Revue d'Economie et de Statistique Appliquée
Volume 22, number 01 , June 2025
ISSN : 1112-234X EISSN : 2600-6642
Pages : 121 - 142

ANALYSIS OF INNOVATION PERFORMANCE IN AFRICAN COUNTRIES: A COMPARATIVE STUDY BETWEEN 2014 AND 2024

[*]**Hadia BRAHIMI**:
National Higher School of Statistics and Applied Economics (ENSSEA),
Laboratory for Applied Quantitative Economics to Development (Algeria).
Email : brahimi.hadia@learning.enssea.edu.dz

Reçu le: 28 /12 /2024 **Accepté le :** 13 /04 /2025 **Publication en ligne le**: 03/06/2025

ABSTRACT:
This study aims to analyze the innovation performance of African countries for the years 2014 and 2024 by evaluating the changes that occurred during this period. A descriptive-analytical approach, complemented by principal component analysis and clustering analysis was applied to the innovation performance indices and conducted using R-studio software. The study's findings revealed a significant difference in the global innovation index scores of African countries between 2014 and 2024. Additionally, two distinct clusters were identified: one comprising of developing economies facing persistent structural challenges, and the other including countries with more established innovation systems and infrastructure. These results support the confirmation of the two hypotheses formulated for this study.

Key words: Performance, Innovation, Africa, Indices, Clustering

I INTRODUCTION

Innovation serves as a strategic lever for the development and competitiveness of nations in an increasingly globalized world. It enables countries to enhance their international standing and address complex challenges such as ecological transition, digitalization, and sustainable development. Furthermore, innovation determines the strength of economies and their competitive advantage, to which it is positively linked.

In developed economies, innovation acts as a key driver for maintaining a competitive edge through substantial investments in research and development, advanced education systems, and entrepreneurship-friendly ecosystems. In emerging economies, innovation is seen as an opportunity for technological catch-up and economic diversification, helping to reduce reliance on primary sectors like agriculture and extractive industries.

[*]Hadia BRAHIMI

Innovation performance can be measured through composite indices that evaluate economies' ability to generate and adopt innovations. Among the most recognized tools is the "Global Innovation Index," which includes multiple indicators covering different dimensions, providing a comprehensive overview of the strengths and weaknesses of nations' innovation systems while enabling international comparisons.

Between 2014 and 2024, many countries made notable progress driven by policy reforms, investments in infrastructure, education, and research, as well as the rise of digital technologies. However, some countries experienced stagnation or regression, often due to a lack of structural reforms or heavy dependence on primary sectors with limited innovation potential. Africa, with its diverse economies, offers a strategic ground for studying innovation performance. Analyzing the innovation landscape in African countries helps uncover their potential and track their progress in an increasingly competitive world. This research is positioned within this context and seeks to answer the following central question:

To what extent has the innovation performance of African countries evolved between 2014 and 2024?

To address this primary question, the following sub-questions are considered:

- Is there a difference in the Global Innovation Index for African countries between 2014 and 2024?
- What are the clusters of African countries exhibiting similar innovation performance characteristics in the two periods studied?

Hypotheses:

- There is a significant difference in the Global Innovation Index for African countries between 2014 and 2024.
- African countries can be grouped into two main clusters: one representing economies with advanced structures and innovation performance, and the other consisting of countries with less developed infrastructure and innovation capacities.

The objectives of the study:

The main objective of this study is to analyze the innovation performance of African countries for the years 2014 and 2024. Specific objectives include:

- Classifying African countries based on innovation indices.
- Comparing the innovation performance of African countries between 2014 and 2024.

This study is of particular importance as it identifies key developments and provides insights into future strategies to strengthen innovation performance in Africa.
To achieve the objectives of this study and answer the posed questions, a descriptive and analytical approach was adopted, analyzing the innovation performance indices of African countries for the years 2014 and 2024. Other statistical methods were also employed, including Principal Component Analysis and classification using the k-means method, through the RStudio statistical software.
To address the issue of this study, a theoretical section was first developed, presenting previous research on innovation performance as well as an overview of innovation performance indices. The practical section was then introduced, aimed at answering the main question and sub-questions of this research through the analyses conducted.

II LITERATURE REVIEW:

Numerous studies have focused on the concept of innovation. Among them, we can mention:
The study by Juracka Denis et al. (2024), which aimed to assess the performance of European countries in eco-innovation by analyzing their progress from 2013 to 2022 to identify trends, leaders, and opportunities for improvement in implementing eco-innovation strategies. It relied on various tools, such as graphical maps, cluster analysis, and correspondence analysis, conducted using SPSS software. The results showed that, since 2013, all the countries studied, except Romania, had improved their scores. Northern European countries, notably Luxembourg, Austria, Finland, Sweden, and Denmark, stood out by achieving the best long-term results, positioning themselves as leaders in innovation. In contrast, Bulgaria remained at the bottom of the ranking for several years.
The study by Mahmood Haji-Rahimi (2024), aimed to examine the factors influencing the development of a knowledge-based economy in Iran, by focusing on the analysis of the innovation index, which included seven main sub-indices. The results revealed that Iran ranks low for indicators related to institutions and business complexity, with equally a weak performance in market complexity. However, the country excels in the fields of human capital and research. Although Iran has notable strengths for knowledge-driven initiatives, it faces structural obstacles in creating an environment conducive to advanced innovation and broader economic growth.
The study by Ceko et al. (2024), which aimed to analyze the relationship between the innovation index and the global B2C e-commerce index. It used descriptive and interdisciplinary methods. An exploratory approach based on correlation and regression analysis was employed to evaluate this relationship. The results showed that the links between innovation and B2C e-commerce are statistically significant and strong. This indicates that, to gain a competitive advantage, successful companies should invest in innovation, e-commerce, and quality management.
The study conducted by Zuzanna Ostrazewska and Agnieszka Tylec (2024) aimed to analyze the innovation profile of Poland in comparison with the European Union countries. It was based on the synthetic innovation index. The goal was to position the Polish economy on the

European innovation map. The results showed that Poland stands out mainly in three areas: the use of information technologies, intellectual assets, and digitization. However, although these are the country's best performances, they remain insufficient to classify Poland as an innovative or knowledge-based economy.
The study by Kotarina Janoskova and Pavol Kral (2019) aimed to analyze the influence of innovation indicators on the creation of value for the global innovation index. The study focused on the national innovation systems of the Visegrad Group (V4) countries: Poland, Hungary, the Czech Republic, and Slovakia. Its goal was to identify the strengths and potential weaknesses of each country in this area and assess how they influence their innovation position. The results highlighted that several indicators have a significant impact on the innovation index in each country. For instance, employment emerged as a key area for Poland, Slovakia, and Hungary, while business investments dominate in the Czech Republic. Additionally, the study identified similarities between Slovakia and the Czech Republic, as well as between the latter and Hungary.

The current study, in line with previous research on innovation performance analysis, is unique in its focus on African countries, covering a sample of 30 countries for the years 2014 and 2024. It aims to identify changes in innovation performance in these countries over time.

III OVERVIEW OF THE INNOVATION PERFORMANCE :

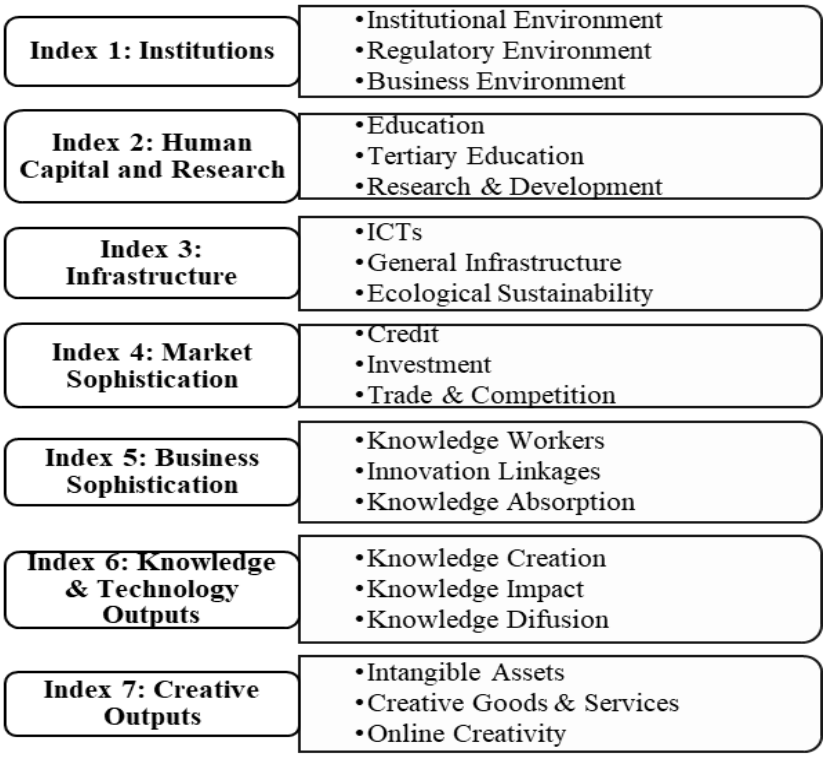
According to the definition by the Organisation for Economic Co-operation and Development (OECD), innovation performance refers to the implementation of new products, processes, marketing methods, or organizational practices in business activities. It encompasses any initiative aimed at introducing innovations in products or services, production processes, marketing strategies, and management systems. This concept includes both technological changes and process revisions aimed at improving efficiency, meeting market needs, and enhancing the competitiveness of the company in an ever-evolving environment[1].Thus, innovation performance can be understood as the ability to transform innovation inputs into tangible outcomes, and therefore the ability to convert skills and innovation efforts into market applications. The success of this innovative performance is reflected in the commercial success of the innovation. It encompasses all stages of measuring innovation, from research and development (R&D) to patent filings and the introduction of new products[2].The innovation performance of countries represents a crucial measure of the innovative capabilities and achievements of various countries around the world, reflecting their economic and political environments. It takes into account factors such as institutions,

[1] AL-Khatib, Ayman Wael. « Intellectual Capital and Innovation Performance: The Moderating Role of Big Data Analytics: Evidence from the Banking Sector in Jordan ». *EuroMed Journal of Business* 17, nº 3 (16 août 2022): 391-423. P. 393. https://doi.org/10.1108/EMJB-10-2021-0154.
[2] Zizlavsky, Ondrej. « Innovation Performance Measurement: Research into Czech Business Practice ». *Economic Research-Ekonomska Istraživanja* 29, nº 1 (janvier 2016): 816-38. P. 818. https://doi.org/10.1080/1331677X.2016.1235983.

human capital, research, infrastructure, market sophistication, and business sophistication, and is measured through the Global Innovation Index[3].

According to the report by the World Intellectual Property Organization (WIPO) published in 2014, the Global Innovation Performance Index is measured by 21 sub-indices grouped into 7 indices, of which, five represent the sub-indices of innovation inputs and two represent the sub-indices of innovation outcomes. The figure below illustrates these indices:

Figure 1: Innovation performance indices and their sub-indices



Source: Created by the author based on the 2014 report of the World Intellectual Property Organization. https://www.wipo.int/edocs/pubdocs/en/economics/gii/gii_2014.pdf

Index 1: Institutional Environment

This index evaluates the institutions of a country. It measures the country's ability to attract businesses and promote growth through good governance. It consists of the following sub-indices:

- **Institutional Environment**: It measures the stability of the government, the quality of

[3] Leogrande, Angelo. « The Global Innovation Index ». Zenodo, 31 juillet 2024. https://doi.org/10.5281/ZENODO.13142578.

public and administrative services, as well as the ability of authorities to develop and implement effective policies.
- **Regulatory Environment**: It assesses the ability of authorities to design and implement consistent policies that promote the development of the private sector while ensuring respect for the rule of law. It also considers the costs associated with economic layoffs, expressed in weeks of salary, including notice periods and severance pay.
- **Business Environment**: It focuses on three aspects that directly influence private environmental initiatives through World Bank indicators, on the ease of starting a business, resolving insolvencies, and paying taxes.

Index 2: Human Capital and Research

This index measures the human capital of countries and it is composed of three sub-indices:
- **Education**: It measures the outcomes of primary and secondary education, based on indicators such as public expenditure on education, expected years of schooling, and the student-teacher ratio.
- **Tertiary Education**: It measures the enrollment rate in higher education, which is important for the advancement of economies, with priority given to disciplines related to innovation.
- **Research and Development**: This sub-index aims to reflect the presence of quality institutions in each economy, without assessing all institutions. It measures the level and quality of research and development activities through indicators such as the number of researchers, total R&D expenditure, and the quality of scientific institutions, assessed by the ranking of the best global universities.

Index 3: Infrastructure

This is a composite measure that evaluates the infrastructure aspect of a country, which is essential for supporting innovation. It consists of[4]:
- **ICTs**: It includes four indicators developed by international organizations, measuring internet penetration, availability of fiber optics, mobile network coverage, and the adoption of information and communication technologies by businesses and citizens, as well as the quality and accessibility of these services, which are fundamental for developing innovation capacities.
- **General Infrastructure**: This is a composite indicator of logistics performance and gross fixed capital formation, including investments in fixed assets and land improvements. High-quality general infrastructure is essential for an innovative economy, as it facilitates the production, distribution, and sale of goods and services both within and outside a country.
- **Ecological Sustainability**: Ecological sustainability evaluates a country's policies that

[4] Leogrande, Angelo. « The Infrastructure Index at Global Level ». Zenodo, 24 août 2024. P. 01. https://doi.org/10.5281/ZENODO.13368241.

promote a sustainable economy, the use of renewable energy, and the management of natural resources. It is measured by GDP per unit of energy used (energy efficiency), the environmental performance index, and the number of ISO 14001 certifications related to environmental management systems.

Index 4: Market Sophistication

It is measured through the following sub-indices:
- **Credit**: It measures the ease of access to credit by assessing how well laws on collateral and bankruptcy facilitate lending by protecting the rights of borrowers and lenders, as well as the rules and practices influencing the coverage, scope, and accessibility of credit information.
- **Investment**: Investment in the context of the Global Innovation Index refers to all resources allocated by a country or company to support innovation. It includes an indicator on investor protection, as well as three indicators on the level of transactions. It helps understand a nation's ability to foster and maintain an environment conducive to innovation by evaluating not only the results in terms of patents, new products or services but also the investments needed to create these results[5].
- **Trade and Competition**: This measures trade and competition and it is assessed through two indicators: the average import tariff rate and the access to foreign markets for non-agricultural products. A third indicator, based on a survey, measures the competitiveness of local markets.

Index 5: Business Sophistication

This pillar aims to assess the level of sophistication of businesses to determine how much they stimulate innovation. Companies enhance their productivity, competitiveness, and innovation potential by employing highly skilled professionals and technicians. Human capital plays a key role in this pillar. It is composed of three sub-indices:
- **Knowledge Workers**: Knowledge workers are highly skilled professionals whose primary contribution to the economy lies in their ability to generate, manage, and apply knowledge[6]. This pillar is measured in knowledge-intensive services, the availability of formal training within companies, the share of research and development conducted by businesses in the GDP, and the financing of R&D expenditures by companies.
- **Innovation Linkages**: This refers to the degree of connection and collaboration between the different actors of a country's innovation system. It relies on both qualitative and quantitative data, collaboration between businesses and universities in R&D, the existence of well-developed clusters, and the funding of R&D, as well as the number of strategic partners, in addition to international patents. Innovation linkages are fundamental because

[5] Leogrande, Angelo. « Investments in the Global Innovation Index ». Zenodo, 17 septembre 2024. https://doi.org/10.5281/ZENODO.13776819.
[6] Leogrande, Angelo. « Knowledge Workers in the Global Innovation Index ». Zenodo, 29 septembre 2024. https://doi.org/10.5281/ZENODO.13857471.

they promote the exchange of knowledge, resources, and skills, which are essential to improving economic competitiveness[7].
- **Knowledge Absorption**: This pillar reflects a country's capacity to absorb and diffuse knowledge. It evaluates a country's ability to acquire, integrate, and use knowledge, whether internal or external, to improve its innovation potential. It takes into account elements such as royalty and license payments, high-tech imports, communication services, and incoming foreign direct investments. This indicator is crucial as it shows how an economy can absorb new technologies, ideas, and know-how from abroad and use them effectively to foster economic and technological development[8].

Index 6: Knowledge and Technology Outputs

This pillar is part of the outcomes of innovative activities within the economy, encompassing variables considered the fruits of inventions or innovations.
- **Knowledge Creation**: It includes these indicators derived from inventive and innovative activities, such as patent applications filed nationally and internationally, utility models, scientific and technical articles published in peer-reviewed journals, and articles from an economy that has received at least H citations.
- **Knowledge Impact**: This indicator measures the effect of innovation and generated knowledge on the economy and society. It evaluates how the results of research, technology, and innovation impact the economic and social development of a country, going beyond the mere creation of new knowledge[9]. It considers net outflows of foreign direct investments as a percentage of GDP.
- **Knowledge Diffusion**: This is a key indicator to assess a country's openness and its ability to integrate and use innovation, thus contributing to global economic progress and increased competitiveness[10]. It is based on knowledge diffusion, which is the inverse reflection of the knowledge absorption sub-index from Index 5. It includes four indicators:

- Royalties and license receipts as a percentage of total trade;
- High-tech product exports;
- Exports of communication and information technology services as a percentage of total trade;
- Net outflows of foreign direct investments as a percentage of GDP.

Index 7: Creative Outputs

[7] Leogrande, Angelo. « Innovation linkages at the global level ». Zenodo, 27 août 2024. https://doi.org/10.5281/ZENODO.13381639.
[8] Leogrande, Angelo. « Knowledge Absorption at a Global Level ». Zenodo, 23 septembre 2024. https://doi.org/10.5281/ZENODO.13826421.
[9] Leogrande, Angelo. « Knowledge Impact in the Global Innovation Index ». Zenodo, 29 septembre 2024. https://doi.org/10.5281/ZENODO.13857383.
[10] Leogrande, Angelo. « Knowledge Diffusion in the Global Innovation Index ». Zenodo, 27 septembre 2024. https://doi.org/10.5281/ZENODO.13851898.

The Global Innovation Index highlights creativity as a key component of its innovation output sub-index. It focuses on creative results and includes three sub-indices:
- **Intangible Assets**: This includes statistics on trademark applications filed by residents with national offices, as well as surveys on the use of information and communication technologies in business and organizational models. It also covers areas related to process innovations, intellectual property, patents, industrial designs, copyrights, and even technical and organizational skills. These sub-indicators are analyzed to understand how a country can transform intellectual and creative capital into tangible and marketable innovations[11].
- **Creative Goods and Services**: This measures the creative outputs of an economy through indicators such as national film production per capita, exports of cultural goods and services, advertising, market research, and cultural information services.
- **Online Creativity**: This includes indicators such as top-level domains (.com, .org), contributions to Wikipedia, and videos uploaded to YouTube, adjusted for the population aged 15 to 69.

IV RESEARCH METHODOLOGY:

The methodology of this study can be summarized in these two points:

IV.1. Data Presentation:

The data used in this study primarily consists of the scores of the indices that make up the Global Innovation Index, published by the World Intellectual Property Organization in its annual reports for 2014 and 2024, the two periods of interest. These indices, which form the variables of our study, numbered seven in total, with 21 indicators.
The data also includes observations represented by African countries, our area of interest. We selected 30 countries after excluding certain countries due to the absence of innovation index data for both periods.

IV.2. Analysis Methods:

To meet our research objectives, we chose a descriptive analytical approach, using various specific analysis tools through the statistical software RStudio:
- **Descriptive Analysis of Global Innovation Index**: This approach offers an essential perspective on the changes in the Global Innovation Index scores of African countries for the years 2014 and 2024.
- **Principal Component Analysis (PCA)**: PCA, a multivariate analysis method, will be used to visualize the countries in our study in a two- or three-dimensional space. This will facilitate the interpretation of the relationships between countries in terms of innovation performance.

[11] Leogrande, Angelo. « Intangible Assets at a Global Level ». Zenodo, 8 septembre 2024. https://doi.org/10.5281/ZENODO.13732206.

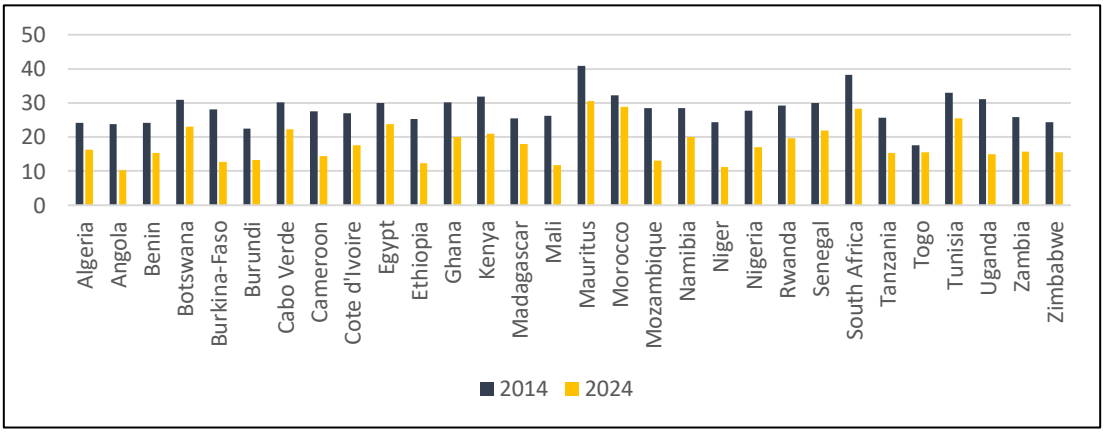
- **Clustering Analysis**: Clustering, an unsupervised learning method, will be used to group African countries into homogeneous clusters in terms of innovation performance. This approach will help identify groups of countries with similar characteristics, enabling a deeper analysis of differences and similarities in their innovation performance.

V PRESENTATION AND ANALYSIS OF THE STUDY RESULTS:

V.1. Evolution of the "global innovation" index Between 2014 and 2024:

The figure below illustrates this evolution for each country in the study sample (African countries).

Figure 2: Changes in the global index of innovation between 2014 and 2024



Source: Created by the author using Excel 2019 software

According to the bar chart presented above, it can be observed that Mauritius held the top position in the global innovation index in 2014, followed by South Africa and Tunisia. By 2024, Mauritius remains in the first position, but is now followed by Morocco and South Africa. However, a negative trend has been observed for all the African countries in our sample. The most significant decline was recorded by Uganda, while the smallest decrease was observed in Tanzania.

This chart also shows notable differences between the scores recorded in 2014 and 2024. To statistically analyze these differences and check their significance, it would be appropriate to use a statistical test, specifically the paired sample t-test. This test will help determine whether the variations observed between these two periods are statistically significant, and whether the performance gaps in innovation between 2014 and 2024 reflect real changes or are simply due to random fluctuations.

The first condition for applying this test is that the sample size must be at least 30, which is met in our study. However, the second condition, concerning the normality of the data representing the difference between the global innovation index scores of 2014 and 2024, still needs to be verified.

H0: The data follow a normal distribution.
H1: The data do not follow a normal distribution.

The Kolmogorov-Smirnov normality test applied to these data provided the following results:

Table 1: Results of the Kolmogorov Smirnov test

		différence
N		30
Paramètres normaux[a,b]	Moyenne	-9,9873
	Ecart-type	3,29334
Différences les plus extrêmes	Absolue	0,130
	Positive	0,129
	Négative	-0,130
Z de Kolmogorov-Smirnov		0,712
Signification asymptotique (bilatérale)		**0,691**

Source: Created by the author using SPSS 20

It is observed that the Kolmogorov-Smirnov test value is 0.712 with a p-value of 0.691, which is greater than the significance threshold of 5%. This indicates that the data follow a normal distribution. Therefore, the paired t-test can be applied.

H0: There are no statistically significant differences at the 5% level in the global innovation indices of African countries between 2014 and 2024.
H1: There are statistically significant differences at the 5% level in the global innovation indices of African countries between 2014 and 2024

Table 2: Results of the paired T -test for two samples

	Mean	SD	SE	T Test	ddl	GIG
Global index 2014-Global index 2024	9.987	3.29334	0.60128	16.610	29	**0.000**

Source: Created by the author using R studio software

It is observed that the value of the paired t-test statistic is 16.610, with a significance value of 0.000, which is lower than the 5% threshold. This leads to the rejection of the null hypothesis (H0) and the acceptance of the alternative hypothesis (H1). Therefore, it can be concluded that there are statistically significant differences between the innovation index scores from 2014 to 2024.

V.2. Principal Components Analysis :

To better visualize the observations (countries in the region) and variables (Innovation indices) over the two periods studied, it is important to carry out two separate analyses: one for the 2014 data and the other for the 2024 data.

V.2.1. Principal Component Analysis of Innovation Performance Indices in 2014:

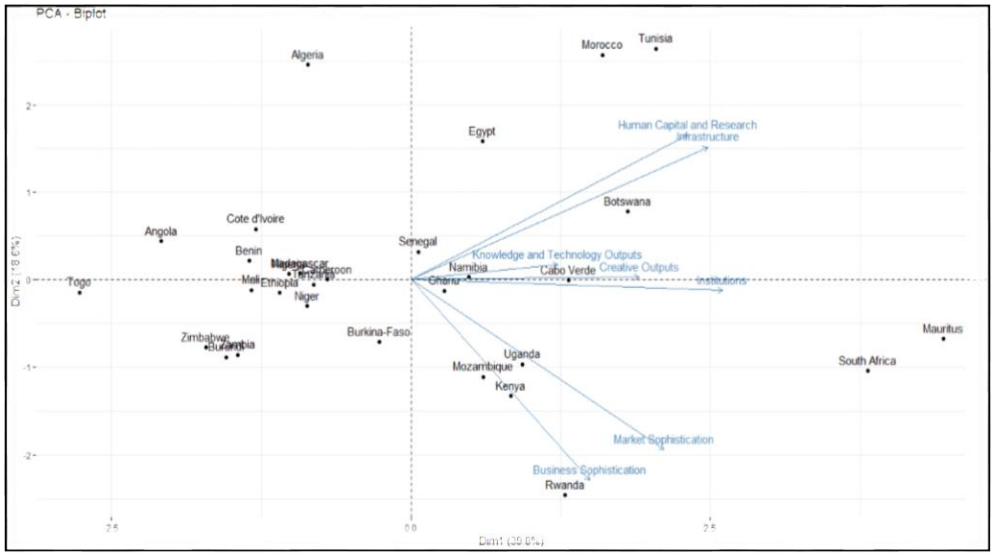
From the eigenvalue table presented below, the analysis focuses on the first two components, as the inertia percentage is 58.4%. This means that the first principal component explains 58.4% of the total information.

Table 3 : Eigenvalues from PCA for 2014 data

	Pca 1	Pca 2	Pca 3	Pca 4	Pca 5	Pca 6	Pca 7
Standard deviation	1.6687	1.1414	0.9659	0.8786	0.7346	0.6132	0.5403
Proportion of variance	0.3978	0.1861	0.1333	0.1103	0.0771	0.0537	0.0417
Cumulative proportion	0.3978	0.5839	0.7172	0.8275	0.9046	0.9583	1

Source: Created by the author using R-studio

Figure 3: Graphical representation of countries and indices - 2014



Source: Created by the author using Rstudio

According to the graphical representation presented above, the first axis explains 39.78% of the total inertia, corresponding to the largest eigenvalue, which is 1.667.
Regarding the quality of the representation of the variables, we note that all of them are positioned on the same side of axis 1, indicating that they contribute in the same direction to

the formation of this axis. Furthermore, there is a notable positive correlation between the indices "Human capital and research" and "Infrastructure," as well as between "Market sophistication" and "Business sophistication," showing the existence of an important relationship between these variables. The variables that contribute most strongly to this axis are "Institutions," "Infrastructure," "Human capital and research," and "Market sophistication."

When analyzing the individuals (the African countries in the study), axis 1 divides these countries into two distinct groups. On one side, the countries positioned on the positive side of the axis, which contribute strongly to it, are: Mauritius, South Africa, Tunisia, and Botswana. These countries stand out for their high values in the indices "Institutions," "Infrastructure," "Human capital and research," and "Market sophistication." On the other side, the countries located on the negative side of the axis, such as Togo and Angola, exhibit significant weaknesses in these same indices.

Thus, axis 1 highlights a key dimension of innovation related to structural and organizational factors. The countries that contribute most to this axis are those that have established a solid foundation in terms of institutions, infrastructure, human capital, research, and market sophistication, thereby fostering innovation performance.

The second axis, in turn, explains 18.61% of the total inertia and corresponds to the second eigenvalue, which is 1.141. On this axis, Tunisia, Morocco, and Egypt stand out for their high scores in the indices "Human capital and research" and "Infrastructure," reflecting their positive contribution to this axis. In contrast, they show low scores in the indices "Business sophistication" and "Market sophistication". On the opposite side, Rwanda and Kenya are characterized by high scores in "Human capital and research" and "Infrastructure," contributing strongly to the negative side of axis 2.

Thus, the positive side of axis 2 can be interpreted as representing an innovation model based on fundamental structural factors, such as education, scientific research, and infrastructure. In contrast, the negative side illustrates an innovation model relying more on the sophistication of markets and businesses.

V.2.2. Principal Component Analysis of Innovation Performance Indices In 2024:

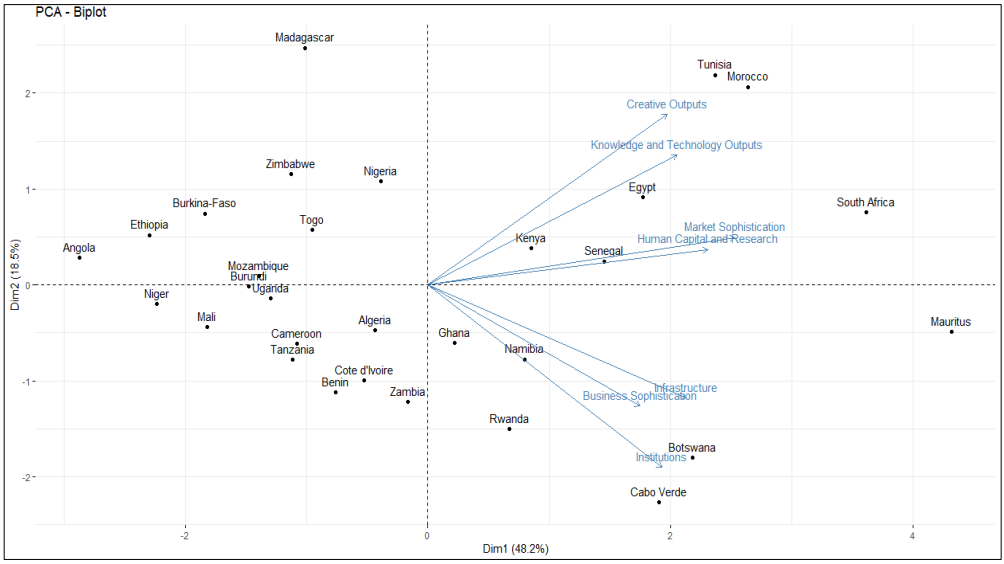
Based on the eigenvalue table presented below, the analysis focuses on the first two components, as the inertia percentage is 66.66%. This means that the first plane explains 66.66% of the total information.

Table 4 : Eigenvalues from PCA for 2024 data

	Pca 1	**Pca 2**	**Pca 3**	**Pca 4**	**Pca 5**	**Pca 6**	**Pca 7**
Standard deviation	1.8360	1.1382	0.8399	0.7646	0.6234	0.6015	0.5416
Proportion of variance	0.4815	0.1851	0.1008	0.0835	0.0555	0.0517	0.0419
Cumulative proportion	0.4815	0.6666	0.7674	0.8509	0.9064	0.9581	1

Source: Created by the author based on results extracted from the Rstudio software

Figure 4 : Graphical representation of countries and indices - 2024



Source: Created by the author using Rstudio software

According to the graphical representation presented, the first axis explains 48.15% of the total inertia, meaning it captures nearly half of the information contained in the data. All the variables contribute in the same direction to the formation of this axis, as they are positioned on the same side of axis 1. Furthermore, there is a notable positive correlation between 'Infrastructure' and 'Institutions' on the one hand, and between 'Market sophistication' and 'Human capital and research' on the other, indicating a strong relationship between these variables. The most significant contributions to this axis come from 'Market sophistication' and 'Human capital and research.'

Regarding the countries, those that contribute positively to this axis include Mauritius, South Africa, Morocco, and Tunisia. These countries stand out for their high scores in the indices 'Market sophistication' and 'Human capital and research,' reflecting structured and dynamic economies with sophisticated markets supporting investment, entrepreneurship, and human capital development through investments in education and research. In contrast, Ethiopia and Niger, located on the negative side of the axis, have low scores in these same indices, indicating unsophisticated markets, difficulties in mobilizing financial resources, and a lack of human capital, reflecting deficiencies in education systems and research and development capacities.

Thus, axis 1 reflects a contrast between innovative countries with advanced economies and structurally fragile countries. Furthermore, it provides a global measure of the level of innovation development in African countries.

The second axis, in turn, explains 18.51% of the total inertia, corresponding to an eigenvalue of 0.1851. On this axis, Madagascar, Tunisia, and Morocco stand out for their high scores in

the indices 'Knowledge and technology outputs' and 'Creative outputs,' reflecting their positive contributions. These countries showcase concrete and visible results in innovation, whether through patents, technological applications, or creative productions such as cultural content and publications.

In contrast, Botswana, Rwanda, Zambia, and Cabo Verde, located on the negative side of this axis, have good scores in 'Institutions' but low scores in 'Knowledge and technology outputs' and 'Creative outputs'. This reflects an innovation model more focused on structural strength and institutional policies, but with a low realization of innovative results.

In summary, axis 2 differentiates countries based on their tangible results in innovation (both technological and creative) and their ability to materialize performance, compared to those whose strengths mainly lie in solid institutional foundations but are less productive in terms of innovation outputs.

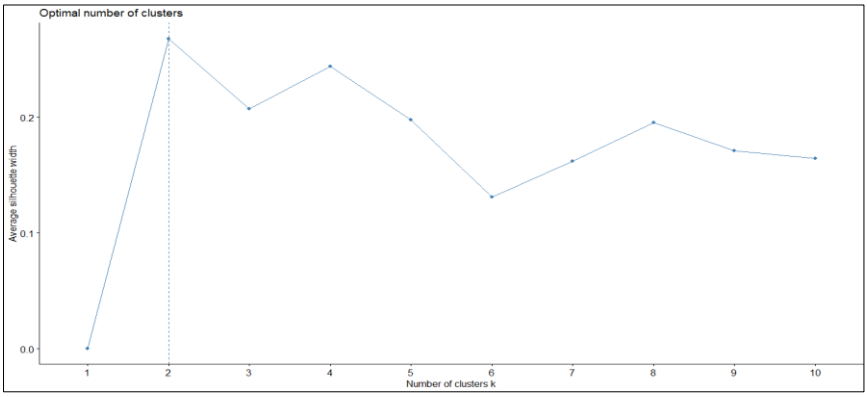
V.3. Clustering Analysis:

The method used to create homogeneous clusters of countries in terms of innovation performance for the periods 2014 and 2024 is K-means clustering method.

V.3.1. Clustering Analysis for The Year 2014:

To choose the optimal number of clusters, the silhouette index was used, and the results of this index for the 2014 data are presented in the graphic below:

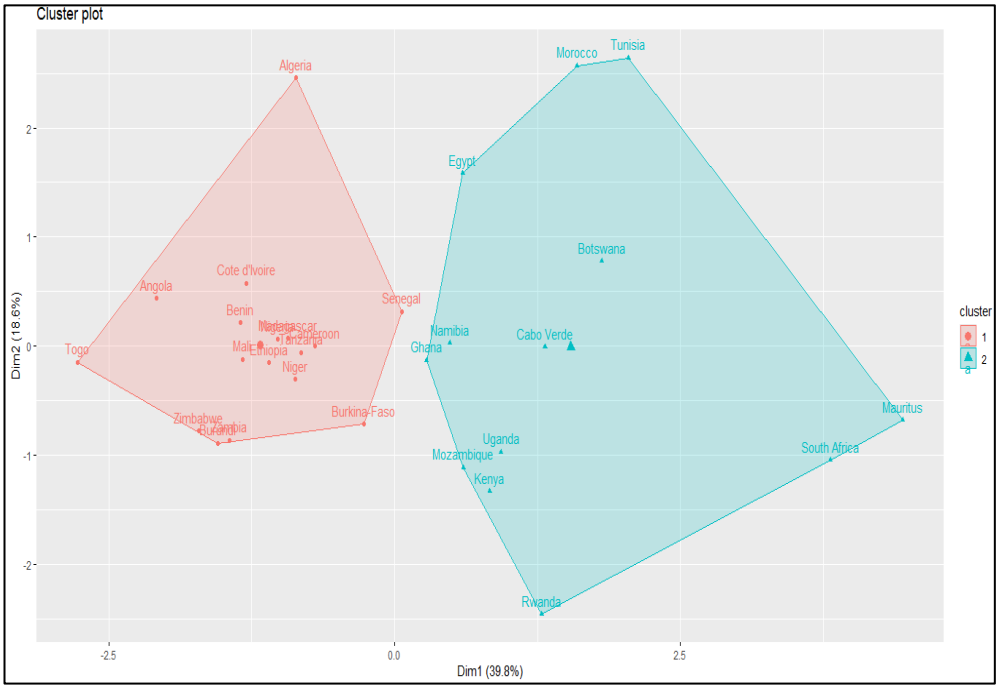
Figure 5 : Optimal number of clusters according to the Silhouette index - 2014



Source : Created by the author using Rstudio

The silhouette index scores indicate that the optimal number of clusters is two. The grouping of countries within each cluster is illustrated below:

Figure 6 : Visualization of clusters from the k-means method - 2014



Source: Created by the author using Rstudio

The clustering analysis revealed that the African countries representing the sample of the study are divided into two clusters in terms of innovation performance in 2014. These clusters are:

Cluster 1: This cluster includes Algeria, Angola, Benin, Burkina Faso, Burundi, Cameroon, Ivory Coast, Ethiopia, Madagascar, Mali, Niger, Nigeria, Senegal, Tanzania, Togo, Zambia, and Zimbabwe. Some of these countries share similar socio-economic, institutional, or infrastructural characteristics. These countries might be characterized by:

- Developing economies with less advanced or diversified structures.
- Medium to low levels of innovation and market sophistication.
- Limited infrastructures or underdeveloped educational and research systems. In general, this cluster could represent countries facing significant structural challenges, particularly in terms of investing in human capital, strengthening infrastructures, and mobilizing resources to support innovation.

Cluster 2: This cluster includes the following countries: Tunisia, Morocco, Uganda, South Africa, Namibia, Mozambique, Mauritius, Kenya, Ghana, Egypt, Cabo Verde, Botswana, and Rwanda, which appear to share more favorable socio-economic and institutional characteristics. These countries might be characterized by:

- Diversified economies and stronger integration into regional or global trade.
- Relatively developed infrastructures and well-established educational and research systems.
- Higher innovation capacity, with a dynamic entrepreneurial environment and increased market sophistication.
- Stronger governance and institutions, facilitating a climate conducive to growth and investment. In general, this cluster could represent countries that have successfully leveraged their resources to build solid foundations in innovation, economic development, and infrastructure.

To compare between the two clusters, we can rely on the averages of each innovation performance index from 2014, presented in the table below

Table 5 : The means of the variables (innovation performance indices) for each cluster in 2014

	Index 1	**Index 2**	**Index 3**	**Index 4**	**Index 5**	**Index 6**	**Index 7**
Cluster 1	48.21	14.25	21.96	41.72	24.00	20.34	20.75
Cluster 2	60.49	23.77	31.04	48.92	29.13	23.35	27.05

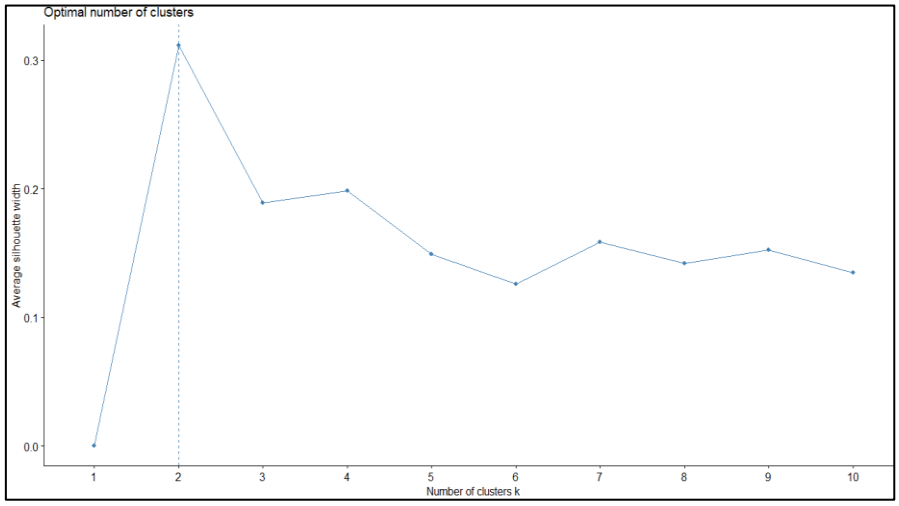
Source : Created by the author based on the results of the study

According to the presented results, Cluster 2 shows significantly higher averages for all the innovation performance indices compared to Cluster 1. This suggests that Cluster 1 includes developing countries that need to intensify their efforts to strengthen their infrastructures, invest more in education and research, and diversify their economies. In contrast, Cluster 2 includes countries characterized by strong institutional foundations, more sophisticated markets, and a better capacity to produce innovative results compared to the countries in Cluster 1.

V.3.2. Clustering Analysis for The Year 2024:

To choose the optimal number of clusters, the silhouette index was used, and the results for the 2024 data are presented in the graphic below:

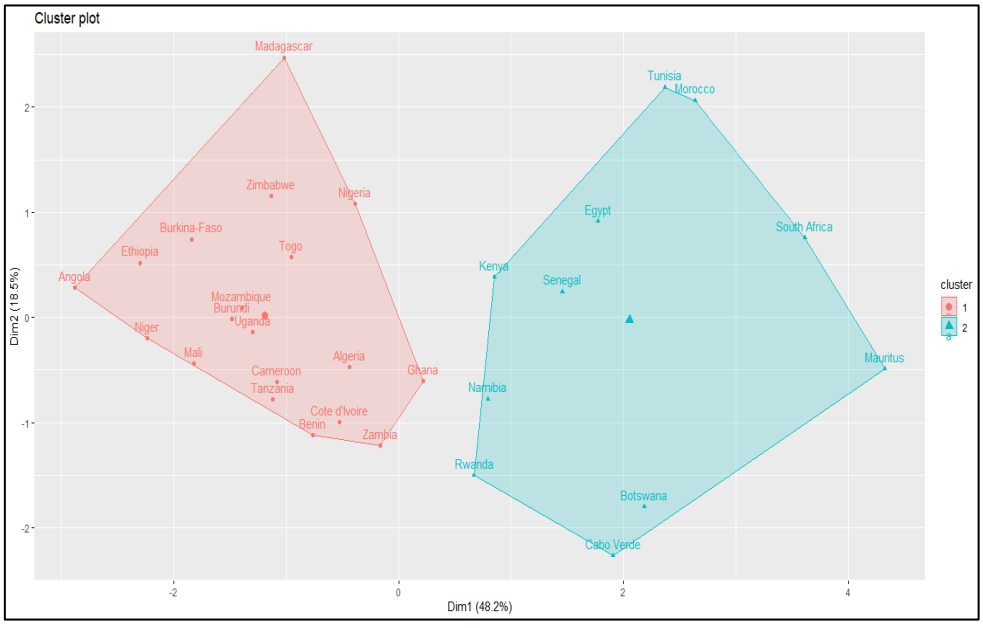
Figure 7 : Optimal number of clusters according to the Silhouette index - 2024



Source: Created by the author using Rstudio

The silhouette index scores indicate that the optimal number of clusters. The grouping of countries within each cluster is illustrated in the figure below:

Figure 8 : Visualization of clusters from the K-means method – 2024



Source: Created by the author using Rstudio software

Cluster 1: This group includes countries such as Madagascar, Nigeria, Ghana, Zambia, Algeria, Benin, Ivory Coast, Togo, Zimbabwe, Burkina Faso, Ethiopia, Angola, Niger, Mali, Cameroon, Tanzania, Mozambique, Burundi, and Uganda. These countries share common characteristics that reflect structural challenges or similar levels of development. This cluster could be characterized by:

- Limited infrastructures, although some improvements may be underway.
- Less efficient educational and research systems, hindering their ability to innovate.
- Low market sophistication, limiting investments and entrepreneurship.
- Economic dependence on primary sectors such as agriculture, mining, or oil extraction. In summary, this cluster includes countries that still require significant investments in strengthening their structural and organizational foundations to improve their innovation and economic competitiveness performance.

Cluster 2: This group includes countries such as Tunisia, South Africa, Mauritius, Senegal, and others. These countries stand out due to more favorable characteristics, such as:

- Relatively developed infrastructures, promoting connectivity and economic growth.
- Better established educational and research systems, supporting higher innovation capacity.
- Increased market sophistication, facilitating investments, entrepreneurship, and the development of new economic sectors.
- Stronger institutions, enhancing governance and economic stability. This cluster thus includes countries that have built solid foundations in terms of innovation and exhibit superior economic and structural performance compared to the countries in Cluster 1.

To compare the two clusters, we can refer to the averages of each innovation performance index for 2024, as presented in the table below:

Table 6 : The means of the variables (innovation performance indices) for each cluster in 2024

	Index 1	**Index 2**	**Index 3**	**Index 4**	**Index 5**	**Index 6**	**Index 7**
Cluster 1	31.61	15.98	22.28	14.26	17.12	9.36	9.14
Cluster 2	48.47	25.27	32.96	28.81	20.95	16.41	17.27

Source: Created by the author based on the results of the study

According to the presented results, Cluster 2 shows significantly higher averages for all innovation performance indices, particularly for 'Knowledge & technology outputs' and 'Creative outputs,' compared to Cluster 1. This suggests that Cluster 1 includes developing countries, facing significant structural challenges, requiring increased efforts to strengthen their infrastructures, develop human capital, and diversify their economies. Moreover,

Cluster 2 represents more advanced countries, with the ability to generate innovative results and maintain sustainable economic competitiveness.

V.3.3. Analysis of Changes in Clusters Between 2014 and 2024:

According to the presented results, Cluster 2 shows significantly higher averages for all innovation performance indices, particularly for 'Knowledge & technology outputs' and 'Creative outputs,' compared to Cluster 1. This suggests that Cluster 1 includes developing countries, facing significant structural challenges, requiring increased efforts to strengthen their infrastructures, develop human capital, and diversify their economies. Moreover, Cluster 2 represents more advanced countries, with the ability to generate innovative results and maintain sustainable economic competitiveness.

VI CONCLUSION:

At the conclusion of this study on the analysis of innovation performance indices in 30 African countries, several conclusions can be drawn. First, the overall innovation indices showed statistically significant variations between 2014 and 2024, thus confirming the first hypothesis formulated in this research.

Second, the clustering analysis identified two distinct clusters in 2014. The first cluster included Algeria, Angola, Benin, and 14 other countries, characterized by developing economies with generally low to medium innovation levels. These countries exhibited limited market sophistication and often insufficient infrastructures to support innovative dynamics. The second cluster, on the other hand, included Tunisia, Egypt, and 10 other African countries. These countries were distinguished by more diversified economies, relatively developed infrastructures, better organized educational and research systems, a dynamic entrepreneurial environment, and increased market sophistication.

Third, the clustering analysis for the year 2024 also identified two clusters. The first cluster includes Algeria and 18 other countries, of which 73.68% were already part of Cluster 1 in 2014. This group is marked by the persistence of structural challenges, such as limited infrastructures, less efficient educational and research systems, and economic dependence on primary sectors such as agriculture, mining, or oil extraction. However, a significant change is noted with Senegal's shift to the second cluster, highlighting the progress made by this country. The second cluster in 2024 includes 10 of the 13 countries that were already in this group in 2014, a proportion of 76.92%, while Uganda, Mozambique, and Ghana moved to the first cluster. This group remains characterized by relatively developed infrastructures, promoting sustained economic growth, better-established educational and research systems, higher innovation capacity, and strong institutions. These characteristics allow these countries to maintain their position in the cluster of the continent's most innovative economies.

In conclusion, this analysis validates the second hypothesis of the study by revealing coherent groupings of countries based on their innovation performance and highlighting their development progress over time.

VII REFERENCES:

AL-Khatib, A. W. (2022). Intellectual capital and innovation performance : The moderating role of big data analytics: evidence from the banking sector in Jordan. *EuroMed Journal of Business*, *17*(3), 391-423. https://doi.org/10.1108/EMJB-10-2021-0154

Ceko, E., Mulita, R., & Karras, D. A. (2024). On Relations Between the Index of Innovation and the B2c E-commerce Index (a Regressive Analysis), Using a Quality Management Holistic Approach, as Well as Descriptive Statistics for Western Balkans. *Financial Engineering*, *2*, 361-375. https://doi.org/10.37394/232032.2024.2.34

Juracka, D., Nagy, M., Zvarikova, K., & Popescu, G. (2024). Eco-Innovation : Analysis of EU Member States Performance in the EU Eco-Innovation Index 2013–2022. *Systems*, *12*(11), 452. https://doi.org/10.3390/systems12110452

Leogrande, A. (2024a). *Innovation linkages at the global level*. Zenodo. https://doi.org/10.5281/ZENODO.13381639

Leogrande, A. (2024b). *Intangible Assets at a Global Level*. Zenodo. https://doi.org/10.5281/ZENODO.13732206

Leogrande, A. (2024c). *Investments in the Global Innovation Index*. Zenodo. https://doi.org/10.5281/ZENODO.13776819

Leogrande, A. (2024d). *Knowledge Absorption at a Global Level*. Zenodo. https://doi.org/10.5281/ZENODO.13826421

Leogrande, A. (2024e). *Knowledge Diffusion in the Global Innovation Index*. Zenodo. https://doi.org/10.5281/ZENODO.13851898

Leogrande, A. (2024f). *Knowledge Impact in the Global Innovation Index*. Zenodo. https://doi.org/10.5281/ZENODO.13857383

Leogrande, A. (2024g). *Knowledge Workers in the Global Innovation Index*. Zenodo. https://doi.org/10.5281/ZENODO.13857471

Leogrande, A. (2024h). *The Global Innovation Index*. Zenodo. https://doi.org/10.5281/ZENODO.13142578

Leogrande, A. (2024i). *The Infrastructure Index at Global Level*. Zenodo. https://doi.org/10.5281/ZENODO.13368241

Rahimi, M. H. (2024). Factors Affecting the Development of Knowledgebased economy in Iran According to the Global Innovation Index. *Agricultural and Rural Economics*, *2*(1). https://doi.org/10.30490/etr.2024.130727

University of Zilina, The Faculty of Operation and Economics of Transport and Communications, Janoskova, K., Kral, P., & University of Zilina, The Faculty of Operation and Economics of Transport and Communications. (2019). An In-Depth Analysis of the Summary Innovation Index in the V4 Countries. *Journal of Competitiveness*, *11*(2), 68-83. https://doi.org/10.7441/joc.2019.02.05

World Intellectual Property Organisation. (2014). *The Global Innovation Index 2014* (p. 1-30). https://www.wipo.int/edocs/pubdocs/en/economics/gii/gii_2014.pdf

World intellectual property organization. (2024). *The Gloabl Innovation Index 2024*. https://www.wipo.int/web-publications/global-innovation-index-2024/assets/67729/2000%20Global%20Innovation%20Index%202024_WEB3lite.pdf

Zizlavsky, O. (2016). Innovation performance measurement : Research into Czech business practice. *Economic Research-Ekonomska Istraživanja*, *29*(1), 816-838. https://doi.org/10.1080/1331677X.2016.1235983

Zuzanna Ostraszewska & Agnieszka Tylec. (2024). Analysis of Poland's Innovation Profile Based on the Decomposition of the Summary Innovation Index (SII). *European Conference on Knowledge Management*, *25*(1), 609-618. https://doi.org/10.34190/eckm.25.1.2387