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The International Energy Security Risk Index in Sustainable Energy and Economy Transition Decision Making—A Reliability Analysis

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Abstract: The world economy and society are in a complex process of transition characterized by a high degree of uncertainty. Therefore, further development and management of the transition will largely depend on the quality of the decisions made and, accordingly, on the decision-making process itself. The main goal of this study is to analyze the reliability of International Energy Security Risk Index as a tool to support the process of energy and economy transition decision making, as closely related and highly interdependent phenomena. The index is composed of 29 aggregated variables (grouped into eight categories), and the research is conducted on a research sample of 25 countries over a period of 36 years. The reliability assessment is performed by using Multiple Regression Analysis. Multicollinearity test, plus Multicollinearity test with Variance Inflation Factors, is used for methodological verification. The test results indicate a high degree of unreliability of the Index, as is concluded based on the observed errors in its methodological settings. These errors primarily relate to a high degree of multicollinearity in all 29 variables, whereby independent variables lose their independence and thus jeopardize reliability of the total Index. Out of the eight groups of variables, the fuel imports group is the only one that does not show big methodological errors. The paper presents a recommendation for the improvement of the observed Index (review of the role of individual variables found to be particularly methodologically indicative), as well as a recommendation for different distribution of weighting coefficients.

Keywords: energy and economy transition; decision making; international energy security risk index; multiple regression analysis; multicollinearity test; multicollinearity test with variance inflation factors

1. Introduction

Energy, geopolitical and economic transition, along with changes in other fields of development, represents a great challenge facing humanity in the XXIst century [1]. In such a situation, decision making, as an already complex and demanding process, becomes even more difficult because it is associated with a high degree of uncertainty on several grounds [2]. Firstly, decisions must be made in the unforeseen circumstances that characterize the present time, with extremely difficult possibilities for predicting future events: geopolitical turmoil at the global level (as well as in some countries and regions), economic crises and problems at the micro and macro levels, the consequences caused by the Covid-19 virus pandemic, social tensions and unrest, changes in the field of security, resource exploitation, environmental concerns, climate change challenges and the like. Decision making in conditions of such a high degree of uncertainty, risk and ambiguity, is an extremely demanding and very important issue that calls for adequate solutions by taking into account specific circumstances [3]. Therefore, these solutions cannot be universal [4]. Secondly, decision making is hampered by the fact that decisions can be made in different ways, while using different approaches: from extremely subjective to milti-attribute decision making, which is supported by the objective fact that some decisions must be made in an extremely short time, caused by certain emergencies. Therefore, robust decision-making approaches are useful, yet, studies on them are rare [5]. In addition, there is no consensus on or uniform guidance about which decision-making method should be used under what conditions or for what purpose [6].

Since energy and economy transition takes place in the same conditions, with positive causal relationship [7]. Energy and macroeconomic variables are highly connected and evaluated in scientific literature [8]. Upon analysing the relation between energy security and macroeconomic variables in European countries, it was found that increase of Gross Domestic Product (GDP) is positively correlated, while the Consumer Price Index (CPI) is negatively correlated with energy security [9]. Analysing the relation between energy security and five macroeconomic variables (GDP, inflation, current account balance, foreign direct investment, and employment) in EU countries, Granger causality tests of the panel VAR model reveal that in the short run only employment may be negatively affected by energy security. Thess results may suggest to EU policy makers that the focus of energy policy should be primarly devoted to technological advances and energy consumption efficiency [10]. Empirical research based on 10 Asian economies provides evidence that energy price volatility has a positive impact on GDP in the short-run and the opposite in the long-run [11]. Another study [12] confirmed that increases in oil prices have a lower effect on GDP growth the lower the oil-to-energy ratio. These results are in line with the hypothesis that a higher energy import dependency makes a country more vulnerable to price variations. Facing a decline of oil-to-energy ratios, the decreasing influence of oil price fluctuations on GDP growth during the past 40 years can be explained. Emprirical research in which the impact of unexpected oil price changes on macroeconomic indicators in 19 major oil-related countries was analysed [13] showed that the macroeconomic overview of energyiimporting countries is under the higher pressure due to the fact they must pay more attention to the oil price shock response system. Therefore, further research should be implemented not only to analyse the relation between energy and macroeconomic indices, but also to design advanced indicators of energy security [14,15].

Taking into consideration the strong connection between energy and economy transition, decision making in this field is also complex and has certain additional specifics [16]. Namely, every country strives to adapt to the conditions of transition and, at the same time, to achieve and maintain a satisfactory level of economic stability and energy security for as long as possible, which allows it to create important preconditions for economic development, political stability and quality of life. In addition, transition decision making should take into account a large number of parameters [17], with specifics to be considered when it comes to developed or developing countries [18], among which many have been changed and aligned with the requirements of sustainable development [19]. Decisions in this area are more complex when developing a common energy policy in countries that have their own differences [20].

The decision-making process in the energy security area is further aggravated for several reasons. First of all, energy security is not defined in a unique way and, therefore, methodologies for measuring energy security can be considered questionable. However, with the increasing importance of energy security, efforts to solve this problem to some extent are growing as well. Therefore, a number of approaches and indices for measuring energy security have been developed and measurements have been carried out in individual countries, regions or globally, with the aim of determining the situation, defining the trends and predicting the future [21].

Energy security can be viewed in different ways, but for the purpose of decision making it is necessary to first clearly define the parameters that make up energy security [22]. On this point, there are already different views and analyses made on the basis of energy security concepts [23] that are set differently, i.e., insufficiently defined relations between the dimensions that make up energy security [24], with differences in conceptualization for decision with long and short-term impact [25]. The European Commission agrees as it defines energy security as the "uninterrupted physical availability of energy products on the market, at a price which is affordable for all consumers (private and industrial), while respecting environmental concerns and looking towards sustainable development" [26], whereby it considers availability and accessibility of supply, economic affordability and environmental sustainability to be basic dimensions.

Energy security can be viewed as an indicator of availability, accessibility, affordability, and acceptability [27], whereby it is proposed to add fifth dimension (efficiency) to the four dimensions mentioned [28]. In the Energy Trilemma Index case (World Energy Council), energy security is observed through the unity of four dimensions: energy security, environmental sustainability, energy equity and country context [29]. Efforts are also evident to develop special measurement methods for countries with certain specificities. Thus, in the case of energy import dependent countries that are, at the same time, large consumers, energy security is viewed as a unity of vulnerability, efficiency and sustainability [30]. In the case of highly industrialized countries, it is recommended to use a four-dimensional energy security model: availability, affordability, energy efficiency, and environmental stewardship [31]. Different combination of indicators is used in case of assessing energy security in Baltic States. In this case, combination of technical, economic, geopolitical and sociopolitical aspects of energy security has been used [32]. On the other hand, energy security should be planned and implemented by respecting sustainability prerequisites [33]. Energy security could be evaluated as the ability of the energy system to resist disruptions [34]. It can be concluded that the list of dimensions that make up energy security is continuously expanding. At the same time, there is an emphasized impossibility of developing all dimensions in parallel and simultaneously, and it further complicates decision making [35].

By analyzing the literature, it can be said with a high degree of certainty that a single definition will probably never be adopted. However, it is much more important to analyze the existing methods and to find ways to improve and adapt them [36].

After analyzing 63 studies on measuring energy security, some conclusions have been defined and they can, in a sense, serve as directions of further research. For the purposes of this paper, the selected conclusions relate to the assessment of the reliability of the methods applied. A multivariate analysis (usually in the form of Principal Component Analysis) was performed in only 10 studies, while more complex sensitivity and robustness analyses are even rarer. "During the process of building an index, many decisions are made, such as the selection of the indicator set, data normalization, indicator weighting and aggregation. The validity of these decisions and the resulting indices may thus be contested. Uncertainty, sensitivity and robustness analysis support the confidence into an index and its underlying policy messages". Regardless of its importance, this analysis was performed in only three studies. In summary, out of a total of 63 studies, certain assessment of the methodological settings of the index under observation, and analysis of its reliability, was conducted in only 13 cases [37].

Due to all of the above, and primarily due to the great importance of decision making in energy transition, with an emphasis on energy security as an important goal of energy and economic transition strategies, a study on the International Energy Security Risk Index (hereinafter IESRI), created by the U.S. Chamber of Commerce, is conceived and implemented in this paper, with an emphasis on the analysis of its methodological settings, the variables used, the assessment of correlation between them, the assessment of multicollinearity—all with the aim of drawing a conclusion on its reliability for the application in energy transition decision making, and with recommendations for improvement.

The paper is divided in five sections. The Introduction section presents the background, subject and goal of the research, as well as a review of the literature related to it. In the Material and Methods section, the research is presented, the sample is defined and the methods used are described. The results of the research are presented in the Results section. The interpretation of the obtained results, along with certain comments and recommendations, are provided in the Discussion section. Finally, an overview of the study, its basic results and interpretations are provided in the Conclusions section, along with indications of the directions of further research.

2. Materials and Methods

A reliability assessment in this research was conducted for International Index of Energy Security Risk which tracks variables in the field of energy security in 25 selected countries, grouped per regions [38]:

The European region includes 11 countries: Denmark, Germany, France, Italy, Norway, The Netherlands, Russian Federation, Poland, Spain, Ukraine and United Kingdom.

The Americas includes four countries: Brazil, Mexico, Canada and United States of America.

The Asian region is represented by China, India, Indonesia, Japan, South Korea, Thailand and Turkey.

Australia and New Zealand.

The only country from Africa represented in this study is South Africa.

The International Index of Energy Security Risk consists of eight groups of variables, presented as follows:

- The *Global fuels* group is represented by six variables: Global oil reserves, Global gas reserves, Global coal reserves, Global oil production, Global gas production and Global coal production.
- *Fuel imports* consists of five variables: Oil import exposure, Coal import exposure, Gas import exposure, Fossil fuel import expenditure per GDP and Total energy import exposure.
- *Energy expenditures* are explained with four variables: Crude oil prices, Retail electricity prices, Energy expenditure intensity and Energy expenditure per capita.
- *Price and market volatility*: GDP per capita, Energy expenditure volatility, Crude oil price volatility and World oil refinery usage.
- *Energy use intensity* includes Energy intensity, Energy consumption per capita and Petroleum intensity.
- *Electric power sector* is described with two variables: Electricity diversity and Non-carbon generation.
- *Transportation sector*, includes two variables: Transport energy intensity and Transport energy per capita.
- *Environmental* group is presented with three variables: CO_2 emission trend, CO_2 GDP intensity and CO_2 per capita.

The research was conducted for the period from 1980 to 2016 with data updated for that period, and the methods used in this paper are:

- Multiple Regression Analysis, selected because it allows one to define the contribution of each selected predictor to the level of the variance of the total Index [39], which is the first important assumption for the analysis of the methodological settings of the observed index.
- The Multicollinearity test is used to determine whether and to what extent the independent variables under observation are correlated. The occurrence of a high degree of correlation is certainly a significant methodological problem, because independent variables thus lose their presumption of independence as one of the most important preconditions for their use.
- A Multicollinearity test with Variance Inflation Factors (VIF) was conducted in addition to a Multicollinearity test, with the aim of establishing whether there is a real possibility to reduce

multicollinearity to a satisfactory framework. The VIF value between 1 and 5 indicates a correlation, but not significant enough to be subject to correction. If the VIF value is greater than 5, it indicates a high degree of multicollinearity and shows that methodological corrections are necessary [40].

The research started from the hypothesis that the existing methodology for IESRI assessment is too complex and that it can be simplified. In each of the six groups special metrics were developed to express the values of its variables. Not all of the variables from one group have the same importance. This difference is expressed by weighting factors (weights) assigned to them. Thus, the importance of a group represents the cumulative value of weighting factors of its parameters.

In order to examine the impact of the parameters on IESR, Multiple Regression Analysis was performed first. Given a large number of parameters which together describe 100% of IESRI, the verification of methodological correctness was performed by using a Multicollinearity test. The main purpose of this test is to detect mutual corelations among the IESRI parameters as independent variables. The large number of variables used in model indicated the necessity of the Multicollinearity test. Variance Inflation Factor (VIF) and Tolerance were used as measures to detect multicollinearity. We used both of them as they have reciprocal nature based on coefficient of determination (R). Both factors express a degree of contribution of observed parameter to the standard error. Emphirically, if the VIF values are less than 10, and the Tolerance values are above 0.1, cross-correlation of variables is considered to be within the tolerance, i.e., variables are considered as independent. In other words, if the VIF values are 10 and higher and the Tolerance values are less than 0.1, in that case there is a large cross-correlation between the variables, i.e., not all variables are independent.

3. Results

The formation of IESRI from variables of unequal importance, as determined by affiliation to a group and by weighting factors assigned, may seem like a satisfactory solution, however, when all variables are observed together (since only in this way do they determine the index completely to 100%), multicollinearity or mutual overlap (correlation) between the variables is much higher than allowed. This finding was confirmed by the Multicollinearity test.

Table 1 provides a set of the variables, their importance for the formation of IESRI, and their cross-correlation. Presented coefficients (Beta, T-test, Sig, Partial, VIF) are important for reliable determining candidates (parameters) for removing from the model (shown in Bold). The Beta coefficient determines how changes of predictor parameters influence on change of IESRI as a dependent variable. It is important only if the T-test value is greater than 2. Then then Beta coefficient has satisfactory significance for further consideration about the predictor. A significance or p-value (*Sig*) greater than 0.05 shows that there is no significant partial correlation with IESRI (dependent variable) and observed parametar is a candidate for exclusion.

Table 1. Multicollinearity and partial correlation without influence on IESRI.

Parameter	Beta	T test	Sig	Partial	VIF
(Constant)		−0.702	0.497		
Global_Oil_Reserves	0.044	8.685	0.000	0.934	32.369
Global_Oil_Production	**0.022**	**1.078**	**0.304**	**0.309**	**527.363**
Global_Gas_Reserves	0.037	4.185	0.002	0.784	96.703
Global_Gas_Production	0.102	5.880	0.000	0.871	376.293
Global_Coal_Reserves	0.043	2.752	0.019	0.639	296.586
Global_Coal_Production	0.060	3.154	0.009	0.689	448.817
Oil_Import_Exposure	0.037	2.617	0.024	0.619	252.046
Gas_Import_Exposure	0.136	13.090	0.000	0.969	133.207
Coal_Import_Exposure	0.160	10.640	0.000	0.955	280.947

Table 1. *Cont.*

Parameter	Beta	T test	Sig	Partial	VIF
Transport_Energy_Intensity Exposure	**0.037**	**1.745**	**0.109**	**0.466**	**558.111**
Energy_Expenditure_Intensity	0.224	4.045	0.004	0.677	335.98
Fossil_Fuel_Import_Expenditure_per_GDP	0.096	2.870	0.015	0.654	1390.620
Energy_Expenditure per Capita	0.123	3.477	0.005	0.724	1543.139
Crude_Oil_Prices	0.305	29.979	0.000	0.994	128.419
Retail_Electricity_Prices	0.074	10.958	0.000	0.957	57.219
Crude_Oil_Price_Volatility	0.283	79.371	0.000	0.999	15.807
Energy_Expenditure_Volatility	0.144	32.418	0.000	0.995	24.645
World_Oil_Refinery_Utilization	0.025	2.592	0.025	0.616	118.180
GDP per Capita	**0.099**	**1.168**	**0.267**	**0.332**	**8862.667**
Energy_Consumpiton per Capita	0.059	3.993	0.002	0.769	266.549
Petroleum_Intensity	**0.071**	**1.386**	**0.193**	**0.386**	**3234.543**
Energy_Intensity	0.108	2.998	0.009	0.665	198.808
Non-Carbon Generation	**0.002**	**0.337**	**0.743**	**0.101**	**66.905**
Electricity_Diversity	0.062	5.247	0.000	0.845	172.240
Transport_Energy_Intensity	0.102	2.287	0.001	0.545	76.555
Transport_Energy per Capita	0.104	3.037	0.011	0.675	1462.486
CO_2 per Capita	**−0.043**	**−0.657**	**0.525**	**−0.194**	**5299.321**
CO_2_Emission_Trend	0.224	1.892	0.667	0.747	112.003
CO_2 GDP Intensity	**0.178**	**2.076**	**0.062**	**0.530**	**9160.721**

The partial correlation indicator with dependent variable (Partial) indicates a very low contribution of all variables to the formation of the index, given that the partial correlation with dependent variable (IESRI average value for OECD countries) is statistically insignificant ($p > 0.05$). In addition, there is a problem of mutual collinearity a large degree of overlap with other independent variables (the VIF indicator significantly higher than 10). Based only on the value of VIF it is noticed that none of the 29 variables used in the calculation of IESRI meet the condition of independence. Variables with high VIF value, significance (Sig) greater than 0.05 (which shows that the partial correlation with IESRI as dependent variable is not significant) and low significance of the Beta coefficient due to low value of T-test are marked and they represent candidates for possible exclusion from the model.

Given an excessively high degree of correlation between independent variables on the one hand, as well as their low contribution to the formation of the total IESRI on the other hand, the procedure was repeated at the level of all 8 groups of variables. The goal of this approach is not to change the model based on the entirety but based on an insight gained into the behavior of individual variables within the group to which they belong. This refers to an insight into whether some variables are redundant and whether they can be replaced by other variables without significant losses after the formation of IESRI. The following sections describe the groups and associated variables in more detail.

3.1. Global Fuels

Based on the regression analysis, six variables from the Global Fuels group jointly show a high coefficient of determination for this group in relation to the linear model being described. Their contribution to the formation of the total IESRI is almost 87.90%, as presented in Table 2.

Table 2. The result of Multiple Regression Analysis for six parameters from the Global Fuels category.

Model	R	R Square	Adjusted R Square	Std. Error Estimate
1	0.938	**0.879**	0.855	28.82304

Multicollinearity and partial correlation of parameters from this category are shown in Table 3. Constant is included as an artificial parameter (a technical part of the statistical model) that provides zero mean of residuals. It represents the response value in case of zero values of predictor variables.

Constant provides the consistent regression line. Without it, the regression line will not fit the model. In other words, the absence of Constant will produce additional bias of regression coefficients used in analysis.

Table 3. Multicollinearity and partial correlation of the parameters from the Global Fuels group.

Parameter		Beta	T test	Sig	Partial	Tolerance	VIF
(Constant)		−0.579	0.567				
Global_Oil_Reserves	**0.304**	**1.458**	**0.155**	**0.257**	**0.093**	**10.782**	**10.782**
Global_Oil_Production	**−0.162**	**−0.715**	**0.480**	**−0.129**	**0.078**	**12.803**	**12.803**
Global_Gas_Reserves	−0.309	−2.027	0.052	−0.347	0.174	5.763	5.763
Global_Gas_Production	−0.783	−3.291	0.003	−0.515	0.071	14.092	14.092
Global_Coal_Reserves	**2.281**	**4.156**	**0.000**	**0.604**	**0.013**	**74.894**	**74.894**
Global_Coal_Production	**0.916**	**4.454**	**0.000**	**0.631**	**0.095**	**10.526**	**10.526**

In contrast to the summary results presented in Table 1, statistical indicators (primarily the Beta weight) at the level of this group show a greater differentiation of the importance of parameters for the formation of IESRI. For example, the Global Coal Reserves and Global Coal Production parameters are of much greater importance for the formation of IESRI values (because they show the highest Beta values), while the Global Oil Reserves and Global Oil Production parameters (shown nin Bold) are at the level of redundant parameters and are almost insignificant for the formation of IESRI (in addition to smaller Beta values, they also show a high degree of overlap with other parameters from the same category (Tolerance values < 1, VIF > 10)).

Based on the Pearson correlations of parameters from the Global Fuels group, the problem of multicollinearity is noticeable in Global Coal Reserves-GCR, Global Oil Production-GOP, Global Gas Production-GGP, Global Gas Reserves-GGR Table 4, where the values of Pearson coefficient are greater than limit of 0.7 (shown in Bold), as shown in Table 4.

Table 4. Pearson Correlation parameters from the *Global Fuels* group.

	IESRI	GOR	GOP	GGR	GGP	GCR	GCP
IESRI	1.000	−0.739	0.693	0.464	0.470	0.648	0.274
Global_Oil_Reserves	−0.739	1.000	−0.314	−0.289	−0.257	−0.404	−0.505
Global_Oil_Production	0.693	−0.314	1.000	**0.701**	**0.785**	**0.887**	−0.263
Global_Gas_Reserves	0.464	−0.289	**0.701**	1.000	**0.876**	**0.837**	−0.272
Global_Gas_Production	0.470	−0.257	**0.785**	**0.876**	1.000	**0.928**	−0.424
Global_Coal_Reserves	0.648	−0.404	**0.887**	**0.837**	**0.928**	1.000	−0.416
Global_Coal_Production	0.274	−0.505	−0.263	−0.272	−0.424	−0.416	1.000

It can be noted that the greatest correlation exists between the Global_Gas_Production and Global_Coal_Reserves variables (0.928). Cross-correlation of these variables indicates the need to separate these variables, i.e., not to place them in the same group (if the above proves to be justified).

3.2. Fuel Imports

The Fuel Imports category contains the most important parameters, given that their contribution to the formation of the total IESRI is 92.9%. The results of the analysis of this group of variables are presented in Table 5.

Table 5. The result of Multiple Regression Analysis for parameters from the Fuel Imports group.

Model	R	R Square	Adjusted R Square	Std. Error Estimate
1	0.964	**0.929**	0.917	21.78287

In addition to satisfactory R Square values (0.929), no special methodological problems were observed regarding the Fuel Imports group, as was confirmed by multicollinearity analysis and presented in Table 6.

Table 6. Multicollinearity and partial correlation of parameters from the Fuel Imports group.

Parameter	Beta	T test	Sig	Partial	Tolerance	VIF
(Constant)		4.004	0.000			
Total_Energy_Import_Exposure	−0.157	−2.362	0.025	−0.391	0.518	1.929
Gas_Import_Exposure	0.285	3.089	0.004	0.485	0.270	3.699
Oil_Import_Exposure	0.251	2.246	0.032	0.374	0.183	5.458
Coal_Import_Exposure	0.361	3.396	0.002	0.521	0.204	4.910
Fosil_Fuel_Import_Expenditure per GDP	0.545	4.415	0.000	0.621	0.151	6.639

The results of this analysis show that the variables that make up this group do not overlap significantly (Tolerance min = 0.151, VIFmax = 6.639). In accordance with the obtained results, it can be said that there is no need for methodological changes in variables from the *Fuel Imports* group.

3.3. Energy Expenditure

The Energy Expenditure category contains variables that contribute 84.4% to the variance of the total IESRI (84%). The results of Multiple Regression Analysis for this group are shown in Table 7.

Table 7. The result of Multiple Regression Analysis for parameters from the Energy Expenditure group.

Model	R	R Square	Adjusted R Square	Std. Error Estimate
1	0.918	**0.844**	0.824	31.77544

Further analysis of parameters from the Energy Expenditure category and, as verified, multicollinearity test, show their polarized nature as presented in Table 8.

Table 8. Multicollinearity and partial correlation of parameters from the Energy Expenditure group.

Parameter	Beta	T test	Sig	Partial	Tolerance	VIF
(Constant)		9.94	0.000			
Energy_Expenditure_Intensity	**0.371**	**3.524**	**0.001**	**0.529**	**0.440**	**2.270**
Energy_Expenditure per Capita	−0.032	−0.157	0.0877	−0.028	0.115	8.674
Retail_Electricity_Prices	0.150	1.553	0.130	0.265	0.526	1.902
Crude_Oil_Prices	**0.597**	**2.908**	**0.007**	**0.457**	**0.116**	**8.621**

Although there is no methodological problem of multicollinearity, the low value of Beta coefficient in the Energy Expenditures per Capita and Retail Electricity Prices parameters indicates that they have no importance within this group for the formation of IESRI values. Therefore, their contribution to IESRI formation should be further considered in more detail.

3.4. Price and Market Volatility

As shown in Table 9, parameters from the Price and Market Volatility category are important for the formation of the total IESRI (77.5%).

Table 9. The result of Multiple Regression Analysis for parameters from the Price and Market Volatility group.

Model	R	R Square	Adjusted R Square	Std. Error Estimate
1	0.880	**0.775**	0.747	38.12479

The multicollinearity test results for this group of variables are given in Table 10.

Table 10. Multicollinearity and partial correlation of parameters from *the Price and Market Volatility* group.

Parameter	Beta	T test	Sig	Partial	Tolerance	VIF
(Constant)		3.877	0.000			
Crude_Oil_Price_Volatility	**0.476**	**3.426**	**0.002**	**0.518**	**0.364**	**2.748**
Energy_Expenditure_Volatility	**0.310**	**2.025**	**0.051**	**0.337**	**0.301**	**3.322**
World_Oil_Refinery_Utilization	−0.389	−10.960	0.059	−0.327	0.178	5.607
GDP per Capita	−0.166	−0.847	0.403	−0.148	0.184	5.447

It is noticeable that the GDP per Capita and World Oil Rafinery Utilization variables do not contribute significantly to the formation of the total IESRI (the significance of World Oil Rafinery Utilization is at the limit value of 0.05, while it is far below the significance limit for GDP per Capita). None of the variables in this category have a multicollinearity problem. It is evident that the Crude Oil Price Volatility and Energy Expenditure Volatility variables have a significant impact on the formation of IESRI.

3.5. *Energy Use Intensity*

Multicollinearity test for the Energy Use Intensity group shows that variables from this group contribute the least to the formation of the total IESRI (40.4%, shown in Bold), as shown in Table 11.

Table 11. The result of Multiple Regression Analysis for parameters from the Energy Use Intensity group.

Model	R	R Square	Adjusted R Square	Std. Error Estimate
1	0.636	**0.404**	0.350	61.07523

Further analysis showed that only one of the three parameters (Energy Consumption per Capita) statistically significantly (Sig value, shown in Bold) contributes to the formation of IESRI, while Energy Intensity and Petroleum Intensity do not make a significant contribution, as shown in detail in Table 12.

Table 12. Multicollinearity and partial correlation of parameters from the Energy Use Intensity group.

Parameter	Beta	T test	Sig	Partial	Tolerance	VIF
(Constant)		2.646	0.012			
Energy_Consumption per Capita	−0.563	−3.121	**0.004**	−0.477	0.554	1.805
Energy_Intensity	2.710	1.701	0.098	0.284	0.007	140.643
Petroleum_Intensity	−2.969	−1.916	0.064	−0.316	0.008	132.928

As regards the Energy Intensity and Petroleum Intensity parameters, a significant problem is evident in multicollinearity which is reflected in an extremely high VIF index and in a low Tolerance indicator (shown in Bold). A more detailed insight is provided in the correlation table obtained from Pearson analysis, as shown in Table 13.

Table 13. Pearson Correlation parameters from the *Energy* Use Intensity group.

	IESRI	Energy_Consumption per Capita	Energy_Intensity	Petroleum_Intensity
IESRI	1.000	−0.516	0.080	0.035
Energy_Consumption per Capita	0.516	1.000	−0.578	−0.543
Energy_Intensity	0.080	−0.578	1.000	**0.995**
Petroleum_Intensity	0.035	−0.543	**0.995**	1.000

Correlation between the Energy Intensity and Petroleum Intensity parameters, which is almost 100%, unequivocally indicates that they do not individually contribute to the explanation of IESRI as a dependent variable.

3.6. Electric Power Sector

Electric Power Sector is a group of variables that do not contribute significantly (48.7%) to the formation of IESRI values, as defined by multiple regression and shown in Table 14.

Table 14. The result of Multiple Regression Analysis for parameters from the Electric Power Sector group.

Model	R	R Square	Adjusted R Square	Std. Error Estimate
1	0.698	**0.487**	0.457	55.82863

The multicollinearity test identified the only two parameters from this category (Electricity Diversity and Non-Carbon Generation), and these parameters statistically significantly (Sig, shown in Bold) contribute to the IESRI explanation, as shown in Table 15.

Table 15. Multicollinearity and partial correlation of parameters from the Electric Power Sector group.

Parameter	Beta	T test	Sig	Partial	Tolerance	VIF
(Constant)		−1.808	0.080			
Electricity_Diversity	**−0.614**	**−3.191**	**0.003**	**−0.480**	**0.407**	**2.456**
Non-CO_2_Emitting_Share_of_Electricity_Generation	**1.050**	**5.457**	**0.000**	**0.683**	**0.407**	**2.456**

At the same time, the Electricity Diversity and Non-Carbon Electricity Generation parameters meet the condition of mutual independence (values of Tolerance > 0.1 and VIF values < 10).

3.7. Transportation Sector

Transportation Sector is a group of variables that, as in the case of the Energy Use Intensity group, record the smallest contribution (40.2%, shown in Bold) to the formation of IESRI values Table 16.

Table 16. The result of Multiple Regression Analysis for parameters from the Transportation Sector group.

Model	R	R Square	Adjusted R Square	Std. Error Estimate
1	0.634	**0.402**	0.367	60.26841

The only two parameters from this category: Transportation Energy per Capita and Transportation Energy Intensity, statistically significantly (Sig value, shown in Bold) contribute to the IESRI explanation Table 17.

Table 17. Multicollinearity and partial correlation of parameters from the Transportation Sector group.

Parameter	Beta	T test	Sig	Partial	Tolerance	VIF
(Constant)		8.327	0.000			
Transportation Energy per Capita	**−0.805**	**−4.718**	**0.000**	**−0.629**	**0.604**	**1.654**
Transportation Energy Intensity	**−0.610**	**−3.579**	**0.001**	**−0.523**	**0.604**	**1.654**

At the same time, these two parameters from the Transportation Sector category meet the condition of mutual independence (Tolerance values greater than 0.1 and VIF less than 10).

3.8. Environmental

Parameters for the Environmental category contribute 58.4% (shown in Bold) to the formation of the total IESRI Table 18.

Table 18. The result of Multiple Regression Analysis for parameters from the Environmental group.

Model	R	R Square	Adjusted R Square	Std. Error Estimate
1	0.764	**0.584**	0.547	51.00798

All individual parameters within this category significantly (Sig << 0.05, shown in Bold) contribute to the determination of IESRI, and the problem of multicollinearity exists in each of them (extremely high VIF indicator), as shown in detail in Table 19.

Table 19. Multicollinearity and partial correlation of parameters from the Environmental group.

Parameter	Beta	T test	Sig	Partial	Tolerance	VIF
(Constant)		2.550	0.016			
CO2_Emissions_Trend	5.553	5.005	**0.000**	0.657	0.010	**97.750**
CO2_ Emissions per Capita	−4.474	−5.637	**0.000**	−0.700	0.020	**50.029**
CO2_GDP_Intensity	2.679	4.599	**0.000**	0.625	0.037	**26.957**

Pearson correlation test shows the existence of a significant positive correlation between the CO_2 Emissions Trend and CO_2 Emissions per Capita parameters, as well as a high negative correlation between the CO_2 Emissions Trend and CO_2 GDP Intensity parameters (shown in Bold). The results of this test are shown in Table 20.

Table 20. Pearson Correlation parameters from the Energy Use Intensity group.

	IESRI	CO_2_Emissions_Trend	CO_2_ Emissions per Capita	CO_2_GDP_Intensity
IESRI	1.000	−0.286	−0.491	−0.008
CO_2_Emissions_Trend	−0.286	1.000	**0.866**	**−0.733**
CO_2_ Emissions per Capita	−0.491	**0.866**	1.000	−0.309
CO_2_GDP_Intensity	−0.008	**−0.733**	−0.309	1.000

The correlation between the the CO_2 Emissions Trend and CO_2 Emissions per Capita variables imposes the conclusion that there is no need to use them together, as this impairs the methodological correctness of the model.

4. Discussion and Recommendations

The results of detailed analyses of the variables included in the IESRI calculation indicate weaknesses of the methodology used. The authors sought to create a model whose complexity is also its greatest weakness. The essential problem lies in a large number of variables (29) and in a way in which the variables are distributed by groups. The variables were grouped in order to apply common metrics to them. The importance of variables is determined by weighting values assigned to them. Thus, the importance of a group is expressed as the sum of weighting values of its variables. Given that the sum of all weights in the IESRI calculation model is 100%, it is concluded that the authors used an empirical model to express the significance of groups and variables. To prove this claim, the regression analysis of variables by groups (as independent variables) was used in the research in order to express the importance of each group for the formation of IESRI (as dependent variable).

The obtained R squared values were used to express the significance of individual categories (Section 3.1, Section 3.2, Section 3.3, Section 3.4, Section 3.5, Section 3.6, Section 3.7, Section 3.8). If normalized, these values could be used for a different distribution of weighting values by categories Table 21.

Table 21. IESRI vs proposed weight distribution.

Model	Global Fuel	Fuel Import	Energy Consumptions	Price & Market Volatility	Energy use Intensity	Electric Power Sector	Transportation Sector	Environmental
IESRI model	14	17	20	15	14	7	7	6
Proposed model	16.6	17.5	15.8	14.7	7.5	9.2	7.5	10.9

Table 21 shows small differences in some groups of variables (Fuel import, Price & Market Volatility and Transportation), but significant differences in most categories. The defined IESRI model gives too much importance to the Energy consumptions and Energy use intensity categories. The model proposed by the authors shows a more uniform distribution of weighting values by categories (the standard deviation of the proposed model is 4.15 compared to the IESRI model where it is 5.21). It emphasizes the importance of the Environmental category, and significantly reduces the importance of the Energy consumptions and Energy use intensity categories, giving added importance to the Global fuel, Fuel import and Electric power sector categories.

Another, no less significant result is the assessment of mutual correlativity of the parameters for verifying the correctness of the method of obtaining IESRI. Multicollinearity test is used as an instrument, and the obtained result at the IESRI level shows that none of the variables meet the VIF criterion < 10. In order to decompose the problem, multicollinearity test was performed at the category level.

The obtained results indicate that only the Electric power sector and Transportation sector groups meet the determination and correlativity conditions. The correlativity condition indicates that individual variables from the same group should be combined, i.e., that two or more variables should be replaced by one variable. For example, the Energy Intensity and Petroleum Intensity variables in the Energy Use Intensity group are problematic due to their small impact on the formation of IESRI. The inflation of value of these two variables was due to cross-correlation at almost 100%. On the other hand, there are variables whose individual importance for the formation of IESRI is insignificant, although they do not correlate with other parameters from their group. For example, the GDP per Capita parameter from the Price & Market Volatility group is far below the significance limit and represents a candidate for exclusion from the model.

The results of this study indicate the general and the particular problems that exist in the area of decision-making on the basis of data on the level of energy security and energy policy in general. The creators of different quantitative energy security indicators use different approaches and variables in their work, but they still relatively rarely check their reliability and robustness. In general, it is necessary and recommended that, when creating and using the index for measuring energy security, the concept of energy security (for which plans and assessments are made) has to be defined, because it has a different essence in different countries, as well in the same country, but in different time periods. Priorities are certainly changing, which could be followed by the creation of dynamic indices, taking into account the observed specifics, which is often not the case at the moment. Curently, in most cases, the level of energy security is determined on the basis of a methodology that is defined in advance and equal to all, countries are ranked and receive recommendations based on that, very important decisions often are made on the basis of these assessments.

Second, it is necessary to select the variables that will be used to measure energy security. There are a large number of basic, but even more complex variables (as in the case of the index observed in this paper), which are not adequately selected to represent a particular phenomenon, or, which is methodologically absolutely unacceptable, are contained in each other (high degree of overlap observed). Furthermore, it was observed that traditional energy security indicators (related to security of supply and energy prices) still have the greatest weight and significance in describing overall energy security. The inclusion of additional variables is certainly desirable, especially indicators that describe the environmental impact, but the results obtained could be unrealistic and misleading. For example, the indicators of harmful gas emissions (in combination with others) can by no means be attributed solely and exclusively to the use of energy sources. In addition, the use of GPD and GDP related variables is further quesionable, as there are a significant number of criticisms of this macroeconomic indicator, but for now there is no clear replacement.

Due to all the above, it is necessary to re-examine the type and number of variables and it is not necessary to methodologically complicate the assessment (which leads to erroneous results) by including additional indices at all costs. Certainly, energy transition towards more sustainable path is certainly imposed by the need to incorporate new indicators, but their uncontrolled inclusion and neglect of reliable indicators that have been used for decades, does not bring more correct and more accurate results. On the contrary, exaggeration in the number of indicators is both fundamentally and methodologically wrong. The number of variables is nowhere clearly defined, but they can be included gradually, on a previously defined set of indicators that are methodologically reliable, and after the inclusion of each new variable, a reliability check should be done. This iterative procedure allows to immediately include or exclude variables for which a certain reliability assessment is made. Certainly, grouping variables makes sense (as defined by the observed Index), but the groups showed clear differences, with overlaps, so that certain indicators should not be part of the group in which they are classified, or they should be excluded in total. It can be assumed that the grouping of variables and their further analysis within groups (especially the relationship between them) is expedient and can yield significant results in a methodological sense.

The choice of data processing method is a special issue. The research presented in this paper provides an insight into the analysis of the reliabiliyty testing that was applied on the structure of the index itself, which should be applied (and certainly extended) to each index. Therefore, every evaluation of energy security level should be followed by both reliability and robustness check of the methodology used, because energy security is too important issue to be assessed by using methodologically incorrect and questionable procedures.

5. Conclusions

The main goal of this study is to assess the reliability of the International Energy Security Risk Index as an energy and economy transition decision making tool. Transition takes place under conditions of high uncertainty, so decision-making gains increasing importance. If we take into account that said Index refers to energy security and risk indicators, connected with economic and environmental indicators, it is highly necessary to establish whether said Index is sufficiently reliable, whether there are errors in its settings and how they could be corrected.

The research included the data for 25 countries in the period from 1980 to 2016, using Multiple Regression Analysis, Multicollinearity test plus Multicollinearity tests with Variance Inflation Factors and Pearson correlation tests. The study analyzed the impact of 29 variables on the total IESRI variance and the degree of multicollinearity between the variables, both as an entirety and as 8 groups to which the variables belong.

The research showed that the most reliable indicators, which do not show a critical degree of multicollinearity, are variables from the Fuel imports group: Oil Import Exposure, Gas Import Exposure, Coal Import Exposure, Fossil Fuel Import Expenditure per GDP and Total Energy Import Exposure. These variables are indicators of import exposure in general, which indicates great significance of the dependence on energy imports and methodological correctness of the settings of each of these variables. If the number of variables that make up the Index is reduced in further research (in order to increase its consistency and reliability), these variables are certainly to remain part of the Index. On the other hand, a high correlation measured for the Energy Intensity and Petroleum Intensity variables indicates that they insignificantly contribute to IESRI and that their further contribution needs to be reconsidered. Moreover, although the variables from the Transportation sector group (Transportation Energy per Capita and Transportation Energy Intensity) have the smallest contribution to the IESRI variance, both show a high degree of independence and a relatively small degree of overlap, so they should certainly remain part of IESRI.

The analysis of correlation of the economic group of variables showed a high degree of multicollinearity between GDP-related and macroeconomic indicators and pointed to the fact that their use should be further considered in more detail, while some should be excluded. The results show that the Energy Expenditures per Capita and Retail Electricity Prices variables have a negligibly small impact on the formation of IESRI, while the impact of the Crude Oil Price Volatility and Energy Expenditure Volatility variables is much greater.

In summary, the biggest problems are seen in the methodological settings of International Energy Security Risk Index. Specifically, independent variables should be independent in their essence, which is not the case here. On the contrary, all 29 variables show unacceptably high degrees of multicollinearity (>5), that consequently lead to inaccurate results that, accordingly, represent poor output for decision making. A high degree of multicollinearity occurs when weighting coefficients are set incorrectly, while the obtained p-values are certainly misleading. Due to the above, the authors propose a new redistribution of weighting coefficients in accordance with the results of this research.

Based on the presented results, some further research directions can be suggested. There should be a focus on reengineering of this index and on reviewing other globally used indices, in order to obtain reliable indices that can be valuable tools for decision makers. The emphasis should be, above all, on solving the problem of the selection of variables. The extent to which the selection is necessary and the potential overlap with the existing variables should be taken into consideration. Furthermore, when including (or excluding) each variable it should be checked whether changes have occurred in the reliability of the Index. The ultimate goal is to develop an index model that will contain variables relevant to the observed phenomenon and independent (the degree of multicollinearity within the limits allowed), while striving to respect the parsimony principle, i.e., to use only as many variables as really necessary (principle of simplicity), but also to use all those variables that are really necessary (principle of optimality). Modern trends and efforts to include macroeconomic and environmental indicators in the assessment of energy security, in addition to indicators on energy resources and imports, basically represent a sustainable energy transition. However, in this case it has been proven that the selection of variables is highly inaccurate, so it is certainly necessary to conduct a comprehensive audit. Finally, due to a high degree of uncertainty in the field of decision making for energy security and energy transition in general, it is recommended not to use only mathematical models, but also to examine the possibility of using fuzzy logic and other systems for inexact reasoning.

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