Research article

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The External Environment's Influence on RES Development Intensity

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Abstract

The increasing energy consumption associated with scientific and technological progress has led to environmental concerns. The transition to renewable energy sources is a potential solution to mitigate the negative effects of energy consumption. This study's objective is to determine the factors influencing the presence of renewable energy in countries' energy systems and to describe the pattern of their influence. The validated regression model has a high coefficient of determination of 0.9034, indicating the model's reliability in identifying factors influencing the presence of renewable energy in energy systems. The countries were divided into three groups based on their renewable energy usage level using cluster analysis, indicating the importance of the current usage for further development. The study found that the Human Development Index (HDI) is correlated negatively with the share of renewable energy in energy systems. An increase in the innovation index leads to the development of renewable energy. This study allows for an in-depth analysis of the individual countries in the sample and provides meaningful insights into the current state of renewable energy globally. Overall, this research helps to understand the factors influencing renewable energy usage, and the findings can be used to inform policy decisions regarding renewable energy development.

Keywords: renewable energy, regression, cluster analysis, human development index, innovation

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Влияние Внешней Среды на Интенсивность Развития ВИЭ

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Аннотация

Увеличение потребления энергии, связанное с научно-техническим прогрессом, привело к экологическим проблемам. Переход на возобновляемые источники энергии является потенциальным решением для смягчения негативных последствий энергопотребления. Целью данного исследования является определение факторов, влияющих на присутствие возобновляемых источников энергии в энергосистемах стран, и описание характера их влияния. Валидированная регрессионная модель имеет высокий коэффициент детерминации 0,9034, что указывает на надежность модели при выявлении факторов, влияющих на наличие возобновляемых источников энергии в энергосистемах. Страны были разделены на три группы в зависимости от уровня использования возобновляемых источников энергии с использованием кластерного анализа, что указывает на важность текущего использования для дальнейшего развития. Исследование показало, что индекс человеческого развития (ИЧР) отрицательно коррелирует с долей возобновляемой энергии в энергосистемах. Увеличение индекса инноваций приводит к развитию возобновляемой энергетики. Это исследование позволяет провести углубленный анализ отдельных стран в выборке и дает значимое представление о текущем состоянии возобновляемой энергетики в мире. В целом, это исследование помогает понять факторы, влияющие на использование возобновляемых источников энергии, а результаты могут быть использованы для принятия политических решений относительно развития возобновляемых источников энергии.

Ключевые слова: возобновляемая энергетика, регрессия, кластерный анализ, индекс человеческого развития, инновации

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1. Introduction

Humanity's existence is dependent on energy production. Of great interest in the field of energy economics is the relationship between energy use and sustainable development (Khan et al., 2020; Nathaniel et al., 2021; Nawaz et al., 2020). Unfortunately, the increase in energy consumption, led by non-renewable energy sources, has negative environmental impacts (Lv et al., 2021; Wang, 2022). Risks associated with environmental degradation and climate change can in turn affect various aspects of the global economy (Wheeler and Von Braun, 2013; Ye, 2022).

Increasing the share of renewable energy in energy consumption can slow down the negative effects of climate change on the economy (Anwar et al., 2021; Gozgor, 2020). Countries are attempting in various ways, not always successfully (Aguirre and Ibikunle, 2014), to promote RES through policies (Omri and Nguyen, 2014; Shang et al., 2022), financial regulations (Li et al., 2022; Wang and Zhao, 2022) and tax systems (Fang et al., 2022). Despite the impact of the pandemic and rising global commodity prices, the world once again set a record for renewable energy capacity growth in 2021[1].

At the 2021 UN Conference of the Parties serving as the meeting of the Parties to the Paris Agreement, 200 countries signed the Framework Convention calling for accelerating the transition to renewable energy sources and reducing CO_2 emissions by developing more effective strategies in 2022.[2] By the end of 2021, a record number of countries had set zero-emission targets.

The REN21 2022 Global Status Report argues that transitioning from fossil fuels to an energy-efficient economy based on renewable energy sources is a step towards a more affordable, secure and sustainable future[2]. Meanwhile, renewable energy production is highly dispersed across countries, as shown in Figure 1.

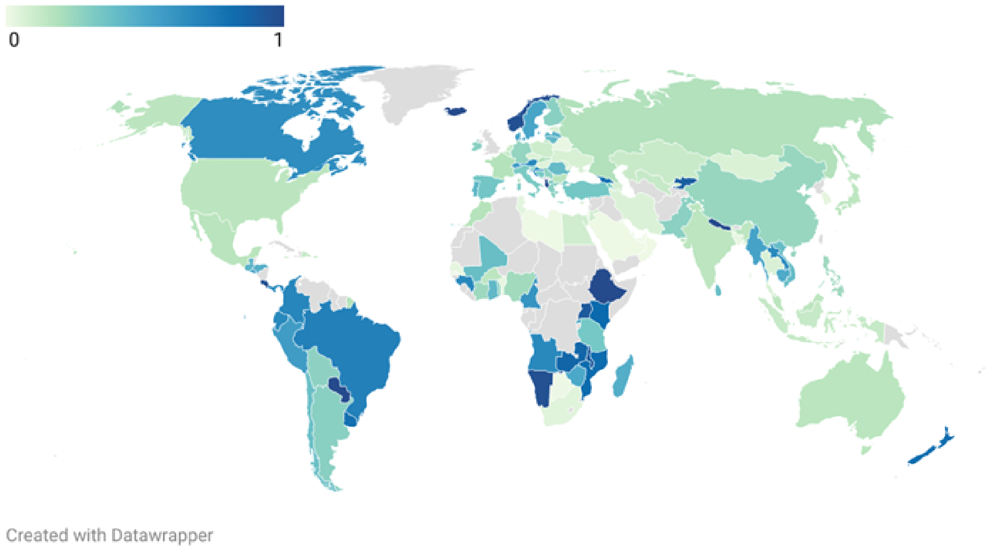

Figure 1. Share of renewable energy, distribution by country.

It is necessary to examine the factors influencing the share of renewable energy in total energy production to understand the trends in renewable energy development. Adjustments were made to the current renewable energy agenda in 2022. In 2014, research showed that respondents were more concerned with environmental threats (rather than security issues) (Sadorsky, 2009), while energy security for fossil fuel-importing countries is now at the top of the list of reasons for promoting renewables[3].

The environmental reasons have not been pressed enough so far. The COP26 convention, the record for zero emissions targets and the record for renewable energy capacity growth in 2021 coexist in the same reality as the record for carbon dioxide (CO2) emissions[3] also set in 2021. Thus, support for

1 Renewables 2022 Global Status Report. URL: https://www.ren21.net/gsr-2022/; Accessed 5 December 2022.
2 Conference of the Parties serving as the meeting of the Parties to the Paris Agreement (2021). URL: https://unfccc.int/sites/default/files/resource/cma2021_L16E.pdf. Accessed 5 December 2022.
3 Renewables 2022 Global Status Report. URL: https://www.ren21.net/gsr-2022/; Accessed 5 December 2022.

renewable energy policies has not been met with the appropriate policies.

Thus, the purpose of this study is to determine the factors affecting the presence of renewable energy in the energy systems of the countries investigated and to describe their influence. This study is significant in its attempt to understand the current state of renewable energy in the world, and it raises questions that could serve as topics for further research.

As energy consumption plays an important role in the existence and development of mankind (Adedoyin et al., 2017), the study of the impact of energy consumption on the economy, progress and ecology occupies a wide niche in the scientific environment (Nawaz et al. 2020; Waheed et al. 2019; Xue et al. 2021). Modern trends make adjustments in the main vectors of such works. More often now the impact of energy consumption is divided (Vo and Vo, 2022), and the impact of traditional (Hussain, et al., 2021) and renewable energy sources (Ehigiamusoe and Dogan, 2022) are considered separately due to the different nature of the impact of these types of energy, for example, EROI (Weißbach, et al., 2013) or the impact on carbon productivity (Adebay, 2022). In addition, the evolution of the energy balance in general (Adams et al., 2018; Shrestha et al., 2022) and the rate of RES adoption (Salim and Rafiq, 2012) are also of interest.

Today's renewable energy sources include[4] hydropower, wind energy, solar energy, geothermal energy, bioenergy and tidal energy; the first three are the most common.

Hydropower can be considered using Russia as an example. At the end of 2020, Russia ranked 5th in the world in terms of energy production by hydropower capacity[4]. Two of the 195 Russian HEPs[5]—Sayano-Shushenskaya and Krasnoyarskaya—are among the 10 largest HEPs in the world; it is the most powerful balancing instrument in Russia's unified energy system and comprises 4.04%[6] of Russian electricity production, with HEP in total covering 20%[7]. At the same time, total RES (HEP excluded) in Russia during 2020 generated 2.194 TWh[4], which is only 0.21% of the produced energy in the country.

Pioneers in RES penetration are Brazil, Canada, Italy, Germany, France and Turkey[6].

The level of renewable energy development for countries is not a definable parameter. It is of interest to researchers as a factor influencing various variables and as a control variable whose influence on factors should be studied.

Considering renewable energy as an influencing factor, the body of research can be divided into groups of studied variables—those related to ecology and those related to economic growth.

CO_2 emissions are often used as an indicator to illustrate the state of the environment. Most researchers agree that the use of renewable energy sources significantly helps to reduce CO_2 emissions and protect the environment (Abbasi et al., 2021; Adebayo et al., 2022; Adebay, 2022; Balcilar et al., 2020; Wang et al., 2022).

Research on the impact of renewable energy on economic growth is less clear (Wang et al., 2022). An analysis of the impact of renewable energy consumption on economic growth using data from OECD countries for the period 1990–2010 found that for every one percentage point increase in renewable energy consumption, the economy grows by 0.105% (Inglesi-Lotz, 2016). In contrast, consuming renewable energy in 27 EU countries has hurt economic growth, explaining the reasons for Europe's poor performance in terms of climate impact (Sharma et al., 2021). Studies on the performance of emerging economies from 1992–2014 found no significant effect of renewable energy consumption on economic growth (Bayar, Y., Gavriletea, M. D., 2019). The above results show that renewable energy consumption can limit the growth of carbon emissions, but the impact of renewable energy consumption on economic growth is inconclusive (Wang et al., 2022).

The reasons for this inconsistency in the relationship between renewable energy consumption and

4 Renewables 2021. Global status report, REN21. URL: https://www.ren21.net/wp-content/uploads/2019/05/GSR2021_Full_Report.pdf. Accessed 1 December 2022.
5 Annual report on the activities of the "NP Market Council" association '20. URL: https://www.np-sr.ru/sites/default/files/1_go_itog.pdf. Accessed 1 December 2022.
6 RusHydro http://www.rushydro.ru. Accessed 1 December 2022.
7 Russian energy 'NP Market Council' association. https://www.np-sr.ru/ru/market/cominfo/rus/index.htm. Accessed 1 December 2022.

economic development have also been highlighted in the scientific literature. Some researchers attribute the divergent effects to the existence of a threshold for renewable energy consumption. When renewable energy production and consumption are below the threshold, renewable energy consumption is of little importance for economic development. Renewable energy indicators above the threshold will positively affect economic growth (Ozcan and Ozturk, 2019; Samoilova, 2022). There are also assumptions about the relationship between the impact of renewable energy on the economy and the degree of the country's dependence on non-renewable energy sources. If the country's non-renewable energy contributes most to economic growth, if it is available and relevant, the relationship between economic development and renewable energy will be weak (Dogan, E., Altinoz, B., Cohen, Y., Taskin, D., 2020).

In identifying the factors influencing renewable energy as a target variable, researchers operate on a broader spectrum, affecting the indicators characterising all the major spheres of society. The groups of factors can be summarised along the following broad lines: economic, environmental, social, political and technological.

Among economic indicators, GDP growth rate and GDP per capita are most often considered; in the economic models of the International Energy Agency, GDP growth rate is the main factor of energy demand. CO_2 emissions (which belong to the group of environmental indicators) are often included in the studied model due to their close relationship with GDP and the economy. Studies of renewable energy consumption in the G7 (Sadorsky, 2009) and E7 (Wang et al., 2022) countries have shown that, in the long run, the increase in real GDP per capita and carbon dioxide emissions per capita are the main factors determining the per capita consumption of renewable energy sources. A study of six major emerging economies—namely Brazil, China, India, Indonesia, the Philippines and Turkey, which are actively accelerating the transition to renewable energy—found similar results: a 1% increase in GDP leads to a 1.228% increase in renewable energy consumption, while a 1% increase in pollutant emissions leads to a 0.033% increase in renewable energy consumption (Salim and Rafiq, 2012). In contrast, a study of EU countries found that increases in CO_2 emissions constrain the development of renewable energy (Marques et al., 2010). Using data separately for the US, economic growth is ineffective in stimulating renewable energy (Shang et al., 2022).

At the intersection of economic and social variables, the level of income is considered an influencing factor; in different samples of countries, its positive impact on RES was found (Marques et al., 2010; Omri et al., 2014; Rodionov et al, 2022; Sadorsky, 2009; Shrestha et al., 2022).

Another economic factor with a political and social dimension is economic openness. Trade openness hurts the development of renewable energy in ASEAN countries, whereas foreign direct investment positively affects it (Huang et al., 2022).

The interest in energy security (i.e., energy independence) resonates with the openness of the economy in terms of the breadth of connections in the factor fields. The energy security indicator is significant for developing renewable energy in EU countries (Marques et al., 2010). Global sample analysis (Omri et al., 2014) shows no impact of energy security problems on renewable energy; on the contrary, it emphasises the importance of public interest in environmental protection. In the example of ASEAN countries, environmental degradation causes the reduction of renewable energy (Huang et al., 2022).

A study of the effect of flexibility in policy priorities on the rate of renewable energy deployment in the EU finds a threshold effect for greenhouse gas emissions, suggesting that public awareness of climate change can only positively affect renewable energy up to a certain level (Oosthuizen and Inglesi-Lotz, 2022). Nevertheless, public opinion as a factor—in one interpretation or another—is given serious attention. A social study conducted in Vietnam shows that respondents concerned about air quality and utility profitability support increases in energy tariffs in case of transition to RES, which can lead to renewable energy development (Yu et al., 2022).

A study of renewable energy impact indicators in the US found that social interests play a primary role in state adoption of clean electricity policies. Population characteristics—as reflected in levels of participation in environmental advocacy groups, income levels and education levels— appear to be determinants of state clean power policies (Vachon and Menz, 2006). A study of the 53 most hydropower-consuming countries also found that human capital has a stronger significant impact on renewable energy than on non-renewable energy consumption (Ponce et al., 2020).

The influence of the political environment stands out as a factor. Uncertainty about climate policy has a positive effect on the use of renewable energy but only marginally, suggesting that any climate change mitigation policy in the US does not encourage people to use clean energy (Rodionov et al., 2022; Shang et al., 2022). Some government policies discourage developing renewable energy (Aguirre and Ibikunle, 2014), which may indicate poor management or competent political lobbying by traditional non-renewable energy industries (Omri and Nguyen, 2014). In the case of EU countries, lobbying for non-renewable energy industries also hinders introducing renewable energy (Marques et al., 2010).

An attempt has been made to assess the relationship between US public policies promoting and developing renewable energy. The results are ambiguous: no relationships were found. In several states promoting renewable energy policies, there is some progress. One of the most promising ideas is that green energy policies should control the share, volume and growth of renewable energy in the state's energy system and the amount of non-green energy purchased from neighbouring states (Carley, 2009).

Political factors are also used to cluster countries. For example, the influence of democratic institutions on the development of renewable energy has been studied; in countries with a higher level of democracy, the development of RES is positively influenced by economic growth, while rising oil prices and increased trade openness in renewable energy are neutral factors. In less democratic countries, economic growth hurts the development of RES, and this influence is exacerbated by the negative impact of increasing economic openness and rising oil prices (Chen et al., 2021; Rodionov et al., 2021).

An empirical analysis of the influence of political factors on using renewable energy in the EU has shown that lobbying in the manufacturing industry hinders the development of renewable energy, standard indicators of governance quality have a positive effect, and left-wing parties have a more positive effect on renewable energy than right-wing parties (Cadoret and Padovano, 2016).

Studies have paid particular attention to normative regulation. For example, China is now actively developing a system of green finance. Introducing green finance positively affects the volume of investment in renewable energy. At the same time, indirectly, developing green finance hurts non-green finance, which implicitly creates a secondary negative effect of green financial instruments on renewable energy (Wang and Zhao, 2022). However, the study of the impact of financial inclusion on green finance confirms the relationship but defines it asymmetrically and heterogeneously (Sadorsky, 2009). In the Belt and Road Initiative countries, a 1% increase in the green tax would lead to a 1.201% increase in renewable energy consumption (but the effect is non-linear) (Fang et al., 2022).

A study of technology's impact on renewable energy growth through economic development showed that high-tech exports and GDP determine renewable energy production in developed countries; however, high-tech exports are not statistically significant in explaining the use of energy sources in developing countries. GDP and CO2 emissions are the main drivers of RES production in developing countries (Bamati and Raoofi, 2020). A higher degree of economic globalisation also contributes to the demand for renewable energy in developed countries (Gozgor et al., 2020; Rodionov et al., 2022).

In one way or another, clustering is becoming one of the main techniques for dealing with global samples of renewable energy data. The heterogeneity between countries in the stages of the implementation process and the role of renewable energy in influencing economic growth is confirmed by research (Shahbaz et al., 2020). Studies have examined the influence of using renewable energy on its further expansion. In the groups of countries with similar indicators of the level of development of renewable energy, there are no significant differences in the rate of further development; however, the difference in the rates increases significantly when comparing countries belonging to the groups with different levels of renewable energy expansion (Li et al., 2022).

Thus, in the studied theoretical array, the following variables can influence RES: GDP, CO_2 emissions, income level, economic growth, trade openness, energy security, environmental protection, political uncertainty, lobbying of traditional energy sources, democratic institutions, globalisation, green finance, financial accessibility and technological development.

2. Materials and Methods

The following indicators are used for the research. The HDI[8] based on three indicators (GDP at PPP, life expectancy and literacy rate) will serve as a composite reflection of the social environment in the model.

Two indicators are used to reflect technological development: the global innovation index[9] and the index of development of information and communication technologies (ICT)[10]. The first is more detailed and informative; the second contains fewer variables. It is assumed that both indices will be included as factors in the model, even though they partially overlap, and the most significant one will be used on the optimized equation.

It is also assumed that the share of non-renewable energy sources in the world reserves[11] by country is a significant indicator of the development of RES, partly explaining the energy dependence/independence of the country and the prospects of its energy efficiency and economic growth.

To understand the information environment, which is an important factor in describing the state of society today, we will use Google Trends data[12], the presence of RES topics in internet queries (as a factor of interest) and the presence of RES topics in the news (as a factor of coverage).

For the control values, despite their presence in the HDI, we will use GDP per capita[13] to test the hypothesis of the non-influence of other GDP factors.

The actual indicator reflecting the presence of RES is an index obtained by weighing the amount of electricity produced from renewable sources against the total amount of energy produced.

The resulting equation (1) contains 7 variables (x_i):

$$y = c + a \times x_1 + a \times x_2 + a \times x_3 + a \times x_4 + a \times x_5 + a \times x_6 + a \times x_7 \quad (1)$$

Table 1 summarises the data on the indicators.

Table 1. A summary array of indicators

Indicator	Designation	Source
RES	y	EES EAEC. World Energy (Electronic resource)[14]
Share in world reserves of traditional energy sources	x_1	EES EAEC. World Energy (Electronic resource)[14]
HDI	x_2	HDI (Electronic resource)[15]
GDP per capita, $	x_3	Rating of countries by GDP (Electronic resource)[16]

8 HDI. URL: https://nonews.co/directory/lists/countries/index-human. Accessed 8 November 2022.
9 Global Innovation Index. URL: https://nonews.co/directory/lists/countries/global-innovation-index. Accessed 17 November 2022.
10 GtMarket ICT Development Index. URL: https://gtmarket.ru/ratings/ict-development-index/. Accessed 10 December 2022.
11 EES EAEC. World energy industry. URL: https://www.eeseaec.org/ees-еаес-мировая-энергетика. Accessed 8 November 2022.
12 Google Trends. URL: https://trends.google.ru/trends/?geo=RU. Accessed 17 November 2022.
13 GDP ranking. URL: https://nonews.co/directory/lists/countries/gdp. Accessed 17 November 2022.
14 EES EAEC. World energy industry. URL: https://www.eeseaec.org/ees-еаес-мировая-энергетика. Accessed 8 November 2022.
15 Human Development Index (HD). URL: https://nonews.co/directory/lists/countries/index-human. Accessed 8 November 2022.
16 GDP ranking. URL: https://nonews.co/directory/lists/countries/gdp. Accessed 17 November 2022.

ICT Development Index	x_4	Information and Communication Technology Development Index—Humanitarian Portal (Electronic resource)[17]
Global Innovation Index	x_5	Rating of countries on the level of innovation (Electronic resource)[14]
Presence in the news	x_6	Google Trends (Electronic resource)[18]
Presence in Google search	x_7	Google Trends (Electronic resource)[18]

Hypothetically, the share of traditional energy sources in the world's reserves would have a negative impact because the higher the share, the more energy secure and energy efficient the country is.

HDI would have a negative impact because as people's quality of life increases, their energy costs increase, which can be offset more cheaply with non-renewable energy sources.

GDP would have a positive impact, as investment in RES is directly related to the availability of money in the economy.

ICT/GI would have a positive impact on renewable energy, as technological progress contributes to the improvement and reduction of the price of the equipment necessary for the introduction and development of renewable energy.

Interest would also have a positive influence, based on the analysis of the theoretical basis, as public opinion is statistically significant for RES development.

Coverage, potentially reducing interest, would in turn have a negative effect.

Figure 2 shows a working conceptual model. It assumes the influence of 7 variables on the indicator reflecting the phenomenon under study—electricity production by RES, weighted by total electricity production.

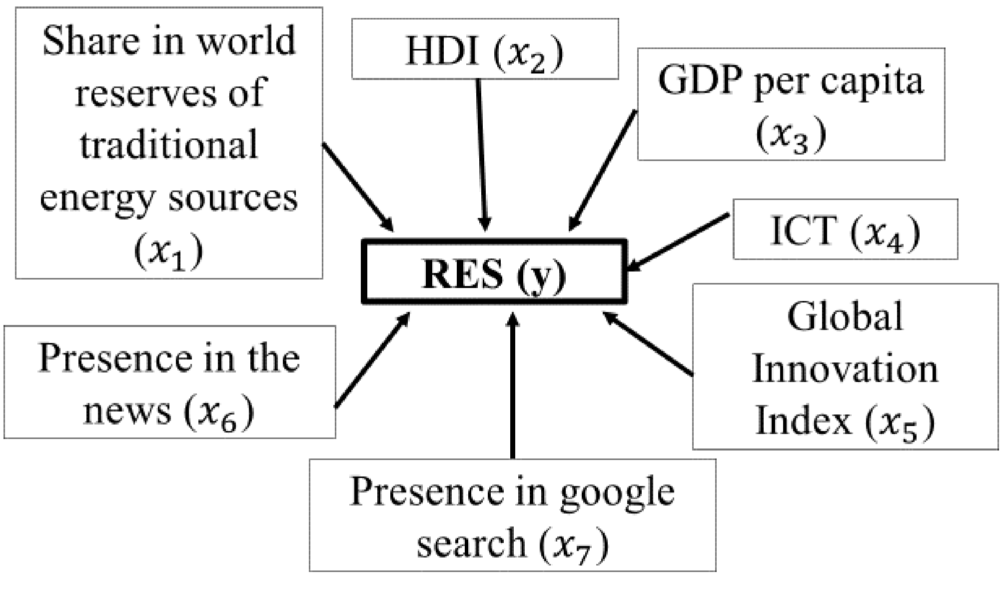

Figure 2. Hypothetical conceptual model

The model was tested for the absence of linear relationships. We then tried to build a significant re-

17 ICT Index – Humanitarian portal. URL: https://gtmarket.ru/ratings/ict-development-index. Accessed 17 November 2022.
18 Google Trends. URL: https://trends.google.ru/trends/?geo=RU. Accessed 17 November 2022.

gression model (in the framework of this study p<0.3 and R>0.6). An equation meeting our requirements was not obtained at the initial stage with the initial sample.

We then divided the data set into clusters, sequentially—by the share of resources, HDI and ICT. The clusters considered did not significantly improve the model.

The research is limited to a sample of 179 countries.

3. Results

Initial analysis of the data did not yield meaningful results. As a result, we therefore used KNIME cluster analysis methods. The sample was divided by RES(y) into three correlated clusters. Figure 3 shows a world map with the resulting distribution of countries by cluster.

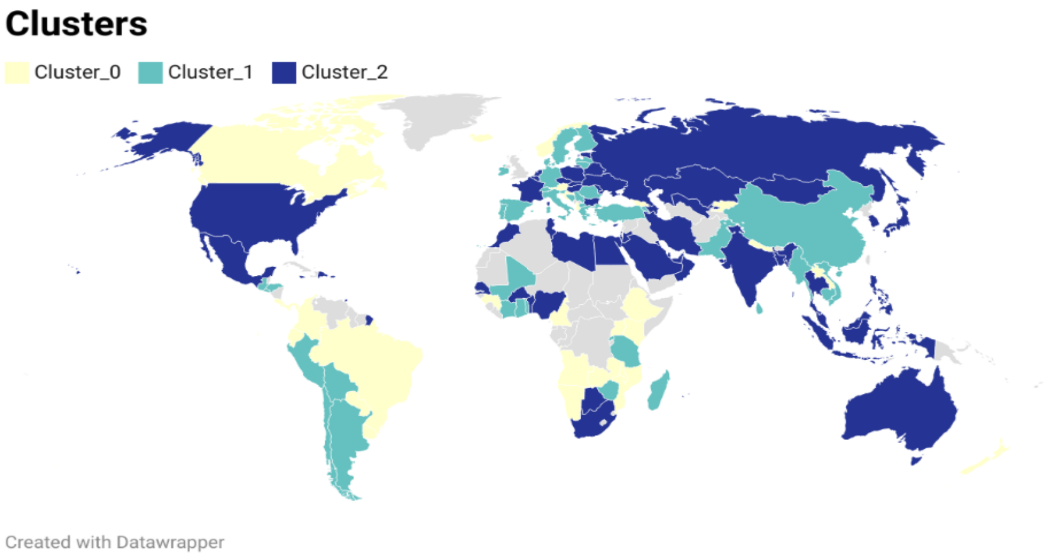

Figure 3. Country cluster distribution

The zero cluster included the countries with the highest indicators of RES; the first cluster included the average values, and the second cluster included the lowest.

The following equations were obtained for clusters 0, 1 and 2, respectively:

$$y_0 = 0,8868 - 0,2306x_2 + 0,0024x_5 + 2,51\times10^{-5}x_7 \quad (2)$$

$$y_1 = 0,4466 - 0,2306x_2 + 0,0024x_5 + 2,51\times10^{-5}x_7 \quad (3)$$

$$y_2 = 0,1607 - 0,2306x_2 + 0,0024x_5 + 2,51\times10^{-5}x_7 \quad (4)$$

The significant variables in the equations remain x_2, x_5, x_7. They explain the variance of RES (y) by 0.9034 (coefficient of determination) (i.e. 90%).

A 1% increase in the HDI (x_2) causes the RES (y) to decrease by 0.2306%. A 1% increase in the innovation index (x_5) leads to a 0.0024% increase in RES (y). Interest in RES topics (x_7) has a weak positive effect on RES (y)—a 1% increase is associated with a 2.51×10^{-6} percent increase in RES (y).

Figure 4 shows the relationship between theoretical and actual values. In the figure, we can see the cluster division.

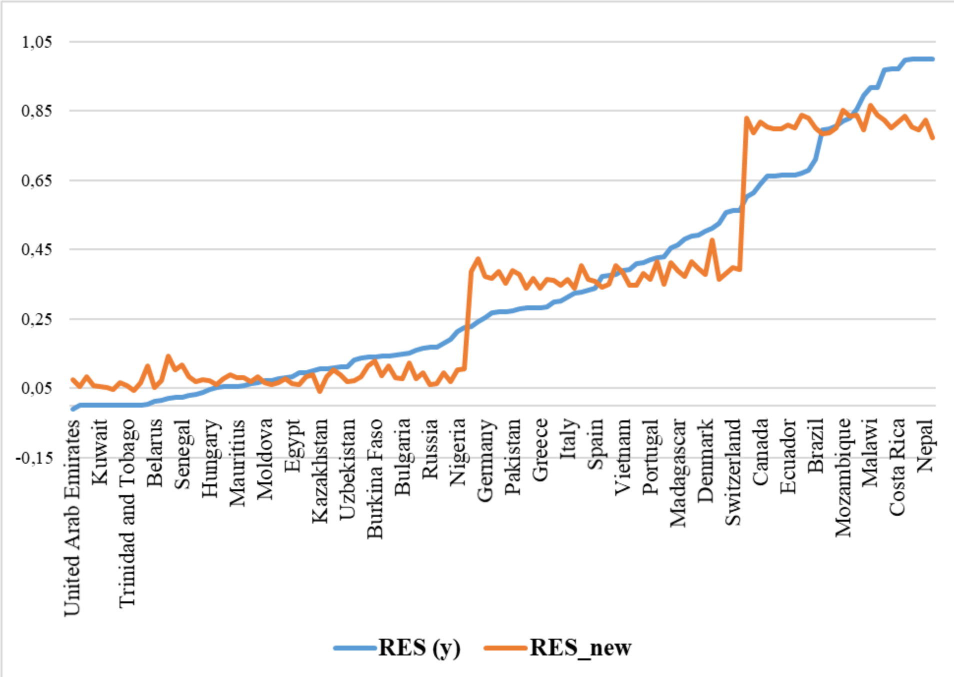

Figure 4. Actual and calculated values of RES (y)

Figure 5 (residuals not described by the model) shows the difference between the control values and the calculated values, distributed by the actual values of the indicator.

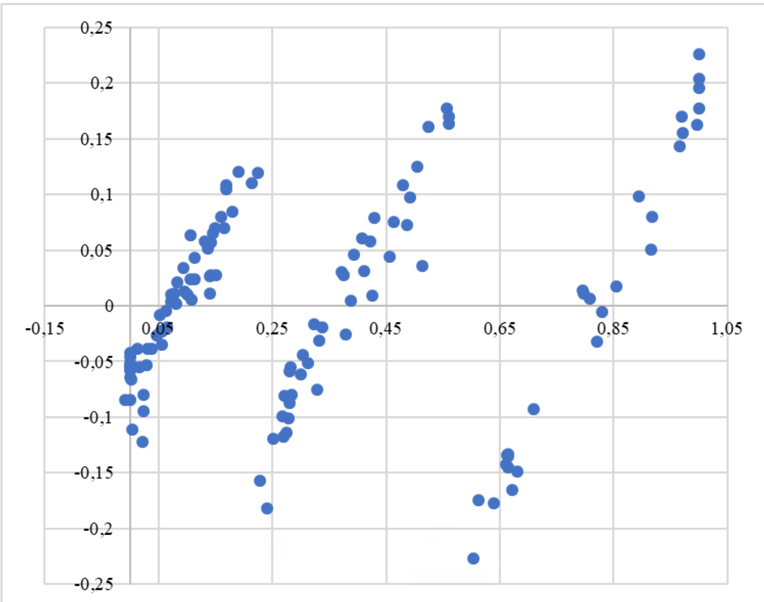

Figure 5. Residuals between the initial and calculated indicators

Figure 6 shows the ratio of the lower and upper bounds of the elasticity coefficient for the indicators of the confirmed model. Accordingly, the closer the bounds of the indicator's elasticity coefficient are to each other, the more we can interpret its impact on the result.

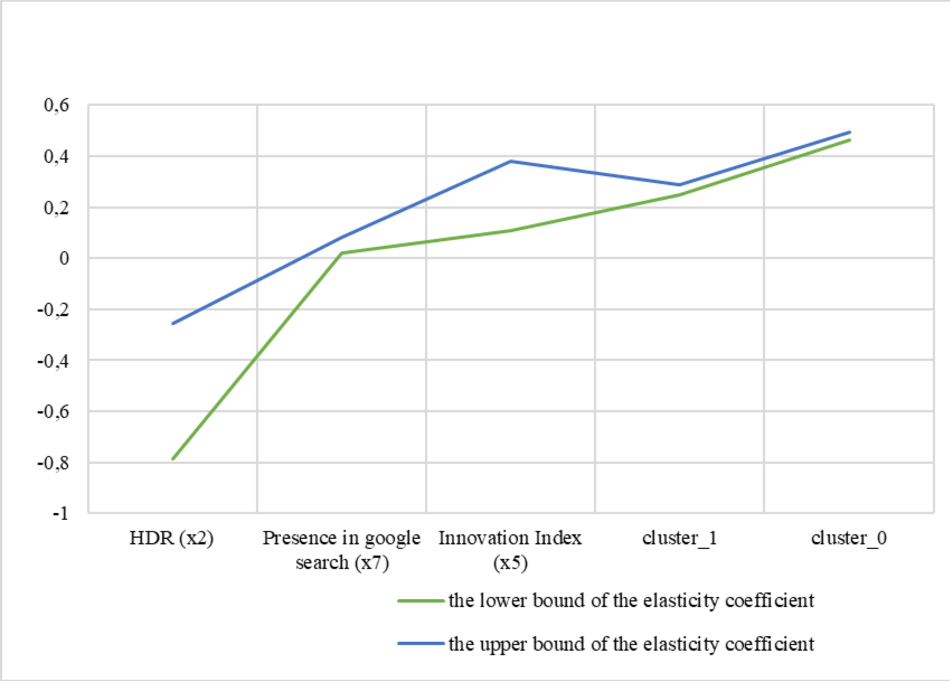

Figure 6. Elasticity bounds

Figure 7 shows the validated conceptual model. Of the 7 variables considered, the influence of 3 variables on the indicator under study—HDI, Global Innovation Index and interest—has been proven.

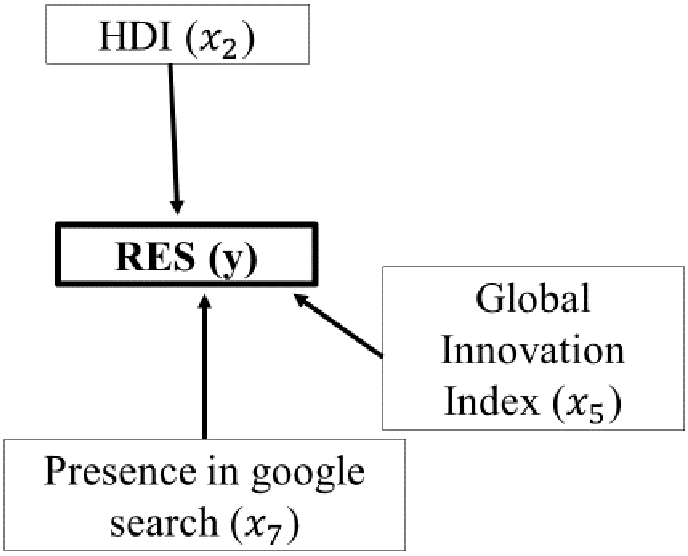

Figure 7. Validated conceptual model

4. Discussion

Three of the six proposed hypotheses were not justified; the statistical significance of their reference indicators was not proven. Of the two indices determining technological development as it was conceived, the more significant remained in the model: the Global Index of Innovation. Thus, we have confirmed the following hypotheses:

1. HDI has a negative impact;

2. The Global Innovation Index has a positive impact;

3. The interest rate also has a positive impact.

HDI's negative impact on RES can be explained by the fact that its growth directly leads to an increase in energy costs; each of the three indicators used to calculate the HDI confirms this (i.e., life expectancy, the longer a person lives, the more energy is consumed; the education coverage rate, the more people study, the greater the total energy consumption for education; and GDP at PPP does not need any comment). This surplus of energy costs must be covered by additional energy; non-renewable energy often wins here both in terms of economic efficiency and energy availability (Weißbach et al., 2013).

Such reasoning, however, is far from obvious. And from the point of view of the studied theoretical material, an alternative logical chain emerges. If a country has a higher level of human development, then society should be more involved in global problems (e.g., environmental problems) and promote green energy policies (Ponce et al., 2020; Vachon and Menz, 2006; Yu et al., 2022). The will of the people should also have more power in such countries, since the more developed a person is, the more difficult they supposedly are to manage—that is, such a society can seriously influence environmental policy.

Why, then, does the indicator reflect the HDI with a negative coefficient value in the resulting model? First, the tendency of the RES indicator to decrease as the HDI increases does not mean that the absolute values of RES are decreasing, as it only shows the relative values. Second, a study's results on the determinants of RES growth (Aguirre and Ibikunle, 2014) show that countries are likely to reduce their commitment to renewable energy sources under energy supply pressure. At the same time, the authors also argue that if the cost of using fossil fuel generators becomes high enough due to creating emission-limiting conditions, renewables will become competitive without the need for any other policy support mechanism.

The positive correlation between the Global Innovation Index and RES is explained by technological development, which stimulates energy production methods, promotes alternative sources and increases the efficiency of traditional sources. The increase in the innovation index indicates the growth of knowledge-intensive human activity, which allows renewable energy to become more relevant.

Based on the value of the HDI coefficient, why, according to the HDI's logic, the innovation index does not hurt the model? An increase in innovativeness and living standards logically implies an increase in energy costs.

The Global Innovation Index is calculated based on 81 indicators[19]. It consists of two subindices: the innovation costs and the innovation results. Each contains several blocks of data. The innovation costs subindex includes indicators weighted to reflect the following areas: institutional structure of the economy, human capital and research, infrastructure, market sophistication and business sophistication. The innovation output subindex is based on knowledge, technology and creative output.

Developing the potentially positive development indicators included in these blocks requires increasing energy consumption. However, the infrastructure block (innovation cost subindex) includes a coefficient based on the average value of electricity generation. The model's RES index is weighted by electricity production. Therefore, the net increase in innovativeness—reflecting only technological improvement—positively affects diffusing renewable energy.

The results on the presence of renewable energy in the Internet queries, reflecting the population's involvement in the issue of renewable energy, correlate with the results of previous studies (Oosthuizen and Inglesi-Lotz, 2022; Ponce et al., 2020; Vachon and Menz, 2006; Yu et al., 2022). As the population becomes more interested in producing electricity from renewable sources, the RES share in the energy system increases a little (1% of interest, 2.51×10^{-5} % RES), indicating the complexity of the implementation system.

Difficulties accompanying the implementation can partially explain the resulting division into clusters. The cluster division of the data set—carried out by the RES indicator (i.e., by the y-value of the model)—gave significant results within this study's framework. This indicates the fundamental importance of the current level of presence of renewable energy in the energy system for predicting this

19 Global Innovation Index. URL: https://nonews.co/directory/lists/countries/global-innovation-index. Accessed 17 November 2022.

indicator by the model.

Our data set was divided into three clusters. Cluster 0 included the countries with the highest indicators of RES development. Figure 8 shows the countries in cluster 0.

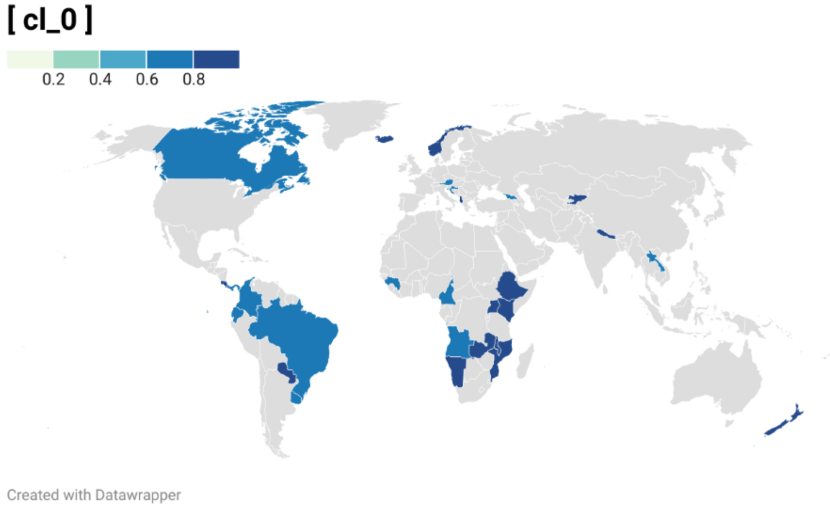

Figure 8. RES development in cluster 0 countries

Cluster 0 includes countries that collectively or individually lack natural fossil fuels, are unable to purchase them, have low total electricity generation, have highly developed green energy policies or have high potential for implementing renewable energy sources.

The countries in the 2nd cluster, assigned to the middle of the data set on the RES development indicator, are visualised in Figure 9.

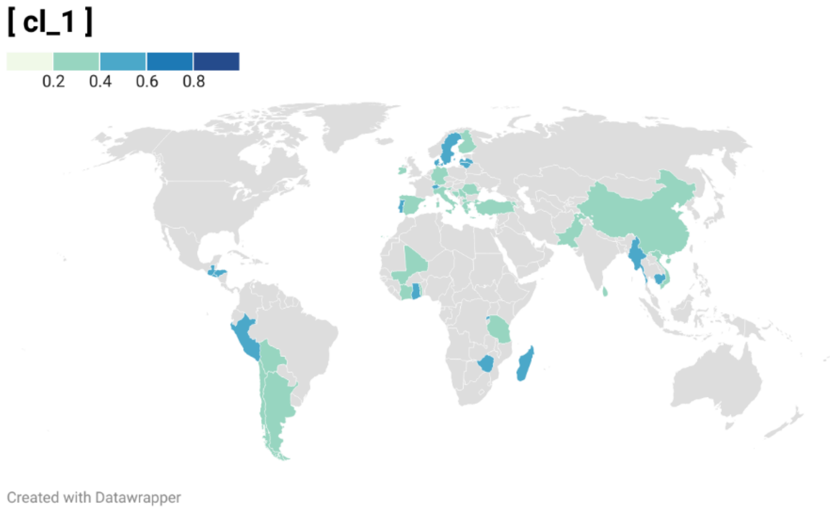

Figure 9. RES development in cluster 1 countries

Cluster 1 comprises countries with favourable economic and geographic conditions for RES development, EU countries supporting the policy of introducing renewable energy, countries satisfied with a low level of electricity generation and China, which is characterised by a high rate of information, policy and technological implementation of RES.

Figure 10 shows the countries with the lowest level of RES presence.

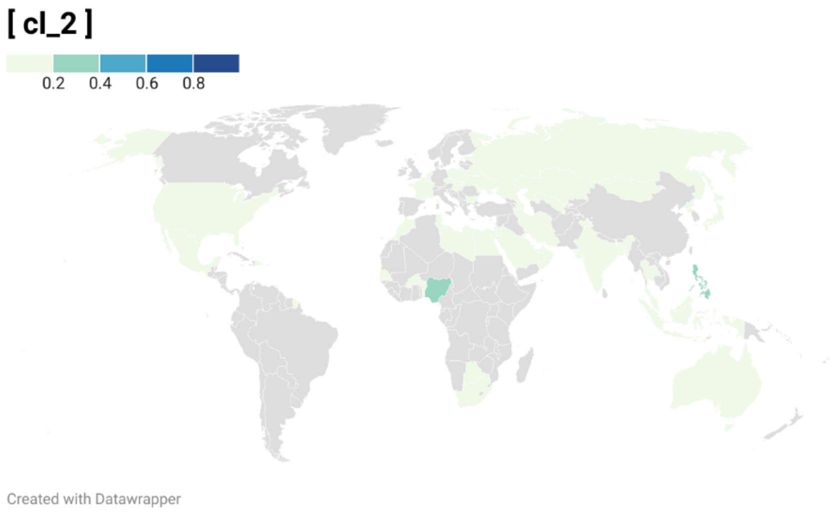

Figure 10. RES development in cluster 2 countries

Countries in cluster 2 include those with the largest quantities of fossil fuels, those with the financial capacity to purchase resources on a large scale and those with a catastrophic need for large-scale power generation but no capacity.

Thus, developing renewable energy is an atypical process, which is currently not a necessary growth stage. Therefore, the clusters of countries when trying to describe unambiguously by indicators of third-party RES may not be obvious. The current level of renewable energy should be considered as a factor reflecting that the country has already adopted a certain RES functionality, which is now being improved in pace, scale and parameters, partially explained by the rule common to the model.

5. Conclusions

This paper examines the influence of several variables on the share of renewable energy in the countries' energy industries. It analyses the relationship between fossil fuel reserves and the share of renewable energy, the impact of technological and human development on green energy policies and the correlation between public interest, news coverage and the share of renewable energy. The conceptual model uses the HDI, the Global Innovation Index, the Information and Communication Technology (ICT) Development Index, GDP per capita and the presence of renewable energy in Google searches and news coverage as explanatory variables. The dependent variable is the share of electricity produced by RES in total electricity production. That is, the causal relationship between the global position of countries and their participation in renewable energy is examined. The following conclusions are drawn:

1. The HDI hurts the development of RES, which is explained by the increase in energy and economic costs.

2. The Global Innovation Index has a positive impact, contrary to the logic of the impact of the HDI, which is due to the presence of weighted data on electricity production in the indicator.

3. The interest indicator also has a positive (but small) correlation with the outcome variable, which is conceptually consistent with previous research on the importance of public opinion.

Cluster membership (in terms of RES(y)) has the greatest impact on the resulting model. This means that renewable energy is heterogeneously distributed in the world. The current improvement, according to the stages of development, occurs at almost equal rates. But the initial data, which are polarly different, and the reasons for the initial differences are cost-effective or unprofitable for renewable energy economic and geographic conditions; a favourable or unfavourable position in terms of fossil fuels, the climate, higher or lower energy requirements and the country's level of development are also reflected in the amount of energy required.

So far, renewable energy has not become vital compared to non-renewable energy. Therefore, its diffusion is not so large. Perhaps, in the future, when coal, oil and gas are exhausted and the issue of RES transition becomes more urgent, the transition to renewable energy will be—not unlike the Industrial Revolution—an energy revolution, marking, for each country, a new stage of development.

The results give an idea of the functioning of RES in the world today—within the limitations of the 179-country sample. Further research is recommended using narrow groups and chronological data, specifying more substantially the level of development of renewable energy in the systems of interest to the researcher.

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