four clusters were formed: representatives of the highest first (Austria, Germany, France, Spain, Sweden, and Luxembourg) are strategic benchmarks for all EU countries, and representatives of other clusters are tactical benchmarks for countries from lower clusters. The average values of all 10 indicators of energy development were calculated. Their low values are a sign that this direction should be a priority when carrying out reforms, and their quantitative estimates can be used as specific targets when setting strategic and tactical tasks (transition to a higher cluster or achieving average values in one’s cluster).

Keywords sustainable energy, energy reform, energy consumption, renewable sources, energy efficiency

JEL Classification Q48, Q42, P28, Q51

INTRODUCTION

The rapid growth of energy production and consumption, the high energy intensity of GDP, and the significant level of technological backwardness of most sectors of the economy of individual countries are prerequisites for the worsening of the energy problem in the world. The COVID-19 pandemic and the war in Ukraine had a significant impact on the European gas markets. Their consequences were manifested in a significant decrease in natural gas supplies to EU countries, a sharp increase in energy costs, and a reorientation of global natural gas flows. The reduction of own gas production in Europe also contributed to the strengthening of the energy deficit in the world and the actualization of the need to revise certain international requirements and recommendations in the field of energy production and consumption.

The consequences of these processes made the international community revise its requirements for energy management systems and energy efficiency. The European Commission, together with the European

Parliament and the Council, strengthened the directives on energy efficiency and renewable energy sources in order to reduce greenhouse gas emissions. The energy efficiency target indicators should increase to 11.7% by 2030; the share of the use of renewable energy sources should stay at a minimum level of 42.5% by 2030; net greenhouse gas emissions should be reduced by at least 55% by 2030; and governments should introduce measures to stimulate the production and consumption of renewable energy, financing energy efficiency, attracting investments.

In addition to normative regulation, international organizations implement measures to minimize the consequences of the energy crisis in the world. Thus, since September 2021, European countries have allocated 651 billion euros to protect consumers from rising energy costs (e.g., EU – 540 billion euros, Great Britain – 103 billion euros).

At the same time, given the scale of the consequences of the global energy crisis and the impossibility of completely neutralizing the factors of excessive energy consumption, the effectiveness of these measures is insufficient. Given that an ineffective energy policy has a negative impact not only on the environment and the health of the population but also on the economic indicators of the country's development, the determination of the most effective reform tools for the world energy market is becoming a key element in the development of the public management system.

Under these conditions, it is crucial to develop a toolkit to assess the effectiveness of reforms to eliminate obstacles in the development of sustainable energy and determine the priority directions of the state energy policy depending on the level of energy development of the country.

1. LITERATURE REVIEW

Periodic aggravation of the energy problem draws the attention of scientists and practitioners to the issue of the effectiveness of existing state energy programs (Vakulenko et al., 2023; Chygryn & Shevchenko, 2023; Oe et al., 2022; Bhandari, 2023; Singh & Pandey, 2023; Márquez-Sobrino et al., 2023). The global reduction of carbon dioxide emissions stimulates the international community to introduce green imperatives to reduce the use of fossil fuels and develop alternative energy (Skowron et al., 2023; Melnyk, 2016; Sotnyk et al., 2023).

Increasing energy efficiency can be ensured in several ways. One can introduce more efficient technologies, modify existing building structures (Worrell et al., 2009; Mills, 2011; Artyukhova et al., 2022; Bilan et al., 2020; Wang et al., 2023; Kyshakevych et al., 2024), change the behavior of energy consumers and producers (Matvieieva & Hamida, 2022; Youcef, 2023; Letunovska et al., 2021), and introduce preferential taxation system (Vostrykov & Jura, 2022).

At the same time, each country has its own set of regulations and policies for the use and supply of energy, which are constantly changing under the influence of a changing environment. Ineffective provisions are removed, while successful ones continue to be applied (Oe et al., 2023; Lee et al., 2015; Pashkuda et al., 2022). Thus, evaluating the effectiveness of measures to stimulate the transition to renewable energy and energy efficiency methods is a key condition for reforming the country's energy market (Matvieieva et al., 2023; Ziabina et al., 2023b; Hilorme et al., 2019).

Jonek-Kowalska (2022) evaluated the effectiveness of energy policy implementation in 11 countries. The results proved a low level of implementation of environmental goals and average progress in energy transformation in terms of four components: ecological, energy resource, economic, and energy security. The study showed that the most effective tool for energy transformation is the policy of diversification, which involves abandoning non-renewable resources and simultaneously replacing them with hydropower and nuclear energy. Indicators characterizing the effectiveness of energy policy include the level of use of renewable energy sources, CO_2 reduction, the level of GDP per capita, the structure of the energy balance, and the ability to independently meet energy needs.

http://dx.doi.org/10.21511/ppm.22(3).2024.01

The implementation of measures to eliminate obstacles in the development of sustainable energy is based on the use of stimulating and restrictive measures. Some scientists claim that incentive policies are less effective than regulatory policies. According to Lee et al. (2015), incentives alone will not be enough to attract users to the energy-saving policy. In addition, the voluntary nature of the incentive policy leads to a low level of awareness of these measures and the desire to use them. At the same time, the policy of mandatory regulation enforces compliance with legal requirements and is ensured with the help of industry professionals.

Economic policy has a significant impact on the effectiveness of reforms in sustainable energy development (Njegovanović, 2023; Patel et al., 2023; Didenko et al., 2021; Kuzior et al., 2021; Didenko et al., 2020; Lyeonov et al., 2021; Melnyk, 2013). Economic policy stimulates or hinders certain actions and investments aimed at the efficient use of energy, reducing its consumption and greenhouse gas emissions (Kwilinski et al., 2024; Pimonenko et al., 2022; Ziabina & Acheampong, 2023; Bozhenko et al., 2023). The introduction of energy efficiency norms not only contributes to the saving of resources but can also have economic benefits, including a decrease in energy prices (Sotnyk et al., 2021) or an increase in the country's competitiveness (Reuter et al., 2020; Malinauskaite et al., 2019; Henriques & Catarino, 2016).

Digitalization of the economy is considered an effective tool for reforming the energy sector (Tymoshenko et al., 2023; Chygryn et al., 2023; Oe & Yamaoka, 2023; Klymenko & Nehrey, 2022). In contrast, Kuzior et al. (2022a) and Kuzior et al. (2022b) argue that digitization is not the main factor in reducing greenhouse gas emissions.

The low effectiveness of energy consumption reforms is caused by a lot of barriers (Shwom & Lorenzen, 2012; Artyukhova et al., 2022; Bilan et al., 2020; Wang et al., 2023; Kyshakevych et al., 2024). Lack of financing, barriers to the adoption of energy efficiency technologies, resistance to policy and regulatory measures, limited technical capacity, and rebound effect are the main barriers on the way to increasing energy efficiency (Mushafiq et al., 2023; Zhang et al., 2022; Yang & Masron, 2022; Zhu et al., 2023; Haile & Min, 2023).

Lin et al. (2016) emphasized the need for the government to implement a policy to increase the share of renewable energy in total electricity consumption. At the same time, factors contributing to the growth of renewable energy consumption include GDP per capita and trade openness.

State economic policy instruments that promote energy efficiency include subsidies, tax incentives, and market-based mechanisms (Mushafiq et al., 2023). Moreover, in European countries, incentives and subsidies exert the greatest positive influence on the achievement of planned goals (Kaime & Glicksman, 2015).

Governments can solve energy problems by facilitating improvements in the pricing mechanism and the introduction of a mandatory soldering policy for renewable energy that is not related to hydroelectric power plants (Hu et al., 2016). At the same time, Tu and Mo (2017) concluded that mixed policy instruments for renewable energy development (carbon pricing and renewable electricity subsidies) have a better impact on achieving policy goals compared to a single policy instrument.

When determining the key components of state reforming of the energy sector, scientists emphasize that the use of tools to stimulate economic entities to switch to renewable energy sources should be fundamental (Sotnyk et al., 2022; Skrynnyk, 2023; Ziabina & Acheampong, 2023; Naseer et al., 2023).

China's current public policy toward the transition to renewable energy sources includes four instruments: general target planning, green tariffs, cost sharing, and tax preferences. However, the system of legal support for the development of the renewable energy industry in China has several shortcomings. Laws and regulations need revision, and legal guarantee mechanisms need significant improvement (Song et al., 2022). In turn, Karim et al. (2018) point to the lack of a best management model for the transition to renewable energy.

Krause (2023) argues for a holistic approach in supply chain management (SCM) and business processes, emphasizing that such an approach is crucial for a successful, efficient, and sustainable transition of industries, including the energy sector. By integrating holistic sustainability and circular economy strategies, businesses can significantly improve their resilience and adaptability to changing environmental and economic conditions. Krause's framework, which involves implementing holistic sustainability strategies, highlights the interconnectedness of different business activities and the need for comprehensive, system-wide changes to achieve long-term sustainability goals. This perspective is essential for understanding the complexities of the energy transition and ensuring that reforms are effective and sustainable in the long run.

Thus, the literature review indicates the absence of a single set of tools for state regulation of the country's energy development. Therefore, this study aims to comprehensively evaluate the effectiveness of energy reforms in the EU countries for 2010–2021. Next, it clusters these countries according to the integral indicator to identify benchmark countries whose best practices can be taken as guidelines when developing strategies and tactics for reforms. Finally, it seeks to outline a range of specific directions in which the respective country needs to make progress in carrying out energy reforms.

2. METHODOLOGY

This study evaluates the effectiveness of reforms to eliminate obstacles in the development of sustainable energy using a complex indicator. It combines ten indicators: electricity production from renewable sources (SED_1); electricity production from low-carbon sources (SED_2); renewable energy consumption (SED_3); primary energy consumption from hydropower per capita (SED_4); primary energy consumption from low-carbon sources per capita (SED_4); primary energy consumption from solar energy per capita (SED_5); primary energy consumption from wind energy per capita (SED_6); CO2 emissions (SED_7); greenhouse gas emissions (SED_8); carbon intensity of electricity (SED_9); the energy intensity level of primary energy (SED_{10}).

The object of the study is the EU countries. These countries were the first to implement reforms to achieve sustainable energy. The research period is 2000– 2021.

Considering different measurement units of the indicators, at the first stage, their normalization is carried out based on the minimax approach:

$$NSED_{i_t} = \begin{cases} \dfrac{\dfrac{SED_{i_t}}{SED_{i_{\max}}} - \dfrac{SED_{i_{\min}}}{SED_{it}}}{SED_{i_{\max}} - SED_{i_{\min}}}, \\ 1, \left[\begin{array}{l} SED_{i_t} \geq \overline{SED}_{i_{\max}} \\ SED_{i_t} \leq \overline{SED}_{i_{\min}} \end{array} \right. \end{cases} \quad (1)$$

where $NSEDi_t$ is the normalized i-th indicator in the year t; $SEDi_t$ is the current value of the i-th indicator in the year t; $\overline{SED}i_{max}$ is the maximum value of the i-th indicator; $\overline{SED}i_{min}$ is the minimum regulatory value of the i-th indicator; $SEDi_{min}$ is the minimum value of the i-th indicator; $SEDi_{max}$ is the maximum value of the i-th indicator.

The general indicator of the effectiveness of reforms to eliminate obstacles in the development of sustainable energy is determined based on a linear mathematical model:

$$SED = \sum_{i=1}^{n} w_i \cdot NSED_{i_t}, \quad (2)$$

where w_i is a weighting coefficient of i-indicator of effectiveness of reforms to eliminate obstacles in the development of sustainable energy.

Weighting coefficients for variables are determined using the Fishburn formula:

$$w_i = \frac{2 \cdot (n - i + 1)}{n \cdot (n + 1)}, \quad (3)$$

where n is the total nur of indicators in the calculation of $NSED$; i is the rank of an indicator.

The rank of an indicator is determined based on the cluster analysis and expert assessment.

To evaluate the effectiveness of reforms according to (2), it is necessary to establish the priority of each indicator and determine the value of the weighting coefficients. Among the ten indicators that determine the effectiveness of reforms, it is possible to single out groups of indicators that characterize the same component of sustainable energy development. In the evaluation process,

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the same priority is determined for these indicators. These are pairs SED_1 – SED_2 (electricity production from renewable sources and electricity production from renewable sources), SED4 – SED_5 – SED_6 (primary energy consumption from hydropower per capita; primary energy consumption from solar energy per capita; primary energy consumption from wind energy per capita), and SED_9 – SED_{10} (carbon intensity of electricity; the energy intensity level of primary energy).

3. RESULTS AND DISCUSSION

Among the analyzed indicators, CO2 emissions have the highest priority since the reduction of this indicator is the target of most international and national directives and strategies. The second priority is renewable energy consumption, as it reflects the result of the state's policy regarding the transition to renewable energy sources. The third priority includes indicators that reflect the country's transition to electricity production from those sources that have a minor impact on the environment (electricity production from renewable sources and electricity production from low-carbon sources). The group of indicators SED_4 – SED_6 has the fourth priority and characterizes the amount of energy consumption from individual renewable sources. In the last place there is a pair of indicators SED_9 – SED_{10}, characterizing the intensity of energy.

The same priority is set for those indicators that characterize the same component of development of sustainable energy. The rank of indicators is determined as the average value of their rank positions, subject to different priorities. Table 1 shows the results of determining the weighting factors, priorities, and ranks of the analyzed indicators.

Table 1. Weighting coefficients for the assessment of the effectiveness of reforms to eliminate obstacles in the development of sustainable energy

Variables	Priority	Rank, *i*	w_i
SED_1	3	3.5	0.1364
SED_2	3	3.5	0.1364
SED_3	2	2	0.1636
SED_4	4	6	0.0909
SED_5	4	6	0.0909
SED_6	4	6	0.0909
SED_7	1	1	0.1818
SED_8	5	8	0.0545
SED_9	6	9.5	0.0273
SED_{10}	6	9.5	0.0273

These calculations help assess the effectiveness of reforms to eliminate obstacles in the development of sustainable energy. Figure 1 shows the values of the reform efficiency indicator. Thus, it is possible to distinguish four clusters of countries. Cluster 1 (blue) includes countries with a reform efficiency level of more than 0.6. Cluster 2 (green) unites countries with an efficiency level between 0.5 and

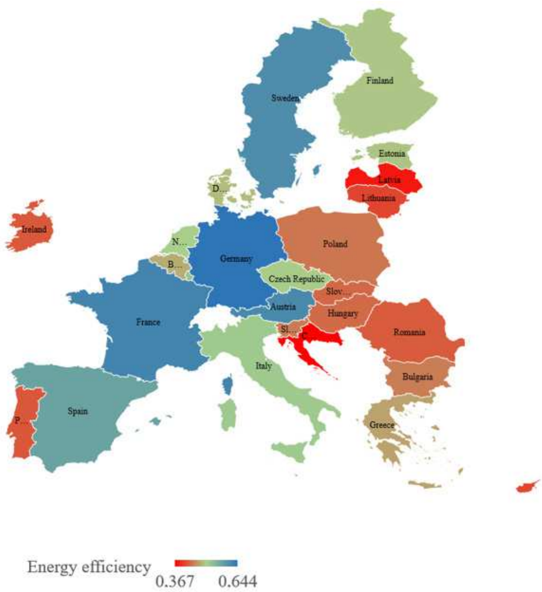

Figure 1. Cluster distribution

Table 2. Clusters of countries according to the reform effectiveness rank

Cluster 1: 0.525-0.612	Cluster 2: 0.474-0.517	Cluster 3: 0.425-0.466	Cluster 4: 0.367-0.415
Austria – 0.612	Italy – 0.515	Bulgaria – 0.451	Cyprus – 0.415
Germany – 0.644	The Netherlands – 0.505	Slovenia – 0.450	Lithuania – 0.413
France – 0.620	Czech Republic – 0.502	Poland – 0.446	Malta – 0.397
Sweden – 0.607	Finland – 0.499	Hungary – 0.439	Latvia – 0.383
Spain – 0.575	Estonia – 0.497	Slovak Republic – 0.436	Croatia – 0.367
Luxembourg – 0.525	Denmark – 0.492	Romania – 0.428	
	Belgium – 0.482	Ireland – 0.427	
	Greece -0.474	Portugal – 0.425	

0.6. Countries with a value of the complex indicator from 0.42 to 0.5 can be classified into the third cluster (orange). The fourth cluster (red) unites countries with a value of the reform effectiveness indicator below 0.42.

The dispersion analysis confirmed the feasibility of dividing the countries into four clusters (Table 2). Six countries are assigned to the first (0.525-0.612) and fourth (0.367-0.415) clusters, and eight countries are assigned to the second (0.474-0.517) and third (0.425-0.466) clusters. The leaders in terms of reform effectiveness are the countries of the first cluster: Austria – 0.612; Germany – 0.644; France – 0.620; Sweden – 0.607; Spain – 0.575; and Luxembourg – 0.525. The countries of the fourth cluster have the lowest values of the complex indicators: Cyprus – 0.415; Lithuania – 0.413; Malta – 0.397; Latvia – 0.383; Ukraine – 0.369; and Croatia – 0.369.

Based on the k-means clustering method, four clusters of countries of the same size, balanced by the number of cases, were formed. The division of countries into a larger and smaller number of clusters is impractical due to the significant unevenness of the distribution of countries between clusters and the incomplete reflection of differences in the implementation of reforms to eliminate obstacles in the development of sustainable energy. Figure 2 shows the mean for the variables in each of the clusters.

The comparison of the average values of the indicators for each cluster showed significant gaps in the values for almost each of the analyzed indicators. SED3 and SED4 have similar values within each of the selected clusters. Thus, it can be concluded that these indicators may not be considered when grouping countries.

Figure 2. Plot of means for each cluster

http://dx.doi.org/10.21511/ppm.22(3).2024.01

Table 3. Cluster means

Variables	Cluster 1	Cluster 2	Cluster 3	Cluster 4
SED_1	0.937523	0.451046	0.599042	0.449743
SED_2	0.756609	0.423442	0.528556	0.444275
SED_3	0.515629	0.491180	0.870500	0.535611
SED_4	0.515629	0.491180	0.870500	0.535611
SED_5	0.975255	0.726221	0.591855	0.539185
SED_6	0.774297	0.604682	0.643846	0.544564
SED_7	0.380475	0.523299	0.285003	0.320118
SED_8	0.449944	0.648601	0.310361	0.352295
SED_9	0.433502	0.491698	0.289465	0.282072
SED_{10}	0.304115	0.353049	0.313281	0.442112

According to the rest of the indicators, the clusters have significant differences. The first cluster has high values of the SED_1 and SED_5 indicators, while the SED_{10} indicator is the lowest. The second cluster shows the lowest values of SED_1-SED_4 and the highest values of SED_7-SED_9. Cluster 3 is characterized by the highest value of SED_3-SED_4 and the lowest value of SED_7-SED_{10}. The fourth cluster includes countries with sufficiently low values of all analyzed indicators.

Table 3 shows average values of the analyzed indicators for each of the selected clusters. Clusters 1, 2, and 4 are characterized by a significant range of indicator values. Thus, for cluster 1, the average values of the indicators vary from 0.3 (SED_{10}) to 0.975 (SED_5). Only for cluster 3, the fluctuations of indicator values are the smallest (from 0.35 to 0.73).

The two-way joining results presented in Figure 3 prove that for most of the analyzed countries, the values of the indicators are at the average level. SED_5, SED_3, and SED_4 are characterized by the highest values, while the value of the SED_7, SED_9, and SED_{10} indicators for most of the analyzed countries does not exceed 0.3.

The obtained results differ from the results of previous studies both in terms of research methodology and the volume of the data set used.

Thus, in contrast to Juarez-Rojas et al. (2023), who evaluated renewable energy policies in 20 countries

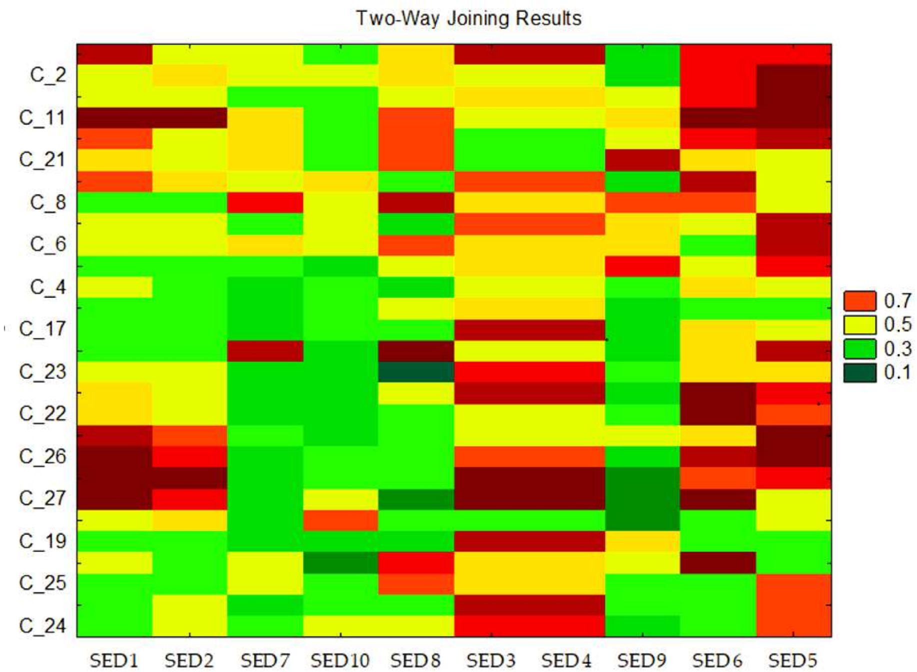

Figure 3. Two-Way joining results

(Liechtenstein, Norway, Sweden, Iceland, Uruguay, Denmark, Niue, Tajikistan, Portugal, Costa Rica, USA, China, Japan, Germany, Great Britain, India, France, Italy, Canada, and Russia), this study considered indicators of the development of renewable and non-renewable energy sources. In addition, Juarez-Rojas et al. (2023) were limited to the relationship of renewable energy policy with the development of green entrepreneurship, while this current paper considers the relationship of energy policy with different actors of the economy.

The results of this study differ from the results by Ortiz and Vítor (2020). They analyzed policy evaluation practices regarding public policies on energy. The authors proposed a set of indicators characterizing the state energy policy in terms of the following components: affordability, accessibility, economic competitiveness, environmental impacts, equity, health, governance effectiveness, and efficacy. At the same time, this study quantitatively assessed energy reforms to identify problematic aspects and the most priority ways of improvement.

Alyamani et al. (2026) used multi-perspective modeling and a simulation approach to evaluate the state of Florida's renewable energy policy from the perspectives of various stakeholders (customers, utilities, environmental agencies, and public service commissions). In contrast, this study provides a more comprehensive understanding of the reforms' effectiveness in the field of energy, using the example of a much larger number of countries (EU countries).

Nikolaev and Konidari (2017) determined the most priority directions for reforming Bulgaria's policy on renewable energy by analyzing the national framework. In comparison, this study offers an approach to improving the country's energy policy, taking into account the cluster in which it is located. This approach can be applied to any country as it is based on more comprehensive indicators rather than national frameworks.

CONCLUSION

This study is devoted to the integral assessment of reforms in the field of energy in the EU countries for 2010–2021. It clustered these countries according to the integral indicator and determined priority directions in which the respective country needs to achieve progress. Based on the linear mathematical model, a comprehensive indicator of the effectiveness of energy reforms was calculated. The results show the insufficient level of effectiveness of reforms in the field of energy development. For most EU countries, the level of efficiency indicates the expediency of reviewing the existing instruments of energy market reform and the need to apply influence measures that are close to the realities of the development of their energy sector. Based on dispersion analysis, four clusters of countries were distinguished.

This study identifies the characteristic features of reforms to remove obstacles to the development of sustainable energy for each cluster and to determine tools for increasing their efficiency (by moving from one cluster to another). The countries of the first cluster should focus their efforts on scaling up the production of renewable energy sources, increasing the level and efficiency of their development and integrated use in most sectors of the economy. For the second cluster, the priority tasks should be to ensure a high level of electricity production from renewable sources and primary energy consumption from solar energy. The countries of the third cluster should focus their attention on the growth of primary energy consumption from low-carbon sources and renewable energy sources. For the countries of the fourth cluster (Cyprus, Lithuania, Malta, Latvia, and Croatia), the development of hydropower should be the priority.

Thus, the conducted analysis allowed for determining the most priority components of energy policy from the point of view of state influence within each of the selected clusters. This will bring the country's policy closer to the realities of the energy sector, align them with the declared goals, and increase the speed and efficiency of its implementation.

http://dx.doi.org/10.21511/ppm.22(3).2024.01

FURTHER PERSPECTIVES

One of the critical elements in achieving sustainable energy transitions is the active engagement of all relevant stakeholders. Policymakers must collaborate closely with the private sector, civil society, and international organizations to create an inclusive framework that supports innovation and sustainable practices. Effective stakeholder engagement can lead to more robust policies that reflect the diverse interests and needs of society, ensuring broad support and successful implementation.

Considering the diverse economic, social, and technological statuses of countries is essential when formulating energy policies. High-income countries may focus on technological innovations and stringent regulatory measures to reduce greenhouse gas emissions, whereas lower-income countries might prioritize access to affordable and reliable energy to support economic development and poverty alleviation. Tailoring energy reforms to the specific context of each country can enhance the effectiveness and sustainability of these initiatives.

Energy policies must also address social aspects, ensuring that transitions to sustainable energy sources do not exacerbate inequalities or create social unrest. Equitable access to energy, job creation in the renewable energy sector, and support for communities affected by the transition from fossil fuels to renewable energy sources are vital components of a socially inclusive energy policy. Policies should be designed to protect vulnerable populations and promote social cohesion.

Investment in research and development (R&D) and the promotion of technological innovation are critical for advancing sustainable energy solutions. Governments and private sector entities should collaborate to foster technological advancements in renewable energy, energy storage, and energy efficiency. Policies that incentivize R&D, such as grants, tax credits, and public-private partnerships, can accelerate the development and deployment of cutting-edge technologies.

Effective financial mechanisms are necessary to support the transition to sustainable energy. These can include subsidies for renewable energy projects, carbon pricing to discourage the use of fossil fuels, and green bonds to attract investment in sustainable infrastructure. International financial institutions and development banks can play a significant role in providing the necessary funding and financial expertise to support energy transitions in developing countries.

Raising public awareness about the importance of sustainable energy and educating citizens about energy-saving practices are essential for the long-term success of energy reforms. Educational programs and public awareness campaigns can help build a culture of sustainability and encourage behavioral changes that reduce energy consumption and support the adoption of renewable energy technologies.

In conclusion, a holistic approach to tackling energy problems requires the integration of environmental, economic, and social dimensions, active engagement of all stakeholders, and the consideration of the specific contexts of different countries. By adopting such an approach, it is possible to create energy policies and reforms that are not only effective but also equitable and sustainable, benefiting people and the planet alike.

AUTHOR CONTRIBUTIONS

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ACKNOWLEDGMENT

The research was funded by a Fellowship agreement for a research fellowship in the framework of the 11th funding round within the Philipp Schwartz Initiative of the Alexander von Humboldt Foundation.

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