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Measuring Countries' Performance in Ecological Security

***Mohamad CHEHABEDDINE*[1*], *Manuela TVARONAVIČIENĖ*[2]**
and ***Irina VINOGRADOVA ZINKEVIC*[3]**

Authors' affiliations and addresses:
[1] Department of Business Technologies and Entrepreneurship, Vilnius Gediminas Technical University (VILNIUS TECH), Saulėtekio al. 11, LT-10223 Vilnius, Lithuania.
e-mail: mohamad.chehab-eddine@vilniustech.lt

[2] Department of Business Technologies and Entrepreneurship, Vilnius Gediminas Technical University (VILNIUS TECH), Saulėtekio al. 11, LT-10223 Vilnius, Lithuania
General Jonas Žemaitis Military Academy of Lithuania, Šilo Str. 5A, LT-10322 Vilnius, Lithuania
Institute Humanities & Social Sciences, Daugavpils University, LV-5401 Daugavpils, Latvia
e-mail: manuela.tvaronaviciene@jssidoi.org

[3] Department of Information Technologies, Vilnius Gediminas Technical University, Vilnius, Lithuania
e-mail: irina.vinogradova-zinkevic@vilniustech.lt

***Correspondence:**
Mohamad Chehabeddine, Department of Business Technologies and Entrepreneurship, Vilnius Gediminas Technical University (VILNIUS TECH), Saulėtekio al. 11, LT-10223 Vilnius, Lithuania.
e-mail: mohamad.chehab-eddine@vilniustech.lt

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Abstract
The research aims to construct a novel secure regional development index focusing on ecological security aspects of eight Sustainable Development Goals (SDGs). The index building is based on the Sustainable Development (SD) Security Model that measures ecological threats' harm to the regional ecosystem. The ultimate goal is to construct a tool to manage facets of sustainable regional development. The research study is focused on G20 countries. The databank of the World Bank organisation was utilised to get secondary data of selected security indicators to measure security for the Sustainable Development Goals (SDGs) of the G20. The methodological approach relies on grouping ecological security indicators (Clustering using the K-Means method). It suggests a meaningful shortlist of indicators in each group, which would obtain a structured system of indicators suitable for constructing a novel Secure Regional Development Index using the multiple criteria decision-making TOPSIS method that selects the best alternative from a set of alternatives according to several criteria.

Keywords
Clustering; TOPSIS; Sustainable Development Goals SDGs; Regional Development; Model; World Bank; Ecological threats; Green Infrastructure; Pollution, Security Index.

Introduction

It is unanimously agreed that a prosperous future for countries, regions, and our planet can be achieved only by fostering a sustainable way of living. Sustainability is a sufficiently broad notion; therefore, sustainable development goals have been introduced. Our research will focus specifically on the ecological facets of sustainable development. To go further, the environmental state of countries can be perceived as an ecosystem in which economic and social development occur. Therefore, in this research, we will tackle the ecological security of regional development, which is a comparatively novel approach towards sustainable development.

In the recent literature, the ecological facets of sustainable development are strongly associated with the circular economy (e.g. Rezk et al., 2023; Zecca et al., 2023; Piccinetti et al., 2023: Pceļina et al., 2023; Aly Hussien Aly Abdou, 2023). Alas, despite the immense importance of a green economy, regional development threats are less emphasised, or their research is rather sporadical, concentrating on separate phenomena instead of adopting a more systemised approach. A list of threats for regional development that cover the eight security SDGs proposed by the OSCE security organisation, including environmental and ecological types, are provided in Table 1 (Sustainable Development and Security – the Global Agenda and Its Reflections in the OSCE | OSCE, n.d.)

Scientists analyse the listed threats in their most recent studies. Hence, the impact of immigration on secure development was studied by Beňuška and Nečas (2021). Water unavailability in East Africa and possible solutions were discussed by Stelian and Juhasz (2022) and Mutandwa and Vyas-Doorgapersad (2023). Means for reducing food insecurity were scrutinised by Tireuov et al., 2018; Mizanbekova et al., 2023; Vyas-Doorgapersad et al., 2023. Extremism and terrorism are elaborated in the works of Agbaje (2022), who focussed on kidnapping crimes and Bamigboye (2023), who disclosed practices of commercial soldiers used for fighting terrorism in Africa. Somogyi and Nagy (2022) analysed climate threats to critical infrastructure and showed that heat waves caused by global warming harm critical infrastructure. Increasing dangers caused by a lack of cyber security were discussed by Kovács (2022), who pointed to the phenomenon of ransomware. The insufficient involvement of women in STEM was analysed by Msosa et al. (2022).

Table 1. Threat Types

Regional Threats	*Threat types*				
	A	*B*	*C*	*D*	*E*
	State Centered national defense	*Human*	*Hybrid*	*Environmental*	*Ecological*
Massive Migration			✓		
Gender-Based Violence		✓			
Water Availability				✓*SDG6*	
Food Insecurity		✓	✓		
Populist Security		✓			
Extremist & Terrorism			✓		
Corruption			✓		
Critical Infrastructure					✓*SDG9*
Climate Change				✓*SDG13*	
Geoengineering					✓*SDG11*
Cyber security threats			✓		
STEM			✓		
Energy Insecurity				✓*SDG7*	
Supply Chain Risks & Uncertainty			✓		
Oil Price shock	✓				
Global Trade war	✓		✓		
Invisible foes, micro-enemies, Pathogens and Global health insecurity					✓*SDG13,* ✓*SDG14,* ✓*SDG15*

Source: The authors, based on (Chehabeddine et al., 2022)

The threats to sustainable development are sufficiently diverse. Countries need standardised and trustworthy indicators to monitor and assess their growth (Nagy, Benedek, and Ivan, 2018; Krishna et al., 2020).
As mentioned above, we will focus on ecological security measurement in the provided study. In our case, a selected object of research is G20 countries.

Ecological Security model

The authors select the ecological threat indicators related to the 17 UN Sustainable Development Goals (SDGs) from the World Bank database. Analysis showed that ecological threats affect eight of the seventeen SDGs containing 43 security indicators that measure ecological threats based on the SD Ecological Security model.

The security indicators are shown in the SD Ecological Security model provided in Figure 1 below. The model clearly shows the relationship between regional sustainable development, sustainability pillars and ecological security indicators.

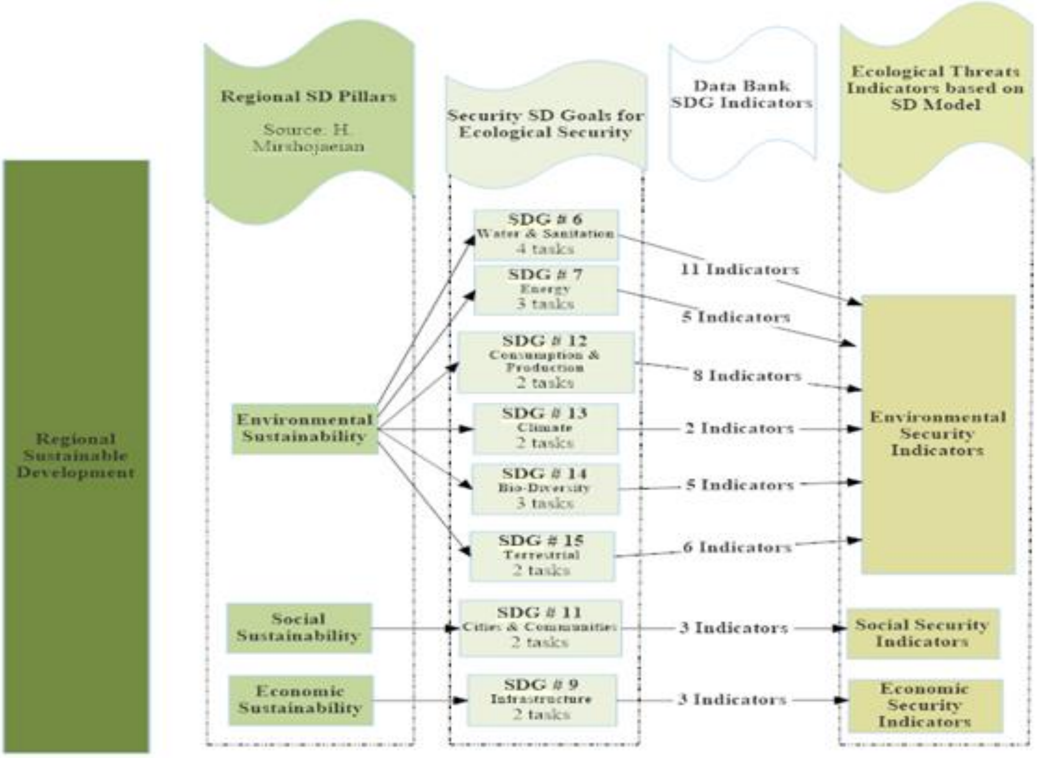

Figure 1. SD Ecological Security model. Source: (Chehabeddine et al., 2022)

Indicators Identification

We reduced the number of indicators from 43 to 34 since data has been missing for more than 25% of the total data across the last ten years. The remaining 34 indicators will be used to construct a tool for measuring countries' performance in ecological security (the process of reducing the indicators' list is described below). This tool will be an index. We intend to use the built index to measure G20 countries' secure sustainable development and manage the processes through relevant economic policies.

Dimension Analysis

Dimension Analysis looks at the relationships between indicators to find the most important ones and reduce the number of dimensions. The relationships between the events being measured in reality could only sometimes be reflected in the correlations between indicators.

The homogenous analysis can handle a variety of different types of indicators. It may be used if the indicators do not strongly correlate and do not suggest weight manipulation through ad hoc restrictions (Mayer, 2007). The system's limitation is the linear behaviour assumption between the indicators and the composite. Data is also needed to generate estimates with well-known statistical features.

The variables gathered under each category of ecological security, economic efficiency, and social equality may be correlated with one another, a phenomenon known as multi-collinearity, which can be used to reduce the data dimensionality. To minimise the dimensionality of the data in the current study while keeping the majority of the variability found in the original data, Principal Component Analysis (PCA) was applied.

Non-Homogenous Indicators

This study also employed Principal Component Analysis to choose a small number of indicators to visualise objects in two-dimensional space to study the trend better.

Not all indicators have the same impact on the result; an indicator's impact may be positive or negative.

Material and Methods

Indicators' Clustering Methodology

The clustering method K-Means was used to segregate the security indicators into different aspects. PCA was utilised to make the data less dimensional (Krishna et al., 2020). The authors seek to cluster selected SD security indicators. The resulting groups of indicators would lead to a hierarchic system, which will be used for building an index.

Indicators' clustering

The clustering of indicators assists in understanding their distribution and characteristics to create a system of indicators for helping experts weigh them to develop an accurate index that can measure the security of the country's sustainable development.

Table 2 lists 43 security indicators, their sustainability pillar, and the targeted change direction. For maintaining the security targets under eight security SDGs (Water, Energy, Infrastructure, Cities, Resource consumption, Climate change, Aqua systems, and Biodiversity), these indicators need to be redefined according to clustering results to create an index that can measure the ecological threats' harm on our regional ecosystem.

Many methods can be used to choose an indicator system. The authors can select indicators subjectively, basing their opinion on the literature review or their expertise. In this case, we decided to cluster sustainable development security indicators provided by the World Bank. The object of our research is G20 countries. For clustering, it is important that data is available. We found that some data cannot be obtained from the databank.

Therefore, we adopted the following strategy. The indicators for which data could not be restored were removed. We removed indicators from the list with more than 75% missed data. Hence, as mentioned above, nine were removed out of the selected 43 indicators. Indicators with numbers (11, 25, 27 & 39) were removed, in contrast to indicators that have less than 25% of their data missed, which can be utilised after restoration, such as indicators having numbers 1, 12, 26, and 30 were restored, constructing an array of countries against indicators.

Table 2. List of 43 Security Indicators

No	Indicator Description	Sustainability Pillar	SDGs	Targeted direction of change	Data Availability
1	People using at least basic drinking water services (% of population)	Environmental	6	↑	Yes
2	People using safely managed drinking water services (% of population)	Environmental	6	↑	Yes
3	People practising open defecation (% of population)	Environmental	6	↓	Yes
4	People using at least basic sanitation services (% of population)	Environmental	6	↑	Yes
5	People using safely managed sanitation services (% of population)	Environmental	6	↑	Yes
6	People with basic handwashing facilities including soap and water (% of population)	Environmental	6	↑	Yes
7	Annual freshwater withdrawals, total (% of internal resources)	Environmental	6	↓	Yes
8	Level of water stress: freshwater withdrawal as a proportion of available freshwater	Environmental	6	↓	Yes
9	Renewable internal freshwater resources per capita (cubic meters)	Environmental	6	↑	Yes
10	Water productivity, total (constant 2010 US$ GDP per cubic meter of total freshwater withdrawal)	Environmental	6	↑	Yes
11	Change in the extent of water-related ecosystems over time	Environmental	6	↓	No
12	Access to electricity (% of population)	Environmental	7	↑	Yes
13	Access to clean fuels and technologies for cooking (% of population)	Environmental	7	↑	Yes
14	Renewable electricity output (% of total electricity output)	Environmental	7	↑	Yes
15	Renewable energy consumption (% of total final Energy consumption)	Environmental	7	↑	Yes
16	Energy intensity level of primary energy (MJ/$2011 PPP GDP)	Environmental	7	↓	Yes
17	Air transport, passengers carried	Environmental	12	↓	Yes
18	Railways, passengers carried (million passenger-km)	Environmental	12	↓	Yes
19	CO2 emissions (kg per PPP $ of GDP)	Environmental	12	↓	Yes
20	Number of deaths, missing persons and directly affected persons attributed to disasters per 100,000 population	Environmental	12	↓	No
21	Direct economic loss in relation to global GDP, damage to critical infrastructure and number of disruptions to basic services attributed to disasters	Environmental	12	↓	No
22	PM2.5 air pollution, mean annual exposure (micrograms per cubic meter)	Environmental	12	↓	Yes

23	*Adjusted net savings, excluding particulate emission damage (% of GNI)*	*Environmental*	*12*	↑	*Yes*
24	*Coal rents (% of GDP)*	*Environmental*	*12*	↓	*Yes*
25	*Forest rents (% of GDP)*	*Environmental*	*13*	↓	*Yes*
26	*Mineral rents (% of GDP)*	*Environmental*	*13*	↓	*Yes*
27	*Natural gas rents (% of GDP)*	*Environmental*	*14*	↓	*Yes*
28	*Oil rents (% of GDP)*	*Environmental*	*14*	↓	*Yes*
29	*Total natural resources rents (% of GDP)*	*Environmental*	*14*	↑	*Yes*
30	*Number of sustainable tourism strategies or policies and implemented action plans with agreed monitoring and evaluation tools*	*Environmental*	*14*	↑	*No*
31	*Droughts, floods, extreme temperatures (% of population, average 1990-2009)*	*Environmental*	*14*	↓	*Yes but no available records*
32	*Disaster risk reduction progress score (1-5 scale; 5=best)*	*Environmental*	*15*	↑	*Yes but no available records*
33	*Proportion of national exclusive economic zones managed using ecosystem-based approaches*	*Environmental*	*15*	↑	*No*
34	*Aquaculture production (metric tons)*	*Environmental*	*15*	↑	*Yes*
35	*Capture fisheries Production (metric tons)*	*Environmental*	*15*	↓	*Yes*
36	*Total fisheries Production (metric tons)*	*Environmental*	*15*	↓	*Yes*
37	*Marine protected areas (% of territorial waters)*	*Environmental*	*15*	↓	*Yes*
38	*Forest area (% of land area)*	*Social*	*11*	↑	*Yes*
39	*Terrestrial and marine protected areas (% of total territorial area)*	*Social*	*11*	↑	*Yes*
40	*Terrestrial protected areas (% of total land area)*	*Social*	*11*	↑	*Yes*
41	*Fish species, threatened*	*Economic*	*9*	↓	*Yes*
42	*Mammal species, threatened*	*Economic*	*9*	↑	*Yes*
43	*Plant species (higher), threatened*	*Economic*	*9*	↓	*Yes*

The K-Means clustering (K-Means) method is one of the most popular methods in data analysis and machine learning. It is used to divide a data set into groups, called clusters, so objects within one cluster are more similar than objects in other clusters. The K-Means method starts with the initial idea that the mean values of the objects in each cluster (centroids) are the best representatives for that cluster. The Elbow method is often used to determine the optimal number of clusters in the K-Means method. This method involves running the K-Means algorithm with different values of K (number of clusters) and estimating the intra-cluster variance (Within-Cluster Sum of Square, WCSS metric) for each value of K. The WCSS is then plotted against the number of clusters. Visually, one can often observe an "elbow" on the graph - the point where WCSS decreases with less intensity. This value of K corresponds to the optimal number of clusters for a given dataset.

Starting by varying the number of clusters (K) from 1 – 10 for the obtained security indicators provided in Table 2, calculating WCSS (Within-Cluster Sum of Square) for each value of K; the sum of the squared distances between each point and the cluster's centroid. A plot resembling an Elbow will result from plotting the WCSS with the K value. The WCSS value will begin to drop as the number of clusters rises. The highest WCSS value is at K = 1. Until the graph rapidly changes at a point that creates an Elbow shape. The graph then starts to travel nearly parallel to the X-axis from this point on. The best K value, or the most clusters, is the one that corresponds to this location.

A curve is drawn for K clusters from 2 to 10. An explicit transition is seen at points 3 and 9; the graph shows a clear Elbow point in cluster number 6, as shown in Figure 2.

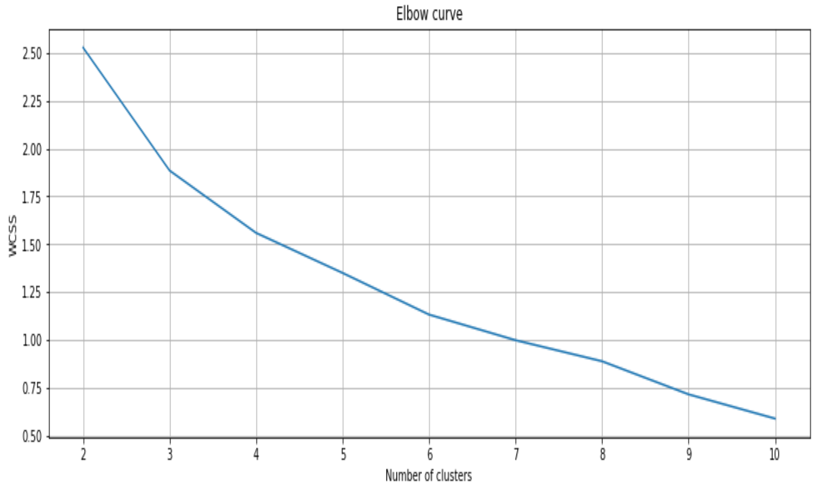

Figure 2. Elbow curve with 6-clustering
Source: authors

The Results of the six clusterings are shown in the array. The below array data resulted from the K-means method, where the number of clusters is the highest number in the array plus one since the clusters start from Zero. Clustering of six : [0 0 0 4 2 4 3 4 0 5 0 4 0 5 2 4 5 2 0 0 1 0 0 0 4 0 3 0 0 0 0 0 2 3 0].

Figure 3. Dividing into 6 clusters

Data reduction was applied using the Principal Component Analysis (PCA) method. The Graphic representation of clusters in two-dimensional space is shown in Figure 3. As a result, sustainable development security indicators were attributed to 6 clusters, as shown below in Table 3.

Table 3. Indicators' clusters

Cluster	*Indicator Number according to World Bank*	*Indicator*	*Indicator characteristic*	*Cluster Summary*
C1 (18 indicators)	*13*	*Access to clean fuels and technologies for cooking (% of population)*	*Green Energy*	*Green energy use, the health of forests and water, economic gain composition from using natural and renewable resources*
	12	*Access to electricity (% of population)*	*Energy security*	
	23	*Adjusted net savings, excluding particulate emission damage (% of GNI)*	*Green savings*	
	19	*CO2 emissions (kg per PPP $ of GDP)*	*Pollution*	

	16	*Energy intensity level of primary energy (MJ/$2011 PPP GDP)*	*Pollution*	*Cluster 1. Green infrastructure and human health*
	38	*Forest area (% of land area)*	*Level of resources used for restoration from pollution*	
	37	*Marine protected areas (% of territorial waters)*	*Level of resources used for restoration from pollution*	
	1	*People using at least basic drinking water services (% of population)*	*Maintaining Health*	
	3	*People using at least basic sanitation services (% of population)*	*Level of water quality preservation*	
	5	*People using safely managed sanitation services (% of population)*	*Level of water quality preservation*	
	43	*Plant species (higher), threatened*	*Health of plants*	
	22	*PM2.5 air pollution, population exposed to levels exceeding WHO guideline value (% of total)*	*Minimise Air pollution (exceeding some set guidelines)*	
	14	*Renewable electricity output (% of total electricity output)*	*Green energy percentage*	
	15	*Renewable energy consumption (% of total final energy consumption)*	*Green energy percentage*	
	9	*Renewable internal freshwater resources per capita (cubic meters)*	*Health of water*	
	39	*Terrestrial and marine protected areas (% of total territorial area)*	*Health of water*	
	40	*Terrestrial protected areas (% of total land area)*	*Health of forests and plants*	
	10	*Water productivity, total (constant 2010 US$ GDP per cubic meter of total freshwater withdrawal)*	*Health of water resources*	
C2 (1 indicator)	*2*	*People practising open defecation (% of population)*	*Maintaining Health(Pollution of water)*	*People practising open defecation related to maintaining health Cluster 2: It is embedded within Cluster 1*
C3 (4 indicators)	*7*	*Annual freshwater withdrawals, total (% of internal resources)*	*Maintaining Health (deterioration of fresh water)*	*Deterioration occurred to natural resources (freshwater) caused by using natural resources. Cluster 3: Ecological Degradation caused by natural resources use*
	8	*Level of water stress: freshwater withdrawal as a proportion of available freshwater resources*	*Maintaining Health*	
	28	*Oil rents (% of GDP)*	*Economic rents (oil rents are gains received from oil for the deterioration caused by the use of natural resources)*	
	29	*Total natural resources rents (% of GDP)*	*Economic rents embracing coal, and gas rents*	
C4 (3 indicators)	*34*	*Aquaculture production (metric tons)*	*Health of water resources*	*Sustainable aqua life, transportation Cluster 4: Health of aquacultures*
	18	*Railways, passengers carried (million passenger-km)*	*Green Transportation*	
	36	*Total fisheries production (metric tons)*	*Sustainable aqua life*	

C5 (6 indicators)	*17*	*Air transport, passengers carried*	*Polluting transport*	*Deterioration of life in air, water and air transport pollution. Cluster 5: Air Transportation Threats*
	X (only indicator data available is for 2018 for all countries)	*Bird species, threatened*	*Health of environment*	
	19	*CO2 emissions (kg per PPP $ of GDP)*	*Pollution level*	
	41	*Fish species, threatened*	*Aqua life threats*	
	42	*Mammal species, threatened*	*Aqua life threats*	
	43	*Plant species (higher), threatened*	*Aqua life threats*	
C6 (6 indicators)	*24*	*Coal rents (% of GDP)*	*Enhancing GDP (Pollution)*	*Economic rents from deterioration of natural resources Cluster 6: Economic rents threaten natural resources*
	25	*Forest rents (% of GDP)*	*Enhancing GDP (Pollution)*	
	26	*Mineral rents (% of GDP)*	*Enhancing GDP (Pollution)*	

Source: authors

Discussion

The nexus between Green Infrastructure and Human Health

Some studies link the advantages of green infrastructure to health (Suppakittpaisarn et al., 2017). However, others have brought up issues related to poor study quality and significant levels of heterogeneity (Twohig-Bennett and Jones, 2018).

The benefits of green infrastructure may include a decline in cardiovascular disease, stroke, diabetes, and total mortality despite not necessarily asserting a direct cause-and-effect relationship. Gascon et al. (2016) further comment on circulatory disease (Mitchell, Astell-Burt, and Richardson, 2011) on obesity, (Sanders et al., 2015) on respiratory disease morbidity, such as asthma and other atopic disorders (Lambert et al., 2017), and increased senior adults' longevity (Takano, Nakamura, and Watanabe, 2002), pain control (Han et al., 2016), and immune function (Hartig et al., 2014).

This awareness is growing as its consequences on air pollution and human health are better understood. However, few facts show a connection between green infrastructure projects and measurable health advantages (e.g., reduced mortality, hospital admissions, life years, and mental disorders) (Tiwari et al., 2019).

The performed research goes beyond the discussion since the authors attempt to integrate the listed and other indicators into one set with different weights, which would allow the use of the tool to manage the resulting position of countries in their ecological security performance.

Clusters Categorisation

Cluster 1 can be considered as Green Infrastructure, and Cluster 2 can be regarded as Human health for the following reasons.

Cluster 1 indicators' study shows the following:

- Access to clean fuels, electricity, and technologies; Renewable electricity output; Renewable energy consumption; and Energy intensity reduction help to improve green Energy.
- Increase in Forest areas, Terrestrial and Marine protected areas, reduction of CO2 emissions, and PM2.5 air pollution help to improve the green environment.
- Increase in People's use of at least basic drinking and sanitation water services; using renewable energy sources, natural resources, and energy innovation enhances environmental quality.
- Increase in the use of renewable energy sources reduces CO2 emissions (e.g., Balsalobre-Lorente et al., 2018). The usage of renewable electricity and economic growth interact. Regulations for Renewable Energy are necessary to increase renewable sources and encourage energy innovation, which will lessen the impact of energy and fossil fuels on environmental degradation (Balsalobre-Lorente et al., 2018).

Cluster 2 embracing indicators of People practising open defecation is related to maintaining health, which is embedded in cluster 1 containing the following indicators: People using at least basic sanitation services, People using at least basic sanitation services, and People using at least basic drinking water services. Due to the similarity of their contents, both clusters can be combined into one Cluster (A) named Green Infrastructure and Human Health.

Cluster 3 can be considered Economic rents damaging sustainable growth, and Cluster 6 can be Economic rents that threaten natural resources for the following reasons:

Cluster 3 indicators analysis shows Ecological Degradation caused by natural resource use according to the below indicators:

- Annual freshwater withdrawals and level of water stress are related to water governance.
- Oil and Total natural resources rents are related to environmental protection.
- Economic rents, which are used for green management and impact economic growth, reflect the benefit resulting from the harm that the exploitation of natural resources has caused.

Economic rents received from non-renewables negatively affect ecological security. Cluster 6 indicators analysis shows Economic rents threaten natural resources. Numerous studies have examined the effects of economic complexity on the rents from natural resources. Over the years 2002–2017, a sample of 90 economies from around the world,27 Low and Lower-Middle Income Economies (LMEs), 22 Upper-Middle Income Economies (UMEs), and 41 High-Income Economies (HIEs), were divided into three subsamples (Canh, Schinckus, and Thanh, 2020), The authors showed that reduced threats to natural resources are related to coal, forest, and mineral rents.
Therefore, both mentioned clusters can be combined into one Cluster (B) named Economic Rents from Non-renewables.

Cluster 4 can be considered Health of aquacultures, and Cluster 5 can be considered Transportation threats for the following reasons. Cluster 4 indicators analysis shows the following:
Aquaculture and Total fisheries production related to aquatic life

- The negative environmental impacts of the Ports and Water Transportation on the Aquatic Ecosystem (Selamoglu, 2021); most industrial and economic activities profoundly impact wildlife (Selamoglu, 2021).
- Diverse environmental effects brought on by human activities in the water or on land affect aquatic ecosystems (Selamoglu, 2021). Ecological deterioration in oceans worldwide is caused by ship-generated
- trash waste.

Cluster 5 indicators analysis shows Air transportation threats affect economic growth and Aqcua lives as follows:

- Air transport passengers carry CO2 emissions related to air transportation threats on the birds, fish, mammals, and Plant species.

Examples of transportation infrastructure where aviation events result in the construction of geotechnical systems are provided through an investigation of geotechnical systems produced in anthropogenic emergency zones during aviation events (Nikolaykin et al., 2023).

A hierarchy of ecological extreme zone levels is offered to the developing systems levels to analyse the aviation incident's environmental impact. It also supports the idea that increasing flight safety is the best and most practical way to lessen air travel's environmental impact (Nikolaykin et al., 2023).
Green transportation can reduce pollution and promote sustainable aquatic life that benefits fish health.

Therefore, both mentioned clusters can be combined into one Cluster (C) named Pollution impacts on lives.

As commented on clusters' characteristics and their indicators interrelationships, Cluster 1 dominated Cluster 2 indicators. The clusters merged into Cluster A "Green Infrastructure". Cluster 3 and 6 indicators' characteristics have similar interrelationships and merge into Cluster B "Economic rents". Cluster 4 and Cluster 5 integrated into Cluster "C" Transportation threats". The summary is provided below in Table 4.

Table 4. Clusters Summary

Clusters Summary		
Main Cluster	*General Aspects*	*Merging Clusters*
A	*Green infrastructure*	*C1 & C2*
B	*Economic rents as ecological threats*	*C3 & C6*
C	*Pollution impacts on lives*	*C4 & C5*

The Dominant main cluster

The six clusters can be combined into three clusters (A, B, C) (see Table 5). However, Cluster A was found to be the dominant among the other two main clusters for the following arguments. Around the world, many initiatives have attempted to mitigate the effects of anthropogenic air pollution. A detailed investigation of the relationships between air pollution, green infrastructure, and human health would help decision-makers quickly and intelligently choose how to use and manage green infrastructure in urban environments. Social, economic, and environmental benefits can be obtained via green infrastructure. The relationship between green infrastructure, air quality, and human health suggests that using it strategically could reduce pollutant exposure downwind (Kumar et al., 2019). Significant efforts must be made in decarbonisation and climate change mitigation to provide services to these metropolitan centres that are constantly expanding. It is anticipated that air pollution will be a problem in the developed environment for decades to come in particular (Landrigan et al., 2018). It is projected explicitly that air pollution in the built environment will be a problem for decades to come (Heal, Kumar, and Harrison, 2012) (Kumar et al., 2015). The relationship between air pollutants and green infrastructure design (such as species choice and spatial positioning) can benefit or negatively impact individual exposure and human Health (Abhijith et al., 2017).

The result is the system of 15 indicators related to the dominant cluster A, which is related to "green infrastructure, health, pollution" listed in Table 5. Hence, the six clusters merged into three clusters: A, B & C, with the dominant Cluster A. We assume that indicators provided in Cluster A comprise an indicators system divided into 4 groups (Table 5). This system will be further used for constructing a novel ecological security index.

Table 5. System of 15 indicators related to securing the ecosystem from ecological threats

#	Aspect	Main cluster A indicator # (15 indicators)	Main Cluster A Indicators names				
1	Green Infrastructure	13,14,15	Access to clean fuels and technologies for cooking (% of population)	Renewable electricity output (% of total electricity output)	Renewable energy consumption (% of total final energy consumption)		
2	Sustainable economic growth	10,23	Water productivity, total (constant 2010 US$ GDP per cubic meter of total freshwater withdrawal)	Adjusted net savings, excluding particulate emission damage (% of GNI)			
3	Human Health	1,2,3,5,9	People using at least basic drinking water services (% of population)	People practising open defecation (% of population)	People using at least basic sanitation services (% of population)	People using safely managed sanitation services (% of population)	Renewable internal freshwater resources per capita (cubic meters)	
4	Pollution	16,19,22,37,38	Energy intensity level of primary energy (MJ/$2011 PPP GDP)	CO2 emissions (kg per PPP $ of GDP)	PM2.5 air pollution, population exposed to levels exceeding WHO guideline value (% of total)	Marine protected areas (% of territorial waters)	Forest area (% of land area)	

Source: authors

These indicators have an extended definition, which the World Bank Organization provides in the Data availability statement for reference.

As mentioned above, the ultimate aim is to build an index that can serve as a tool to manage secure regional development based on the ecological security model (Figure 1). Indicators for mitigating ecological threats are listed in Table 2, which displays 43 indicators for G20 countries. The list is reduced to 34 indicators after eliminating indicators that can not be restored. The indicators then clustered these indicators into 6 clusters and merged the similar clusters into three clusters (A, B, C). It was found that one cluster, i.e., cluster A, is the dominant one with 15 indicators. Those 15 indicators will further serve as an indicator system for constructing an index. For that purpose, we employ experts who will evaluate the importance of distinguished aspects and weigh indicators characterising each aspect of ecological security of sustainable development.

Calculations - Index Formulation

The following requirements are formulated for the method:

- Collected indicator data have to be used (there are methods that do not use statistical data; therefore, the work done would not be used using such methods);

- The obtained results must be instrumental in formulating advice for G-20 countries. To put it into other words, we have to create a tool that would allow us to tell each country what indicator out of 15 has to be improved to receive an overall better ecological state.

Considering the formulated requirements, It is suggested to use TOPSIS (data of indicators will be used, and weights of indicators provided by experts).

To calculate the index of secure regional development, use the multiple criteria decision-making TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) method. TOPSIS is used to select the best alternative from a set of alternatives according to several criteria (Hwang & Yoon, 1981). Let n - be the number of alternatives (countries), m - be the number of criteria (indicators). Set of alternatives $i = 1, \dots, n$, each of which is evaluated according to several criteria $j = 1, \dots, m$.

The best alternative V^+ and the worst alternative V^- were calculated by

$$V+= \{V_1^+, V_2^+, \dots, V_m^+\} = \{(\max_i \omega_j \tilde{r}_{ij} \,/\, j \in J_1), (\min_i \omega_j \tilde{r}_{ij} / \, j \in J_2)\},$$
$$V^- = \{V_1^-, V_2^-, \dots, V_m^-\} = \{((\min_i \omega_j \tilde{r}_{ij} / \, j \in J_1), ((\max_i \omega_j \tilde{r}_{ij} \,/\, j \in J_2)\},$$

where J_1 is a set of indices of the maximised criteria, J_2 is a set of indices of the minimised criteria.

The method uses a vector normalisation:

$$\tilde{r}_{ij} = \frac{r_{ij}}{\sqrt{\sum_{i=1}^{n} r_{ij}^2}} \;,$$

where $\tilde{r}_{ij}$ is the normalised value of j-th criterion for i-th alternative.

The distance D_i^+ of every considered alternative/country to the ideal (best) solutions and its distance D_i^- to the worst solutions were calculated:

$$D_i^+ = \sqrt{\sum_{j=1}^{m} (\omega_j \tilde{r}_{ij} - V_j^+)^2}, \; D_i^- = \sqrt{\sum_{j=1}^{m} (\omega_j \tilde{r}_{ij} - V_j^-)^2}$$

The criterion $Index_i$ of the method TOPSIS was calculated by

$$Index_i = \frac{D_i^-}{D_i^+ + D_i^-}, (0 \le Index_i \le 1).$$

Two additional hypothetical alternatives (worst and best) were used to calculate a score ranging from 0 to 1. Estimates from this interval are interpreted as percentages. The criteria weights in this study were set by experts with experience in sustainable development indicators, especially from the World Bank organisation; the most important criterion indicator is assigned the most significant weight. The sum of the criteria weights must be equal to 1.

The following steps were used to prepare the results provided in Table 6:

Receiving complete response letters from experts by rating groups of indicators and assigning their rank (the 1st, the 2nd, the 3d or the 4th);

Assign a weight, expressed in per cent of each indicator in a group (e.g., a group green infrastructure "contains 3 indicators, and the expert can assign, let's say, 30 per cent for the first, 40 per cent for the second and 40 per cent for the third, or any other way; the main thing that resulting sum was 100 per cent)

7 experts took part in the evaluation. Experts are from Poland, Lithuania, Italy, South Africa, Germany, Saudi Arabia, and India. All experts have required expertise in the area, which is formally confirmed or by high-impact publications in Web of Science and SCOPUS databases, and have experience in leading European Union-funded projects in sustainable development or experience in working in the World Bank.

Next to each indicator indication, it is mentioned that these indicators tend to be Min or Max depending on their desired direction, ex. Which go up means (Max), and which go down means (min). Using the TOPSIS method, the best statistical value achieved by a country will become the best alternative, measured by 1. Other values will obtain a value from 0 to 1.

An index comprises indicators' values showing how far they are from the ideal alternative (the ideal alternative is the best value achieved). That tool will allow us to manage the ultimate result (ecological security); the method will enable us to get a tool similar to an index.

All experts' reviews are gathered in one table for evaluation, as shown in Table 6 below:

Table 6. Experts review for ranking from various countries

#	Groups of indicators	Security SD Indicators	Experts Location	Indicator (13) Weighting (%)		Indicator (14) Weighting (%)		Indicator (15) Weighting (%)		Total Weights (%)		Ranking (place rating No1, No2, No3 or No4) According to high-importance
1	Green Infrastructure	13, 14, 15	1. Ireland	10	(13) Access to clean fuels and technologies for cooking (% of population)	40	(14) Renewable electricity output (% of total electricity output)	50	(15) Renewable energy consumption (% of total final energy consumption)	100		3,3,3,2,3,1,4 =MEDIAN (3,3,3,2,3,1) = 3
			2. India	10		30		60				
			3. Italy	10		20		70				
			4. Poland	10		40		50				
			5. Lithuania	10		30		60				
			6. Pakistan	35		35		30				
			7. Saudi Arabia	25		25		50				

#	Groups of indicators	Security SD Indicators	Experts Location	Indicator (10) Weighting (%)		Indicator (23) Weighting (%)		Total Weights (%)		Ranking
2	Economic growth	10, 23	1. Ireland	50	(10) Water productivity, total (constant 2010 US$ GDP per cubic meter of total freshwater withdrawal)	50	(23) Adjusted net savings, excluding particulate emission damage (% of GNI)	100		4,4,4,4,4,3,2 =MEDIAN (4,4,4,4,3,2) = 4
			2. India	40		60				
			3. Italy	30		70				
			4. Poland	40		60				
			5. Lithuania	30		70				
			6. Pakistan	40		60				
			7. Saudi Arabia	50		50				

#	Groups of indicators	Security SD Indicators	Experts Location	Indicator (1) Weighting (%)		Indicator (2) Weighting (%)		Indicator (3) Weighting (%)		Indicator (5) Weighting (%)		Indicator (9) Weighting (%)		Total Weights (%)	Ranking
3	Human Health	1, 2, 3, 5, 9	1. Ireland	10	(1) People using at least basic drinking water services (% of population)	10	(2) People practising open defecation (% of population)	10	(3) People using at least basic sanitation services (% of population)		(5) People using safely managed sanitation services (% of population)	60	(9) Renewable internal freshwater resources per capita (cubic meters)	100	2,2,2,3,2,4,1 =MEDIAN (2,2,2,3,2,4, 1)= 2
			2. India	20		10		10		10		50			
			3. Italy	30		10		10		10		40			
			4. Poland	20		10		10		10		50			
			5. Lithuania	10		10		10		10		60			
			6. Pakistan	20		15		18		20		27			
			7. Saudi Arabia	50		0		25		25		0			

4	Pollution	16, 19, 22, 37, 38	*Experts Location*	*Indicator (16) Weighting*		*Indicator (19) Weighting*		*Indicator (22) Weighting*		*Indicator (37) Weighting*		*Indicator (38) Weighting*		*Total Weights (%)*	*1,1,1,1,1,2,3 =MEDIAN(1,1,1,1,1,2,3)= 1*
			1. Ireland	5	*(16) Energy intensity level of primary energy (MJ/$2011 PPP GDP)*	65	*(19) CO2 emissions (kg per PPP $ of GDP)*	20	*(22) PM2.5 air pollution, population exposed to levels exceeding WHO guideline value (% of total)*	5	*(37) Marine protected areas (% of territorial waters)*	5	*(38) Forest area (% of land area)*	*100*	
			2. India	10		50		20		10		10			
			3. Italy	5		35		30		10		20			
			4. Poland	10		50		20		10		10			
			5. Lithuania	10		60		20		5		5			
			6. Pakistan	25		20		23		15		17			
			7. Saudi Arabia	10		10		0		40		40			

- After wrapping up the experts' ratings for the 15 targeted indicators in one table.

Filtered the data indicators of G20 countries to have only the targeted 15 indicators,"our focus indicator", and added one column named "indicator #" for the filtered 15 indicators.

- Adding one column named" symbol for the Max and Min where the coloured indicator cell in green is the Max that has an upward direction whereas the coloured indicator cell in yellow is the min that has a downward direction.
- Adding the Mean "Average" for each of the selected indicators from 2010 to 2019.
- Selecting all G20 to check if it needs to reduce them based on the counties clustering.

At each data analysis stage, we used the TOPSIS method to calculate the evaluations.TOPSIS method was used to calculate the percentage, whereas Python program was utilised in the programming and the calculation of this method to get the above results.

The considerations of the hypothetic bad alternative and hypothetic good alternative are based on the following:

- If the indicator is **maximised**, then its performance is best at the maximum value of the indicator, and the maximum value of this criterion for all countries is taken.
- If the indicator is **minimised**, then its performance is best at the minimum value of the indicator.

Six countries lack data for one criterion; therefore, we cannot calculate their scores for all 15 indicators. In this case, the weights for the 14 criteria are also recalculated. However, we evaluate the remaining 14 countries for all 15 indicators.

Alternatively, we have contemplated an alternative approach involving the distinct evaluation of Argentina, Indonesia, India, Turkey, South Africa, and the European Union.

This distinct assessment would account for the absent data while appropriately excluding indicators for unknown values.

It is worth noting how the evaluation for Turkey is calculated. Due to the absence of data for criterion 13, Turkey's effectiveness is calculated based on the two remaining indicators, specifically 14 and 15. This leads to a recalculation of weights: the weights are recalculated as 0.31 / (0.31 + 0.53) and 0.53 / (0.31 + 0.53), resulting in new weight coefficients of 0.37 and 0.63. For Turkey, three data columns are used: evaluations of the worst-case alternative "a", Turkey's evaluation, and evaluations of the best hypothetical alternative "b".

Verification of the Results using Concordance and $\chi 2$

The coefficient of concordance (W) for Aspect **Green Infrastructure** that contains indicators #13, 14,15 is found to be = 0.55, **indicating the presence of an average degree of consistency of experts' opinions**. The calculated $\chi 2$ is compared with the tabular value for the number of degrees of freedom $K = n$-1 = 3-1 = 2 and at the given significance level $\alpha = 0.05$; furthermore, the calculated $\chi 2$ is 7.69 ≥ the tabular value (5.99146), $W = 0.55$ is not a random value, and therefore the **obtained results make sense and can be used in further research**.

The coefficient of concordance (W) for Aspect **Economic Growth** that contains indicators #10,23 is found = 0.71, indicating the **high degree of consistency** of experts' opinions. The calculated $\chi 2$ is compared with the tabular value for the number of degrees of freedom $K = n$-1 = 2-1 = 1 and at the given significance level $\alpha = 0.05$;

furthermore, the calculated $\chi 2$ is 5 ≥ tabular (3.84146), W = 0.71 is not a random value, and therefore **the obtained results make sense and can be used in further research**.

The coefficient of concordance (W)for **Human Health** that contains indicator #1,2,3,5,9 is found = 0.59, indicating an average degree of consistency in experts' opinion**s**. The calculated $\chi 2$ is compared with the tabular value for the number of degrees of freedom $K = n$-1 = 5-1 = 4 and at the given significance level α = 0.05; furthermore $\chi 2$ calculated 16.46 ≥ tabular (9.48773), W = 0.59 is not a random value, and therefore **the results obtained make sense and can be used in further research.**

The coefficient of concordance (W) **for pollution** that contains indicators #16,19,22,37,38 is found to be=0.39, **indicating the presence of a weak degree of consistency of experts' opinions.** The calculated $\chi 2$ is compared with the tabular value for the number of degrees of freedom $K = n$-1 = 5-1 = 4 and at the given significance level α = 0.05; furthermore, the calculated $\chi 2$ is 10.91 ≥ the tabular value (9.48773), W = 0.39 is not a random value, and therefore **the obtained results make sense and can be used in further research**.

Results

Alternative calculations for G20 Countries

Table 7 below shows the results of the indicators alternatives related to the main cluster A for the g20 group countries, which will assist us in determining the criteria for ranking the ecological security of the countries.

Table 7. Alternative Results for G20 Countries:

Alternatives (G20 for 4 – Aspects)		*Hypothetic Bad Alternative*	*1. Saudi Arabia*	*2. Argentina*	*3. Australia*	*4. Brazil*	*5. Canada*	*6. France*	*7. Germany*	*8. Italy*	*9. Japan*	*10. Indonesia*	*Hypothetic good alternative*
Green Infrastructure	*%*	*0.00%*	*10.90%*	*27.68%*	*21.49%*	*99.30%*	*59.05%*	*27.92%*	*30.14%*	*37.99%*	*17.32%*	*59.86%*	*100%*
	Rank		*20*	*11*	*14*	*1*	*4*	*10*	*9*	*5*	*17*	*3*	
Economic growth	*%*	*0.00%*	*45.20%*	*11.11%*	*24.61%*	*25.94%*	*19.21%*	*29.54%*	*45.15%*	*15.32%*	*18.16%*	*28.34%*	*100%*
	Rank		*3*	*19*	*12*	*11*	*14*	*7*	*4*	*16*	*15*	*10*	
Human Health	*%*	*0.00%*	*25.74%*	*11.21%*	*36.85%*	*42.11%*	*97.67%*	*26.78%*	*26.43%*	*26.93%*	*27.10%*	*15.30%*	*100%*
	Rank		*14*	*19*	*4*	*3*	*1*	*9*	*12*	*7*	*6*	*17*	
Pollution	*%*	*0.00%*	*43.97%*	*56.58%*	*55.94%*	*73.28%*	*50.71%*	*74.08%*	*70.86%*	*64.46%*	*62.21%*	*62.89%*	*100%*
	Rank		*17*	*12*	*13*	*2*	*15*	*1*	*3*	*7*	*9*	*8*	
Combined Results			*0.3052*	*0.3141*	*0.3555*	*0.6219*	*0.5967*	*0.4134*	*0.4113*	*0.4003*	*0.3399*	*0.4215*	*1*
Security Ecological Index percentage			*30.52%*	*31.41%*	*35.55%*	*62.19%*	*59.67%*	*41.34%*	*41.13%*	*40.03%*	*33.99%*	*42.15%*	*100%*
General Rank			*19*	*17*	*11*	*1*	*2*	*5*	*6*	*7*	*14*	*4*	

Alternatives (G20 for 4 – Aspects)		*Hypothetic Bad Alternative*	*11. India*	*12. Mexico*	*13. Russian Federation*	*14. South Africa*	*15. Turkey*	*16. United States*	*17. United Kingdom*	*18. Korea, Rep.*	*19. China*	*20. European Union*	*Hypothetic good alternative*
Green Infrastructure	*%*	*0.00%*	*60.96%*	*22.49%*	*16.89%*	*30.63%*	*30.79%*	*21.17%*	*18.72%*	*11.82%*	*27.58%*	*36.62%*	*100%*
	Rank		*2*	*13*	*18*	*8*	*7*	*15*	*16*	*19*	*12*	*6*	
Economic growth	*%*	*0.00%*	*42.71%*	*14.65%*	*19.67%*	*4.73%*	*28.36%*	*14.58%*	*51.24%*	*44.64%*	*50.91%*	*28.76%*	*100%*
	Rank		*6*	*17*	*13*	*20*	*9*	*18*	*1*	*5*	*2*	*8*	
Human Health	*%*	*0.00%*	*8.76%*	*25.74%*	*44.60%*	*13.20%*	*26.27%*	*29.21%*	*26.71%*	*26.45%*	*25.70%*	*26.82%*	*100%*
	Rank		*20*	*14*	*2*	*18*	*13*	*5*	*10*	*11*	*16*	*8*	
Pollution	*%*	*0.00%*	*48.94%*	*62.01%*	*35.72%*	*11.10%*	*58.79%*	*68.19%*	*67.70%*	*51.15%*	*14.32%*	*66.24%*	*100%*
	Rank		*16*	*10*	*18*	*20*	*11*	*4*	*5*	*14*	*19*	*6*	
Combined Results			*0.3894*	*0.3438*	*0.308*	*0.1833*	*0.4001*	*0.3525*	*0.396*	*0.3248*	*0.3142*	*0.4365*	*1*
Security Ecological Index percentage			*38.94%*	*34.38%*	*30.80%*	*18.33%*	*40.01%*	*35.25%*	*39.60%*	*32.48%*	*31.42%*	*43.65%*	*100%*
General Rank			*10*	*13*	*18*	*20*	*8*	*12*	*9*	*15*	*16*	*3*	

Figure 2 shows diagrams graphically comparing the combined results among G20 countries obtained in Table 7.

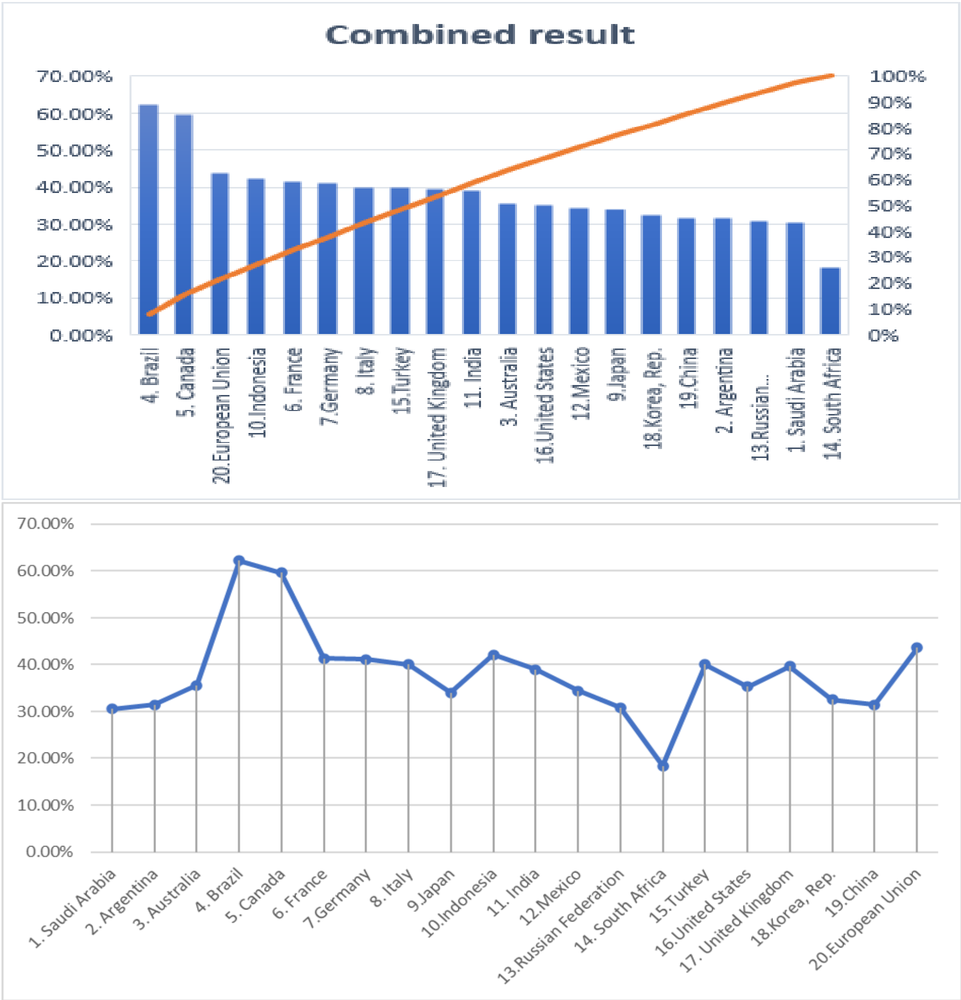

Figure 2. The combined obtained results diagrams.

******Notes*. The value Zero "0" represents zero efficiency. For example, in Saudi Arabia, the indicator " People practising open defecation (% of population)" is"0", which means No implementation of defecation. Regrettably, there is a lack of data available for the 13th, 5th, and 16th indicators, necessitating consideration for their removal. Noticeably, the 5th indicator exhibits the most significant data deficiency. However, eliminating these indicators could potentially mar the integrity of the proposed indicator system.

The Interpretation of the Obtained Results

The object of our analysis was 19 countries plus the European Union, a set comprising the G20 or Group of 20. The alliance has set aims (among others) to address issues of sustainable development and climate change mitigation; ecological security management is an integral part of the aims set.

Measurement of ecological security of the selected countries has led to exciting results, which we will discuss below.

The ultimate results are presented in Figure 2 above. Let us divide all considered countries into several bigger groups: the first group would embrace countries with a relatively best performance. We attribute to these group countries that are remoted from their potential ideal state, or alternative, as we call this state in this research context, by less than 60 per cent. This group consists of just two countries, which have achieved the following results: Brazil nears the ideal state by 62,19 per cent, and Canada nears the ideal alternative by 59,67 per cent, respectively.

The second conditional group will embrace countries that get into the 45 per cent to 40 per cent interval. In our case, this group would consist of the European Union, Indonesia, France, Germany, Italy, and Turkey, which is somewhat surprising that Turkey falls into the group with 40,01 per cent).

The third group countries, which show comparatively worst performance in the area of ecological security, specifically, being below a benchmark of 40 per cent, are the United Kingdom (has reached only 39,60 per cent of the ideal state), the United States, Australia (with 35,55 per cent), China (with the result in the group of 31,42 per cent), then Korea, Saudi Arabia. In contrast, South Africa appears to be the most ecologically insecure country, with 18,33 per cent).

The reasons why countries fell into one or other groups vary since the result is a composite indicator, which we will further call an "index", comprised of selected indicators with different weights. The weights are presented in Table 7.

Let us recall that the index is composed of three groups, with different weights, comprising 100 per cent.

The indicators inside each group have their weights, too, as indicated in Table 7. It is important to emphasise that in the first group countries, Green Infrastructure, the 15th indicator, "CO2 emissions (kg per PPP $ of GDP) "has the most significant weight, i.e. 0,121.

In the second group countries, "Green Economic Growth", the 23rd indicator, "Adjusted net savings, excluding particulate emission damage (% of GNI) "has a higher weight than other indicators in the group and is 0,086. In the third group of countries, which is called "Human Health", the 9th indicator, "Renewable internal freshwater resources per capita (cubic meters) "has an attributed weight of 0,111. In the fourth country, "Pollution "group, the most important indicator is the 19th one, "CO2 emissions (kg per PPP $ of GDP) "with a weight of 0,146, which is the highest among all indicators.

Conclusions

The index composition and weights of indicators within are crucial for understanding why the presented results are of one kind or another.

After calculating the security index of any country, compare the results with the following criteria based on the interpretation of the obtained results to determine the status of the country's ecological security.

If the Index value > 60 %, then the country is considered the **most ecologically secure country.**
The country is considered **ecologically secure if the Index value is 40> Index > 60 %.**
If the Index value is 20 > Index > 40 %, the country is considered **ecologically insecure.**
If the Index value < 20, then the country is considered a most **ecologically insecure country.**

The above instrumental tool will be used to alert insecure countries to mitigate the related threats of this index, leading to a secure region's development. The decision-makers of each country will decide the mitigation actions depending on each country's rules, regulations and policies.

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