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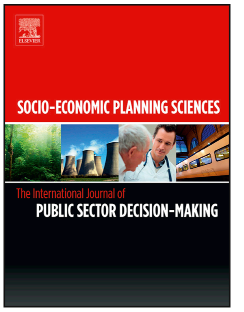

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Uneven Paths Toward Sustainability in Africa: A Multidimensional and Spatio-Temporal Assessment of SDG Progress (2000–2022)

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Abstract

The present study undertakes an analysis of the progress of African countries towards achieving the Sustainable Development Goals (SDGs) from 2000 to 2022. The study employs the DP2 index to evaluate the dimensions of sustainable development across the continent. In addition, the application of cluster analysis facilitates the identification of groups of countries with similar development patterns. The results highlight that, despite some localized progress, deep inequalities persist among African countries, with diverging sustainable development trajectories and a tendency for polarization between groups of countries. Temporal analysis highlights incremental and positive transitions to SDGs in different countries, while others experience negative inertia. The originality of this study lies in the temporal and spatial comparison of African countries' SDGs and the identification of differences in evolutionary patterns. The research makes an original contribution to theory by outlining typological differences at a country- and regional level. Policymakers can leverage these findings to develop effective context-specific strategies for advancing transition toward SDGs.

Keywords: sustainable development goals, SDGs, emerging countries, Pena Distance (DP2), cluster analysis, Africa.

1. Introduction

The Sustainable Development Goals (SDGs) established by the United Nations (UN) in 2015 signify a pivotal moment on a global scale, marking a shift towards the pursuit of shared objectives among nations to attain a more inclusive and sustainable future from economic, social, and environmental standpoints (Sorooshian, 2024; Işık et al., 2024; Dzhunushalieva and Teuber, 2024). The 17 Sustainable Development Goals (SDGs) are designed to address one of the major challenges currently facing the global population: the need to meet the basic needs of all people whilst protecting the ecosystem (Henderson and Loreau, 2023). In order to quantify the achievement of SDGs, academic literature has divided them based on the three key dimensions of sustainable development to which they belong: economic, social, and environmental (Pawłowski, 2008; Strezov et al., 2017; Ferguson et al., 2021; Huang and Akbari, 2024). For instance, Ciacci et al. (2024) employed this subdivision to assess digital sustainability in European countries through these dimensions. A substantial body of research has been dedicated to the development of methodologies for evaluating the impact of the SDGs across various domains, including business (Giri and Chaparro, 2023), education (Kioupi and Voulvoulis, 2019), urban health (Ramirez-Rubio et al., 2019), and tourism (Lara-Morales and Clarke, 2024). However, there is a paucity of SDG studies focusing on emerging markets (Halim and Rahman, 2022; Feng et al., 2024; Gao et al., 2024). To the best of our knowledge, there is no research conducted on emerging countries that analyse the evolution of the SDGs along the three dimensions of sustainable development. In this study, we aim to fill this gap by examining the behaviour of African countries in achieving the SDGs over a period of more than twenty years (2000-2022). Africa has received attention in the academic literature so far either in reference to single SDGs (Mugagga and Nabaasa, 2016; Chitonge et al., 2020) or to single countries or regions (Nhemachena et al., 2018). One of the few studies that has analysed a sufficiently large group of countries (31) over a suitably extended period (1980–2019) is the work by Chatterjee et al. (2024), who investigated the impact of income inequality on health and education in these regions. This study, which analyses all the SDGs at the continental level of Africa, aims to make new contributions to research by highlighting the different patterns that exist between countries and their performances over time.

The sets of indicators typically used to assess the SDGs have not always proved adequate for monitoring country performance (Hák et al., 2016). For this reason, we decided to employ the Pena Distance (DP2) method, which can measure both the performance of each individual dimension and the aggregate scenario over time. To ensure methodological transparency and robustness, we considered the relative strengths of different composite index methods. While PCA, TOPSIS, and the Mazziotta-Pareto Index (MPI) are widely used, the DP2 method was selected due to its ability to preserve information structure and avoid compensation effects between dimensions. This property is particularly suitable in contexts such as Africa, where disparities are multidimensional and asymmetric. Moreover, as highlighted in the OECD-JRC Handbook (2008), methods based on distance-from-reference approaches offer interpretability and robustness in temporal and spatial comparisons. This allows us to reveal the differences existing within the African countries by measuring each country's SDGs-related performance.

The aim of this study is threefold: (i) to measure the evolution of SDG achievements in African countries from 2000 to 2022 using a multidimensional index; (ii) to explore spatial and temporal disparities through a robust classification of countries; and (iii) to provide policy-relevant insights based on typological differences across countries. The key research question is: *To what extent do African countries exhibit convergent or divergent paths toward sustainable development, and which factors are associated with persistent inequality or upward transitions?*

The present research makes an original contribution to understanding typological differences between sustainability profiles at a country-level and heterogeneous trajectories of socioeconomic and environmental development. The work thus aims to inform the construction of context-specific data-driven strategies aimed at designing effective public policies (Villar-Roldan et al., 2025), contributing to the translation of the SDGs into governmental sustainable development practices.

This research contributes to the current literature by addressing the methodological challenge of measuring sustainable development through a multi-method statistical approach. The DP2 method, combined with cluster analysis, can provide an innovative empirical tool to monitor sustainability over time and space. In addition, the focus on African countries addresses the need to fill the analytical gap related to emerging markets, in which traditional indicators often fail to capture deep structural inequalities. Among the available composite index methodologies, the DP2 distance approach is particularly suited for non-compensatory and multidimensional phenomena such as SDG progress, allowing for both cross-sectional and longitudinal comparisons (Ivaldi et al., 2020; Traversa and Ivaldi, 2024). Recent applications in social and regional inequality measurement have acknowledged the DP2 distance approach's flexibility and robustness (Somarriba and Peña, 2009; Jiménez-Fernández et al., 2022).

From the perspective of policy implications, the paper highlights how effective paths toward sustainable development in Africa require differentiated policies at the national, regional, and continental levels, with priorities on political stability, financial inclusion, economic diversification, and environmental protection. The analysis provides useful tools for decision-makers to guide targeted and coordinated interventions.

The paper is organised as follows. In Section 2, we present the theoretical background underlying this study. In particular, the dimensions of sustainable development are analysed based on previous literature (Section 2.1), and the African scenario is presented with reference to the Environmental Kuznets Curve (EKC) (Section 2.2). Section 3 describes the methodology and data used for the analysis; while results are presented and discussed in Section 5. Finally, Section 6 provides conclusions, insights into this work, limitations, and future research directions.

2. Theoretical Framework

This section first presents an analysis of the most important international literature on the three dimensions of sustainable development. Keeping in mind the research conducted by Pham-Truffert et al. (2020), which elucidates the intricate interrelationships between the SDGs and the associated synergies and trade-offs among diverse objectives and targets, the present study refers to the subdivision made by Costanza et al. (2016) and then taken up in several subsequent works (e.g. Dhahri et al., 2021): economic (SDGs 7, 8, 9, 11, 12), social (SDGs 1, 2, 3, 4, 5, 10, 16, 17) and environmental domain (SDGs 6, 13, 14, 15). Secondly, this section briefly describes the key theory underlying this work, i.e., the Environmental Kuznets Curve.

2.1 Literature review

2.1.1 Economic dimension

One of the three pillars of sustainable development is economic sustainability (Pawłowski, 2008; Strezov et al., 2017). There are various definitions of this dimension in the literature. Most authors agree that long-term sustainable economic growth must be inextricably linked to social and environmental aspects. This is the case, for example, in the definitions provided by Texeira et al. (2016), for whom economic sustainability is achieved through a greater production of goods and services in a unit of time, while at the same time achieving a collective increase in income for a certain category of people, and Kosmopoulos (2024, p. 42), for whom it is a "*set of actions and strategies aimed at ensuring economic prosperity without negatively impacting social, environmental and cultural aspects of a community*". However, Interlenghi et al. (2023, p.36) argue that for a realistic measurement of economic sustainability, it is necessary to estimate what is known as economic efficiency, that is "*optimally using/distributing all resources to producers/consumers in such a way as to maximize value and minimize waste, that is, to generate more value with less material and less energy*". The SDGs that fall under this dimension of sustainable development, as reported in the works of Costanza et al. (2016) and Dhahri et al. (2021), are presented in Table 1.

Table 1. SDGs in economic dimension

SDG	Objective

SDG 7	Ensure equal access to sustainable energy
SDG 8	Promote inclusive economic growth and incentivize safe and dignified workplaces for all
SDG 9	Build resilient infrastructure and promote durable and innovative industrialization
SDG 11	Create cities that are inclusive, safe, and resilient to extreme climate events
SDG 12	Implement sustainable consumption and production processes

Source: Authors' elaboration on SDGs description.

2.1.2 Social dimension

Since the publication of "Our Common Future" in 1987, social sustainability has been overshadowed by economic and environmental domains. It is only recently, as Vallance et al. (2011) point out, that due attention has been paid to this crucial aspect. The authors identify three dimensions that underlie social sustainability: "development sustainability" (i.e. creating equity and justice), "bridge sustainability" (i.e. changing people's daily habits to better protect the planet) and "maintenance sustainability" (i.e. preserving and maintaining cultural characteristics and local traditions). Eizenberg and Jabareen (2017) identify four drivers of social sustainability: urban form (the transformation of urban places into human-scale spaces that are resilient to climate change), equity (economic, social and environmental justice), security (the human right to be protected and feel safe) and eco-prosumption (producing, consuming and profiting in sustainable and inclusive ways). Barron et al. (2023) argue that social sustainability is based on cohesion, inclusion, resilience and 'process legitimacy' (fair and clear policymaking). The SDGs in the social dimension are in Table 2.

Table 2. SDGs in social dimension

SDG	**Objective**
SDG 1	Eradicate poverty in all its forms
SDG 2	End world hunger
SDG 3	Promote healthy and active lives at all ages
SDG 4	Ensure equal access to quality education
SDG 5	Achieve gender equality in all aspects of society
SDG 10	Reduce inequalities between countries
SDG 16	Promote peaceful societies, equal justice and inclusive institutions
SDG 17	Renew the global partnership for sustainable development

Source: Authors' elaboration on SDGs description.

2.1.3 Environmental dimension

The turning point in global attention to protecting the environment in which we live can be traced back to the publication of the Club of Rome's[1] "Limits to Growth" report in 1972. The study warned the world's population of the risks associated with uncontrolled economic growth, which would over time deplete the planet's finite natural resources. This report linked the global economy and the environment for the first time (Turner, 2008) and from the outset sparked a global debate on the need for common sustainability policies. In this context, environmental sustainability plays a leading role in promoting harmony between mankind and land (Zhang et al., 2022). The historical belief that the planet's resources are inexhaustible has been completely disproved by the last two centuries of industrial progress (Guo and Shahbaz, 2024). One of the most destructive effects of human activity on the planet, climate change, could cost up to $2 trillion a year by 2030 (Uralovich et al., 2023). The SDGs in the environmental dimension are in Table 3.

Table 3. SDGs in environmental dimension

SDG	Objective
SDG 6	Ensure equitable access to water for all
SDG 13	Address climate change and its consequences
SDG 14	Protect and sustainably use sea and ocean water resources
SDG 15	Conserve terrestrial ecosystems and combat desertification, environmental degradation and biodiversity loss

Source: Authors' elaboration on SDGs' description.

2.2 The Environmental Kuznets Curve

This work is rooted in the theoretical debate surrounding the Environmental Kuznets Curve. In the 1950s, the economist Simon Kuznets (1901 - 1985) illustrated the relationship between economic development and income inequality: income inequality initially rises as a country's industrial process grows and then, after a turning point, begins to fall as per capita income expands due to greater employment in high productivity sectors (Kuznets, 1955; Piketty, 2006). This relationship was then taken up again in the early 1990s by some scholars (e.g. Shafik and Bandyopadhyay, 1992; Panayotou, 1993; Grossman and Krueger, 1995), who for the first time identified an inverted U-shaped relationship between income and environmental degradation (Jaeger et al., 2023; Mahmood et al., 2023; Kaya Kanlı and Küçükefe, 2023).

The underlying assumption of these studies is that environmental degradation increases in the early stages of a country's industrialisation as the government gives top priority to material production and people prefer to find jobs and have a good income rather than care for the environment (Dasgupta

[1] Non-profit association of scientists, industrialists and academics founded in Rome in 1968 to find solutions to issues such as economic and population growth on a global scale.

et al., 2002; Dinda, 2004; Prieur, 2009). At this stage, government environmental policies are rather permissive in order to maximise production. In subsequent stages of economic progress, people reach a certain level of prosperity where they begin to place greater value on protecting the environment in which they live (Stern, 2004), and as a result government environmental policies become more restrictive.

The EKC has been the subject of numerous criticisms. The main one is that proponents of the EKC are promoting the economic growth of underdeveloped countries at the expense of environmental protection since governments may feel justified in relaxing their environmental regulations in the early stages of strong economic development. Furthermore, opponents argue that it is rather dangerous to assume that growing economic development will lead to a rebalancing towards the environment over time: in fact, some of the environmental impacts of production processes may be irreversible, causing biodiversity loss and contributing to climate change (Karsch, 2019). Kaika and Zervas (2013), in their study on the critical issues of the EKC, report that other criticisms relate to the methodology used in EKC studies, such as the use of panel data instead of time series data (List and Gallet, 1999), errors in the calculations of econometric models (Aslanidis, 2009), or even the basic assumption that developing countries must go through the same evolutionary process as already developed countries (Roberts and Grimes, 1997). Indeed, a number of events are currently casting serious doubt on the validity of the EKC, according to which rising per capita income is associated with greater environmental protection. For example, the United States presents an environmental budget deficit, and countries such as Germany and Austria have resumed buying coal for electricity and home heating following the outbreak of the Russian-Ukrainian war in 2022 (Guan et al., 2023; Wang et al., 2024).When it turns to the African scenario, there is a plethora of papers that have tested the validity of EKC in African countries in recent years (Orubu and Omotor, 2011; Osabuohien et al., 2014; Ben Jebli et al., 2015; Shahbaz et al., 2016; Gara, 2019; Tachega et al., 2021).

For the purposes of our work, one of the most important studies is that of Shahbaz et al. (2016), which examines the existence of EKC in the economies of 19 African countries over the period 1971-2012. The authors relate CO2 emissions to four key aspects (real GDP, real GDP squared, energy intensity and globalisation). The results show that the sample studied is extremely heterogeneous: the four factors have different effects on environmental degradation depending on the country of reference, without a common pattern. Another relevant study is that of Adu et al. (2019), who tested the validity of the EKC in 12 East African countries using data from 1990-2013. The results of this study suggest that, in the long run, the relationship between economic growth and environmental degradation (C02 emissions) takes a form that is opposite to the EKC: above a certain income threshold, emissions increase (bell-shaped). The authors therefore conclude that investment in the modernisation of production processes and the adoption of environmental protection policies are necessary to combat CO_2 emissions in the long term.

This study does not intend to test the EKC on African countries, but through the use of DP2 method, it aims to assess the state of achievement of the SDGs by almost all countries on the African continent. In this way, the paper intends to estimate the degree of sustainability of each country, both in absolute terms and in its economic, social and environmental dimensions. The results of this work, which provide evidence on the progress of sustainability policies in African countries, add further insights to the literature on the relationship between developing countries and environmental protection.

3. Data and methods

The SDG Transformation Centre's data[2] is utilised in this study. Specifically, annual data pertaining to SDG indicators from 2000 to 2022 has been collated for almost all African countries[3]. It was established that all original data was consistently expressed in percentage terms. Table 4 shows descriptive statistics for SDG indicators.

Table 4. SDG indicators' descriptive statistics.

Indicator	Min.	1st Qu.	Median	Mean	3rd Qu.	Max.
SDG goal 1	0.00	20.60	31.50	37.40	52.15	98.10
SDG goal 2	7.70	45.30	53.30	50.93	58.70	73.20
SDG goal 3	5.90	26.30	35.60	38.59	48.00	79.80
SDG goal 4	0.00	25.20	42.30	43.08	61.35	96.00
SDG goal 5	3.50	33.15	43.70	45.23	57.00	88.40
SDG goal 6	23.30	44.40	50.20	50.43	56.00	71.10
SDG goal 7	0.10	19.30	32.30	34.21	43.95	85.10
SDG goal 8	40.00	56.70	63.70	61.90	67.10	78.70
SDG goal 9	0.00	8.80	14.20	17.55	22.50	70.80
SDG goal 10	0.00	23.20	43.00	44.92	65.30	97.00
SDG goal 11	13.80	41.40	51.20	52.60	64.90	92.60
SDG goal 12	74.40	91.10	95.30	93.12	96.40	99.00
SDG goal 13	77.50	95.80	98.40	96.54	99.20	99.90
SDG goal 14	0.00	0.00	57.20	43.25	68.45	84.50
SDG goal 15	26.00	58.60	67.90	66.48	74.40	89.90
SDG goal 16	29.40	43.50	50.60	51.90	60.65	84.60

[2] Data are available at: Kaggle.com. It is worth noting that this database has been previously used by Sachs et al. (2023) to develop the 2023 Sustainable Development Report.

[3] The following countries are excluded from the analysis since there are no available data: Guinea-Bissau, Libya, Mayotte, and Saint Helena.

SDG goal 17	26.00	42.50	47.40	50.12	57.15	83.00

Source: Authors' elaboration.

The construction of an aggregative index was achieved by applying the Pena Distance (DP2) method, a multivariate statistical technique primarily employed for the development of composite indicators (Ivaldi et al., 2025). This method involves the creation of a single index that serves to summarise multiple variables or indicators (Ivaldi and Ciacci, 2021; Pena, 1977; Somarriba and Pena, 2009). DP2 is also applied in the computation of economic, social, and environmental development indicators (Bruzzi et al., 2020; Ivaldi et al., 2020; Montero et al., 2010; Pena-Trapero, 2009; Penco et al., 2020), including SDGs analyses (Bartiromo et al., 2022). Its applicability extends beyond well-being to encompass similar concepts, and in various studies, it has proven effective in addressing challenges that other methodologies have struggled to resolve adequately (Jiménez-Fernández et al., 2022; Martín Martín et al., 2020; Somarriba Arechavala et al., 2015)[4].

A salient characteristic of the DP2 method is its capacity to facilitate meaningful and consistent comparisons across diverse units, such as regions or countries, both in terms of space and over time (Podgorna et al., 2020). This is achieved by measuring quantitative distances from a reference point, thereby ensuring the integrity and reliability of the data (Sommariba and Peña, 2009; Norman 2010, Landi et al 2017; Ivaldi and Ciacci, 2023).

DP2 calculation procedures imply multiple iterations or rearrangements of matrices.

The initial step begins with a matrix V of dimensions (K, m), where m represents the number of countries and K is the total number of partial indicators, encompassing both interpolated objective and subjective variables. Each element in this matrix, denoted as v_{kj}, signifies the status of partial indicator k in countries j. Since all SDGs have positive polarity, any increase or decrease in the values of a partial indicator corresponds to an improvement or worsening of sustainable development. In the subsequent stage, a distance matrix D is computed, where each element, d_{kj}, for every spatial unit j is defined as follows (Montero et al., 2010):

$$d_{kj} = |v_{kj} - v^*_{kj}|$$

Where v^*_{kj} is the kth component of the base vector $v^*_j = \{v^*_{1j} v^*_{2j} \dots v^*_{Kj}\}$ in the country. To enable the comparison of sustainable development across different countries for each partial indicator, it is essential to establish a reference value. It is common to adopt the minimum value as the reference point (Montero et al., 2010). Consequently, a higher value in DP2 indicates a superior sustainable development level, as it represents a greater distance from a theoretical 'undesired' situation. This characteristic not only allows for the ranking of countries based on sustainable development but also implies that d_{kj} measures the distance between partial indicator k in country j and its reference value.

[4] For an in-depth explanation of DP2 and its advantages and properties please refer to Appendix A.

Subsequently, in a third stage, to express all indicators in comparable abstract units, the initial global index, known as the DF (see Jiménez-Fernández et al., 2022), is defined as:

$$DF(j) = \sum_{k=1}^{K} \frac{d_{kj}}{\sigma_k} = \sum_{k=1}^{K} \frac{|v_{kj} - v_{kj}^{*}|}{\sigma_k}; j = 1, 2, \ldots, m$$

Here, σ_k represents the standard deviation of partial indicator k. The distance between two statistical units, d_{kj}, for each partial indicator, is scaled by the inverse of σ_k. In other words, the contribution of each d_{kj} to the global indicator is inversely proportional to the standard deviation of its corresponding indicator. This approach, resembling those employed in heteroscedastic models, assigns less significance to distances with higher variability and vice versa.

While DF serves as a valid distance concept in a theoretical scenario of uncorrelated indicators, in practical situations where there is a direct relationship between partial indicators, DF may incorporate duplicated information. To address this issue, DF requires correction to eliminate the dependence effect, assumed to be linear and resulting from redundant information in other variables. Consequently, for each country j, DF represents the maximum value achievable by DP2 and is defined as (Pena, 1977; Zarzosa Espina and Somarriba Arechavala, 2013):

$$DP2(j) = \sum_{k=1}^{K} \frac{d_{kj}}{\sigma_k} \left(1 - R^2_{k,k-1,k-2,\ldots,1}\right); j = 1, 2, \ldots, m$$

Here, $R^2_{k,k-1,k-2,\ldots,1}$ represents the determination coefficient resulting from the regression of each partial indicator k on the others (k – 1, k – 2,...,1). It quantifies the proportion of the variance in k that is linearly explained by the remaining partial indicators. Consequently, the correction factor $\left(1 - R^2_{k,k-1,k-2,\ldots,1}\right)$ deducts the portion of the observed values' variation explained by linear dependence. R^2 is an abstract concept independent of the indicators' measurement units.

DP2 index addresses the issue of heterogeneous measurement units by normalizing through division by the standard deviation. This process ensures that the partial indicators are represented in standardized, abstract units (Martín Martín et al., 2020; Ray, 2014).

The DP2 process involves a decision on the order of entry for partial indicators in the computation. This entails determining the sequence in which partial indicator k contributes its variance to the overall index. In this process, the first indicator (k = 1) contributes all its information to the global index (d_1/σ_1). However, the second indicator (k = 2) only adds the portion of its variance uncorrelated with the first indicator: $(d_2/\sigma_2)(1 - R^2_{2\cdot 1})$. Similarly, the third indicator contributes to DP2 the portion of its variance uncorrelated with either the first or the second indicators: $(d_3/\sigma_3)\left(1 - R^2_{3\cdot 2,1}\right)$, and so on. The order of inclusion of partial indicators in the DP2 computation follows a sequential logic based on their contribution to variance and mutual independence. Specifically, indicators are entered starting from the one with the highest variance, followed by those that add the least redundancy, assessed via their partial correlation with previously included indicators. Appendix A provides a complete description of the applied DP2 index procedure.

The abovementioned DP2 procedure is repeated for calculating the values of each constitutive dimension of sustainable development and, finally, to obtain an overall sustainable development measure based on the aggregation of the single three dimensions.

Since the SDGs represent a system of interdependent and often non-compensatory goals, the DP2 methodology proves particularly adequate. Unlike methods allowing full compensation across dimensions, DP2 penalizes redundancy and values distinct contributions, thus enhancing the interpretative power of multidimensional sustainability scores (Sommariba Archevala et al. 2015).
In this study, DP2 functions as a multidimensional index that integrates the various SDGs into the three dimensions of sustainable development as per detailed in Section 2.1.
The process of constructing the comprehensive DP2 index[5] entailed the identification and classification of the SDGs in accordance with the framework proposed by the Costanza et al. (2016). Subsequently, a first-level DP2 index was calculated for each of the three dimensions of sustainable development. Ultimately, these results were aggregated in a second-level calculation to derive an overall performance value relative to the SDGs.
Compared to other composite index methods such as PCA or TOPSIS, DP2 avoids compensation across dimensions and preserves the distinct contribution of each indicator. While PCA emphasizes variance maximization and orthogonality, and TOPSIS focuses on distance from ideal solutions, DP2 measures effective distance from a theoretical minimum, penalizing redundancy and enhancing interpretability over time and space (see also Peña, 1977; Ivaldi and Ciacci, 2021; Ivaldi and Antonicelli 2025).

Following the calculation of DP2, a cluster analysis was also conducted, with the objective of establishing a bivariate classification of countries based on their DP2 scores with regard to sustainable development6. This procedure has been applied for each sustainable development dimension and overall index. In other words, this cluster analysis served as a method to divide statistical units into groups of similar entities (Berkhin, 2006) and capture broader spatial and temporal trends. To determine the optimal number of clusters, we used the Elbow Method, a well-established decision-making method in clustering analysis. This approach involves plotting the total within-cluster sum of squares (WCSS) against the number of clusters (k) and identifying the point at which the WCSS decreases less rapidly—i.e., when adding an additional cluster no longer substantially improves the model fit. In our case, the curve clearly inflects at k = 3, suggesting that three clusters strike the best balance between explanatory power and parsimony. Consequently, we

[5] The DP2 construction has been performed by using the R package 'p2distance'.
[6] The cluster analysis was performed through the JMP software.

fixed the number of clusters at three for all years considered (2000, 2011, and 2022), in order to ensure comparability over time.

This balance between parsimony and variance explained was consistent across all years analysed. The key idea behind the elbow method is to identify the point where adding more clusters may significantly inhibit the model's ability to explain the variance in the data (Bholowalia and Kumar, 2014). In other words, applying the elbow method allows us to find a balance between fitting the data and avoiding overfitting. Cluster 1 indicates highly developed countries, while clusters 2 and 3 indicate moderately and less developed countries respectively.

4. Results

4.1 Temporal evolution: three separate dimensions (first-level DP2)

From the economic perspective, the first-level DP2 analysis of the African countries over the years 2000, 2011, and 2022 (Table 5) reveals that, in 2000, the most developed African countries were South Africa (DP2 score = 11.14), Morocco (10.41), Mauritius (9.93), Egypt (9.86), and Tunisia (9.58). In the same year, the less developed countries were Chad (5.01), Congo, Rep. (4.75), Lesotho (4.75), Mauritania (4.23), and South Sudan (3.98). In 2011, the top five best performers remained the same as in 2000. Among them, Egypt significantly improved its economic performance, with a DP2 increase of 0.76. Looking at the lower end of the ranking, compared to the previous period, South Sudan (3.87) suffers from a reduction in its economic SDGs, with a decrease in the DP2 coefficient of 0.10. Together with Lesotho (5.44), Congo, Rep. (5.42), Chad (5.21), and the Central African Republic (5.05), South Sudan emerges among the countries with the least developed economic SDGs. The analysis for the year 2022 reveals the rise of Ghana (12.66) and Algeria (12.48), while South Africa (13.94), Morocco (13.54), and Egypt (13.06) confirm their positions at the top of the ranking. In contrast, some variations occur at the bottom of the ranking, where Comoros (6.86), Sudan (6.56), Chad (6.07), Central African Republic (5.06), and South Sudan (3.47) occupy the lower end positions.

Table 5. DP2 scores for the three SDG dimensions in 2000, 2011, and 2022.

Country	Economy 2000 score	Economy 2011 score	Economy 2022 score	Society 2000 score	Society 2011 score	Society 2022 score	Environment 2000 score	Environment 2011 score	Environment 2022 score
Algeria	8.93	10.14	12.48	16.82	18.69	19.06	10.33	11.09	10.81
Angola	6.71	6.80	7.58	8.98	11.79	10.33	10.13	10.48	11.65
Benin	7.98	7.85	9.56	9.64	10.44	12.91	10.98	11.10	11.11
Botswana	7.66	8.04	11.47	12.85	13.25	14.23	8.57	9.61	10.60

Burkina Faso	7.16	7.60	9.43	7.86	10.07	11.07	10.27	10.67	10.51
Burundi	5.68	6.16	7.04	9.37	12.45	12.97	10.26	10.52	10.66
Cabo Verde	7.66	8.63	10.05	15.67	16.53	18.30	11.38	12.14	13.33
Cameroon	7.33	7.98	10.29	8.28	10.19	11.19	11.15	11.95	12.12
Central African Republic	5.08	5.05	5.06	4.75	5.35	5.30	11.15	10.62	10.26
Chad	5.01	5.21	6.07	5.37	5.54	7.76	9.22	9.25	9.40
Comoros	5.46	5.66	6.86	9.83	10.87	11.83	9.01	11.27	11.11
Congo. Dem. Rep.	6.84	6.81	7.49	6.79	7.74	9.22	11.22	11.33	11.52
Congo. Rep.	4.75	5.42	7.01	9.17	11.32	11.30	10.48	11.38	12.17
Cote d'Ivoire	8.63	8.66	11.53	9.13	9.41	13.92	12.68	12.92	12.86
Djibouti	6.92	6.82	8.14	8.00	9.95	12.32	8.87	8.85	8.65
Egypt. Arab Rep.	9.86	10.62	13.06	17.14	16.86	17.77	12.22	12.31	12.33
Eswatini	5.80	6.82	9.47	10.54	11.92	12.52	6.75	7.52	8.13
Ethiopia	8.23	8.66	9.71	6.97	9.86	11.91	7.54	7.25	7.46
Gabon	6.65	7.76	10.74	11.27	12.16	13.03	8.69	11.70	12.65
Gambia. The	8.03	8.57	9.35	7.51	8.88	12.39	13.11	13.82	13.86
Ghana	9.37	10.14	12.66	12.40	14.90	15.43	11.04	11.32	11.61
Guinea	7.52	7.29	8.55	8.01	9.43	11.66	11.38	11.94	11.60
Kenya	8.47	8.78	11.81	10.27	12.42	14.60	10.55	10.78	10.63
Lesotho	4.75	5.44	7.89	10.57	11.93	11.84	8.30	8.92	9.82
Liberia	6.30	6.25	7.05	7.24	8.47	10.28	9.27	10.91	11.04
Madagascar	7.22	7.80	8.29	7.64	9.54	10.47	8.66	9.47	9.78
Malawi	8.63	8.80	9.83	9.75	11.40	13.44	8.77	9.17	9.43
Mali	7.60	8.35	9.88	8.84	11.50	12.49	8.11	11.35	12.36
Mauritania	4.23	5.46	7.10	8.66	10.85	13.17	8.62	10.41	11.22
Mauritius	9.93	10.50	12.42	17.05	17.51	18.16	9.74	9.40	9.26
Morocco	10.41	11.70	13.54	13.34	16.20	17.78	10.54	12.05	13.27
Mozambique	7.82	8.23	9.23	7.74	10.04	11.11	9.35	10.61	11.92
Namibia	7.77	8.27	9.74	12.40	13.43	15.76	10.64	12.05	13.17
Niger	6.80	7.19	7.60	6.15	8.92	9.76	7.36	8.01	9.39
Nigeria	6.72	7.34	9.70	8.77	10.04	10.94	10.52	12.24	12.92
Rwanda	7.02	7.56	10.18	9.77	13.50	15.79	9.35	10.20	10.50
Sao Tome and Principe	7.11	7.62	8.64	14.02	15.75	16.06	7.77	12.65	13.18
Senegal	8.66	9.09	12.22	9.39	11.88	14.36	11.15	12.35	13.08

Sierra Leone	7.03	6.95	7.87	8.47	10.44	13.13	9.62	11.04	11.69
Somalia	5.71	6.72	7.38	5.91	5.74	7.55	9.46	9.55	10.16
South Africa	11.14	11.73	13.94	13.32	14.20	15.30	8.95	9.03	9.85
South Sudan	3.98	3.89	3.47	5.03	5.44	5.47	8.85	8.96	9.18
Sudan	5.13	5.64	6.56	7.28	8.39	9.37	6.95	7.33	8.19
Tanzania	7.45	7.63	10.56	9.64	11.99	12.96	10.16	10.63	11.38
Togo	7.26	7.53	9.35	9.48	10.44	12.75	11.83	12.49	12.65
Tunisia	9.58	10.49	12.07	17.05	18.73	19.52	11.16	11.51	12.44
Uganda	7.58	7.78	10.09	9.27	11.24	12.85	8.58	8.77	9.11
Zambia	7.16	7.59	9.34	8.81	10.33	12.15	9.18	9.62	9.83
Zimbabwe	8.18	8.73	9.78	9.66	10.34	11.49	10.18	9.96	9.74

Source: Authors' elaboration.

From the perspective of social SDGs, in 2000, Egypt (17.14), Mauritius (17.05), Tunisia (17.05), Algeria (16.82), and Cabo Verde (15.67) showed the best values of social development. On the other side, the results reveal that Niger (6.15), Somalia (5.91), Chad (5.37), South Sudan (5.03), and the Central African Republic (4.75) are the socially less developed countries. The best performers' situation slightly changed in 2011, with Egypt moving from first place to fourth in the ranking, due to a decrease of 0.28 points in terms of DP2 score, while the other countries confirmed their positive trends. Somalia (5.74), Chad (5.54), South Sudan (5.44), and the Central African Republic (5.35) continue to occupy the last positions, while Niger significantly improved its performance in social SDGs compared to the previous period (DP22011 – DP22000 = +2.76). This resulted in the downgrading of Congo, Dem. Rep. (7.74) among the five worst performers. In 2022, Tunisia (19.52), Algeria (19.06), Cabo Verde (18.30), and Mauritius (18.16) strengthened their position at the top of the ranking, while Morocco (17.78) replaced Egypt (17.77) in the top five. The worst performers remain the same as in 2011, with Chad (7.76) overcoming Somalia (7.55) in the ranking's position 46.

The DP2-based analysis of environmental SDGs reveals that Gambia (13.11), Cote d'Ivoire (12.68), Egypt (12.22), Togo (11.83), and Guinea (11.38) show the highest levels of development in 2000. On the other side, Sao Tome and Principe (7.77), Ethiopia (7.54), Niger (7.36), Sudan (6.95), and Eswatini (6.75) occupy the end positions of the ranking, signaling lower environmental development. In 2011, The Gambia maintained its top position with a score of 13.82. Cote d'Ivoire (12.92), Sao Tome and Principe (12.65), Togo (12.49), and Senegal (12.35) complete the top five ranking. In particular, Sao Tome and Principe improved significantly during the 2000-2011 timeframe, moving from the bottom five to the top five countries, with an increase of its DP2 environmental score of 4.88. Uganda (8.77), Niger (8.01), Eswatini (7.52), Sudan (7.33), and Ethiopia (7.25) occupy the ranking’s lowest positions. In 2022, The Gambia maintained the leadership with a score of 13.86. Cabo Verde (13.33), Morocco (13.27), Sao Tome and Principe (13.18), and Namibia (13.17) exhibit significant improvements, confirming the effort to develop environmental valorization strategies. In 2022, the DP2 analysis highlights that Uganda (9.11), Djibouti (8.65), Sudan (8.19), Eswatini (8.13), and Ethiopia (7.46) show the most evident weaknesses in terms of environmental development.

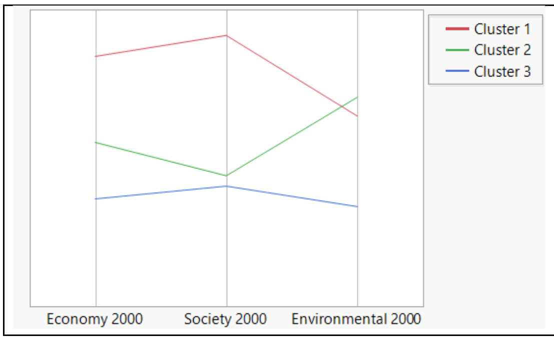
4.2 Temporal evolution and cluster distribution: aggregate results (second-level DP2)

The overall analysis of SDGs performance of African countries over the years 2000, 2011, and 2022 reveals distinct trends among the best and worst performers. In 2000, Egypt (8.09), Tunisia (7.35), Morocco (6.94), Mauritius (6.73), and Cote d'Ivoire (6.67) represented the top performers, showcasing the highest overall sustainable development scores. On the contrary, in the same year, Niger (2.38), Eswatini (2.12), Mauritania (2.11), South Sudan (1.63), and Sudan (1.46) occupied the last positions of the overall ranking. In 2011, Morocco (8.81) gained the overall ranking's leadership, while Egypt (8.49) and Tunisia (8.23) demonstrated consistently strong performance. Algeria (7.81) and Ghana (7.44) complete the top five, increasing their overall scores by 1.28 and 0.88 points respectively. Eswatini (3.25), Central African Republic (3.21), Chad (2.55), Sudan (2.07), and South Sudan (1.70) resulted as the worst overall performers in 2011.

By 2022, Morocco (10.64) confirms its leadership in the overall DP2 ranking, significantly improving its overall performance compared to the previous timeframe (+1.83). Egypt (9.87), Tunisia (9.65), Senegal (9.40), and Cabo Verde (8.97) consistently demonstrated a growth trajectory, securing a position among the top performers across the years. On the other hand, the five worst performers remain the same as the previous timeframe, namely Niger (4.40), Chad (3.36), Sudan (3.15), Central African Republic (3.00), and South Sudan (1.62), signaling the progressive growth of Eswatini (+1.76 on 2011 and +2.89 on 2000) and its overcoming on several African countries in the ranking.

Examining the results for the overall DP2 along the entire period of observation, it emerges that a group of consistently high-performing countries, i.e. Algeria, Cabo Verde, Cote d'Ivoire, Egypt, Gambia, Ghana, Mauritius, Morocco, Namibia, Senegal, South Africa, and Tunisia, maintains first positions in ranking, indicating a high level of overall development. Conversely, Chad, South Sudan, and Sudan consistently fall behind over the entire timeframe, indicating countries still have to face more severe challenges. The most significant ranking improvements include Botswana, Cameroon, Gabon, Mali, Nigeria, Sao Tome and Principe, and Tanzania, indicating increases in SDG overall performance. On the other side, the Central African Republic, Benin, and Guinea experienced negative trends, necessitating additional efforts in promoting sustainable development across its multiple domains.

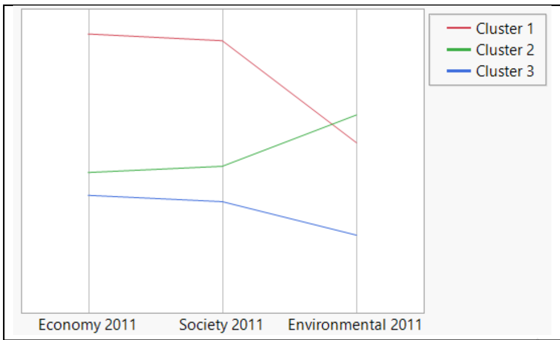
Figure 1a. Cluster analysis years 2000



Cluster 2000	Numbers	Economy	Society	Environmental
1	8	9,61	15,35	10,67
2	15	7,65	9,05	11,06
3	26	6,36	8,59	8,80

Source: Authors' elaboration.

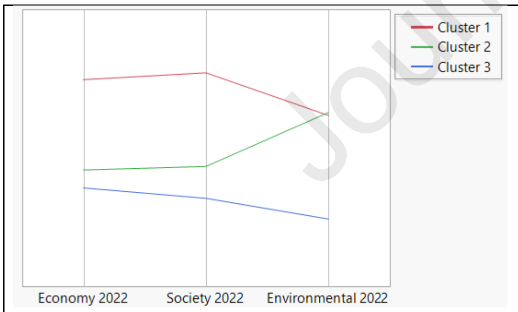
Figure 1b. Cluster analysis years 2011



Cluster 2011	Numbers	Economy	Society	Environmental
1	7	10,76	16,73	10,96
2	25	7,47	11,14	11,55
3	17	6,93	9,57	9,00

Source: Authors' elaboration.

Figure 1c. Cluster analysis years 2021



Cluster 2022	Numbers	Economy	Society	Environmental
1	15	11,72	16,40	11,79
2	18	8,62	11,87	11,87
3	16	8,01	10,33	9,32

Source: Authors' elaboration.

Cluster analysis related to the three indicators considered jointly for the years 2000, 2011 and 2022 (Figures 1a, 1b, and 1c) allows us to observe the evolution of sustainable development profiles among African countries, not only in terms of overall score (already examined with the DP2 indicator), but also with respect to the nature of the specific components of the composite indicator, i.e. economy, society, and environment. The cluster-based approach makes it possible to capture the typological differentiation between groups of countries and to monitor their structural transformation over time. While rank analysis is based on DP2 scores for each dimension, clusters result from a multivariate analysis combining economy, society, and environment dimensions, and therefore reflect more complex patterns.

Clustering defines a clear distinction between groups of countries in 2000. Cluster 1, comprising only 8 countries, has significantly higher average values on all dimensions (economy = 9.61, society = 15.35, environment = 10.67). This cluster indicates a group of countries with relatively advanced sustainable development in a multidimensional perspective. Cluster 2, comprising 15 countries, has intermediate scores, while cluster 3, the most numerous with 26 countries, is significantly distanced, especially in the economic dimension (mean = 6.36), reflecting a widespread structural weakness.

Clustering shows the tendency to rebalance the distribution from 2000 to 2011. Cluster 1 shrinks to 7 countries, further improving its values, particularly in the social dimension (mean = 16.73). This result confirms a gradual strengthening of sustainable development in virtuous countries. Cluster 2, expanding to 25 countries, suggests a dynamic of relative convergence of improving countries. Over this period, the cluster's average values increase in all dimensions, particularly in the social and environmental domains. Cluster 3, on the other hand, shrinks to 17 countries and continues to show moderate values with slight improvements since 2000.

Clustering shows a significant change in cluster configuration in 2022. Cluster 1 expands significantly to include 15 countries, with increasing average scores for economy (11.72), society (16.40) and environment (11.79). This expansion indicates an upward transition of many countries that have strengthened their performance in all dimensions, particularly the environmental sphere. Cluster 2 in 2022 includes 18 countries with increasing and well-balanced average values (around 11-12). This may indicate greater homogeneity in the middle cluster. Finally, cluster 3 shrinks to 16 countries, with higher scores than before, but still lower than the other groups (economy = 8.01, society = 10.33, environment = 9.32).

Overall, the analysis shows a gradual upward convergence, with a generalised improvement in performance and a narrowing of the gap between clusters. However, some inequalities remain mainly due to starting bias and variable speed of progress. The growth of cluster 1 in 2022 suggests the emergence of a dynamic group of African countries, able to combine economic development, social inclusion and environmental sustainability. At the same time, although the gradual reduction of countries in cluster 3 is a positive sign, the analysis of the scores shows that the gap with the other clusters is not yet closed, particularly with regard to the integration of economic growth and environmental sustainability.

This typological view confirms the validity of the multidimensional approach adopted: economic growth alone is not enough to define the multifaceted concept of sustainable development. The fastest advancing countries are those that have simultaneously strengthened the three dimensions by developing policies consistent with the 2030 Agenda. Lastly, the results confirm that Africa does not follow a unified path of development, but differentiated trajectories that require ad hoc socio-economic planning interventions adapted to the specific nature of each context.

Table 6 shows the cluster membership and overall DP2 scores of African countries in the years 2000, 2011 and 2022. The analysis confirms differentiated sustainable development trajectories, with some countries showing stable paths of advancement, others in upward mobility, and a significant part of the continent in structurally fragile conditions.

The first group of countries, including Morocco, Egypt and Tunisia, remains at the top throughout, with consistently high scores and consistent progression. Algeria, Ghana and Mauritius also show relative stability in the top cluster. Alongside these, there are countries that are steadily progressing, such as Namibia, Rwanda, Botswana, Côte d'Ivoire, and São Tomé and Príncipe, which, while starting from intermediate or low positions, have significantly improved their performance, reaching cluster 1 in 2022.

Senegal, Ghana, and Cabo Verde represent noteworthy examples of upward mobility within the sustainability clusters, demonstrating consistent improvements across economic, social, and environmental dimensions. These countries have implemented targeted policies that integrate development planning with long-term sustainability goals. In Senegal, the Plan Sénégal Émergent has promoted infrastructure development, renewable energy, and institutional reforms aimed at inclusive growth. Ghana has advanced its performance through investments in energy diversification, education, and digital financial services, fostering both economic resilience and social inclusion. Cabo Verde, despite its small size and insularity, has leveraged good governance, regional integration, and strategic investments in education and health care to achieve steady progress. These experiences may offer useful policy blueprints for other countries seeking to transition toward more balanced and inclusive development models.

However, a group of countries remained in underdeveloped conditions and anchored in cluster 3 throughout the period. Among them, Sudan, South Sudan, Chad, Niger, Central African Republic, Somalia and Djibouti show particularly low and, in some cases, regressive scores, as in the case of South Sudan. The persistence of countries such as South Sudan, Sudan, and Chad in the lowest-performing cluster depends on a combination of factors. South Sudan’s low scores may primarily stem from protracted conflict and state fragility, while Sudan has suffered economic collapse and institutional breakdown. Chad’s stagnation appears linked more to climate vulnerability and limited infrastructure investment.

An intermediate group of countries (Nigeria, Kenya, Mozambique, and Cameroon) register improvements in DP2 scores, although they fail to change clusters. In these contexts, positive dynamics are fragmented or unbalanced, often suffering from environmental weaknesses or persistent social inequalities.

Overall, the longitudinal reading of the data suggests a trend toward partial but not generalised convergence, with a core of emerging countries able to integrate economic development, social cohesion and environmental protection, and others still distant from similar conditions. The joint use of the DP2 indicator and cluster analysis proves effective in capturing both the quantitative dimension of progress and the typological structure of inequality.

Table 6. DP2 scores and clusters for the overall DP2 in 2000, 2011, and 2022.

2000			2011			2022		
Cluster	Country	Overall DP2	Cluster	Country	Overall DP2	Cluster	Country	Overall DP2
1	Egypt, Arab Rep.	8.09	1	Morocco	8.81	1	Morocco	10.64
1	Tunisia	7.35	1	Egypt, Arab Rep.	8.49	1	Egypt, Arab Rep.	9.87
1	Morocco	6.94	1	Tunisia	8.23	1	Tunisia	9.65
1	Mauritius	6.73	1	Algeria	7.81	1	Cabo Verde	8.97
1	Ghana	6.56	1	Ghana	7.44	1	Ghana	8.95
1	Algeria	6.53	1	Mauritius	6.90	1	Algeria	8.89
1	South Africa	6.42	1	South Africa	6.88	1	South Africa	8.60
1	Cabo Verde	6.31	2	Cabo Verde	7.35	1	Mauritius	7.88
2	Cote d'Ivoire	6.67	2	Gambia, The	7.24	2	Senegal	9.40
2	Gambia, The	6.39	2	Senegal	7.08	2	Cote d'Ivoire	8.88
2	Senegal	5.86	2	Sao Tome and Principe	7.01	2	Namibia	8.38
2	Kenya	5.55	2	Cote d'Ivoire	6.85	2	Gabon	8.24
2	Togo	5.55	2	Namibia	6.70	2	Gambia, The	8.12
2	Namibia	5.53	2	Togo	6.18	2	Kenya	7.87
2	Benin	5.46	2	Kenya	6.12	2	Sao Tome and Principe	7.87
2	Guinea	5.24	2	Mali	6.10	2	Botswana	7.62
2	Zimbabwe	5.12	2	Gabon	6.08	2	Nigeria	7.58
2	Cameroon	5.05	2	Cameroon	6.07	2	Mali	7.57
2	Tanzania	4.74	2	Nigeria	5.89	2	Togo	7.50
2	Congo, Dem. Rep.	4.64	2	Guinea	5.61	2	Cameroon	7.47
2	Nigeria	4.45	2	Benin	5.57	2	Tanzania	7.43
2	Burkina Faso	4.41	2	Mozambique	5.44	2	Rwanda	7.12
2	Angola	4.26	2	Tanzania	5.40	2	Mozambique	6.81
2	Zambia	3.93	2	Burkina Faso	5.15	2	Benin	6.77
2	Uganda	3.87	2	Sierra Leone	5.08	2	Guinea	6.36
3	Malawi	4.58	2	Angola	4.87	2	Sierra Leone	6.26
3	Botswana	4.38	2	Congo, Dem. Rep.	4.81	2	Congo, Rep.	5.85
3	Mozambique	4.22	2	Burundi	4.65	2	Angola	5.72
3	Rwanda	4.08	2	Comoros	4.61	2	Mauritania	5.61
3	Sierra Leone	4.07	2	Congo, Rep.	4.61	2	Congo, Dem. Rep.	5.45
3	Burundi	3.85	2	Liberia	4.39	2	Comoros	5.26
3	Sao Tome and Principe	3.81	2	Mauritania	4.02	2	Burundi	5.24
3	Gabon	3.72	3	Zimbabwe	5.36	2	Liberia	5.11
3	Mali	3.56	3	Rwanda	5.32	3	Burkina Faso	6.12
3	Djibouti	3.53	3	Botswana	5.21	3	Malawi	6.04

	Madagascar	3.52		Malawi	5.10		Zimbabwe	5.93
	Congo, Rep.	3.48		Zambia	4.60		Uganda	5.91
	Central African Republic	3.44		Madagascar	4.51		Zambia	5.84
	Liberia	3.34		Uganda	4.34		Lesotho	5.06
	Ethiopia	3.32		Ethiopia	3.75		Madagascar	5.06
	Comoros	3.11		Djibouti	3.73		Eswatini	5.01
	Somalia	2.97		Somalia	3.51		Ethiopia	4.67
	Lesotho	2.45		Lesotho	3.32		Djibouti	4.60
	Chad	2.41		Niger	3.31		Somalia	4.42
	Niger	2.38		Eswatini	3.25		Niger	4.40
	Eswatini	2.12		Central African Republic	3.21		Chad	3.36
	Mauritania	2.11		Chad	2.55		Sudan	3.15
	South Sudan	1.63		Sudan	2.07		Central African Republic	3.00
	Sudan	1.46		South Sudan	1.70		South Sudan	1.62

Source: Authors' elaboration.

5. Discussions

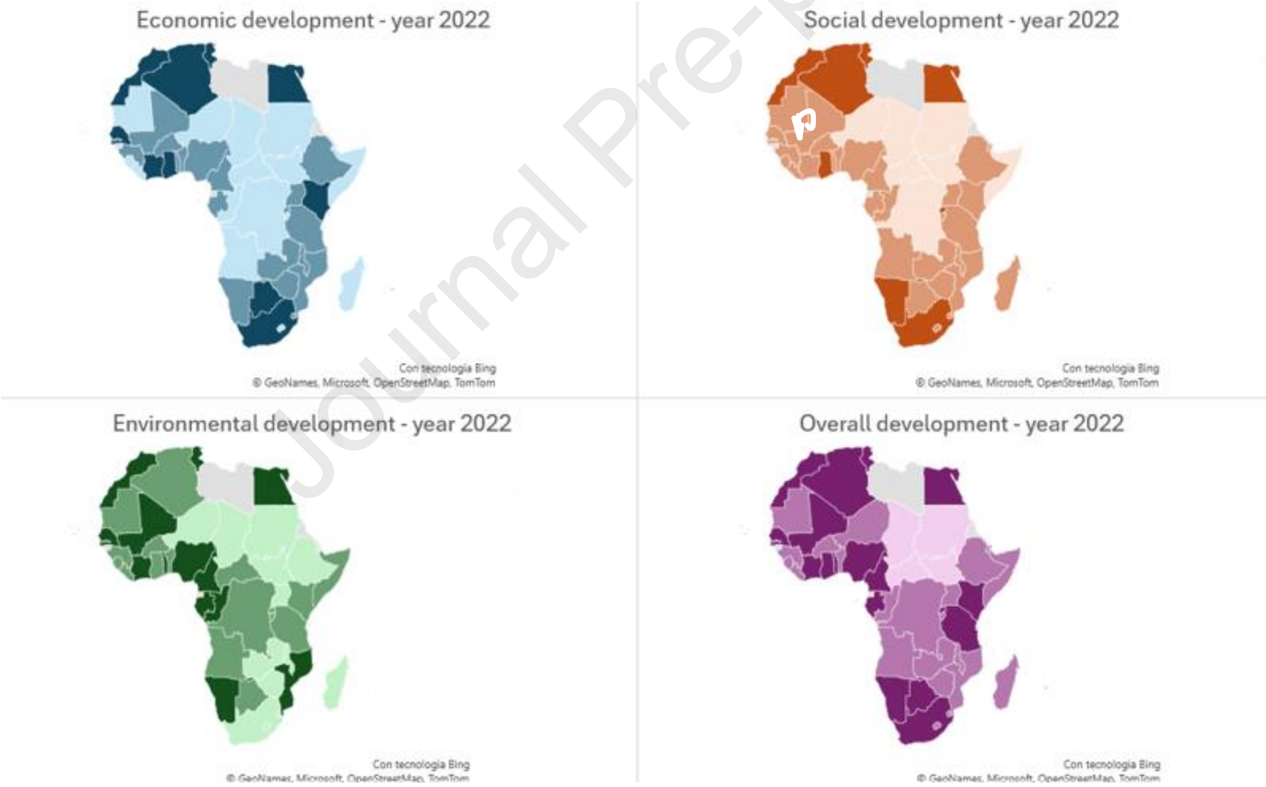
From the economic perspective, South Africa, Morocco, Egypt, Mauritius and Tunisia made notable progress at the turn of the millennium, while Chad, Lesotho, Congo, Mauritania and South Sudan performed less well. Twenty-two years later, Ghana and Algeria have risen to prominent positions. The clusters show that countries with the most robust economies (cluster 1) have continued to grow, while those with more fragile economies (cluster 3) have not experienced significant fluctuations. Some countries, such as Botswana and Eswatini, have made progress, moving from an intermediate band to a higher one (cluster 2). On the other side, several countries, including Angola, Djibouti, Niger, Congo, Dem. Rep., Liberia, Madagascar, Malawi and Sierra Leone, have experienced a deterioration in their economic situation.

In terms of social progress, Egypt, Tunisia, Mauritius, Algeria and Cape Verde made notable progress in 2000, while Niger, Somalia, Chad, South Sudan and the Central African Republic recorded less encouraging results. In 2011, Egypt experienced a decline in its ranking, while in 2022, Tunisia, Algeria, Cape Verde and Mauritius confirmed their exemplary performance. Over time, the first cohort of countries has consolidated its lead in social well-being, while cluster 3 has failed to close the gap, with some countries in the middle remaining largely unchanged.

The Gambia has been a leader in environmental protection since 2000, maintaining this role until 2022. On the other hand, Uganda, Djibouti, Sudan, Eswatini and Ethiopia face increasing obstacles. The overall picture shows that many countries, including Cabo Verde, Cameroon, Côte d'Ivoire, Egypt, Gambia, Morocco, Namibia, Nigeria, Senegal and Togo, have demonstrated a sustained commitment to sustainability. Conversely, other countries, such as Eswatini, Ethiopia, Niger and Sudan, continue to face persistent obstacles in implementing environmentally sustainable policies.

It is interesting to look at the differences from a broader geographical perspective to capture regional dynamics. Figure 2 illustrates the status of the African continent in 2022, with reference to each dimension from an aggregate perspective.

Figure 2. Geographic patterns in Africa's dimensions of SDGs and overall performance in 2022.



Note. More intense colours indicate a higher degree of development.

Source: Authors' elaboration.

Looking at the overall trend shown in Figure 2, the most economically and socially developed regions in Africa include most of North Africa (with the exception of Libya, for which data are not available), the main countries in Southern Africa (namely South Africa, Botswana and Namibia), two countries in East Africa (Tanzania and Kenya) and a significant part of West Africa (including Ghana, Côte d'Ivoire and Togo).

These areas are benefiting from a combination of factors, including greater political stability, investment in infrastructure and access to international markets. North Africa, which is economically linked to the European Union, has seen an improvement in living conditions as a result of sustainable development and economic diversification policies (e.g. Morocco's Vision 2030). These policies have been designed to reform the public sector, reduce unemployment and make public spending more efficient, in line with the arguments put forward by Albassam (2022).

From an environmental perspective, North African countries have promoted strategies since the 2000s to address environmental challenges and foster energy transition. Morocco, in particular, has significantly invested in renewables, with symbolic projects such as the Noor solar and new plants in Midelt and wind power with the aim to achieve 80 percent renewable generation by 2050 (Laaroussi et al., 2021; Anouar, 2022; Zemlickienė et al., 2024).

Egypt, with the Benban Solar Park (among the largest in the world, costing about $4 billion), aims to reach 62.6 GW from renewable sources by 2035 (Moharram et al., 2022). Algeria has set a target of 22 GW by 2030 (Chemmou, 2012), and Tunisia aims for 4.7 GW, with attention also given to biodiversity and waste management (Rekik and El Alimi, 2024). These countries seek to reduce dependence on fossil fuels by integrating environmental and economic goals. This highlights the need for an integrated and holistic approach, involving local communities and international actors, to ensure sustainable development in the region.

The socioeconomic success of Southern African countries is largely due to the abundance of exportable natural resources (Tivatyi et al., 2022) and the growth of ecotourism (Snyman, 2020), with activities such as safaris in Botswana and South Africa or visits to the Namib Desert in Namibia. In terms of environmental sustainability, these countries have adopted significant policies in recent years to address environmental challenges and promote sustainable development. South Africa launched the National Development Plan in 2012, with targets on renewable energy and emissions reduction (NPC, 2012), aiming for 1.7 GW from renewable sources by 2030 (Akinbami et al., 2021), along with initiatives for sustainable water resource management and biodiversity conservation (Calverley and Walther, 2022). In Namibia, the Community-Based Natural Resource Management (CBNRM) program, active since the 1990s, enables local communities to manage natural resources, generating income through tourism in conservancies, locally managed protected areas (Koot et al., 2002). Botswana promotes sustainable tourism and environmental conservation (Mogomotsi et al., 2018), dedicating about 40 percent of its territory to parks and nature reserves, such as Chobe National Park, home to the world's largest elephant population (Gaodirelwe et al., 2020).

In Kenya, the introduction of the M-Pesa mobile banking service in 2007 revolutionized access to financial services. This innovation has facilitated an increase in household daily consumption and a reduction in poverty levels, thereby facilitating the launch of economic activities and enabling the country to achieve the goals set out in the SDGs (Natile, 2020). However, significant inequalities and structural challenges remain, hindering an even development across the country. In Tanzania, the so-called blue economy, driven by aquaculture and marine tourism, is the main contributor to the country's economic development, poverty reduction, social progress and protection of natural resources (Rutaba, 2024).

Both countries are integrating environmental sustainability into economic and social policies. Kenya, with its National Climate Change Action Plan (2018-2022), aims to reduce emissions by 30 percent by 2030 (UNIDO, 2022) and has invested in renewables, particularly geothermal and solar, reaching 83 percent of electricity from clean sources in 2020 (Oluoch et al., 2020). In Tanzania, the government has developed the National Strategy for Growth and Poverty Reduction (MKUKUTA), which includes targets for the sustainable management of natural resources. Tanzania has focused its efforts on developing renewable energy sources, particularly solar and wind power, with the dual aim of diversifying its energy portfolio and reducing its dependence on fossil fuels. However, there has been a 9.1% decline in renewable energy consumption over the period 1999-2019. This suggests that there is not a direct relationship between a country's economic growth, as evidenced by the recorded data, and its consumption of clean energy (Mperejekumana et al., 2024).

Since 2000, West African countries have experienced remarkable economic and social growth, albeit with significant differences between countries. Côte d'Ivoire, for example, experienced GDP growth of 8.2% from 2012 to 2019, supported by policy reforms and the agricultural sector, particularly cocoa production (World Bank, 2024). Ghana has achieved greater economic stability and infrastructure investment (IMF, 2024), while Togo aims to become a regional logistics hub. However, vulnerabilities to economic and climate shocks, high inflation, and wide disparities between urban and rural areas persist, highlighting the need for sustainable and inclusive development (World Bank, 2024).

In terms of environmental sustainability, West African countries face significant challenges but are undertaking major initiatives to develop renewable energy and reduce dependence on fossil fuels. In Ghana, for example, the African Rural Energy Enterprise Development (AREED) programme provides financial support to local entrepreneurs engaged in the production of clean energy (UNEP, 2024). In Senegal, the Plan Sénégal Émergent (Emerging Senegal Plan) has been launched with the aim of transforming the country's energy sector towards greater reliance on renewable resources, with an ambitious target of producing 40% of energy from renewable sources by 2030 (IEA, 2024). Nigeria and Mali are also investing in solar, with projects aimed at improving energy access in rural areas (Somoye, 2023; Oxford Analytica, 2021). In addition, the United Nations Environment Programme (UNEP) has supported numerous initiatives across the region to develop renewable energy facilities and improve the resilience of local communities.

The analysis also identifies countries that have persistently underperformed since the 2000s, maintaining their position within cluster 3. This group includes Chad, South Sudan, Sudan and the

Central African Republic, which has been in cluster 3 since 2011. These countries remain among the most impoverished in Africa, largely as a result of protracted conflict, political instability and economic crises.

The Central African Republic, one of the most impoverished countries in the world, is experiencing economic stagnation and a humanitarian crisis as a result of protracted armed conflicts that have been ongoing in the country for around two decades (World Bank, 2024). The ongoing conflict in Sudan has had a devastating impact on the agricultural sector and business activities, resulting in a significant increase in food prices and a sharp rise in food insecurity. This has put millions of people at risk of hunger (WFP, 2024). Infrastructure deficiencies prevent access to electricity, especially in rural areas (Eldowma et al., 2023).

In South Sudan, oil dependence and hyperinflation have worsened the economic crisis (Pinaud, 2022). In Chad, regional conflicts and climate change, particularly desertification and the shrinking Lake Chad, fuel the food emergency (World Bank, 2024). These countries also face additional challenges, including lack of investment, corruption and difficulties in providing basic services. This makes it difficult to find viable solutions to alleviate poverty and address the ongoing humanitarian crisis.

6. Implications, Conclusions and Future Research

This research has studied for the first time the evolution of the performances of African countries in achieving the SDGs over a period of more than twenty years (2000-2022). This was made possible by the implementation of the DP2 method, which enabled the comparison of the 48 African countries involved in the study. The temporal and spatial comparison of these countries' performances allowed for the identification of differences in evolutionary patterns. This study provides interesting indications to decision-makers to develop ad hoc sustainable development policies at the micro (single state), meso (regional) and macro (continental) levels.

In light of these considerations, some theoretical and practical implications emerge. The analysis suggests that, to enhance their progress towards higher development clusters, African countries should prioritise key areas of intervention. These areas include political stability (1), sustainable tourism (2), climate resilience (3), financial inclusion (4), economic diversification (5), efficient public spending (6) and environmental protection (7).

Political stability (1) is a prerequisite for economic and social progress. Countries with stable and transparent governance can better implement long-term policies, attract investment and ensure sustainable growth. It is therefore imperative that efforts are made to combat corruption and strengthen the rule of law in order to build confidence among investors and the general population.

Two particularly successful case studies are Namibia and South Africa. Namibia only gained independence in 1992 and has since embarked on reforms to promote national prosperity (e.g., the Green Plan and Vision 2030), while focusing on environmental protection and inclusive development (Ruppel and Ruppel-Schlichting, 2011). South Africa has adopted liberalisation policies and social programs to reduce poverty and unemployment and promote education and equal opportunities for women (Masters, 2019; Plagerson et al., 2019). In terms of environmental policy, the National Climate Change Adaptation Strategy has been designed to promote sustainable practices and reduce carbon emissions (Ofoegbu et al., 2019). Despite recent progress, South Africa continues to face significant challenges, including high unemployment, pervasive inequality, widespread corruption (Sayeed, 2023), and a lack of basic infrastructure such as water and transport. From an economic perspective, the transportation sector plays a pivotal role in a country's economic growth (Rehman et al., 2022).

Sustainable tourism (2), integrated with investments in infrastructure, protection of natural resources and enhancement of cultural heritage, can be an engine of economic growth. The best countries since 2000 (cluster 1) are also those with the most developed tourism sectors and the largest annual inflows (World Economic Forum, 2024). Tourism in Africa employed over 24 million people (WTTC, 2019) and reached over 66 million arrivals in 2023 (UNWTO, 2024). It can be a valuable tool for attracting foreign investment and improving accessibility. This contributes to achieving the SDGs, especially those related to poverty reduction and environmental protection.

Climate adaptation and renewables (3), such as solar and wind, promote green employment and strengthen economic and environmental resilience, as demonstrated by the cases of Namibia and Morocco. Expanding access to digital financial services (4), such as M-Pesa in Kenya, has the potential to increase household resilience, facilitate transactions and savings, and strengthen rural economies. Improving internet connectivity and digital services is crucial to support the informal economy and promote inclusion. In addition, economic diversification (5) is a key factor. Rather than relying on natural resources as the sole economic base (as in the cases of Chad and the Central African Republic), countries should support small and medium-sized enterprises (SMEs) through the introduction of tax incentives and access to credit. Such an approach can increase economic resilience and facilitate the growth of strategic sectors, thereby promoting long-term development. Efficient public spending (6), as noted by Albassam (2022), is essential for high levels of development. However, it must be accompanied by civic participation, anti-corruption measures and good governance.

Finally, in order to promote sustainable development from an energy and environmental perspective (7) in least developed countries in Africa, our analysis offers a number of recommendations for policy makers.

Promoting renewable energy, reducing dependence on fossil fuels and expanding access to electricity are key to improving environmental policies. These measures are already taken by many cluster 1 countries, while less developed countries lag behind.

Despite the above strengths, this paper is not without limitations. A key limitation is the reliance on data availability and quality. Despite the use of data from authoritative sources, some dimensions of sustainability may be under-represented, or the quality of data may vary from country to country, which could affect the precision of the results. For example, data related to SDG 14 (Life Below Water) and SDG 15 (Life on Land) present less consistent time series across all countries, due to missing data for certain years. In addition, the DP2-based data aggregation approach, while allowing comparisons across spatial and temporal units, may lead to a loss of specificity of individual variables, reducing our ability to understand detailed aspects of the economic, social and environmental dimensions of the phenomenon. Finally, the analysis does not take into account the antecedents and consequences of sustainable development progress in Africa, which prevents us from developing a causal analysis and leads to a selective analysis and critical examination of the results based on the expertise of the researchers.

The approach adopted has various strengths, but also certain limitations that could serve as starting points for future research. In order to extend the findings of this study and to address some of the limitations identified, future research could consider integrating additional indicators that complement aspects of sustainability. Future research may also explore the integration of digital economy indicators (e.g., internet penetration, mobile financial access, digital infrastructure) to assess their correlation with sustainability transitions and innovation-driven development patterns in African countries. Another possible direction for future research would be to develop within-country analyses, considering differences not only between but also within countries, in order to better capture local dynamics. In addition, future studies could explore the impact of global and regional economic policies on the sustainability of African countries. Future extensions of this study could incorporate digital development indicators—such as internet penetration, mobile phone subscriptions, and digital financial transaction volumes—to more precisely capture the influence of technological infrastructure and innovation on sustainable development trajectories in Africa. The integration of such variables into the DP2-based composite index would enhance its capacity to account for the role of digital inclusion in multidimensional development. In addition, qualitative case study approaches could complement the quantitative framework by offering context-specific insights into institutional dynamics and policy implementation challenges affecting sustainability outcomes.

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Sustainable Development Goals (SDGs) Glossary

Number	**Standardized Label**
SDG 1	No Poverty
SDG 2	Zero Hunger
SDG 3	Good Health and Well-being
SDG 4	Quality Education
SDG 5	Gender Equality
SDG 6	Clean Water and Sanitation
SDG 7	Affordable and Clean Energy
SDG 8	Decent Work and Economic Growth
SDG 9	Industry, Innovation and Infrastructure

SDG 10	Reduced Inequalities
SDG 11	Sustainable Cities and Communities
SDG 12	Responsible Consumption and Production
SDG 13	Climate Action
SDG 14	Life Below Water
SDG 15	Life on Land
SDG 16	Peace, Justice and Strong Institutions
SDG 17	Partnerships for the Goals

Appendix A

DP2 method is a distance-based concept. This type of method relies on comparison by the difference in absolute or squared terms between each indicator of different territorial units or in relation to a considered reference base. Starting from the Frechet distance (DF), Ivanovic (1963) observes that this measure lacks in that it does not account for the varying importance of each indicator or the potential interdependence between them. Building on DF, Ivanovic (1963) introduced the I-distance concept, incorporating partial coefficients as a corrective measure. The I-distance verifies all the desirable properties of synthetic indicator, except for exhaustiveness, since the correction factor, while taking into account the possible dependence between the indicators, does not, however, eliminate duplicated information (Montero et al., 2010; Pena, 1977). Pena introduces two new distance indicators: DP1, discarded due to its sensitivity to initial assumptions, especially regarding the linear dependence among partial indicators; and DP2 (or P2 distance), calculated by considering the variance and standard deviation of each component in relation to a reference base (Pena-Trapero, 2009). The P2 distance method proposed by Pena finally aims to overcome the limitation of the I-distance. As an evolutionary step of I-distance, the correction factor of DP2 deducts the proportion of the variation of the observed values explained by the linear dependence, solving the previous issues of information redundancy (Pena-Trapero, 2009).

Despite several methods allowing aggregate data into a single index (Ciacci et al., 2023; Ciacci et al., 2021; Ivaldi et al., 2023), DP2 presents two specific advantages. First, DP2 adheres to all necessary properties for an acceptable aggregation method. Second, DP2 objectively assigns weights to indicators, unlike the most aggregative methods carry equal weight—a somewhat arbitrary approach lacking a rationale (Folmer and Heijman, 2005). In addition, the primary limitation of a plethora of aggregative methods is their inability to measure disparities between spatial units and/or periods of time, functioning as an ordinary-type indicator (Domínguez and Martos, 2012; Montero et al., 2010; Somarriba and Pena, 2009). For example, principal component analysis (PCA) typically establishes rankings of geographic or temporal aspects without assessing the magnitude of differences (Montero et al., 2010). DP2, as a cardinal measure, quantifies how much a statistical unit is developed compared to another one. At the heart of PCA's approach lies the optimization of variance in new components aimed at reducing indicator dimensionality, provided there is a substantial correlation among them. It is crucial that all indicators exhibit the same polarity, making PCA particularly suitable for reflective models. However, utilizing PCA for composite index construction can result in significant errors, especially when indicators lack correlation. Despite its stability in maintaining composite index rankings upon observation removal, PCA does not differentiate or discriminate against added indicators, which are treated as linear combinations of the principal components (Jiménez Fernández, 2022).

Data envelopment analysis (DEA)-benefit-of-the-doubt (BoD) methodology proves its utility for analyzing the efficiency of individual units, ensuring stability in rankings even with the removal of observations. However, constructing a composite index using this method complicates overall result interpretation and prohibits comparisons between units. Moreover, adding new indicators within DEA tends to render them irrelevant in the model due to the assigned weights (Ivaldi and Ciacci, 2021; Jiménez-Fernández, 2022; Jiménez-Fernández et al., 2022). In contrast, the DP2 method calculates a composite index based on metrics, facilitating comparisons between observations and offering a coherent mathematical framework for comprehensive analysis.

In addition, DP2 has some substantial advantages over the human development index (HDI). Firstly, while the DP2 index satisfies all the essential criteria for a satisfactory aggregation method, the HDI lacks uniqueness. Its geometric mean is not unique under scaling changes, rendering it susceptible to variations in measurement units of the indicators. Secondly, the DP2 method objectively allocates weights to the indicators, whereas in the HDI, all indicators are assigned equal weights (Domínguez

and Martos, 2012). This arbitrary approach lacks justification, especially considering the varied nature of the indicators (Folmer and Heijman, 2005).
In line with Ivanovic (1974), the greater the inclusion of data in the partial indicators related to the subject, the more comprehensive the ultimate synthetic index becomes. This is because each variable inherently harbors distinct and specific information exclusive to it. DP2 removes redundant shared variance, selectively retaining only the original and unique information (Pena-Trapero, 2009; Montero et al., 2010). In other words, DP2's primary advantage is to utilize all pertinent information from the partial indicators while eliminating redundant variance and mitigating multicollinearity issues. More in general, DP2 is distinguished for its numerous statistical properties that make it suitable for a number of studies. These properties encompass existence and determination, monotony, uniqueness quantification, invariance, homogeneity, transitivity, exhaustiveness, additivity, invariance compared to the base reference, conformity, and non-arbitrariness in the significance attributed to the individual indicators (Zarzosa Espina and Somarriba Arechavala 2013)

Below is an overview of each property:

- Existence and determination: The DP2 index assumes a precise value as long as there is variance among its components, ensuring they are finite and non-zero.
- Monotony: Positive changes in variables correspond to positive shifts in the DP2 index, while negative changes lead to negative adjustments.
- Uniqueness quantification: When applied to an ordered set of simple indicators, the DP2 index produces a singular numerical outcome.
- Invariance: The synthetic indicator remains unaffected by alterations in origin and/or scale within the measures of its components.
- Homogeneity: Functioning as a grade 1 homogeneous function concerning the simple indicators, the DP2 index maintains consistent behavior across varying scales.
- Transitivity: If there are three distinct situations, denoted as (a), (b), and (c), each pertaining to the objective measured by the DP2 index, and DP2(a), DP2(b), and DP2(c) represent the corresponding values of the index for these situations, then the following holds:

  $DP2(a) \leq DP2(b)$ and $DP2(b) \leq DP2(c)$ implies $DP2(a) \leq DP2(c)$

- Exhaustiveness: The DP2 index effectively utilizes all the information provided by the simple indicators.
- Additivity: The DP2 index for each country adheres to propositions I to VII. Additionally, the discrepancy between the DP2 index of two statistical units should be equivalent to the DP2 index derived from directly comparing the two statistical units. However, Zarzosa Espina (1996) demonstrates that, generally, the property of additivity does not hold:

  $DP2(r) - DP2(k) \neq DP2(r, k)$

  Nonetheless, Zarzosa Espina (1996) reveals the relationship between the two expressions as follows:

  $|DP2(r) - DP2(k)| \leq DP2(r, k)$

- Invariance compared to the base reference: Building upon Ivanovic's work (1963), it is demonstrated that if the base reference remains constant for two statistical units, and for each indicator it either attains the maximum value or one greater, or the minimum value or one lower from the series of values in that indicator, then the P2 distance between two statistical units, calculated both directly and through the difference between the two distances, remains unchanged, regardless of the reference vector (Pena, 1977).

- Conformity: The result of the P2 distance is influenced by the factor $(1 - R^2_{i,i-1,i-2,\dots,1})$, varying according to the input order of the components. Hence, a method of hierarchization is necessary for the components. The logical approach is to prioritize components based on the information they contribute to the DP2 index. Specifically, components providing the most information about the measured objective should be included first, followed by others in descending order. The importance of each component is determined by its degree of dependency on the objective (Pena, 1977). Therefore, components are ordered from highest to lowest based on the absolute value of the simple correlation coefficient between each component and DP2. If

$$|r(DP_2, I_i)| > |r(DP_2, I_h)|$$

then component i contains more information than h and is included first. Thus, the input order of variables in calculating P2 distance should ensure that the correlation coefficients in absolute terms between the resulting DP2 index and the simple indicators are ranked from highest to lowest. This property underscores the importance of such ordering (Zarzosa Espina, 1996).

- Non-arbitrariness in the importance assigned to the simple indicators (neutrality): One common critique of indexes lies in the arbitrary assignment of weights to the simple indicators, reflecting their perceived significance. In many methodologies, these weights are determined in a somewhat subjective manner. However, the DP2 index prevents this issue by not predefining the importance of simple indicators. Instead, their hierarchical order emerges as a result of the calculation process. The weights are influenced by two factors: firstly, the correction factor, which filters out redundant information, retaining only the pertinent data; secondly, the absolute values of the correlation coefficients between the simple indicator and the DP2 index. These coefficients dictate the sequence used in regression estimation and, consequently, the calculation of the DP2 index (Zarzosa Espina, 1996).

Highlights

- The paper analyses the evolution toward the SDGs in African countries from 2000 to 2022.
- Combines the DP2 index with cluster analysis to provide multidimensional insights.
- Reveals diverging development paths and inequalities across clusters.
- Provides actionable guidance for national, regional, and continental strategies.

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