Czech University of Life Sciences Prague

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Master's Thesis

DATA MINING OF SELECTED SUSTAINABILITY INDICATORS IN AFRICA

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Faculty of Economics and Management

DIPLOMA THESIS ASSIGNMENT

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Informatics

Thesis title

Data Mining of selected sustainability indicators in Africa

Objectives of thesis

The main objective of this study is to conduct a multivariate assessment of selected sustainability indicators in Africa.
Specific objectives include;
1) To identify key sustainability indicators commonly used to assess environmental, social and economic aspects of sustainability in Africa.
2) To assess the patterns and relationships between the sustainability indicators and reduce the data as much as possible.
3) To compare and contrast the sustainability indicators for various regions in Africa includes East, West, Central, Northern, and Southern Africa.
4) To assess the differences and similarities in sustainability development in various African regions.

Methodology

To address the above objectives, the thesis seeks to use a multivariate statistical analysis to explore the relationship between selected indicators, reduce the dimension of the variables/dataset, and find similarities among evaluated countries.

The proposed extent of the thesis

60 – 80 pages

Keywords

Sustainability, multivariate analysis, indicator, development

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Recommended information sources

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Declaration

I declare that I have worked on my master's thesis titled "Data Mining of Selected sustainability Indicators in Africa" by myself and I have used only the sources mentioned at the end of the thesis. As the author of the master's thesis, I declare that the thesis does not break any copyrights.

In Prague on 2024

VALLARY CHEROP PKANIA

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Data mining of selected sustainability indicators in Africa

Abstract

This thesis explores the application of data mining techniques to analyze selected sustainability indicators in Africa. With the continent facing unique environmental, social and economic challenges, understanding and managing sustainability is of paramount importance. The study focuses on identifying key sustainability indicators relevant to African contexts and utilizing exploratory factor analysis and cluster analysis to extract insights from the dataset.

The research methodology involved mining of dataset from world bank on world development indicators pertaining to environmental, social, and economic dimensions of sustainability in African countries. This dataset encompasses indicators such as carbon emissions, renewable energy consumption, biodiversity loss, poverty rates, education levels and economic growth. Data mining techniques such as Principal component analysis and clustering were applied to uncover patterns ,trends and relationships within the data. The findings of this study provide invaluable insights into the current state of sustainability in Africa and highlights the areas of concern and opportunities for improvements.

Through data mining, significant correlation between different sustainability indicators is identified, shedding light on complex interdependencies, and facilitating informed decision making. Moreover, the research contributes to the development of predictive models for assessing future sustainability trends and scenarios in Africa. By harnessing the power of data mining, this study aims to enhance our understanding of sustainability dynamics and support efforts towards achieving a more resilient, equitable and environmentally sustainable future for the continent.

Keywords: Sustainability, Sustainable development, Data mining,Africa, Social indicators, Economic indicators, Environmental indicators, Sustainable Development Goals(SDGs), Multivariate analysis, Economic development.

Data mining vybraných indikátorů udržitelnosti v Africe

Abstrakt

Tato práce se zabývá aplikací technik dolování dat k analýze vybraných indikátorů udržitelnosti v Africe. Vzhledem k tomu, že kontinent čelí jedinečným environmentálním, sociálním a ekonomickým výzvám, má pochopení a řízení udržitelnosti prvořadý význam. Studie se zaměřuje na identifikaci klíčových ukazatelů udržitelnosti relevantních pro africké kontexty a pomocí průzkumné faktorové analýzy a shlukové analýzy k získání poznatků z datového souboru.

Metodologie výzkumu zahrnovala dolování datového souboru Světové banky o indikátorech světového rozvoje týkajících se environmentálních, sociálních a ekonomických rozměrů udržitelnosti v afrických zemích. Tento soubor dat zahrnuje ukazatele, jako jsou uhlíkové emise, spotřeba obnovitelné energie, ztráta biologické rozmanitosti, míra chudoby, úroveň vzdělání a ekonomický růst. Techniky dolování dat, jako je analýza hlavních komponent a shlukování, byly použity k odhalení vzorců, trendů a vztahů v datech. Zjištění této studie poskytují neocenitelný pohled na současný stav udržitelnosti v Africe a zdůrazňují oblasti zájmu a příležitosti ke zlepšení.

Prostřednictvím data miningu je identifikována významná korelace mezi různými indikátory udržitelnosti, což osvětluje složité vzájemné závislosti a usnadňuje informované rozhodování. Kromě toho výzkum přispívá k vývoji prediktivních modelů pro hodnocení budoucích trendů a scénářů udržitelnosti v Africe. Využitím síly dolování dat si tato studie klade za cíl zlepšit naše chápání dynamiky udržitelnosti a podporovat úsilí o dosažení odolnější, spravedlivější a ekologicky udržitelné budoucnosti kontinentu.

Klíčová slova: Udržitelnost, Udržitelný rozvoj, Data mining,Afrika, Sociální indikátory, Ekonomické indikátory, Environmentální indikátory, Cíle udržitelného rozvoje (SDGs), Multivariační analýza, Ekonomický rozvoj.

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1 Introduction

The word "sustainability" is multifaceted and conjures up ideas of people coexisting peacefully with the natural world or an economic structure that benefits each of them. The broadest definition of sustainability relates to actions taken to ensure that present-day needs are met without putting those of future generations at risk. In the past 30 years, the concept of sustainable development has gained widespread attention (Salvia *et al*., 2019), but how to accomplish this aim is still largely unknown. No nation can currently provide for its citizens' fundamental requirements while sustainably utilising resources (O'Neill et al., 2018). New solutions are required to promote a balance between social needs and the environment, as business-as-usual activities won't result in a sustainable socio-ecological system. Sustainable development is "development that meets the needs of the present without compromising the ability of future generations to meet their own needs." this serves as the most frequently cited definition of sustainable development according to the Brundtland Report (Pavlovskaia, 2013).

However, sustainable development is far from simple, and management strategies like restoration and conservation efforts, while well-intended, can hinder the restoration of natural systems and even have a negative impact on the size and well-being of the human population (Henderson and Loreau, 2018; Kaplan-Hallam and Bennett, 2018). However, the United Nations (UN) undertakes ongoing, thoughtful efforts to address present and upcoming difficulties. The 17 UN Sustainable Development Goals (SDGs) and their 169 targets represent a significant development in the global adoption of sustainable practices.

Many African countries face significant obstacles in reducing poverty and feeding their populations; however, it has been stated that other problems first need to be resolved, like access to clean water and improved sanitation (Mugagga and Nabaasa, 2016). The UN's goals are closely linked with the development of urban ecosystems, sustainable consumption, and infrastructure, as well as the availability of energy, food production, medical facilities, and water treatment (Nerini et al., 2018; Beg et al., 2002; Maes et al., 2019). Improving environmental standards is one example of a trade-off related to socio-economic and environmental sustainability. Since raising environmental standards can be expensive and beyond the means of smallholders, trade-offs frequently relate to socio-economic and environmental sustainability (Brandi, 2017). These trade-offs between socio-economic and environmental sustainability can have a negative impact on the desired result by impeding human population well-being (Cazalis et al., 2018), forcing people to move (Brockington and Igoe, 2006), and causing environmental degradation to spread to other areas, ultimately undermining environmental policy (Milner-Gulland, 2012).

According to the Limits to Growth theory from the 1970s, non-renewable resources, agricultural land, and the ability to absorb pollutants will all run out in the 21st century when continuous growth reaches its limit (Meadows et al., 1972). According to the model, pursuing growth at the expense of the environment will result in an unstoppable drop in population and industrial capacity. The model looked into feedback between population, industrial production, food supply, pollution, and non-renewable resources. However, the authors asserted that economic and ecological stability might be attained by limiting consumption and redistributing wealth.

The Brundtland (1987) report, published more than ten years later, introduced the idea of sustainability, and emphasized the importance of preserving both present and future generations' access to resources. More coupled human-environment models are being used to monitor socioecological indicators like inequality (Motesharrei et al., 2016; Henderson and Loreau, 2021), well-being (Dietz et al., 2009; Cazaliset al., 2018), social learning (Barfuss et al., 2017), food trade (Tuet al., 2019), rebound effects (Freeman, 2018), and investment in sustainable development (Ursino, Numerous models have been developed to analyze the overlaps and trade-offs between goals, measure indicators, or quantify goal achievement since the UN SDGs were first introduced (Costanza et al., 2016; Spaiser et al., 2017; Collste et al., 2017; Schulze et al., 2017; De la Poza et al., 2021). Only a small number of the models listed explicitly account for the human population as a function of well-being and feedback from resource utilization. According to recent research by Crist et al. (2022), population size and social infrastructure are crucial in modelling sustainability. The authors warn that population size must be reduced through better human rights to maintain the long-term well-being of all life on Earth.

The necessity to analyze the state of African countries in the context of sustainability indicators is one of the key driving forces behind this study. This kind of development is especially significant in relation to African countries. In contrast to other continents battling issues brought on by socio-economic development such as traffic, climate change, income disparities of specific social groups, refugee immigration, etc. Africa still has to deal with issues that are quite routine from either European or American points of view, such as reducing poverty and being able to feed their population. It has been accepted that sustainability indicators are part of a socio-economic movement focusing on environmental, economic, and social activities for the greater good of this study. On preserving the natural balance and the viability of fundamental natural processes to guarantee that specific communities and residents' basic requirements are met in the present and the future. Sustainability indicators were developed to track the advancement of sustainable development. This resulted in the creation of a significant number of indicators locally at different development scales.

2 Objectives and Methodology

2.1 Objectives

The main objectives include.

- To identify key sustainability indicators commonly used to assess environmental, social, and economic aspects of sustainability in Africa.
- To assess the patterns and relationships between the sustainability indicators and reduce the data as much as possible.
- To compare and contrast the sustainability indicators for various African regions, including East, West, Central, Northern, and Southern Africa.
- To assess the differences and similarities in sustainability development in various African regions.

2.2 Methodology

To address the above objectives, the thesis uses multivariate statistical analysis to explore the relationship between selected indicators, reduce the dimension of the variables/dataset, and find similarities among selected countries. The study employs both qualitative and quantitative methods. The methods applied to address each objective are exploratory factor analysis which includes Principal Component Analysis,Cluster analysis and trend analysis.

2.2.1 Study design

The current study employs an exploratory study design. Specifically, it seeks to establish the factor structure of the 247 indicators of the 169 targets of the 17 SDG goals (United Nations Environment Programme [UNEP], n.d.). While these aspects have been classified broadly as social, economic (230, and environmental (17), such high dimensionality makes comparison across countries cumbersome.

2.2.2 Variable Definition and Data Collection

To evaluate key sustainability indicators commonly used to assess environmental, social, and economic aspects of sustainability in Africa, the study relied on secondary data disseminated by the World Bank related to each of the indicators of the three domains of sustainability. The data was collected from the World Development Index Databases. The SDG framework has 17 goals, 169 targets, and 247 indicators (UNEP, n.d.). The core SDG indicators are broadly classified into the economic (relates to expenditures and investments), environmental (relates to the conservation of energy and natural resources), social (relates to the social well-being of the), and institutional areas. Each of these core indicators has indicators totalling up to 247. Further, each of these indicators is reported by cohorts such as gender and level of education. Othe measures are cumulative measures such as annual freshwater withdrawals disintegrated by agriculture, domestic, and industry.

Consequently, 408 indicators were extracted from the World bank's Sustainable Development Goals (SDGs) database. For example, **Error! Reference source not found.** shows the targets and indicators of SDG1 (No hunger). Indicator 1.1.1 provides the rural and urban settings of individuals below the poverty line, and 1.1.2 classifies them by demographic attributes. To avoid leading redundancy due to the classification of demographic and socio-economic attributes, aggregate levels (totals) are only used. Thus, only national-level estimates, predominantly aggregate (total) measures at national levels regardless of socio-economic status (e.g., rural and urban) or by age or gender, are used in the analysis. Some of the indicators, such as account ownership at a financial institution or with a mobile money service provider (% of population ages 15+), and coverage of social insurance programs (% of the population) were removed.

Goal description	Target	Description	Indicator
1. No hunger	1.1	By 2030, eradicate extreme poverty for all people everywhere, currently measured as people living on less than $1.25 a day.	1.1.1 Proportion of the population living below the international poverty line by sex, age, employment status, and geographic location (urban/rural)
	1.2	By 2030, reduce at least by half the proportion of men, women, and children of all ages living in poverty in all its dimensions according to national definitions.	1.2.1 Proportion of population living below the national poverty line by sex and age
		By 2030, reduce at least by half the proportion of men, women, and children of all ages living in poverty in all its dimensions according to national definition.	1.2.2 Proportion of men, women, and children of all ages living in poverty in all its dimensions according to national definitions

Table 1: Selected indicators of SDG1 (Source: Author)

The basic PCA requirement is that the number of observations (N) should be greater than the number of variables (K). Data is first pulled across the 54 African countries to optimize the samples. Given the high dimensional SDG metrics, analyzing a few countries will result in significant data loss. The aggregate data spanned from 1990 to 2020, resulting in an initial sample size 1674 with 408 indicators. The data preprocessing steps entailed the removal of alternative measures of similar variables usually scaled by units. For instance, GNI and GDP measures can take different units such as constant 2015 US$, constant LCU), constant 2015 US$), per capita (constant LCU), and per capita (current $). Such measures are redundant since they are perfect complements, and their inclusion will increase the chances of violating the $N \geq K$ rule in PCA.

For such measures, percentage growth. Other variables, such as FDI, are expressed as a percentage of GD. Modeled ILO estimates were used for unemployment data since national estimates have substantially higher missing cases. The data ultimately resulted in a 1674 X 371 data frame but with a significant proportion of missing cases. PCA relies on complete case analysis since all the variables are used harmoniously (i.e., pairwise corelation). The percent of all missing data frame values was 60.6% with all the variables having at least one missing value. Given the significant data gap, using all the metrics becomes infeasible.

3 Literature Review

The main areas of this study's literature review are sustainable development, sustainable indicators, and other key selected indicators. This section reviews relevant literature on the subject matter in Africa and beyond.

3.1 The History of Sustainable Development and Its evolution

The history of how sustainable development has changed remains complex yet current. The 1972 Stockholm Conference on the Human Environment (UN, 1972) and the 1980 World Conservation Strategy of the International Union for the Conservation of Nature (IUCN et al., 1980) provided the groundwork for the first pivotal moment in sustainable development. However, the Brundtland Commission first used the term sustainable development in their 1987 report Our Common Future, also known as the Brundtland Report, which continues to serve as the most frequently cited definition of sustainable development (Pavlovskaia, 2013). It states that sustainable development is "development that meets the needs of the present without compromising the ability of future generations to meet their own needs."

The report goes on to say that: "Sustainable development should become a central guiding principle of the United Nations, Governments, and private institutions, organizations, and enterprises, recognizing, in view of the global character of major environmental problems, the common interest of all countries to pursue policies aimed at sustainable and environmentally sound development, convinced of the numerous advantages of sustainable development for all countries, as well as for the environment and the future generations."

This idea of sustainable development was incorporated into succeeding and advanced treaties, conferences, and research. According to Lélé (1991), sustainable development came to be seen as managing a long-term equilibrium between maintaining environmental systems and growing/improving social and economic variables. The next significant event was the Earth Summit in Rio de Janeiro in June 1992, five years after the endorsement and implementation of sustainable development. At this, the largest worldwide environmental meeting to date, 30,000 people attended, together with 100 heads of state. The Convention on Biological Diversity, the Framework Convention on Climate Change (both of which had legal force for signatories), the Principles of Forest Management, the Rio Declaration on Environment and

Development, and Agenda 21 were among the major outcomes of this conference. The UN Commission on Sustainable Development was also founded due to the summit (Meakin, 1992; UN CSD, 2007).

Particularly, Agenda 21 was a strategy for implementing sustainable development. States were advised by Agenda 21 to create national sustainable development reports following its format. The actions carried out to implement Agenda 21, the difficulties and challenges encountered in this regard, and other pertinent environmental and developmental issues are all included in these reports, which are to be submitted to the Commission on Sustainable Development (CSD) (Drexhage and Murphy, 2010). Eight Millennium Development Goals for 2015 were further defined in 2000 by The United Nations Millennium Declaration (UN, 2000), founded on sustainable development. As a result, sustainable development has been thoroughly incorporated into international goal setting and policy.

The following Sustainable Development Goals (SDGs) were born at the UN conference on sustainable development in Rio de Jeneiro in 2012, whose objective was to produce a set of universal goals that meet the urgent environmental, political, and economic challenges facing our planet.

- End poverty in all its forms everywhere.
- End hunger, achieve food security and improved nutrition, and promote sustainable agriculture.
- Ensure healthy lives and promote well-being for all at all ages.
- Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all.
- Achieve gender equality and empower all women and girls.
- Ensure availability and sustainable management of water and sanitation for all
- Ensure access to affordable, reliable, sustainable, and modern energy for all
- Promote sustained, inclusive, and sustainable economic growth, full and productive employment and decent work for all
- Build resilient infrastructure, promote inclusive and sustainable industrialization, and foster innovation
- Reduce inequality within and among countries

- Make cities and human settlements inclusive, safe, resilient, and sustainable.
- Ensure sustainable consumption and production pattern
- Take urgent action to combat climate change and its impact
- Conserve and sustainably use the oceans, seas, and marine resources for sustainable development
- Protect, restore, and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification and halt and reverse land degradation, and halt biodiversity loss
- Promote peaceful and inclusive societies for sustainable development, provide access to justice for all, and build effective, accountable, and inclusive institutions at all levels
- Strengthen the means of implementation and revitalize the global partnership for sustainable development

3.2 Sustainability Indicators

Sustainability Indicators may be traced back to the 1992 Rio Summit (Bell and Morse, 2008) because it was necessary to create indicators that could be used to track advancements toward sustainable development. In light of this, numerous local indicators have been created at different development scales (Bell and Morse, 2008; Science for Environment Policy, 2015; Wu, 2014; Huedo et al., 2016). As a tool for making sustainable decisions, indicators serve various purposes. One-way indicators assist in the decision-making process by conveying and exchanging information systematically (Dahl, 2012; Moldan and Dahl, 2007; Hezri and Dovers, 2006; Munier, 2011). In this way, indicators help us observe and prove the idea of sustainability. Secondly, Indicators aid in putting the idea into practice (Bell and Morse, 2005; Malkina-Pykh, 2002; Halla et al., 2022). Specifically, it fosters explicit addresses regarding how indicators address sustainability dimensions and removes the subject of sustainability from the abstract formulation (Braulio Gonzalo et al., 2022).

To this goal, placing sustainability in a context is helpful. Thirdly, because stakeholders must be involved in producing indicators, this promotes social learning (Bell and Morse, 2004; Coelho et al., 2022). Fourth, the inclusion of Sustainability Indicators in the decision-making process may alter how a society gauges its progress toward sustainability. This can be used as a springboard to address the underlying factors that lead to unsustainable development (Pinter et al., 2012). Indicators are crucial for an assessment to meet some Bellagio Sustainability Assessment and Measurement Principles (STAMP) requirements in addition to these complementary roles, according to Sala et al. (2015). For instance, if indicators are established in a straightforward, clear manner that is simple to understand and comprehend, they may enhance the transparency of the decision-making process (Pinter et al., 2012).

A particular context's driving goal for sustainability may be ascertained using the overall outlook of an indicator. As an illustration, if the indicators are more geared toward environmental concerns, it may imply that the context is more conscious of the environment in its pursuit of a sustainable future. From an evaluation framework's perspective, an indicator's advantages can also be investigated. Indicators can be used as planning tools, pilot instruments, performance evaluation tools, or explanatory tools, claim Shen et al. (2011) and Joss et al. (2013). To attain this goal, the sustainability assessment framework has consistently acknowledged the significant role of context in determining the selection of indicators (Joss et al., 2015; Gazzola et al., 2011; Gazzola, 2008; Fischer, 2005; Fischer and Gazzola, 2006; Fischer and Onyango, 2012; Braulio-Gonzalo et al., 2015).

Context affects how sustainability assessment is developed and implemented, including the indicators and how they are used for decision-making, according to Conte and Monno (2012). For instance, the development phase, which involves comprehending and interpreting sustainability, depends on the setting. In other words, how sustainability is viewed in one context may differ from how it is viewed in another. Values, needs, goals, cultural preferences, and environmental factors primarily influence this view.

3.3 Environmental sustainability

According to Henderson and Loreau (2023), environmental sustainability is the capacity to protect natural resources while maintaining the ecological balance of the planet's ecology. As a result of growing industrial activity and population growth, including the burning of fossil fuels, the environment continues to deteriorate, and air pollution is rising, making it crucial to preserve the environment from climate change. Additionally, there is an increasing need for action to reduce carbon emissions and other pollutants that contribute to environmental degradation and global climate change because they are already linked to Sustainable Development Goals 7 and 13 (Lee et al., 2023; Byaro et al., 2022; Byaro et al., 2022b). The link means that SDG7, which deals with clean and inexpensive energy to promote environmental sustainability, is necessary for implementing climate change action (SDG 13). International initiatives, including the Kyoto Protocol, the Paris Agreement, and finally the COP26 summit were initiated to raise awareness of environmental issues and uphold this commitment for all countries globally.

Statistics demonstrate that despite the importance placed on international efforts to lessen environmental harm, not much has changed, especially regarding the harm brought on by greenhouse gas emissions that contribute to global warming (World Bank, 2022). It has been urged that all nations establish a clear goal of limiting global temperature increase to 1.5 °C between 2030 and 2050. The COP26 suggested raising public sector spending on sustainable energy technology to reach this objective. In light of this, it is reasonable to expect that clean energy technologies will be crucial for meeting the 2030 and 2050 goals. Additionally, by comprehending how clean energy technologies affect environmental sustainability, nations may be able to fulfill their Sustainable Development Goals, such as SDG 13 on climate change and SDG 7 on clean and affordable energy (Caglar, 2022). Given the current rate of environmental degradation in African nations, the deployment of clean energy technology is unavoidable in this sector (Byaro et al., 2022b). Still heavily reliant on non-renewable energy sources, African nations contribute to increased pollution and global warming (Adedoyin et al., 2021). For instance, it has been demonstrated that African nations lack access to clean cooking technology and fuels, which suggests that energy poverty places more strain on the environment and its natural resources (Acheampong, 2023).

Accordingly, maintaining environmental sustainability for present requirements without compromising the well-being of future generations is a major concern for sub-Saharan Africa, as the region's ongoing reliance on polluting sources of energy worsens the state of the environment. Evidently, many sub-Saharan African nations still do not have the necessary infrastructure or financial systems to switch from fossil fuels to clean energy (Acheampong, 2023; Byaro and Mmbaga, 2022). Numerous other important aspects have been identified by researchers that affect environmental sustainability, which include natural resources, environmental laws, FDI, trade openness, power usage, and urbanization (Shahbaz et.,2014; Jiang and Guan,2016; Ansari et al.(2019); Duodu et al.,2022).For instance, Ansari et al.(2019) used fully modified ordinary least squares to examine how the environmental quality of 29 Asian countries was affected by FDI. The study demonstrates that FDI lowers environmental quality, supporting the idea that Asian nations are pollution havens.In addition, Antiweiler et al.(2001) examined how trade openness affected pollution levels in wealthy nations and discovered that environmental benefit comes from global commerce.

Additionally, Al-Mulali and Ozturk(2016) examined how energy prices have changed from 1990 in relation to environmental degradation, and their findings indicate 27 affluent economies. Shahbaz at al. (2014) discovered that energy use lowers CO_2 emissions in the United Arab Emirates (UAE) while CO_2 emissions are worsened by urbanization, again their research demonstrated the presence of environmental Kuznets hypothesis, which asserts that economic growth and CO_2 emissions have an inverted U-shaped relationship in UAE. Lastly, Jiang and Guan (2016) investigated the factors that influenced the growth of global CO_2 emissions in both developed and emerging nations from 1995 through 2009. Among the three fossil fuels they showed (coal, oil, or gas), coal and natural gas CO_2 emissions quickly increased in developed and underdeveloped nations.

Lately, Hassan et al. (2020) examined the degree to which institutions in Pakistan corrected environmental pollution from 1984 to 2016. They discovered, using an autoregressive distributed lag model, that institutions in Pakistan produce more CO_2 emissions due to corruption. In addition, they discovered that using fossil fuels for energy causes CO_2 emissions to rise. If the utilization of sustainable energy sources like renewable energies is ignored, green sustainable development appears to be a mirage. In this study, EFP, MFP, and SDI will be taken into consideration as a gauge of environmental sustainability, and it will offer a comprehensive picture of sustainability and examine how various parameters affect environmental sustainability across different African regions.

4 Practical Part

4.1 Data Analysis

4.1.1 Trend analysis

Trend analysis was used to examine objectives 3 (comparing and contrasting the sustainability indicators for various regions in Africa, which include East, West, Central, Northern, and Southern Africa) and 4 (assessing the differences and similarities in sustainability development in various African regions), and (5) To evaluate the effectiveness of government policies, development aid programs and their impact on sustainability development in Africa. Time series line plots of each of the attributes of major indicators of each of the 17 SDGs by region. National policies and development aid programs implemented in each country were obtained from government databases and international/non-governmental organizations such as USAID. The impact of each intervention is examined by comparing the trends of each attribute.

4.2 Principal Component Analysis

The second objective, to assess the patterns and relationships between the sustainability indicators and reduce the data as much as possible, was examined using exploratory factor analysis. Factor analysis is an analytic technique for reducing many interrelated variables to a smaller number of latent or hidden dimensions. The main goal of factor analysis is to achieve parsimony by using the smallest number of explanatory concepts to explain the maximum amount of common variance. It removes the common variance shared among variables into Groupwise variance with a subset of variables. It takes out the most meaningful data information, reducing the data's dimension.

There are different dimensionality reduction or factor extraction techniques. Principal Component Analysis (PCA) and principal axis techniques are common factor extraction techniques (Akhtar-Danesh, 2017). Although the same techniques might lead to the same number of factors extracted, substantial differences exist for a discretionary selection of the factor extraction method depending on the objective and data distribution at hand. First, PCA is based on the data matrix's singular value decomposition (SVD), which decomposes it into orthogonal components that capture the maximum variance in the data. Principal axis techniques are based on the eigenvalue decomposition (EVD) of the covariance or correlation matrix, which decomposes it into eigenvectors that represent the directions of maximum variance and eigenvalues that represent the amount of variance explained by each eigenvector (Mabel & Olayemi, 2020). PCA is more efficient and robust than principal axis techniques, as it does not require covariance or correlation matrix computation, which can be singular for high-dimensional or sparse data (Bonner, 2012; Cichocki, 2014). PCA can also handle missing values and outliers better than principal axis techniques (Chen, 2002; Hubert et al., 2019; Kärkkäinen & Saarela, 2015).

Moreover, PCA and principal axis techniques can give different results when the data are not standardized or centered. PCA is sensitive to the scaling of the variables as it tries to maximize the variance of the projected data. Principal axis techniques are invariant to the scaling of the variables, as they only depend on the correlation structure of the data (Fabrigar & Wegener, 2011; Wegener & Fabrigar, 2000). PCA and principal axis techniques can also give different results when the data are not normally distributed or have nonlinear relationships. PCA assumes the data are linearly related and follows a multivariate normal distribution (Bursa & Tatlidil, 2020; Garson, 2022). Principal axis techniques can handle non-normality and nonlinearity better than PCA, as they can use different measures of association (such as Spearman's rank correlation) or transformations (such as logarithmic or power transformations) to capture the underlying structure of the data.

With respect to the above comparison, PCA was adopted in this study as a factor extraction method since PCA is better than the principal axis technique because PCA is more efficient and robust than PAT; it does not require the computation of the covariance or correlation matrix which might not be feasible for a singular for high-dimensional data matrix, and it can nadle missing values and outliers better than PAT. Besides, PCA can capture more variance in the data than PAT, as it uses the SVD of the data matrix, which decomposes it into orthogonal components that are optimal for dimensionality reduction. PAT uses the EVD of the covariance or correlation matrix, which may not be optimal for dimensionality reduction.

The steps involved are classified into three key subcategories: data preprocessing to access the suitability of the data, b) factor extraction, and c) factor rotation.

4.2.1 Data preprocessing

The extracted panel data has two key domains that might bias the data: space and time. First, the data is collected from all African countries; hence, there is a significant heterogeneity due to disparity in socio-economic status and population sizes. Thus, the data was standardized by scaling. Secondly, time series induces time trends that induce spurious correlations among the variables (Wooldridge, 2009). Therefore, it is important to test for stationarity of the data. Each of these algorithms is extensively described as follows.

4.2.2 Data standardization

The extracted panel data of SDG indicators of each of the 54 African states is likely to suffer from heteroscedasticity since countries have different levels of socio-economic development. Besides, there are potential outliers in the data due to global shocks such as the 2008/09 global financial crisis and regional shocks such as civil wars, floods, and drought that increase food insecurity. The heteroscedasticity assumption is first tested using the Breusch pagan test for heteroskedasticity, which tests the null hypothesis for the test that the variances are equal for all samples; that's H0: $\sigma_1^2 = \sigma_2^2 = \cdots = \sigma_k^2$ (homoscedasticity) versus the alternate hypothesis that the variances are not equal for one pair or more; H0: $\sigma_1^2 \neq \sigma_2^2 \neq \cdots \neq \sigma_k^2$ (heteroscedasticity). Due to the different scales used in the measures, they violate homoscedasticity. To mitigate this assumption, the data was standardized by scaling.

4.2.3 Stationarity

Data stationarity is a property of time series data that means the statistical characteristics of the data, such as mean, variance, and autocorrelation, do not change over time. Stationarity is important for time series analysis because it induces spurious correlation among the variables due to time or seasonal trends due to time aspect and external shocks such as natural seasons of the year that influence some macro variables simultaneously (Wooldridge, 2009).

This study's panel data combines cross-sectional (across African countries) and time series (over 2000 to 2021) dimensions. Unlike univariate time series, panel data induces heterogeneity and dependence across the cross-sectional units (Pesaran, 2021). This study tested the stationary test using the Augmented Dickey-Fuller (ADF) test and the Kwiatkowski-Phillips-Schmidt-Shin (KPSS) test (Kwiatkowski et al., 1992). The two tests have different algorithms. The ADF test tests the null hypothesis of non-stationarity, or presence of a unit root, versus an alternative hypothesis of stationarity, or absence of a unit root. The ADF test statistic is based on estimating an autoregressive model with lagged differences of the variable to account for serial correlation. The KPSS test has a null hypothesis of stationarity, or absence of a unit root, and an alternative hypothesis of non-stationarity, or presence of a unit root. Its test statistic is based on the estimation of the variance of the residuals from a regression of the variable on a constant or a trend. Since the null hypothesis cannot be predetermined, the results of both ADF and KPSS will be compared.

Essentially, the KPSS test is more appropriate when the cross-sectional units are assumed to be stationary. In contrast, the ADF test is preferred when cross-sectional units are assumed non-stationary. Non-stationary is often corrected by differencing or detrending. Differencing often removes other signals (cyclical and seasonality), unlike detrending, which only removes time trends in the time series. Due to the high dimensionality of the data, the first differenced series was used to mitigate the time effect.

4.2.4 Sampling Adequacy

The sample passes the sample adequacy test since it is panel data from 54 countries between 2000 and 2021. To statistically test this assumption, the Kaiser-Meyer-Olkin (KMO) test for sample adequacy was used. The KMO statistic indicates the proportion of variance in your variables that underlying factors might cause. It is computed using Equation 1.

$$KMO = \frac{\sum_{i \neq j} R_{ij}^2}{\sum_{i \neq j} R_{ij}^2 + \sum_{i \neq j} U_{ij}^2} \qquad (1)$$

Where, R_{ij}^2 is the correlation matrix of the standardized stationary data, and U_{ij}^2 is the associated partial covariance matrix. The KMO statistic ranges from 0 (no variance) to 1 (100%

variance). Therefore, high values (close to 1.0) indicate that the data is well-suited for factor analysis. A rule of thumb for interpreting the KMO statistic is that KMO values between 0.8 and 1 indicate an adequate sample, whereas KMO values less than 0.6 indicate an inadequate sample (Shrestha, 2021). KMO values close to zero indicate a large partial correlation among the variables, leading to the extraction or retaining of more principal components.

4.2.5 Bartlett's Test of Sphericity

The basic principle of PCA or factor analysis is based on correlation. Essentially, correlated items are grouped into their component (Guttman, 1954; Tucker & MacCallum, 1997). Thus, it is essential to pretest whether the variables are suitable for analysis by checking the correlation of items. Aggregately, Bartlett's Test of Sphericity allows us to test this presumption. It tests the null hypothesis, H_0: The variables are orthogonal; that is, the resultant correlation matrix is an identity matrix [|R| =1], implying that the variables are unrelated and, hence, factor analysis is not feasible. Its alternative hypothesis, H1, is that the variables are not orthogonal [|R| ≈ 0]; the variables have a substantial correlation. Bartlett's test of Sphericity follows a chi-square distribution, computed using Equation 2 (Shrestha, 2021).

$$\chi^2 = \left[n - 1 - \frac{2p - 5}{6}\right] \times \ln |R| \tag{2}$$

Where p is the number of variables, n is the sample size, and R is the correlation matrix. Thus, rejection of the null hypothesis, $p < 0.05$, will support the factor extraction to identify the underlying structure of the selected sustainability indicators. Strong evidence against the null hypothesis is desirable if few factors are to be extracted since it indicates a higher degree of intercorrelations among the variables.

4.2.6 Factor Extraction

Factor extraction entails determining the minimum number of factors or principal components (PC) that best capture the total variance in the databases based on their interrelationships among the high-dimensional input variables. In this study, the input matrix is a time series of measures of SDGs (selected based on data availability). PCA is used to analyze the data structure of the selected sustainability indicators using data across African countries (input data). The main goal is to assess the patterns and relationships between the sustainability indicators and reduce the data as much as possible for easy interpretation. Essentially, each of the input data is first treated as a component.

4.2.7 PCA Algorithm

PCA is a technique for reducing the dimensionality of a data set by finding a new set of variables, called principal components, that capture the maximum variance in the data. The PCA algorithm is useful in reducing a large redundant dataset. In this case, the SDG framework has 17 goals, 169 targets, and 247 indicators (UNEP, n.d.), which could be complex and tedious to evaluate. Such a high dimensionality of the variables makes examining how each country is doing in the major sub-scales of SDGs difficult. Thus, this study used PCA to reduce the dimensions of indicators within each of the three domains.

The basic principle is based on the correlation of items. The PCA algorithm identifies patterns in data and expresses correlated observed variables as a linear combination of optimally weighted onto a given latent factor known as the principal component such that it minimizes the variation in scores. The ultimate goal is to explain the maximum variance with the fewest principal components, reducing the number of variables using their regression weights to avoid data redundancy due to multicollinearity (Tefas & Pitas, 2018). The PCA algorithm is described as follows: Consider a set of p-variables at time t to $t + k$, expressed in the matrix in Equation 3.

$$\begin{bmatrix} X_{1,t} & X_{2,t} & \cdots & X_{p,t} \\ X_{1,t+1} & X_{2,t+1} & \cdots & X_{p,t+1} \\ \vdots & \vdots & \ddots & \vdots \\ X_{1,t+k} & X_{1,t} & \cdots & X_{p,t} \end{bmatrix} \tag{3}$$

The PCA algorithm seeks to find a linear combination of X variables expressed as $Z_1, Z_2, \dots, Z_3, \dots, Z_k$ that are uncorrelated, so-called, factor pattern/structure matrix, as Expressed in Equation 4.

$$Z_i = a_{i1}X_1 + a_{i1}X_1 + \cdots + a_{ik}X_k \qquad \forall\, i = 1 \dots k; k < p \tag{4}$$

The factor pattern matrix comprises the regression weights, a_i, identical to regression coefficients obtained in multiple regression analysis. The weights are the corresponding eigenvector (weights) of the computed principal component, Z_i, scaled such that they add up to 1. Once the pattern matrix is constructed, the variance-accounted-for statistics is generated to help determine the amount of variance contributed by each factor. Two key- variance-accounted-for statistics are eigenvalues and communalities derived from the variance of the principal component matrix Z, denoted S (Equation 5).

$$S = \begin{bmatrix} S_{1,1} & \dots & S_{1,k} \\ \vdots & \ddots & \vdots \\ S_{1,p} & \dots & S_{k,k} \end{bmatrix} \tag{5}$$

Since the regression weights, a_i, of each of the component matrix Z are ordered based on their importance such that $a_{i1} > a_{i2} + \cdots > a_{ip}$. Consequently, it follows that $var(Z_1) \geq var(Z_2) \geq \dots \geq var(Z_p)$. Like in regression analysis, the weights reflect the relative importance of a variable to the extracted factors or components, excluding the influence of other variables (Kieffer, 1998).

Define λ_i, as the eigenvalue of the i_{th} principal component Z_i, the eigenvalues for the covariance matrix, S, are strictly non-negative entries and ordered based on the regression weights of the component. That is, $\lambda 1 \geq \lambda 2 \geq \cdots \geq \lambda p \geq 0$. The sum of the eigenvalues equals the number of variables of the input data frame since the initial assumption is to treat each variable as an independent observed variable; hence, the eigenvalues help compute the proportion of variance explained by each principal component according to Equation 6.

$$\vartheta_i = \frac{\lambda_i}{\sum \lambda_i} \tag{6}$$

In PCA, Eigenvalues can be used to measure the effect size because each eigenvalue can be divided by the number of the variables in a given dataset, expressed as a percentage of the total variance for a given factor can be computed. The second variance-accounted-for statistic is the communality coefficient, h^2, which refers to the proportion of total variance for a given variable reproduced by the extracted factors. It is calculated as the sum of the squared loadings of the variable on all the principal components' matrix Z row-wise for each variable. The communality coefficient can range from 0 to 1, where 0 means no common variance and 1 means all common variance. A high communality means that the principal components represent the variable well, while a low communality means that the variable is mostly unique and unrelated to the other variables.

4.2.8 Factor Retention

At the initial stage of decomposition, each variable is treated as each of the variables is treated as a factor. Three techniques are used to determine the number of factors/ principal components to be extracted or retained: Kaiser's Criterion, scree plot/test, and parallel analysis.

The Kaiser's criterion: The Kaiser's criterion is based on the Eigenvalues. In PCA, the eigenvectors and eigenvalues of the covariance matrix are obtained by matrix decomposition to identify the directions and magnitudes of the principal components, respectively. In PCA, the eigenvalue of a factor represents the amount of the total variance explained by that factor (see Equation 4). According to Kaiser (1970), factors having eigenvalue greater than one are retained since it indicates that the component or factor explains more common variance than unique variance. Components with eigenvalues greater than 1.0 are retained (Kaiser, 1960).

Kaiser's criterion is a method to determine the number of principal components to retain in a PCA. It is based on the idea that a principal component should explain at least as much variance as a single original variable. Therefore, only the principal components with eigenvalues greater than one are selected. Eigenvalues measure how much variance a principal component captures from the data. Kaiser's criterion is also known as the eigenvalue-one criterion or the Kaiser-Guttman rule. The Kaiser's criterion has been widely adopted due to several advantages including its consistency it has some drawbacks such as reliance of correlation which may lead to extraction of too many components/redundancies, and sensitivity to the scaling such as standardization or normalization (Fava & Velicer, 1992). Therefore, Kaiser's criterion selection of the number of components results were compared with findings from scree plot, proportion of variance explained, and parallel analysis.

Scree plot analysis: The Scree test was used to determine the number of initial unrotated components. The test was proposed by Cattell (1996). It is a graphical test for determining the number of factors that plot eigenvalue on the vertical axis and the number of components on the horizontal axis. The rule of thumb is the number of components at the "elbow' point of the curve; there, the curve is leveling off since it implies that additional components do not add a significant variance in the total variance explained by the existing number of components.

4.2.9 Factor Rotation

The earlier three techniques of determining the number of factors or principal components to be retained, Kaiser's Criterion, scree plot, and parallel analysis, might be biased due to possible significant cross-loadings where several components can be correlated with many variables. Ones the factors are determined, it is essential to rotate the factors to get an optimal solution with a simple interpretable matrix structure and meaningful interpretation from an infinite possible dimension by redistributing the common variance across the already explained factors to achieve a more parsimonious solution (Kieffer, 1998; Thurstone, 1931; 1947; Pedhazur and Schmelkin, 1991). An unrotated structure matrix misrepresents the true nature of the factors (Thompson, 2000). There are two broad domains of factor rotation techniques in factor extraction techniques, such as PCA and principal axis factoring techniques: orthogonal and oblique. The two algorithms have two key differences. Orthogonal rotation is often used if the factors are uncorrelated, whereas oblique rotation is used when the factors are assumed to be correlated.

Orthogonal rotation: Orthogonal rotation shifts the factors in the factor space, maintaining 90-degree angles of the factors to one another to achieve the best simple structure. Since the cosine of the angles between vectors of unit length equals r, and the cosine of a 90-degree angle is zero, this rotation strategy maintains the perfectly uncorrelated nature of the factors after the solution is rotated and often aids in the interpretation process since uncorrelated factors are easier to interpret. In theory, the results of an orthogonal rotation are likely to be replicated in future studies since there is less sampling error ijn the orthogonal rotation due to less capitalization on the chance that would occur if more parameters were estimated, as is the case in oblique rotation. Three are three orthogonal rotation techniques: varimax, quartimax, and equimax.

Varimax Rotation: Among the orthogonal rotation strategies available, one of the most popular techniques is rotation to the varimax criterion developed by Kaiser (1960). In this technique, the factors are "cleaned up" so that every observed variable has a large factor pattern/structure coefficient on only one of the factors. Varimax rotation produces factors with large pattern/structure coefficients for a few variables and near-zero or very low pattern/structure coefficients for the other variables.

Quartimax Rotation: Generally, most factor analyses presume orthogonal factor rotation since they provide easily interpretable solutions and assume that extracted components should be linearly independent, which is the ultimate goal of dimension reduction. Empirically, these methods may largely be dependent on the data. For instance, Akhtar-Danesh (2017) applied principal component and principal axis factoring methods for factor extraction and varimax, equamax, and quartimax factor rotation techniques to three datasets: perceptions of clinical professionalism, simulation, and causes of obesity. The authors compared three-factor rotation techniques, Quartimax, varimax, and equamax, based on the number of Q-sorts loaded and distinguishing statements on each factor and excluded Q-sorts. The authors established that equamax showed a more balanced distribution of factors in the components extracted using PCA and produced considerably fewer items loaded on the factors. For instance, the first four components loaded 17, 10, and 12,4 items using varimax, 10,10,11 and 7 using Equimax, and 35,8,3,2 using Quartimax in the perception of nursing professionalism with 54 indicators. Regarding causes of obesity, the first four components loaded 4, 6, and 10,11 items using varimax, 12,5,10, and 7 using Equimax, and 1,7,6,3 using Quartimax in the perception of nursing professionalism. The authors also observed that Quartimax leads to fewer distinguishing statements for factors rotation than varimax and Equamax rotations. In this study, factor extraction is done using PCA, and the Varimax method was also postulated by Kaiser (1958) as the factor rotation technique since it consistently maximizes the factor loadings after extraction and after rotation (Kaiser, 1958; Thompson, 2004).

4.2.10 Parallel Analysis

Parallel Analysis is preferred over others like the Kaiser criterion or the scree-test because it accounts for the sample size and the randomness in the data, providing a more reliable decision on the number of factors to retain. The technique was introduced by John L. Horn in 1965. It also uses eigen values of a correlation or variance matrix of the input data but applies Monte Carlo simulation to optimize factor extraction (Lautenschlager, 1989; Watkins, 2006). For each simulated dataset, the average eigenvalues are computed for each factor across all simulations. Lastly, factor retention is done by comparing the eigenvalues of the actual data with the mean eigenvalues from the simulated data. Factors are whose actual eigenvalues are greater than the simulated mean eigenvalues are retained.

4.3 Clustering Techniques

Clustering have become instrumental in analysis of panel data. Recently, PARİM, Özkan, and Erhan (2019) used K-means clustering to cluster 54 different countries who are former Soviet Union countries using 14 socio-economic variables such as inflation, economic freedom, exchange rates, and FDI over 1995 and 2015. The authors established three clusters of countries, comprising of 13, 23, and 18.

K-Means Clustering is a popular method in unsupervised machine learning to partition a dataset into K distinct, non-overlapping clusters.

Step 1: Choose the Number of Clusters (K)

Decide the number of clusters, K, you want to identify in your dataset. This is often done using the Elbow Method, which involves plotting the explained variation as a function of the number of clusters and picking the elbow of the curve as the number of clusters to use.

Step 2: Initialize Centroids

Randomly pick K data points as the initial centroids or calculate them based on some other logic.

5 Step 3: Assign Clusters to Points

For each point in the dataset, calculate the distance to each centroid and assign the point to the nearest cluster. The distance is typically calculated using the Euclidean distance, the formula for which is:

$$d(p, q) = \sqrt{(q_1 - p_1)^2 + (q_2 - p_2)^2 + \cdots + (q_n - p_n)^2}$$

where p and q are two points in Euclidean n-space.

Step 4: Recalculate Centroids

Once all points have been assigned to clusters, recalculate the centroids by taking the mean of all points in each cluster.

Step 5: Repeat Steps 3 and 4

Repeat the assignment of clusters and recalculating of centroids until the centroids no longer change significantly, indicating that the clusters are as good as they can be given the current configuration.

Step 6: Model Evaluation

After the clusters have been defined, evaluate the model to ensure it makes sense for your application. This might involve checking cluster coherence, separation, or applying some domain-specific validation. The objective function that K-Means aims to minimize is the sum of the squared distances between each point and its corresponding centroid, which is known as the inertia or within-cluster sum-of-squares. This function is given in Equation 7.

$$J = \sum_{i=1}^{n} \sum_{j=1}^{k} w_{ij} \, |x_i| - |c_j|^2 \qquad (7)$$

Where n is the number of data points, k is the number of clusters, w_{ij} is 1 if data point x_i is in cluster j and 0 otherwise, x_i is a data point, and c_j is the centroid of cluster j. The best clustering result from these runs is then selected as the final model.

To cluster countries, a cross section data was created using average scores across the principal components used extracted from PCA results. Each of the component was computed by equality weighted the variables that fall in that cluster. The data was then aggregated across the years to obtained a cross-section data of countries only with measures of the 9 optimal clusters.

5. Results and Discussion

5.1 Key Sustainability indicators.

Sustainability indicators measure the success of a country's strategies and actions in achieving social, environmental, and economic SDG objectives. The action plan adopted in 1992 at the United Nations Conference on Environment and Development in Rio de Janeiro calls on countries, as well as international, governmental, and non-governmental organizations, to develop indicators of sustainable development that can provide a solid basis for decision-making at all levels (United Nations, 2007). The Commission on Sustainable Development (CSD) Indicators of Sustainable Development developed between 1994 and 2001 and have been used in several countries as a yardstick for national sustainable development indicators. The indicators have been continually revised and updated from the initial 134 indicators by the CSD, including the World Summit on Sustainable Development in 2002. Presently, there are over 400 suitability indicators.

The high dimensional data implies that most indicators often go unstudied or examined by empirical studies. Yet, there is an increasing interest in using a high dimensional indicator to conjointly rank countries since countries can be ranked differently by indicator or domain. Bartniczak and Raszkowsk (2018) selected 30 sustainability indicators in social, economic, environmental, spatial, institutional, and political domains to develop a synthetic measure of development (SMD), a composite index used to rank 48 African countries (others excluded due to significant data gaps) based on the level of implementation of sustainable development goals from 2002 to 2016 (Table 2). Generally, the authors established that African countries have improved their sustainable development level with least ranking countries, including the Democratic Republic of the Congo, Liberia, Chad, Central African Republic, and Eritrea. Bartniczak and Raszkowsk's (2018) division of thematic areas (SDI theme) was inspired by the approach to measuring the sustainable development level adopted by the European Union (Sustainable Development in the European Union, 2015; 2017). In this study, the same subthemes form a basis for examining how often their respective sub-indicators are used.

The current study hinges on the assumption that most recurrent aspects of SDGs could attract researchers while some might go unreported. The SDGs are broadly classified as environmental, social, and governance indicators focusing on sustainability. Over the past five years, Empirical studies relating to the above aspects of sustainability indicators in Africa have been indexed in Google Scholar. The keywords used were “Sustainability,” “Indicators,” “Africa,” “SDG:” and “indicator name.” Studies published over the past five years, from 2018 to 2022, were included.

5.2 Environmental Suitability Indicators

The adverse effects of human activities on air, soil, water quality, and ecosystems are becoming more crucial with the growing population and associated industrialization and urbanization. The key drivers of environmental damage are the rapid expansion of crucial sectors such as agriculture and industry to meet the growing demand for food and other consumer goods. Environmental sustainability indicators (ESI) assess the success of interventions to minimize the negative externalities on the environment emanating from the key five economic sectors: energy, industry, buildings, transport, agriculture, forestry, and other land use practices. These sectors use energy and other resources such as water and raw materials, which can damage the environment through waste generation in terms of solids, liquids, or gases that pollute the environment or from unsustainable use of natural resources. At a national level, ESI measures how a given country governs these externalities. Some examples of ESI include the amount of water used, the life cycle of the product, raw materials used, carbon footprint, and carbon dioxide (CO_2) emissions during transit (APLANET, 2023).

According to the US Environmental Protection Agency (EPA), the sustainability approach should go beyond assessing and managing the risks posed by pollutants that have largely shaped environmental policies and adequate to address complex problems that put current and future generations at risk, such as depletion of natural resources, climate change, and loss of biodiversity (National Academies of Sciences, Engineering, and Medicine. 2011). The key sustainability indicators commonly used to assess environmental aspects of sustainability in Africa are broadly divided into sub-themes.

5.3 Atmosphere: greenhouse gas emissions, air quality

Environmental degradation can be measured using a number of indicators, but largely, the emission the total amount of greenhouse gas emissions (GHG) such as CO2, sulphur oxide (SO2), and methane (NH4), other gases that contribute to global warming that are emitted by a country. Such adverse effects lead to crop failures and cropping calendar disturbance among smallholder farmers who have not adopted modern water irrigation systems – the majority of whom are in Africa. Consequently, it contributes indirectly to food insecurity in arid and semi-arid lands (Omoyo, Wakhungu, & Oteng'i, 2015). Consequently, tracking GHGs emissions has been one of the concerns in empirical studies. Different empirical studies have used CO2, NH4, and NO2 (Abid, 2016; Adzawla, Sawaneh, & Yusuf, 2019; Kumar, Kyophilavong, & Tiberiu, 2016) as indicators of environmental degradation.

Emissions of ozone-depleting substances (ODSs), such as Carbon Tetrachloride, Methyl Chloroform, Methyl Bromide, Hydrochlorofluorocarbons (HCFCs), Carbon Tetrachloride, Halons, and Chlorofluorocarbons (CFCs) have substantially contributed to a sharp decline in stratospheric ozone concentrations since the 1980s. Zero ODS emission is a global goal since it has a high Global Warming Potential (GWP). For instance, CFC-11 and CFC-12 have a GWP of 4,750 and 10,900, respectively, compared to 1.0 for C02 (United Nations Development Programme, 2011). The ozone layer regulates the earth's temperatures and makes earth habitable by absorbing some of the sun's ultraviolet radiation. The emission of large quantities of ozone layer-depleting substances in the post-industrial error has created ozone holes at the earth's poles, exposing life to high ultraviolet radiation levels and increasing the risks of skin cancer in humans.

The global international agreement to reduce emissions of ODGs, including the 1985 Vienna Convention and the 1987 Montreal Protocol agreement, has successfully reduced global emissions by more than 95%. There has been a sharp decline globally in total ODS emissions, from 263.120 thousand Ozone Depletion Potential (ODP) tonnes from 2000 to 16.658 thousand tonnes in 2021, by about 93.67% (UN Environment Programme, 2023). Africa's main contributors are ODSs, HCFCs, and CFCs. The total ODSs declined from 12.482

thousand ODT tonnes (0.530 HCFCs and 11.979 CFCs) from 2000 to 0.858 thousand tonnes (HCFCs only) in 2021, by about 93.13% (UN Environment Programme, 2023).

Since ozone depletion has an adverse effect on climate change, particularly rising temperatures, there is a growing empirical study on tracking countries' consumption and emissions of ODSs (Table 2). Air pollutants are substances that contaminate the air and have harmful effects on human health and the environment. Some of the major air pollutants include particulate matter, ozone, nitrogen dioxide, sulfur dioxide, and carbon monoxide. The main emission sources of theses air pollutants in urban areas in Africa include transport, industry, and biomass burning. Air pollution can cause respiratory and cardiovascular diseases, cancer, premature death, and climate change and affects ecosystems and biodiversity (United Nations, 2007; (World Health Organization [WHO], 2023a; 2023b). Air pollution, such as particulate matter (PM10 and PM2.5), contributes substantially to mortality in urban areas (Dong & Hauschild, 2017). As a result, caping air pollution is one of the key targets in SDGs since it improves health.

There are several empirical African studies on air quality and ambient concentration of air pollutants in urban areas. Ren et al. (2022) showed that Africa's aerosol optical depth (AOD) has a slight downward trend from 2011 to 2020 and has a significant positive correlation with urbanization. The authors established regional heterogeneity. A positive correlation between urbanization and AOD levels was established in Central Africa but negative in Western Africa.

Nitrous oxide (N_2O) is also a substantial GHG with a GWP of 265 compared to carbon dioxide (CO_2). Globally, 40% of total N_2O emissions come from human activities, including agriculture soil management activities, such as the application of synthetic and organic fertilizers), land use, transportation (burning fuels), and industry (a byproduct during the production of chemicals such as nitric acid, adipic acid, anesthesia, and semiconductor manufacturing). Agriculture is a significant N2O, contributing 60% of global N2O emissions largely from fertilizers, which release N2O through ammonia volatilization, animal manure, and crop residues, which are often burnt as fuel for cooking (Barnard, Leadley, & Hungate, 2005; Shakoor et al., 2021; Velthof, & Rietra, 2018). As a result, it is a concern in Africa since agriculture is the main economic activity dominated by smallholder crop farmers. The common crops grown in Africa are cassava, yams, and cereals such as maize and sorghum in Africa.

N_2O contributes about 6% of the GHG-caused global warming effect, which leads to unreliable precipitation, erratic rainfall, and droughts (IPCC, 2014; Thakur & Medhi, 2019; U.S. Environmental Protection Agency, 2024). Sulfur dioxide (N_2O) and N_2O emissions into the atmosphere, usually from human activities such as burning fossil fuels, are associated with stratospheric ozone layer depletion and acid rain formation (Ravishankara, Daniel, & Portmann, 2009). Acid rain contains high levels of nitric and sulfuric acids, which can harm ecosystems, materials, human health, and visibility. If drained to water bodies, it releases toxic aluminum, which can kill aquatic life; it leaches nutrients and minerals from the soil and damages the roots and leaves of plants and trees, corrodes buildings and other materials surfaces such as monuments, statues, and vehicles, reduces visibility and increases the risk of respiratory problems (Fatima et al., 2020; Sonwani et al., 2020).

Nitrogen use efficiency (NUE) in farm lands is becoming an interest since it enhances food security and minimizes eutrophication. It shows the efficient use of nitrogen inputs (from fertilizers) to agricultural produce. Inefficient use of nitrogen indicates potential losses of reactive Nitrogen, which increases N2O to the environment as well as reduces the level of crop yields, hence could lead to food insecurity (Fixen et al., 2015; Sharma & Bali, 2017; Winnie et al., 2022). NUE studies are more of a concern near water bodies since nitrogen leaching to the soil is carried by rained water to river basins or oceans, which further damages the environment by eutrophication (excessive growth of plants such as algae and plankton in a water body due to accumulation of nutrients) (Sharma et al., 2019). For instance, NUE in the Lake Victoria basin is crucial since it supports above 20% of East Africa's population, with freshwater supporting more than 4 million people benefiting from fishery production of about 1 million tons and is a source of river Nile (through the White Nile tributary, flowing from Lake Victoria in Uganda), which also supplies water for human use, animal consumption, and irrigation to other countries, northwards including Ethiopia, Sudan, South Sudan, Egypt, Burundi, the Democratic Republic of Congo, and Eritrea (Winnie et al., 2022). Thus, the reduction of water quality in the lake and the growth of water hyacinth due to nitrogen deposition from neighboring farmlands, such as rice lands in the Nyando area into Lake Victoria, poses a significant threat to food security due to declining fish and fish catchment areas, economic and environmental impacts.

The majority of African countries do not meet the desirable NUE. The European Union Nitrogen Expert Panel (EUNEP, 2016) defines the desirable NUE between 50% and 90%. NUE levels above 90% signify chances of extreme risks of depleting soil Nitrogen stocks (Quemada *et al*., 2020). Yet, African countries have low nitrogen inputs through fertilizers due to farmers' inability to afford and apply the Nitrogenic fertilizer rates in farming (Chianu, Chianu, & Mairura, 2012; Masso *et al*., 2017). Winnie *et al*. (2022) established inefficient Nitrogen cycling due to the depletion of soil Nitrogen pools and low synchronicity between Nitrogen input and output in the Lake Victoria region. The authors observed that NUE values in the Lake Victoria region for maize grown without N range from 25.76 to 140.18% and 81.92 to 224.6% with Nitrogen application – exceeding the EUNEP recommendation. As a result, it leads to the unstainable use of nitrogen. If harvested crops export more N than it was used (NEU > 100%) coupled with losses through means such as volatilization, runoff, and leaching, contribute to soil nutrient depletion and mining of nutrient stock (Zingore et al., 2015; Masso et al., 2017).

The failure of African countries to increase fertilizer usage has led to poor NUE values above 100% (Elrys *et al*., 2020). If unchecked, it compromises efforts toward achieving food sufficiency/ security, poverty reduction, and environmental sustainability in Africa. African governments and development partners have made substantial efforts to enhance fertilizer usage in Africa through subsidies to improve crop yields and majorly stable foods like maize and rice (Alliance for a Green Revolution in Africa [AGRA], 2019). Indeed, there has been a remarkable increase in fertilizer use from 8 kg nutrient/ha in 2006 to above 20 kg nutrient/ha in 2019 (AFDB, 2020; Winnie *et al*., 2022). Such efforts enhance sustainable food security by avoiding soil nitrogen depletion.

Phosphore is another essential macronutrient for the growth and development of plants. Since phosphorus is scarce in most agricultural fields, phosphatic fertilizers act as supplements to address food insecurity driven by increasing food demand due to the rising population. The increasing demand for fertilizer usage has exploited existing mineral phosphate rock reserves, the raw material for phosphatic fertilizers (Yu, Keitel, & Dijkstra, 2021). To ensure sustainability into the future (without depletion of raw materials), Phosphatic fertilizer use efficiency (PFUE) has been a key instrument to measure agricultural productivity and food security sustainability. Yu et al. (2021) established that PFUE among cereal crops had been adversely influenced by climate (high temperature), soil composition such as low pH, and management practices such as crop types, fertilizer types, and quantize applied.

Further, the authors noted that, on average, Phosphorus composition in aboveground biomass in cereal crops increases by 12.4% of the Phosphorus fertilizers applied. Such changes deplete the existing Phosphorus soil reserves, leading to low yields. Thus, there should be a sustainable use of phosphorus in the present generation without compromising the ability of future generations to meet their own food production needs.

Besides, excessive use of phosphorus or underutilization may lead to eutrophication. Thus, reducing Phosphorus loading to inland and coastal waterbodies is critical in lowering eutrophication (Schindler et al. 2016). Sustainable interventions to mitigate the adverse environment impacts include improved wastewater treatment to remove Phosphorus in industrial and agricultural waste discharge, altering farmland, and sustainable management of farm inputs to minimize excessive used of Phosphorus on farms, hence minimise runoff from farms to water bodies of land (Schindler *et al*. 2016).

Theme	**Sub-theme**	**Indicators**	**Authors**	**Region/ country**	**Time frame**
Atmosphere	Climate change/ Emissions of greenhouse gases	CO_2 (core)	Kumar *et al* (2016)	35 Sub-Saharan Africa countries	1960 - 2009
			Abid (2016)	SSA	1996 - 2010
			Pelster et al (2017)	Kenya	2013
			Adzawla *et al* (2019);	SSA	1970 - 2012
			Nassar Aissa & Alsadi (2017).	Libya	1990 - 2013
			DeWitt et (2019)	Uganda	2015 - 2017
		NH_4 emissions	Adzawla *et al* (2019);	SSA	
			Adzawla *et al.* (2019)	SSA	

Theme	Sub-theme	Indicators	Authors	Region/ country	Time frame
		Nitrous Oxide (N_2O)/ NO2 emissions	Pelster et al (2017)	Kenya	2013
		Methane (CH4)	Pelster et al. (2017)	Kenya	2013
		SO2 emissions	Opio, Mugume & Nakatumba-Nabende, 2021).	East Africa	2005 - 2020
			Adon et al (2016)	West Africa	2008 - 2009
		Total greenhouse gas emissions (kt of CO2); CO2 emissions from liquid fuel consumption (kt)	Bartniczak and Raszkowsk (2018).	48 African countries	2002 - 2016
		Aerosol Optical Depth (AOD)	Ren *et a*l (2022)	Africa	2011-2022
	Ozone layer depletion	Consumption of ozone-depleting substances: Hydrochlorofluorocarbons (HCFCs); perfluorocarbons (PFCs); Carbon Tetrachloride, Halons, and Chlorofluorocarbons (CFCs)	Okon (2021)	Nigeria	1970-2018
	Air quality	Ambient concentration of air pollution of particulate matter/black carbon (PM10 and PM2.5) (especially in urban areas)	DeWitt et (2019)	Uganda	2015 - 2017
	Eutrophication	Nitrogen use efficiency in food systems/nitrogen budgets	Ntinyari et al (2022)	Kenya	-
			Masso et al., 2017	SSA	-
			Winnie *et al.* (2022)	Kenya	-
			Elrys *et al.* (2202)	Africa	2010 - 2016
			Ten Berge et al (2019)	SSA	
			Elrys et al. (2019)	52 African countries	1961 - 2016
			Elrys et al (2021)	52 African countries	1961 - 2017
		Phosphorus use efficiency in food production systems	Chauke (2021).	South Africa	
			Ten Berge et al (2019)	SSA	
			Mirriam *et al* (2022)	Uganda	2021
			Agyemang (2020)	Nigeria	-
			Cheptoek *et al* (2022)	Kenya	-
Natural hazards	Vulnerability to natural hazards	Population living in hazard-prone areas	Asare-Kyei et al (2017)	West African	-
			Paul Silva & Amo-Oduro (2022)	African	2020
			Kapuka & Hlásny (2020).	Namibia	-

Theme	Sub-theme	Indicators	Authors	Region/ country	Time frame
		Vulnerability to natural disasters, disaster preparedness, effects/ Human and economic loss due to natural disasters, and response	Barasa et al (2022)	Uganda	2002 - 2018
			Tibara, Wasswa, Semakula (2023).	Uganda	
			Nsabimana et al (2023)	Burundi	
			Michellier et al (2020)	Congo	
			Paul, Silva, & Amo-Oduro (2022).	Africa	
			Mabuku et al. (2019)	Namibia and Zambia	
			Kapuka Hlásny (2020	Namibia	
Land	Land use and status	Land use change	Guzha et al (2018)	East Africa	-
			Namugize, Jewitt, & Graham (2018)	South Africa.	1994 -2011
			Kouassi et al (2021)	West Africa	1987 to 2015
			Bullock, et al (2021)	East Africa	1998 - 2017
		Land degradation	Mani, Osborne, & Cleaver, 2021).	South Africa:	
			Kouassi et al (2021)	West Africa	1987 - 2015
			AbdelRahman (2023)	-	-
	Desertification	Land affected by desertification	Reich et al (2019)	Africa	-
			AbdelRahman (2023)	-	-
			Ghebrezgabher, Yang, Yang, & Wang (2019).	Eritrea	1970 - 2014
			Kipngeno (2020)	Somalia	1982-2019
	Agriculture	Arable and permanent cropland area			
		Fertilizer use efficiency			
		Use of agricultural pesticides			
		Area under organic farming			
	Forests	Proportion of land area covered by forests			
		Percent of forest trees damaged by defoliation			
		Area of forest under sustainable forest management			
		Net forest depletion/forest loss	Okon (2021)	Nigeria	1970-2018

Theme	Sub-theme	Indicators	Authors	Region/ country	Time frame
			Phiri, Chanda, Nyirenda, & Lwali (2022).	Zambia	1972-2016
Oceans, seas and coasts	Coastal zone	Percentage of total population living in coastal areas			
		Bathing water quality			
	Fisheries	Proportion of fish stocks within safe biological limits			
	Marine environment	Proportion of marine area protected			
		Marine trophic index			
		Area of coral reef ecosystems and percentage live cover			
Freshwater	Water quality	Proportion of total water resources used			
		Water use intensity by economic activity			
		Presence of faecal coliforms in freshwater			
		Biochemical oxygen demand in water bodies			
		Wastewater treatment			
		Proportion of the population connected to collective sewers or with on-site storage of all domestic wastewater			
		Accessing the status of clean drinking water	Atangana & Oberholster (2023)	SSA	2017 - 2019
		Number of unimproved pit latrines and open-pit latrines users	Atangana & Oberholster (2023)	SSA	2017 - 2019
Biodiversity	Ecosystem	Proportion of terrestrial area protected, total and by ecological region			
		Management effectiveness of protected areas			
		Area of selected key ecosystems			
		Fragmentation of habitats			
	Species	Change in threat status of species			
		Abundance of selected key species			
Consumption and production patterns	Waste generation and management	Generation of hazardous waste			
		Generation of waste			
		Solid waste management/ treatment or disposal	Muheirwe, Kombe, & Kihila (2022)		

Theme	Sub-theme	Indicators	Authors	Region/ country	Time frame
			Odonkor, S. T., & Sallar, A. M. (2021).	Ghana	2019 - 2020
			Adedara, Taiwo, & Bork (2023)	SSA	
			Kabera, Wilson, & Nishimwe, 2019)	East Africa	
			Ogutu et al (2021)	Kenya	
			Tassie, Endalew, & Mulugeta, (2019)	Ethiopia	
			Dlamini, Simatele, & Serge Kubanza (2019)	South Africa	
			Yong *et al*. (2019)	Malaysia	
			Mlilo *et al*. (2021)	Zimbabwe	
		Management of radioactive waste	Doroh (2020)	SSA	
			Debrah et al (2023)	Ghana	

Table 2: Summary of Environmental degradation (Source: Author)

5.4 Water use and quality

Water use and quality indicators measure the amount and quality of available water used for various purposes, such as agriculture, industry, and domestic use. It can also include the level of water stress, the ratio of water withdrawal to availability, and the level of water pollution, which is the concentration of harmful substances in water bodies.

5.5 Land use and degradation

Sustainable management of land use and cover changes is crucial for human survival since it influences the water cycle. Land use and degradation indicators measure the changes in land cover and land use, such as forest area, cropland, pasture, urban area, and protected area. It can also include the level of land degradation, which is the loss of soil quality and productivity due to erosion, salinization, desertification, or other factors. Empirical evidence has shown that forest cover loss increases surface runoff, stream discharges, and watershed changes (Guzha et al., 2018). Forests act as human catchment areas due to increasing land degradation and rising population. The rising population has increased the demand for human settlement and land for farming. Hence, it comes with consequential increases in forest settlements such as Mau in Kenya (Kitheka, 2019; Ndegwa, 2019). Such human settlements have contributed to forest clearing, drastically reducing the volume of watersheds and menacing climate change. The consequences are loss of biodiversity and loss of human livelihoods due to water dependency on farming activities (Kouassi *et a*l., 2021)

Vegetation established to minimise runoff and watershed loss in catchment areas significantly includes perennial crops such as bamboo and pine plantations and tea plantations (Guzha et al., 2018). Thus, it is essential that as forest land cover is reduced due to human encouragement, farmers embrace mixed cropping with perennial crops to reduce runoff, which enhances the loss of watersheds or water catchment areas.

Desertification in Desertification is becoming a crucial subject in Africa that has far-reaching impacts on human livelihoods and biodiversity. An estimated 60% of the African population lives in arid, semi-arid, dry sub-humid and hyper-arid areas. It arises due to climatic variations and human activities (Reich et al., 2019). Desertification has led to the loss of fertile land, typically due to drought, deforestation, or inappropriate agriculture. In Africa, countries in the northern region, especially the Sahel, remain affected by desertification, threatening livelihoods and causing biodiversity loss due to the loss of plant and animal species. This phenomenon is exacerbated by climate change, leading to extreme weather events like low and unpredictable precipitation and prolonged drought, which contribute to the degradation of land, such as in Eritrea (Ghebrezgabher, Yang, Yang, & Wang, 2019) and Somalia (Kipngeno, 2020). Kipngeno (2020) estimates that about 23 % of forest cover was lost from 79,294 ha to 67,199 ha from 2000 to 2019 in Somalia, representing a loss of 1,058ha annually. The renowned Sahara in Desert in Northern Africa is evidence of how climate change can lead to loss of biodiversity, such as vegetation cover and destroyed wildlife habitats, leading to decreased plant and animal species. It is growing at a rate of 48 kilometres per year, encroaching on arable land and affecting ecosystems.

Humanity is also threatened by rising desertification since it threatens food insecurity as the land available for agriculture diminishes. The critical aspect of human survival is the shortage of drinking water due to the loss of aquifers and livelihoods as farming and pastoral activities become unsustainable. Given the adverse effects of land use and degradation on life sustainability, addressing desertification is crucial for the sustainability of ecosystems and the well-being of the people in Northern Africa. Suggested efforts to combat desertification involve sustainable land management practices such as terracing, crop rotation, mixed cropping, irrigation schemes, soil conservations, afforestation reforestation, and the use of technology such as GIS and remote sensing to monitor and manage land degradation (AbdelRahman, 2023; Megerssa & Bekere, 2019).

5.6 Biodiversity and ecosystem services

This indicator measures the diversity and health of living organisms and the benefits they provide to humans, such as food, water, climate regulation, pollination, and recreation. It can include the number and status of species, the extent and condition of habitats, and the value of ecosystem services. The coastal and marine ecosystems endowments with natural resources, including mangrove cover, coral reefs, and seagrass beds, and services such as coastal recreation and fishing support the livelihoods of the coastal communities (Rao *et al*. 2015; Ghermandi *et al*. 2019). Besides supporting tourist income, the coastal ecosystems play a crucial role in protecting the coast against storms since they dissipate wave energy and lessen flooding risk (Beck *et al*. 2018). Yet, the ecosystem faces threats from development pressures due to the rising coastal population, climate change, limited protection, and poor coastal management (UNEP-Nairobi Convention. 2009; Dasgupta, 2021). Rising sea levels often affect East African countries along the coast, including Kenya and Tanzania. These coastal hazards will likely diminish the coastline and loss of coastal and marine ecosystems, major tourist attraction sites exposing millions of coastal communities to poverty.

According to Ballesteros & Esteves (2021), 22% of East Africa's coastline and 3.5 million people are at higher levels of exposure to coastal hazards, which would increase, respectively, to 39% and 6.9 million people if mangroves, coral reefs, and seagrasses are lost. As a result, protecting the marine environment has been one of Africa's sustainable indicators to promote social and environmental resilience. Some of the crucial indicators are therefore protection of the marine environment, proportion of marine area protected, marine trophic index, area of coral reef ecosystems and percentage live cover, Index of Exposure to Coastal Hazards (assesses the degree to which an area is likely to be impacted by coastal hazards), and social vulnerability index to coastal hazards (which identifies sensitive populations are less likely to respond to, cope with, and recover from natural disasters along the coast (Ballesteros & Esteves 2021; Mabuku *et al*., 2019). According to Ballesteros & Esteves (2021), Kenya and Tanzania are two Eastern African countries that have made significant efforts to protect the natural coastal ecosystem.

5.7 Waste generation and management

Solid waste management is becoming a crucial global concern, especially in urban areas in developing countries. Africa's rapid population, economic development, and urbanization have increased waste generation from industry and households. As of 2016, the volume of waste is about 174 million tonnes (Mt) per year across Africa and is projected to triple to 516 Mt per year by 2050 (New Partnership for Africa's Development [NEPAD] 2019). Yet, waste management does not tally with the collection rate due to the associated high cost of waste disposal. Above 90% of Africa's waste is disposed of at uncontrolled or illegal dumpsites and landfills, often burnt openly. Besides, Africa's average waste collection rate is about 55% of the disposed waste materials (NEPAD, 2019). Adedara, Taiwo, and Bork (2023) established that the waste collection and coverage rates in SSA are 65% and 67% in SSA, respectively. Thus, Africa seems to fall short of 100% waste disposal. Such hazardous waste remains a significant public problem in major cities across Africa.

Many African cities have several uncontrolled landfills filled or illegal dumpsites with solid wastes in Yaoundé, Cameroon (Sotamenou, De Jaeger, & Rousseau, 2019), Addis Ababa in Ethiopia (Tassie, Endalew, & Mulugeta, 2019), Johannesburg, South Africa (Dlamini, Simatele, & Serge Kubanza, 2019), Malaysia (Yong *et al*., 2019), Zimbabwe (Mlilo *et al*., 2021), and cities in Eastern Africa including Kigali; Rwanda; Dar es Salaam, Tanzania; Kampala, Uganda; Nairobi, Kenya, and Maputo, Mozambique (Kabera, Wilson, & Nishimwe, 2019). In Accra, Ghana, Odonkor and Sallar (2021) established that rubber waste types were the leading (26%) among households, followed by tin (19%) and plastic (16%). Further, the majority (50.5%) of the respondents disposed of waste collected in public bins, with about half dumping the waste illegally. In Kenya, Ogutu et al. (2021) established that from 2003 to 2017, the number of unplanned dumpsites increased exponentially from about 7 to 17 hectares in Nairobi city. Thus, enforcing proper waste management practices in Africa is crucial since it has public health implications.

Dumping in cities causes flooding and choke gutters, leading to common epidemics such as cholera and vector-borne diseases like malaria and dysentery (Ghana, Odonkor and Sallar, 2021). Besides, the lumped organic waste undergoes decomposition with time, releasing landfill gas (LFG) or GHGs, majorly methane (CH_4), which affects air quality, contributes to climate change, and leachate, which can pollute ground and surface water. Besides, the open burning of waste substantially leads to air pollution, which impacts human health, causing asthma (Yong et al., 2019). Yet, such wastes could be harnessed to generate energy or recycled to reduce volumes of non-biodegradable solid waste in cities.

The confounding factor of poor waste disposal in African countries is the lack of political will, effective policy on waste management, insufficient funding, lack of environmental education and awareness, corruption, and poor infrastructure (Mlilo *et al*., 2021; Dlamini, Simatele, & Serge Kubanza,2019). Drawing from empirical evidence from a study in Yaoundé, Cameroon, Sotamenou et al. (2019) established that households with easy access to legal waste disposal sites, such as centralized drop-off containers, were less likely to dispose of their waste illegally. Investing in waste collection infrastructure, removing illegal dumpsites, raising awareness, and increasing compliance with environmental waste management policies were suggested as potential tools to improve waste disposal. Kabera et al. (2019) established that Kigali uses public–private partnerships, with franchised tenders issued every three years. Households are charged an affordable fee for the service collected by local security patrols. In Kenya, such charges are collected from business people at the market or stores/shops to help finance waste disposal conducted by the county government.

Policy regulations should stipulate efficient solid waste collection, transportation, storage, and recycling using appropriate technologies or disposal of waste, creation of awareness through education and training on sustainable waste management programmes to instil the need and effective ways to keep our environment clean among the general public, and public-private partnerships to finance the cost of waste management practices and implementation of technology.

5.8 Natural hazards

Natural hazards such as floods, volcanic eruption, drought, earthquakes, floods, hailstorms, landslides, lightning, windstorms, and earthquakes pose a serious threat to the loss of croplands, social amenities such as buildings, schools, and roads, and loss of life (Barasa et al., 2022; Nsabimana et al., 2023; Tibara, Wasswa, Semakula, 2023). In Uganda, Barasa *et al.* (2022) established that the area experiences moderate to high-intensity earthquakes and landslides, low incidences of floods and droughts, and high incidences of flash floods in Kasese and Ntoroko districts, with moderately intensive Hailstorms and windstorms. Countries bordering the Western Indian Ocean are also prone to coastal hazards such as wind and wave exposure. Mozambique and Madagascar are mostly prone to cyclones and extreme weather events (Devi, 2019). For instance, the Cyclone Idai in Mozambique had a death toll of more than 1000 (Devi, 2019). The coastal cities of Mombasa, Kenya, are often prone to flooding, which interferes with daily economic activities and poses a significant negative health and mental impact (Okaka & Odhiambo, 2019).

Generally, such natural hazards retard global efforts toward achieving other SDGs, such as reducing mortality and improving livelihoods. Disaster policy reforms covering resettlement of people living in vulnerable areas, land use planning to keep people away from areas prone to natural areas, early warning systems, and budgetary allocations are common approaches to comparting the devastating effects of natural disasters in Africa (Ishizawa *et al*. 2020; Kudzanayi, 2020).

5.9 Social Sustainability Indicators

Social indicators measure how the company interacts with its local community and society. As with the environmental externalities, these organizations can affect large groups of people, including employees, customers, suppliers, or shareholders. The decisions taken by management can impact these groups directly or indirectly.

- Handling of diversity.
- Compliance with equality policies.
- Transparency in human resources management.
- Support for balancing work and family life.

Theme	**Variables**	**Authors**	**Region/ country**	**Period**
Social inclusion	Individuals using the Internet (% of the population)	Bartniczak and Raszkowsk (2018)	48 African countries	2002-2016
	Age dependency ratio (% of working-age population)	Bartniczak and Raszkowsk (2018)	48 African countries	2002-2016
	Health and safety of employees.			
	Teen pregnancies	Atangana & Oberholster (2023)	SSA	2017 - 2019

Table 3: Social Sustainability Indicators(Source:Author)

Social indicators measure how the company interacts with its local community and society.

At national levels, ensuring that all the population cohort by gender, age, and race participate in national building and equity in access to national resources is crucial. The level of compliance with equality policies such as gender and ethnic discrimination often politically inclined is a predominant subject in Africa. Ethnic factions are common in countries with higher ethnic stratification such as Kenya and Uganda. In this study, common social indicators are broadly classified into social inclusion and gender equity domains.

5.9.1 Social inclusion

Africa has made significant progress toward social inclusion in the past few decades, moving at a pace faster than seen globally in many areas. Social exclusion is driven by identity, including factors like gender, race, ethnicity, religion, age, disability, and location. Gender and the ethnic inclusion/ exclusion dynamics are coming in Africa. There is a generally increasing representation of women in employment and adoption of devolved governments such as in Kenya which has increased ethnic representation in governance across the ethnic groups in Kenya (Nyabira, & Ayele, 2016; Nyaura, 2018). The importance of Social Inclusion in Africa includes Poverty reduction, enhancement of national cohesion and integration by reducing ethnic inequity in access to public resources which often stir marginalization, distrust and heightens ethnic tensions, politically motivated terrorist acts, demonstrations, and armed gangs. Despite these strides, some countries still perform in social gender, age, and ethnic inclusion. Exclusion based on these attributes can lead to lower outcomes in terms of income, education, employment, and access to services among minority groups. Contrarily, decentralization enhances equality by promoting ethnic patronage politics as insiders of a given community or a society are involved in resource sharing (D'Arcy & Cornell, 2016).

The motivation for rapid expansion of digital inclusion in Kenya is due to high demand from the youth population/ Africa's rapidly growing youth population presents both opportunities and risks. By 2050, the continent will have 362 million people aged between 15 and 24. Harnessing their potential through social inclusion is essential for sustainable development. In a population with a high dependency, with fewer people working-age population (aged 15-64 years) relative to aged 0-14 years and 65 years and older, can strain resources and hinder social inclusion efforts.

Table 4 Social Sustainability Indicators

Theme	Variables	Authors	Region/ country	Period
Social inclusion	Individuals using the Internet (% of the population)	Bartniczak and Raszkowsk (2018)	48 African countries	2002-2016
	Age dependency ratio (% of working-age population)	Bartniczak and Raszkowsk (2018)	48 African countries	2002-2016
	Health and safety of employees.			
	Digitalization	Mulugeta Woldegiorgis (2023).	34 African countries	1990 - 2018
	Job creation.	Mulugeta Woldegiorgis (2023).	34 African countries	1990 - 2018
	Industrialization	Mulugeta Woldegiorgis (2023).	34 African countries	1990 - 2018
Gender equity	Gender equality in employment	Anyanwu, & Augustine, 2013	Africa	1991, 2009
	Teen pregnancies	Atangana & Oberholster (2023)	SSA	2017 - 2019
	Gender parity in education	Baten et al (2021)	21 African countries	-
	Average years of school completed by girls			
	Primary and secondary school participation rates	Offiong et al (2021)	Nigeria	
	Probability of girls' completion compared to boys			
	Girls' secondary school completion rates			

	Distribution of women and girls in tertiary education subjects	Odaga (2020)	Uganda	2009-2017
		Sikhosana, Malatji, & Munyoro, 2023	South Africa	-
		Quarshie, Nkansah, & Oduro-Ofori (2023)	Ghana	2021
	Gender disparity in literacy rates	Kyei (2021)	15 countries in the Southern and Eastern Africa	-
	Investment in family planning	Mulugeta Woldegiorgis (2023).	34 African countries	1990 - 2018

In 2021, Africa's age dependency ratio stood at 78%. This implies that for every 100 working-age individuals (aged 15-64 years), there were approximately 78 people in the age groups of 0-14 years and 65 years and older. Over the years, this ratio has generally decreased since 2000, which has led to a lighter burden on the working-age population (Statista, 2023).

Digital inclusion, defined as the activities necessary to ensure that all individuals and communities, including the most disadvantaged, have access to and use of information and communication technologies (The Center for Digital Equity), is also an emerging subject in Africa especially with a higher population of the Generation Z. identified causes of causes of digital exclusion are poverty, low digital literacy skills, inadequate digital infrastructure, lack of relevant content, language barriers, and cultural issues, and lack of awareness about digital opportunities. Consequently, digital exclusion in Africa has contributed to backwardness in other SDG measures such as Economic marginalisation, low level of innovations and development, ignorance, poverty, and bad governance since social media platforms enhances transparency in public administration, respect for law and governance (Kalusopa et al., 2021; Kwanya, n.d.). Thus, studies are increasingly looking at the proportion of individuals using the Internet to proxy digital inclusion (Bartniczak and Raszkowsk, 2018). Internet access reflects connectivity, information sharing, and participation in the digital age.

5.9.2 Gender Equity

Gender equality is a fundamental sustainable development objective, and it plays a crucial role in enabling women and men to participate equally in society and the economy. African states generally lag in reaching Sustainable Development Goal 4, Target 4.5 to "eliminate gender disparities and ensure equal access to all levels of education and vocational training for the vulnerable, including persons with disabilities, indigenous peoples and children in vulnerable situation" compared to developed countries. However, Women in Africa have seen a substantial improvement in economic growth participation rate and are now economically active as farmers, workers, and entrepreneurs due to increasing women education, empowerment, freedom in economic choices and ownership rights and participation in leadership.

Generally, the 2018 UNESCO Institute for Statistics indicates that a good progress in African nations. Some African countries have made significant progress in closing gender gaps in education. For instance, 19 countries (Malawi, Uganda, Tanzania, Zambia, Ghana, Mauritius, Seychelles, Sierra Leone, Kenya, Burundi, Madagascar, Egypt, Burkina Faso, Rwanda, Democratic Republic of Congo, Equatorial Guinea, Zimbabwe, Gabon, and Tunisia) achieved gender parity in primary education for boys and girls within the past decade (Patel, & Jesse, 2019)

Nonetheless women still face barriers that prevent them from contributing fully to Africa's development. With evidence strong cultural norms that still persist today in African societies, women encounter barriers that limit their potential. These include social norms, unequal access to resources, and gender-based violence. Such norms have seen low women representation in leadership. In 2022, the leading countries with the highest proportion of seats held by women in national parliaments in Africa included Rwanda (61.3%), Senegal (46.1%), South Africa (45.6%), Namibia (44.2%), and Mozambique (43.2%). countries that lagged included DRC (12.8%), Botswana (11.1%), Liberia (11.0%), Guinea-Bissau (9.8%), Gambia (8.62%), and Nigeria (3.91%) (Statista, 2023).

Efforts to improve female representation in elective positions in Africa include use legislations of electoral quotas for women. For instance, Kenya uses the two-third gender rule that ensures that every institution employee at least a third of the women. This has been seen in elective positions where seats for women representatives have been created in Kenya and others nominated in the national assembly and the senate under the devolved government to ensure women representation in policy formation implementation making (Kauria, 2018; Onditi, Odera, 2021). The elected women dignitaries have become instrumental in fighting for women rights, empower women through education and social programs such as women groups which receive business funding. Thus, by addressing systemic barriers, promoting women's empowerment African enhances a more inclusive and sustainable development.

However, countries with recurrent political instability and civil wars, and terrorism including Chad, the Central African Republic, and Nigeria, South Sudan are still lagging (Bertoni et al., 2019). For instance, more than 30 percent of primary school-age girls are out of school are in sub-Saharan Africa with a whopping 72% in South Sudan and 30% in Guinea-Bissau. South Sudan has been constantly faced with political instability which can generally created social problems to the victims affecting both male and females to access basic social amenities such as school and healthcare. For instance, education access is still difficult with 64% estimated of the boys in South Sudan are out of school in 2018. Generally, higher education outcomes among women have increased their employment outcomes which further enhances gender representation in both education and employment outcomes. In the All-Africa and Sub-Saharan African regions, increased democracy, more primary education, and a higher urban share of the population contribute to greater gender equality in employment (Anyanwu, & Augustine, 2013).

Other barriers to unequal literacy outcomes to education in Africa are domestic responsibilities. Girls are generally housekeepers responsible for fetching water from distant rivers, cooking, or cleaning. As a result, little time is left as compare to male counterparts. Kyei (2021) established that female pupils in Southern and Eastern Africa are disadvantaged in reading due to barriers such as domestic responsibilities and unfavourable school environments that that inhibit them from fully attending and participating in school (Kyei, 2021). Thus, adequate supply of piped water, and social support to girls in households such as hiring a maiden is instrumental in ensuring that girls in Africa can attend and participate fully in their classes and homework activities without distractions.

There is also evident unequal representation of female students in in tertiary education and particularly in Science, Technology, Engineering, and Maths (STEM) courses such as in computer science (Odaga, 2020; Sikhosana, Malatji, & Munyoro, 2023). In Ghana, Quarshie, Nkansah, & Oduro-Ofori (2023) established that lower female participation in universities are broadly qualification, admissions, and enrolment. Besides, these casual factors of student enrolment are rooted in institutional, socio-cultural aspect of male masculinity, economic, and awareness of STEM policy and opportunities.

Generally, inclusive development requires African countries to harness the demographic heterogeneity through investment in family planning and gender parity to enhance female labour force participation rate, enhance digitalization through increased internet usage and access, industrialization, and job creation (Mulugeta Woldegiorgis, 2023).

5.10 Economic Suitability Indicators

In Table 4, the themes, and sub-themes of economic suitability indicators (ESI) developed by the United Nations (2007) are used as a basis for identifying economic suitability indicators and updated based on empirical evidence. The ESI indicators are multi-dimensional, reflecting sub cross-cutting themes such as poverty, consumption and production, and global economic partnership and governance. Each of these have sub-themes. For instance, poverty sub-themes comprise measures related to income, sanitation, drinking water, energy access, and living conditions.

Poverty and inequality are pervasive and multidimensional challenges in Africa, affecting various aspects of human development, such as health, education, nutrition, and social protection. Poverty and inequality may limit the access and opportunities of the poor and marginalized groups to participate in and benefit from the SDGs. They may also exacerbate the environmental and social impacts of unsustainable practices.

Theme	**Sub-theme**	**Variables**	**Authors**	**Region/ country**	**Period**
Poverty	Income poverty	Proportion of population living below national poverty line			
		Proportion of population below $1 a day			

	Income inequality	Ratio of share in national income of highest to lowest quintile			
	Sanitation	Proportion of population using an improved sanitation facility			
	Drinking water	Proportion of population using an improved water source			
	Access to energy	Share of households without electricity or other modern energy services			
		Percentage of population using solid fuels for cooking			
	Living conditions	Proportion of urban population living in slums			
Governance	Corruption	Percentage of population having paid bribes			
	Crime	Number of intentional homicides per 100,000 Population			
Health	Mortality	Under-five mortality rate			
		Life expectancy at birth			
		Healthy life expectancy at birth			
	Health care delivery	Percent of population with access to primary health care facilities			
		Contraceptive prevalence rate			
		Immunization against infectious childhood diseases			
	Nutritional status	Nutritional status of children			
	Health status and risks	Morbidity of major diseases such as HIV/AIDS, malaria, tuberculosis			
		Prevalence of tobacco use			
		Suicide rate			
		Prevalence of HIV, total (% of population ages 15–49)	Bartniczak and Raszkowsk (2018).	48 African countries	2002-2016
		Life expectancy at birth, total	Bartniczak and Raszkowsk (2018); Lie et al (2021)	48 African countries	2002-2016
		Mortality rate, infant (per 1000 live births)1	Bartniczak and Raszkowsk (2018).	48 African countries	2002-2016
		Health expenditure, total (% of GDP)1	Bartniczak and Raszkowsk (2018).	48 African countries	2002-2016
		Death rate due to road traffic injuries per 100,000 population	Bartniczak and Raszkowsk (2018).	48 African countries	2002-2016

Education	Education level	Gross intake ratio to last grade of primary education			
		Net enrolment rate in primary education			
		Adult secondary (tertiary) schooling attainment level			
		Lifelong learning			
		Expected years of schooling	Lie et al (2021)	51 African countrie	2015
	Literacy	Adult literacy rate			
Demographics	Population	Population growth rate	Atangana & Oberholster (2023)	SSA	2017 to 2019
		Total fertility rate			
		Dependency ratio			
		Birth rate, crude (per 1000 people)	Bartniczak and Raszkowsk (2018).	48 African countries	2002-2016
		Population ages 65 and above (% of total)	Bartniczak and Raszkowsk (2018).	48 African countries	2002-2016
	Tourism	Ratio of local residents to tourists in major tourist regions and destinations			
Economic development	Macroeconomic performance	Gross domestic product (GDP) per capita	Kumar *et al* (2016)	SSA	
			Abid (2016)	SSA	1996 – 2010
			Adzawla *et al* (2019);	SSA	1970 – 2012
			Nassar Aissa & Alsadi (2017).	Libya	1990 - 2013
			Adzawla *et al* (2019);	SSA	1970 – 2012
			Adzawla *et al* (2019);	SSA	1970 – 2012
			Bartniczak and Raszkowsk (2018).	48 African countries	2002-2016
			Okon (2021)	Nigeria	1970-2018
		Gross saving			
		Investment share in GDP			
		Adjusted net savings as percentage of gross national income (GNI)			
		Inflation rate			
		Unemployment, total (% of total labor force)	Bartniczak and Raszkowsk (2018).	48 African countries	2002-2016

			Atangana & Oberholster (2023)	SSA	2017 to 2019
	Sustainable public finance	Debt to GNI ratio			
	Employment	Employment population ratio			
		Labor productivity and unit labor costs			
		Share of women in wage employment in the non-agricultural sector			
		Vulnerable employment			
	Information and communication technologies	Internet users per 100 population			
		Fixed telephone lines per 100 population			
		Mobile cellular telephone subscribers per 100 population			
	Research and development	Gross domestic expenditure on R&D as a percent of GDP			
	Tourism	Tourism contribution to GDP			
Global economic partnership	Trade	Current account deficit as percentage of GDP			
		Share of imports from developing countries and from LDCs			
		Imports of goods and services (% of GDP)	Bartniczak and Raszkowsk (2018).	48 African countries	2002-2016
		Import value index (2000 = 100)	Bartniczak and Raszkowsk (2018).	48 African countries	2002-2016
		Average tariff barriers imposed on exports from developing countries and LDCs			
	External financing	Net Official Development Assistance (ODA) given or received as a percentage of GNI.			
		Foreign direct investment (FDI) net inflows and net outflows as percentage of GDP	Bartniczak and Raszkowsk (2018).	48 African countries	2002-2016
		Remittances as percentage of GNI			
Sustainable production and consumption	Material consumption	Material intensity of the economy/ Domestic material consumption			
	Energy use	Annual energy consumption, total and by main user category			
		Share of renewable energy sources in total energy use			

		Intensity of energy use, total and by economic activity			
		Renewable energy consumption (% of total final energy consumption)	Bartniczak and Raszkowsk (2018).	48 African countries	2002-2016
		Access to electricity	Bartniczak and Raszkowsk (2018).	48 African countries	2002-2016
		Combustible renewables and waste (% of total energy	Okon (2021)	Nigeria	1970-2018
	Transportation	Passenger transportation			
		Freight transport			
		Energy intensity of transport			
	Agriculture	Arable land	Bartniczak and Raszkowsk (2018).	48 African countries	2002-2016
		Crop production index (2004–2006 = 100)	Bartniczak and Raszkowsk (2018).	48 African countries	2002-2016
		Crop yield gap (actual yield as % of attainable yield)			
		Cereal yield growth rate (% p.a.)			
		Livestock yield gap (actual yield as % of attainable yield			
	Natural resources	Forest area (% of land area)1	Bartniczak and Raszkowsk (2018).	48 African countries	2002-2016
		Forest rents (% of GDP)1	Bartniczak and Raszkowsk (2018).	48 African countries	2002-2016
		People using at least basic drinking water services (% of population)	Bartniczak and Raszkowsk (2018); Lie et al (2021)	48 African countries	2002-2016
		People using at least basic sanitation services (% of population)	Lie et al (2021)		
		Improved water source (% of population with access)	Bartniczak and Raszkowsk (2018).	48 African countries	2002-2016
		Total natural resources rents (% of GDP)	Bartniczak and Raszkowsk (2018).	48 African countries	2002-2016

Good governance		Voice and accountability	Bartniczak and Raszkowsk (2018).	48 African countries	2002-2016
		Rule of law	Bartniczak and Raszkowsk (2018).	48 African countries	2002-2016
		Control of corruption	Bartniczak and Raszkowsk (2018).	48 African countries	2002-2016

Table 5: Economic Sustainability Indicators (Source: Author)

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5.11 To Assess the Patterns and relationships

There is a rising interest in correlational studies between SDG indicators across different domains. For instance, greenhouse gas emissions affect environmental sustainability and economic growth. Renown theories such as the environmental Kuznets curve (EKC) hypothesis, according to which environmental pressure or resource use first increases with GDP but, after a certain threshold income level, declines with per capita GDP. The theory suggests that environmental pollution increases at the beginning of economic growth as an industrial error. However, at a certain level of economic growth, technological advancements, such as green technologies in the energy sector and strengthened policies and governance, allow the remediation of environmental degradation. Such theories have been established not to hold in Africa, but rather, a monotonically increasing relationship with GDP is found more appropriate for CO_2 emissions (Abid, 2016).

5.11.1 Stationarity

Most level data was established to be non-stationary at the level. The stationarity test was done using the Hadri (2000) test for balanced panel data and the integrated stationarity test based on the ADF and KPSS tests. The Hadri test is based on estimating ADF regressions for each time series. The Hadri residual-based LM statistic is the cross-sectional average of the individual KPSS statistic. The Hadri tests has a null hypothesis of stationarity, or absence of a unit root, and an alternative hypothesis of non-stationarity, or presence of a unit root. For unbalanced data, Choi's modified P Unit-Root Test was used (Choi, 2001). The Pm test is a Fisher’s type Fisher-type test that combines p-values from tests based on ADF regressions per series.

Table 6: Selected stationarity test results based on the Hadri test and Choi's modified P Unit-Root Test (Source: Author)

Variable	Test	Statistic	p-value	Status
Access to clean fuels and technologies for cooking (% of population)	Hadri	78.255	0.000	Non-Stationary
Access to electricity (% of population)	Pm	15.486	0.000	Stationary
Broad money growth (annual %)	Pm	66.113	0.000	Stationary
CO_2 emissions (kg per 2015 US$ of GDP)	Pm	2.695	0.004	Stationary

Employment in agriculture (% of total employment)	Hadri	120.11	0.000	Non-Stationary
GDP per capita growth (annual %)	Pm	68.981	0.000	Stationary
Renewable energy consumption (% of total final energy consumption)	Pm	-0.687	0.754	Non-Stationary
Unemployment, total (% of total labor force) (modeled ILO estimate)	Hadri	64.167	0.000	Non-Stationary
Urban population growth (annual %)	Hadri	51.984	0.000	Non-Stationary
People practicing open defecation (% of the population)	Pm	39.082	0.000	stationarity

Notes. Hadri statistics are the Z-statistics; Hadri test assumes heteroskedasticity-consistency; Hadri's Alternative hypothesis: at least one series has a unit root (non-stationary); Pm = Choi's modified P Unit-Root Test; $pmax$ between 1 to 4; Pm's alternative hypothesis: stationarity.

To omit time trend impact, the first differenced series was used, as suggested by Wooldridge (2009). Using the first difference ensures that a change in an outcome measure is correspondingly associated with the change from the previous year in another series. It omits spurious regression due to time effects where time series variables could consistently increase over time.

5.11.2 Sampling Adequacy and Bartlett's Test of Sphericity

The KMO statistic shows that the complete data sample 124 with 114 variables is substantially adequate for PCA based on the KMO test (Overall MSA = 0.5). The determinant of the corelation matrix was below .00001, indicating that multicollinearity will not bias the PCA. Given the constrained sample due to data availability, Bartlett's Test of Sphericity results were not computed since the resultant matrix is not invertible (singular). However, the full sample showed rejection of the null hypothesis that the variables are orthogonal, χ^2 (6441) = 235077, p < .001. Nonetheless, the complete case does not limit PCA. Thus, factor extraction was done using a 124 x 114 dimension to identify the underlying structure of the selected sustainability indicators.

5.11.3 Factor Extraction

Factor extraction entails determining the minimum number of factors or principal components (PC) that best capture the total variance in the databases based on their interrelationships among the high-dimensional input variables. In this study, the input matrix is a time series of measures of SDGs (selected based on data availability). PCA is used to analyze the data structure of the selected sustainability indicators using data across African countries (input data). The main goal is to assess the patterns and relationships between the sustainability indicators and reduce the data as much as possible for easy interpretation. Essentially, each of the input data is first treated as a component.

The Scree plot in Figure 1 shows that a 10-factor structure can fit the 114 selected indicators. The graph elbows at of thumb are the number of components at the "elbow' point of the curve; there, the curve is levelling off since it implies that additional components do not add a significant variance in the total variance explained by the existing number of components. The extraction of the ten components from PCA is consistent with the parallel analysis results indicated in Figure 2. Of the 114 possible factors, an optimal of 10 indicators is obtained. The Biplot in Figure 3 represents the PCA results akin to clustering, where each of the observation inputs is mapped based on the observed variables. Variables clustered or aligned on the same planer constitute a principal component.

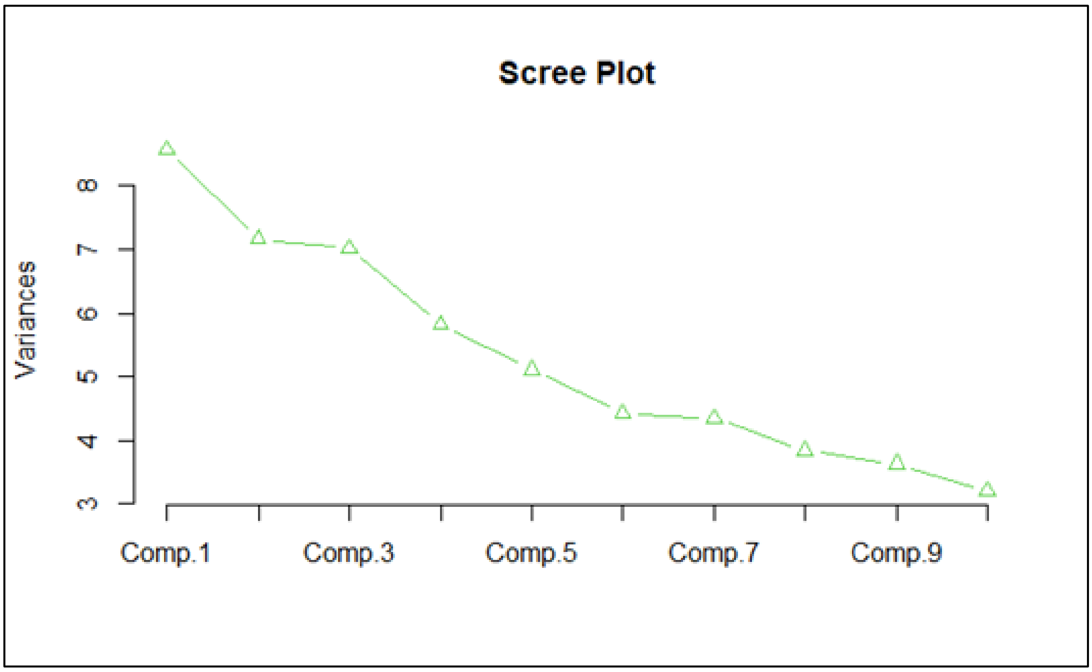


Figure 1: Scree Plot (Source: Author)

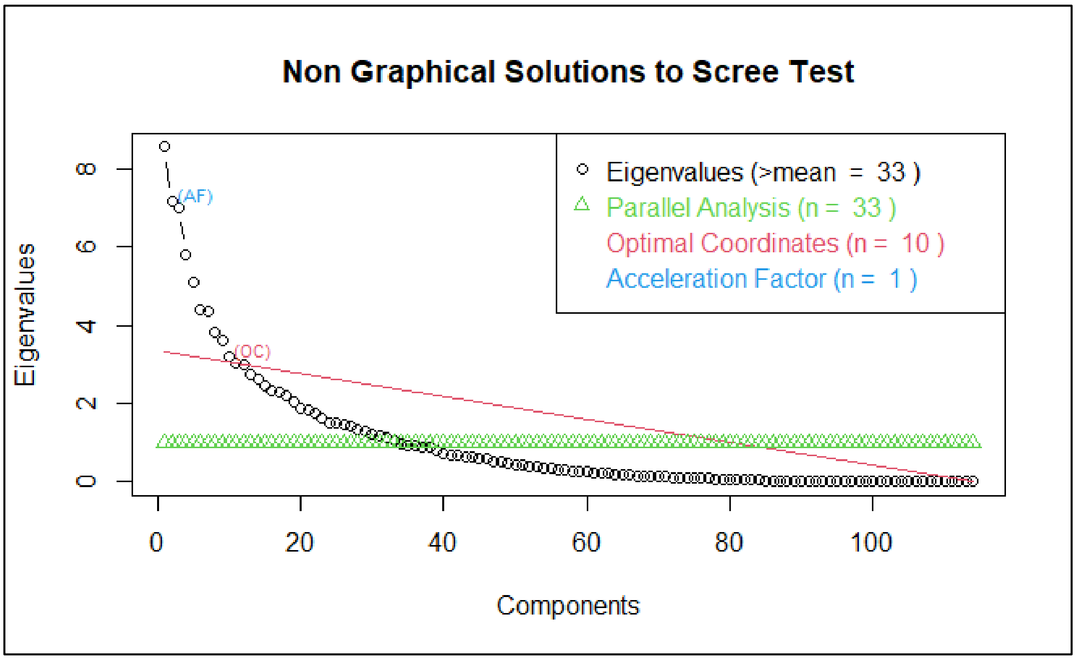


Figure 2:Parallel analysis results (Source Author)

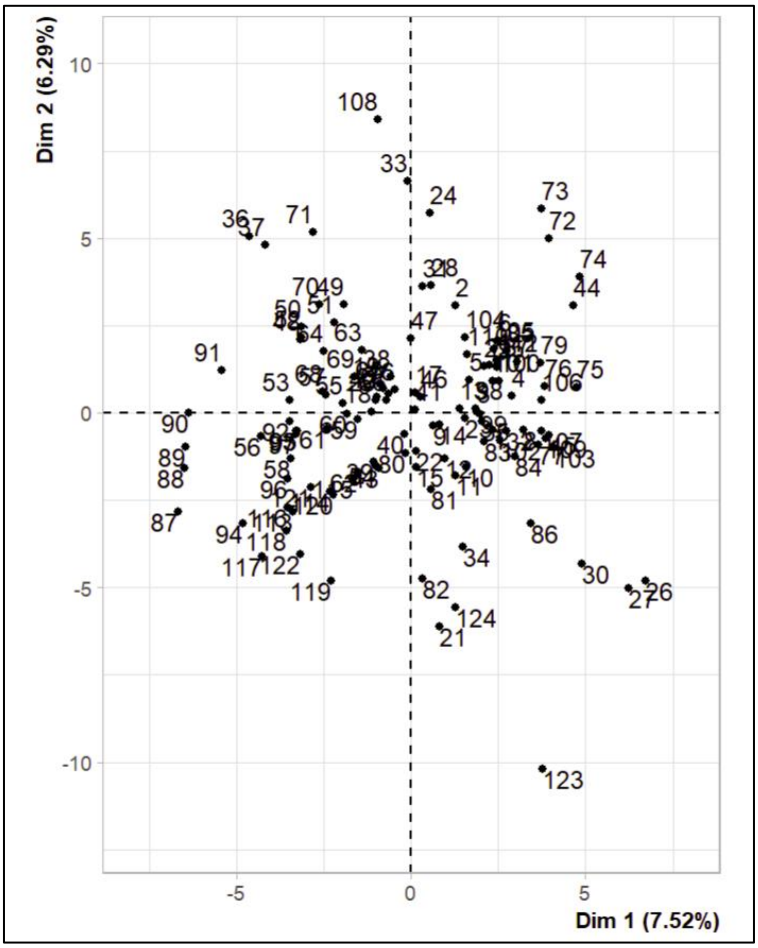


Figure 3: Biplot of clusters of input data using the selected indicators (Source Author)

The model fit was 0.7596, $\chi^2(5346) = 7335.437$, $p < .001$, hence a good fit. The extracted factors explain up to 100% of the variance in the data matrix (Table 6). The findings indicate that the selected indicators can be reduced from 114 to only 10.

Statistic	RC1	RC2	RC3	RC4	RC6	RC5	RC7	RC10	RC9	RC8
SS loadings	7.510	6.305	6.252	5.810	5.449	4.842	4.443	4.402	4.185	3.941
Proportion Var	0.066	0.055	0.055	0.051	0.048	0.042	0.039	0.039	0.037	0.035
Cumulative Var	0.066	0.121	0.176	0.227	0.275	0.317	0.356	0.395	0.432	0.466
Proportion Explained	0.141	0.119	0.118	0.109	0.103	0.091	0.084	0.083	0.079	0.074
Cumulative Proportion	0.141	0.260	0.378	0.487	0.589	0.681	0.764	0.847	0.926	1.000

Table 7:Factor Loading and Variance Explained by The Ten Extracted Factors. (Source Author)

5.12 Indicators in component one

Table 7 shows the indicators loaded onto component 7.

Table 8: Indicators in Component 1 (Source: Author)

No	Variable	MR1	Complexity	Uniqueness
1	People using at least basic drinking water services (% of population)	0.931	1.037	0.103
2	People using at least basic drinking water services, urban (% of urban population)	0.894	1.050	0.175
3	Forest area (% of land area)	-0.831	1.259	0.181
4	Forest area (sq. km)	-0.826	1.185	0.269
5	People using at least basic drinking water services, rural (% of rural population)	0.766	1.307	0.344
6	People using at least basic sanitation services, urban (% of urban population)	0.746	1.394	0.381
7	People practicing open defecation, urban (% of urban population)	-0.524	2.972	0.391
8	Access to clean fuels and technologies for cooking (% of population)	-0.396	4.170	0.575
9	PPP conversion factor, GDP (LCU per international $)	0.351	3.358	0.688
10	Mortality rate, neonatal (per 1,000 live births)	-0.34	2.753	0.776
11	Energy intensity level of primary energy	0.224	3.728	0.884
12	Access to electricity, urban (% of urban population)	0.215	3.926	0.899
13	Urban population growth (annual %)	0.208	3.184	0.906
14	Women Business and the Law Index Score (scale 1-100)	0.166	3.728	0.927

It indicates meaningful correlation patterns. First, people using at least basic drinking water services and forest area covered could be correlated since forests are Africa's major water catchment areas. Forests play a crucial role in regulating and providing water resources. Thus, forest degradation and deforestation threaten the water security and quality in many parts of the continent.

For instance, forest cover loss in Kenya's Mau Forest, the largest water catchment area in East Africa, increased the frequency and severity of droughts and floods in the region (Kitheka, 2019; Ndegwa, 2019). Thus, forest conservation and restoration are key policy reforms in most African countries to enhance the resilience of water resources.

Accessing the status of clean drinking water, sanitation, and hygiene remains a challenge in Africa. Some key indicators used to proxy hygiene are open defecation and usage of open or modern pit latrines. Drawing from empirical evidence from SSA, Atangana, and Oberholster (2023) established that rural and urban population growth would have a statistically significant detrimental influence on eliminating open defecation by 2030. Their findings are consistent with the findings in this study. People practicing open defecation in urban areas are clustered with urban population growth.

While evaluating the prospects of ten SSA countries to eliminate open defecation by 2030, Atangana, and Oberholster (2023) established that there was no significant improvement in the number of modern pit users between 2017 and 2019. Instead, unimproved toilets and open-pit latrines grew linearly over the study period. Confounding factors over the study periods included rising population growth, higher unemployment, and teenage pregnancies. Conjointly, it implies a rising population of low-income earners since early marriages substantially contribute to unskilled employment with low incomes. The authors also observed regional disparity by countries. Nigeria had the highest proportion of pit latrine users (20%) between 2017 and 2019. Ghana had the highest growth rate of open-pit latrine users, growing by 50% from 2001 to 2017, while Democratic Rep. Congo (DRC) registered an increase linearly from 25 to 33% between 2000 and 2017, while Burundi was one of the countries in the region with the lowest number of open-pit latrine users rising from 6.13 to 11.75% between 2017 and 2019. Such a rising trend in Africa threatens water safety. Poverty, inequality, mismanagement of public funds, and insufficient funding constrain millions of Africans from using open-pit latrines (United Nations Children's Fund and World Health Organization

[UNICEF], 2019). Thus, to meet SDG target 6, African countries should prohibit open defecation to ensure citizens have access to safe drinking water, sanitation, and hygiene.

In component one, energy intensity level of primary energy and access to electricity, urban (% of urban population) are correlated. First, the changing urban population reflects an increasing demand for electricity since it is all households' basic clean energy used for cooking and lighting. Thus, this could be a somewhat direct relation. Energy intensity is the energy needed to produce one unit of economic output. The primary energy intensity rate of growth measures how efficiently an economy uses energy to produce goods and services. It refers to the percentage change in the global total energy supply ratio per unit of gross domestic product (GDP). It is used to proxy global energy efficiency (International Energy Agency [IEA], 2023). The lower the energy intensity, the less energy is needed to produce the same output. Energy efficiency tends to slow down whether there are low economic activities that utilize primary energy such as during the Covid-19 pandemic where the energy efficiency growth slowed to 0.6 % in 2020 from the predicted decadal average of 1.8% (IEA, 2023). The main drivers during the pandemic were lockdowns and travel restrictions. Globally, a 3.4% average annual improvement is required to meet SDG7.3 (IEA, 2023).

The positive relationship between energy intensity and access to electricity in urban areas could be associated with adopting modern, clean energies and cooking technologies in businesses, households, and industries. Generally, countries with higher access to electricity tend to have lower energy intensity, as they can use more efficient and modern technologies that require less energy per unit of output. Rural electrification reduces energy intensity, mainly due to substituting traditional biomass fuels with electricity for cooking and lighting purposes with energy-intensive appliances and services in rural households (Elliott, Sun, & Zhu, 2017; Guta et al., 2024).

The Women, Business, and the Law Index Score measures legal differences between men’s and women’s access to economic opportunities. It is based on eight indicators: mobility, workplace, pay, marriage, parenthood (examines laws affecting women’s work after having children), entrepreneurship, assets (considers gender differences in property and inheritance), and pension. A higher score means more gender equality in the legal system (World Bank.

2023). This indicator assumes the woman resides in the economy's main business city. Thus, rising access to electricity in urban areas could enable increased investment opportunities benefitting women.

Besides, clean fuels and cooking technologies can reduce exposure to household air pollution, a major health risk for women and children who spend more time indoors (WHO, 2022). This can improve their well-being and productivity and enable them to pursue more education and economic opportunities. People using at least basic drinking water services have access to improved sources of water that are protected from contamination, such as piped water, boreholes, protected wells, and rainwater. This can reduce the burden of water collection and waterborne diseases, which often fall disproportionately on women and girls in African countries. This can free up their time and energy for other activities, such as schooling and work (Fleifel, Martin, & Khalid, 2019; Ho *et al.*, 2021). Generally, green energy intensity reflects access to modern and efficient energy services, such as electricity, lighting, heating, cooling, and communication. Such business opportunities increase their participation and empowerment in the economy. In turn, it can enhance the quality of life and livelihoods of women, who often face multiple challenges due to poverty, isolation, and lack of infrastructure.

5.13 To compare and contrast the sustainability Indicators

The third objective of the study was to compare and contrast the sustainability indicators for various African regions, including East, West, Central, Northern, and Southern Africa. The results are presented objectively within the five regions and discussed. Some key sustainability indicators commonly used to assess environmental aspects of sustainability in Africa are broadly classified as follows.

Environmental Suitability: Some key sustainability indicators commonly used to assess environmental aspects of sustainability in Africa are broadly classified as follows

Greenhouse gas emissions: Fossil fuels are a major concern in environmental degradation. Oil and gas-producing countries such as Libya cause environmental damage through oil spills, gas flaring, water pollution, and land degradation. Consumption of these fuels in the transport and manufacturing sector increases GHGs in the atmosphere. It is more pronounced in oil-producing countries due to cheaper fossil fuels than green energy. North Africa is the leading contributor of CO2 emissions, averaging 0.736 kg per 2015 USD of GDP over the study period, followed by South Africa (0.538), Central Africa (0.351), West Africa (0.295), and East Africa (0.207).

Libya is the main contributor of CO2 emissions, registering Africa's highest per capita CO2 emissions in 2016, with 11.06 metric tons per person. This was followed by South Africa (7.34), Seychelles (5.34), Algeria (3.99), and Mauritius (3.44). Libya's high CO2 emissions are mainly due to its dependence on oil and gas production, which accounts for more than 95% of its export revenues and 60% of its GDP. Libya has Africa's largest proven oil reserves and the ninth largest globally. However, its oil and gas sector has been affected by political instability, civil war, and sanctions, contributing to fluctuation in its output. For example, its CO2 emissions dropped in 2011, when the country experienced a violent uprising that led to the overthrow of Muammar Gaddafi. Its CO2 emissions increased in 2012 when oil production partially resumed. Its CO2 emissions decreased in 2014 when a new civil war erupted. Its CO2 emissions increased in 2021 when a ceasefire agreement was reached (Kaufman, 2016; Nassar Aissa & Alsadi, 2017).

South Africa had the highest emission over the study period out of the 54 countries, with an average of 1.465kg of CO2 per 2015 US$ of GDP, followed by Libya (1.313), Lesotho (1.160), Equatorial Guinea (1.016), and Algeria (0.821). As indicated in Figure 6, Libya's CO2 emissions per unit of GDP are also high compared to other North African countries. Libya's high CO2 emissions per unit of GDP reflect its low economic diversification, low energy efficiency, and high energy subsidies. Libya relies heavily on oil and gas exports, vulnerable to price and external shocks. The county also has low renewable energy penetration and relies mostly on subsidized domestic fossil fuels for electricity generation and transportation, encouraging carbon emissions.

While oil-dependent countries such as Libya and Algeria heavily rely on precious natural resources for economic development, it challenges their environmental sustainability and social stability. For instance, Libya's oil and gas wealth has enabled it to achieve a high level of human development, with a GDP per capita of $6,871 in 2021 and a Human Development Index of 0.708 in 2019, ranking 110th out of 189 countries. Besides, it uses accruals from oil that can be invested in infrastructure, education, health, and social services, which have improved the living standards of its population. As a result, it might be interesting to examine the degree of such intercorrelations between environmental, economic, and social sustainability indicators.

The size and structure of the economy also influence the degree of CO2 emissions. Countries with more industrialized economies tend to emit more CO2 than countries with smaller and more agrarian economies. For example, South Africa is the most polluting country in Africa, as it has the largest and most diversified economy on the continent, with a high share of mining, manufacturing, and energy-intensive sectors. Comparatively, Seychelles is a small island nation that relies mostly on tourism and fisheries. However, it also has a high per capita income and living standard, increasing its energy demand and CO2 emissions.

The energy mix and efficiency can also influence the degree of intercountry variation in CO2 emissions. Countries that rely more on fossil fuels, especially coal, for their energy supply tend to emit more CO2 than countries that use more renewable or low-carbon sources, such as hydro, solar, or nuclear. For example, oil-dependent North African countries like Libya and Algeria are major oil and gas producers and exporters. However, it also consumes many fossil fuels for electricity generation and transportation, resulting in high CO2 emissions. West African countries, on the other hand, have a lower share of fossil fuels in their energy mix and a higher share of biomass, such as wood and charcoal, which are considered carbon-neutral.

Lastly, the population and urbanization: Countries with larger and more urbanized populations tend to emit more CO2 than countries with smaller and more rural populations. Urban areas have higher energy demand and consumption and more transport and industrial activities than rural areas. For instance, Nigeria is the most populous country in Africa, with over 200 million people, and it also has a high urbanization rate, with over 50% of its population living in cities. This contributes to its high CO2 emissions despite its relatively low per capita incom[1]. East African countries, on the other hand, have smaller and less urbanized populations, which reduce their energy demand and CO2 emissions. From the data used in this study, the least-ranking countries in terms of CO2 emissions are Chad (0.131), Uganda (0.130), Burundi (0.110), and Congo Dem. Rep. (0.073), and South Sudan (0.064).

Given the adverse effects of CO_2, African countries with high C02 emissions due to heavy reliance on cheap fossil fuels should transition to clean renewable energy sources to reduce their carbon footprint and mitigate the impacts of climate change, which pose risks to water security, food security, and public health.

Table 9:CO2 Emissions (kg per 2015 US$ of GDP (Source: Author)

Region	**n**	**Min**	**Max**	**Mean**	**SD**
North Africa	186	0.289	1.954	0.736	0.290
South Africa	372	0.156	1.636	0.538	0.389
Central Africa	248	0.049	3.848	0.351	0.429
West Africa	465	0.080	0.964	0.295	0.129
East Africa	403	0.000	0.934	0.207	0.124

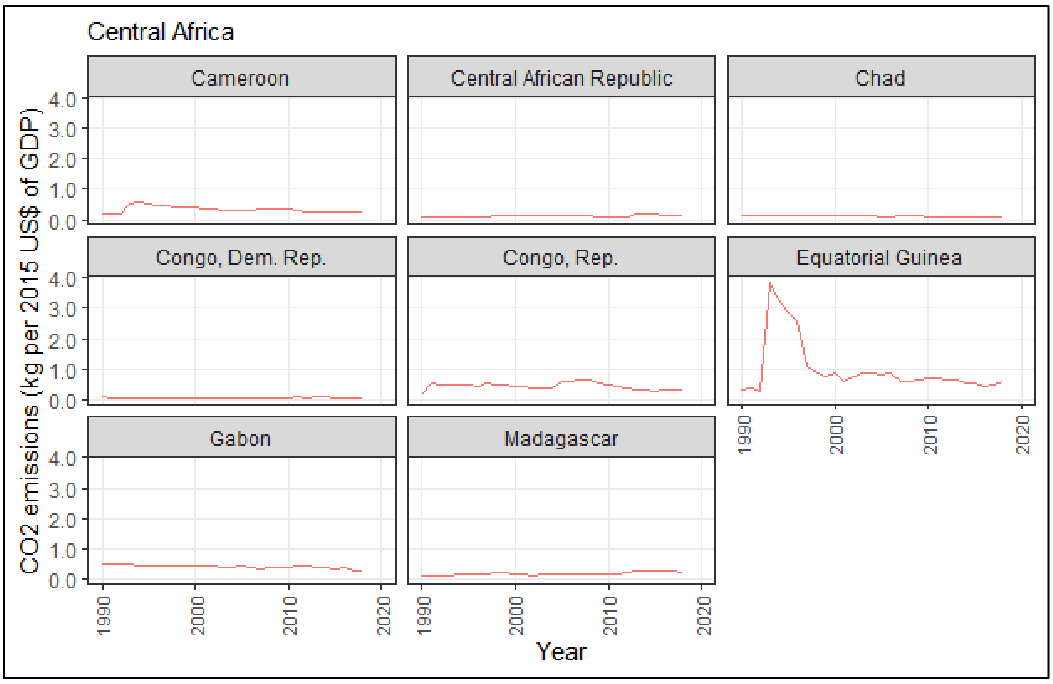


Figure 4: CO2 emissions (kg per 2015 US$ of GDP) in Central Africa (Source: Author)

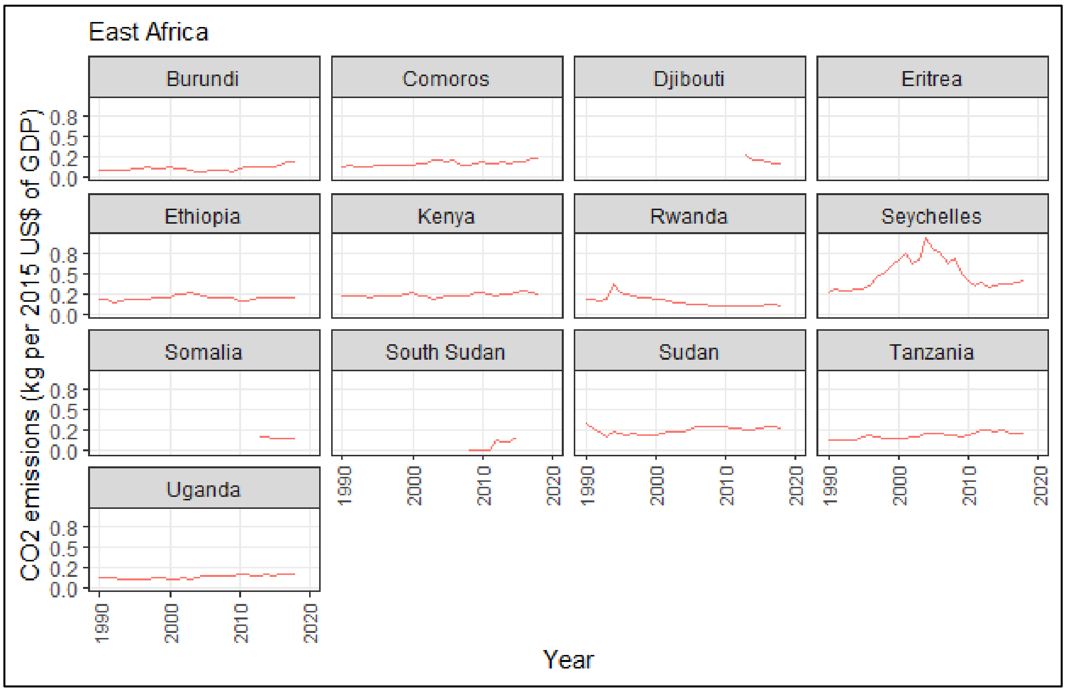


Figure 5: CO2 emissions (kg per 2015 US$ of GDP) in East Africa (Source: Author)

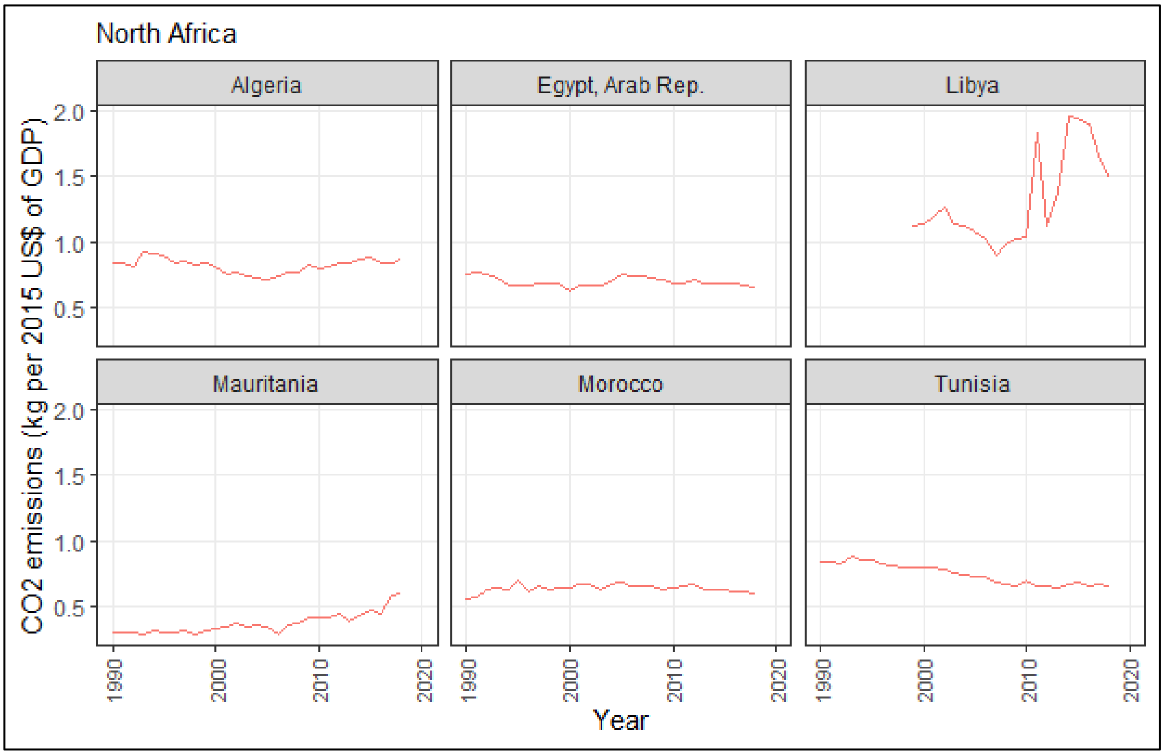


Figure 6: CO2 emissions (kg per 2015 US$ of GDP) in North Africa (Source: Author)

South Africa:

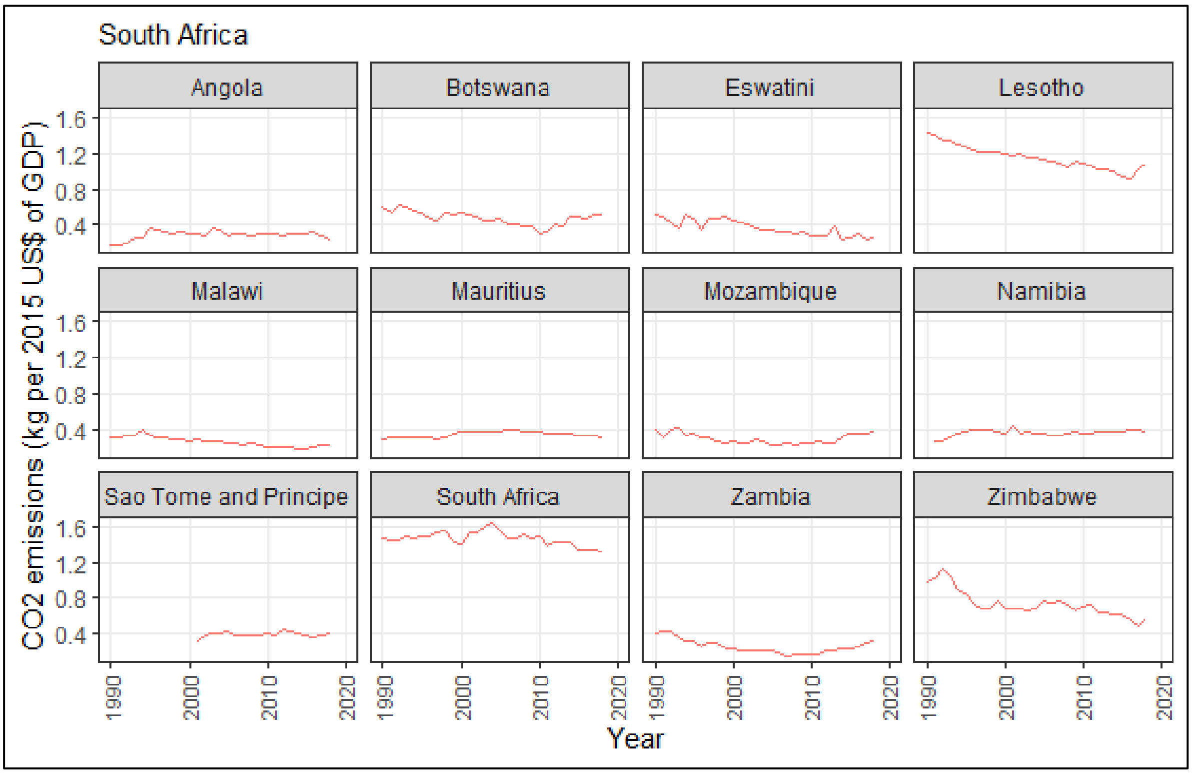


Figure 7: CO2 emissions (kg per 2015 US$ of GDP) in South Africa (Source: Author)

West Africa:

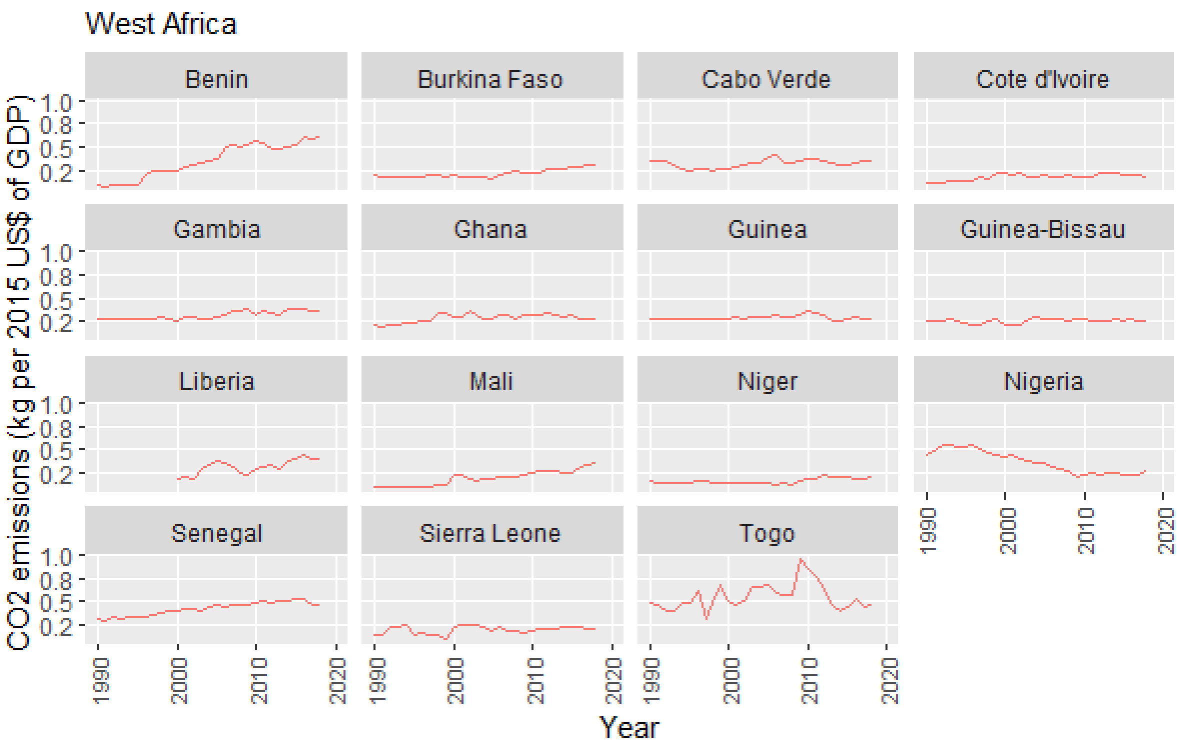


Figure 8: CO2 emissions (kg per 2015 US$ of GDP) in West Africa (Source: Author)

Overall, the data indicates that the decarbonization of energy systems' progress toward reducing GHG emissions to level zero by 2050 in Africa seems slow and, hence, infeasible. Several African countries have not embraced an aggressive shift towards delivering low and zero-carbon services across sectors, especially in the industry and transport sectors.
The switch from fuel to green energy in Africa has received little attention. For instance, Kenya has recently introduced electric motorcycles, intended to address the high cost of fuels but also contribute to reducing GHG emissions into the atmosphere. Yet, such innovations and the adoption of electric cars in Africa are still a blueprint.

As a developing country, industrialising is still rising in most African countries, implying that fossil-based energy systems or demand can keep expanding since industrialization and transport are rising conjointly due to heavy reliance on supply chains of goods by roads. The building and construction industry is also rising, and urbanization continues to expand in Africa. The industry also contributes to substantial land degradation through sand and water use and transporting raw materials across the country. Such persistent growth in climate-damaging sectors in Africa plays a substantial role in environmental degradation through land, air, and water pollution.

Nonetheless, Africa contributes minimally to global GHG emissions but is susceptible to rising temperatures as a global phenomenon. Since Africa is predominantly agricultural, climate change has significant adverse shocks on food security in the region. Thus, there should be regional efforts to cap GHG emissions to ensure Africa is food secure.

5.14 Proportion of seats held by women in national parliaments (%)

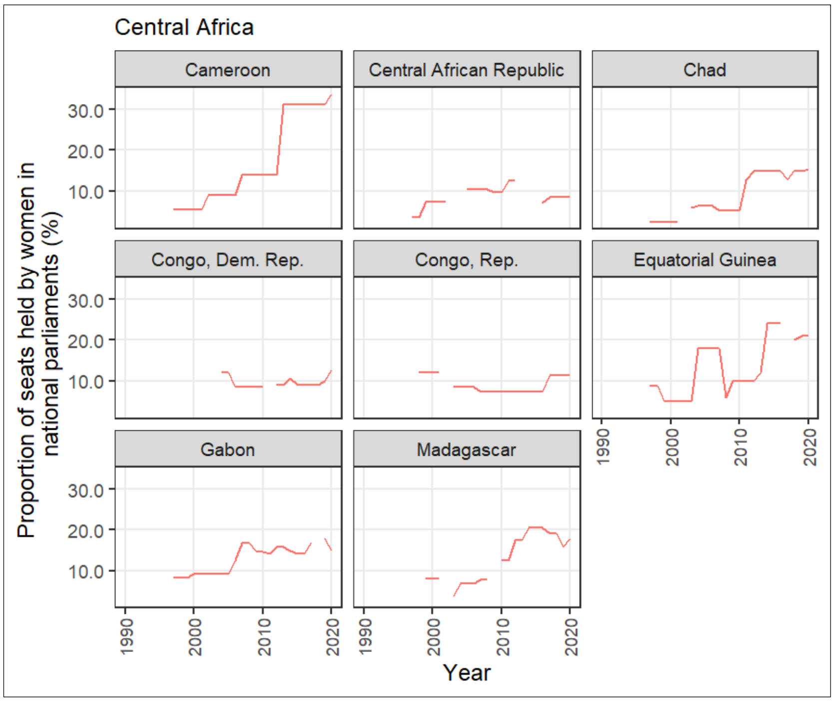


Figure 9: Proportion of seats held by women in national parliaments (%) in Central Africa

(Source Author)

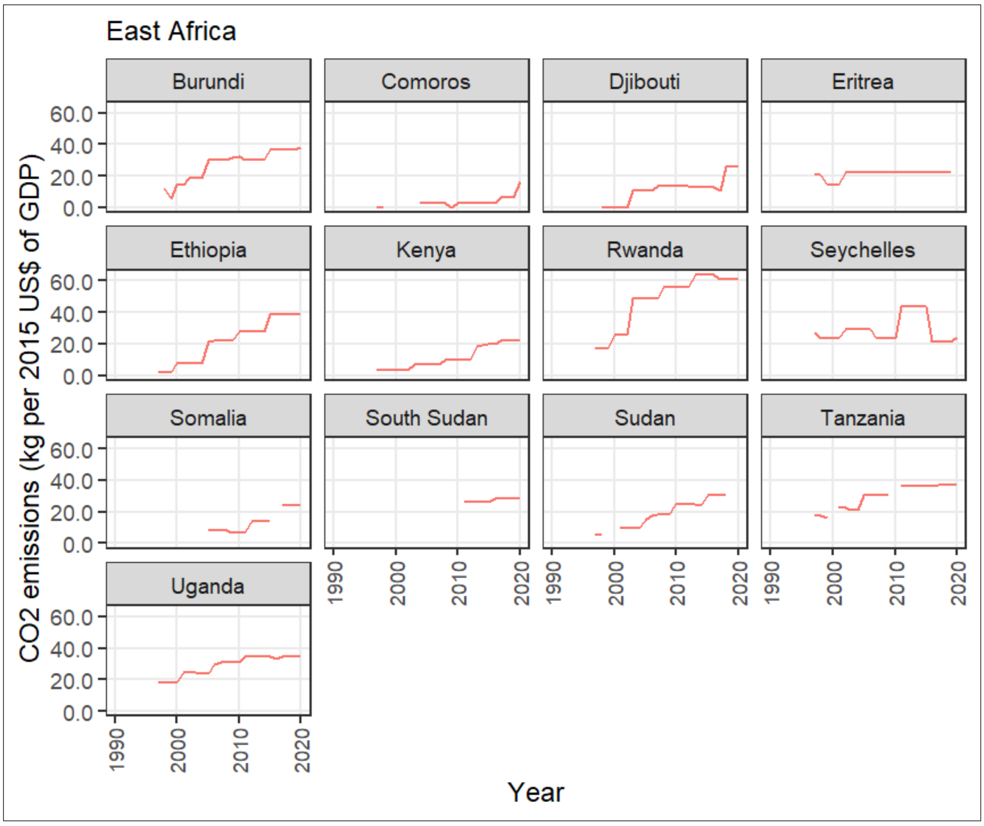


Figure 10: C02 emissions (kg per 2015 US$ of GDP) (Source Author)

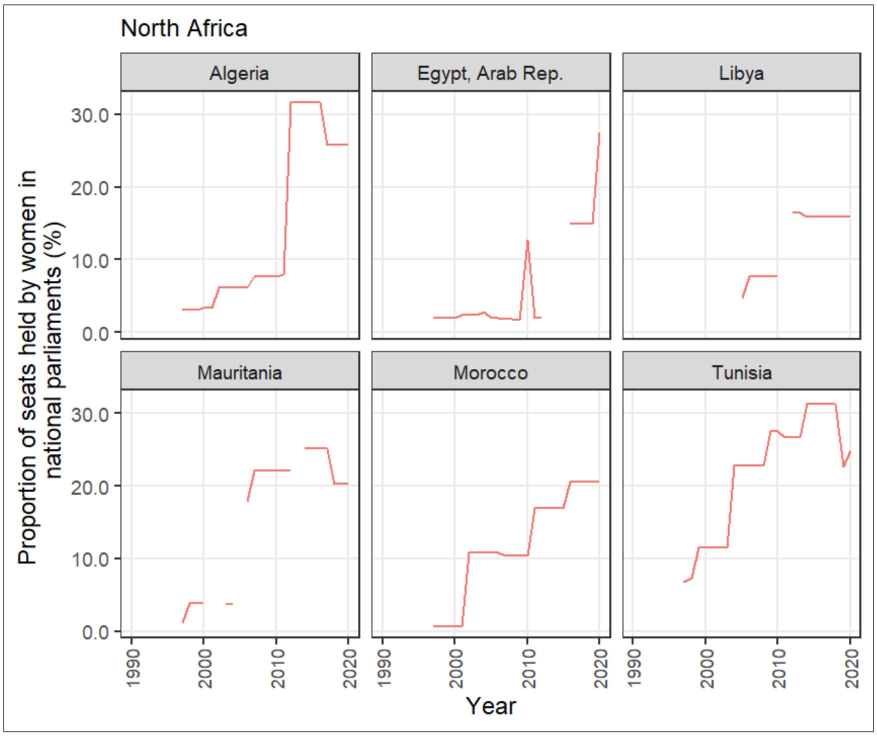


Figure 11: Proportion of seats held by women in national parliaments (%) (Source Author)

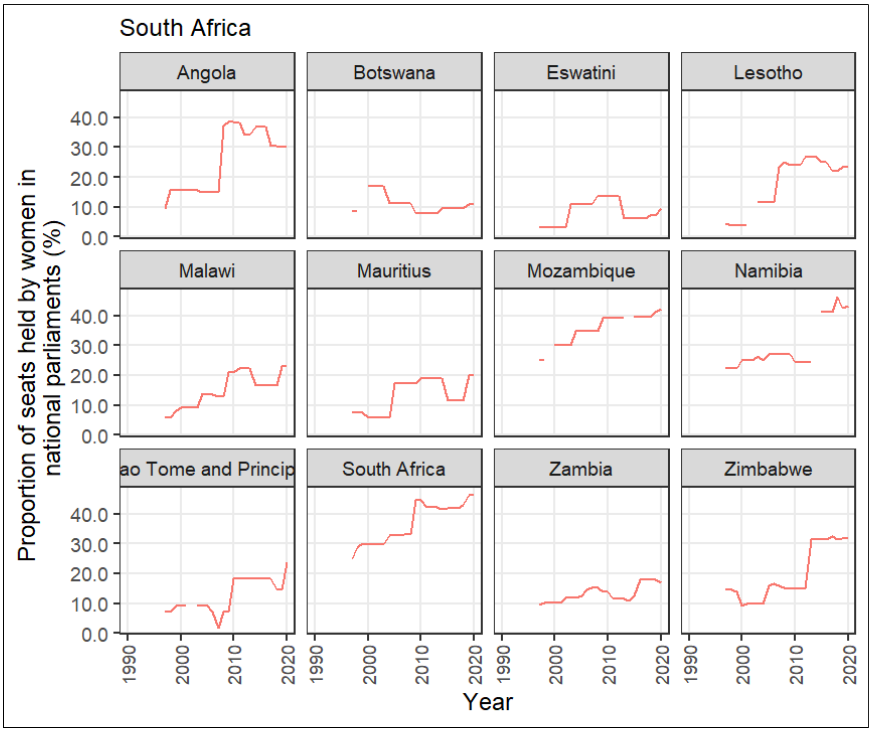


Figure 12: Proportion of seats held by women in national parliaments (%) (Source Author)

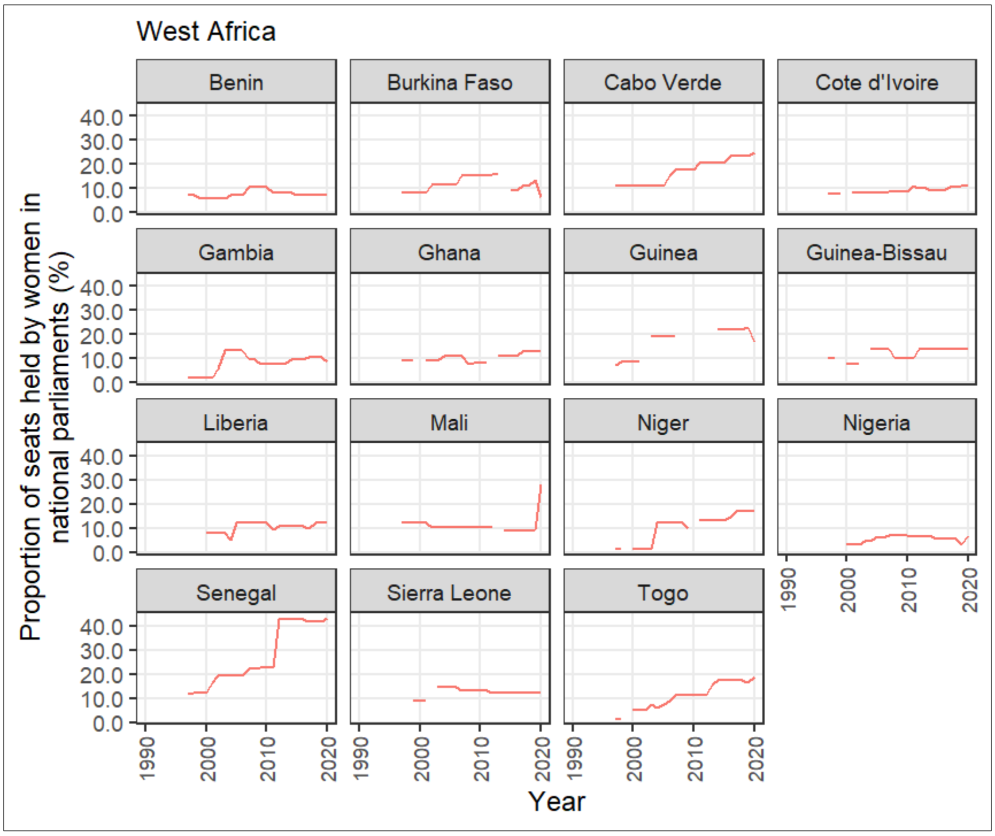


Figure 13 Proportion of seats held by women in national parliaments (%) in West Africa(Source Author)

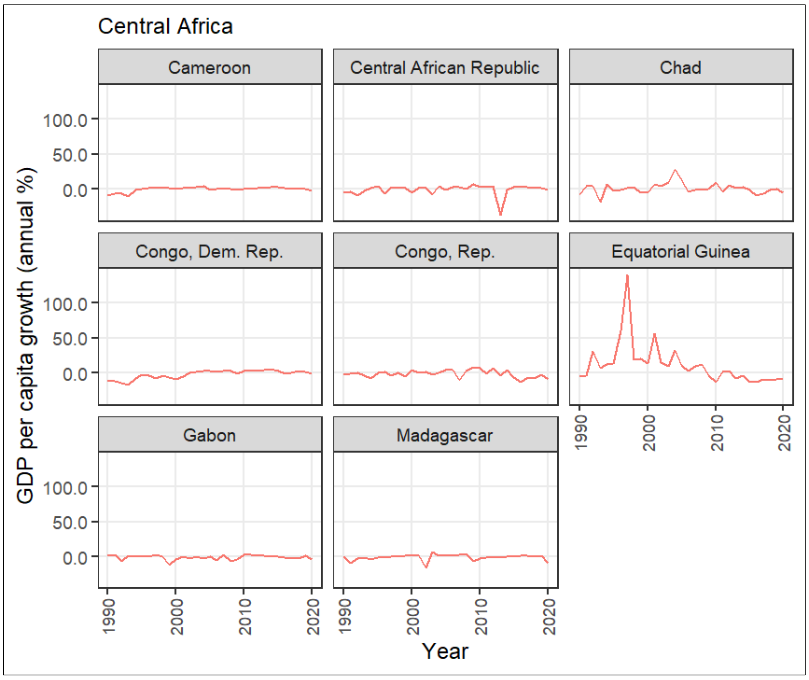


Figure 14 GDP per capita growth (annual %) (Source Author)

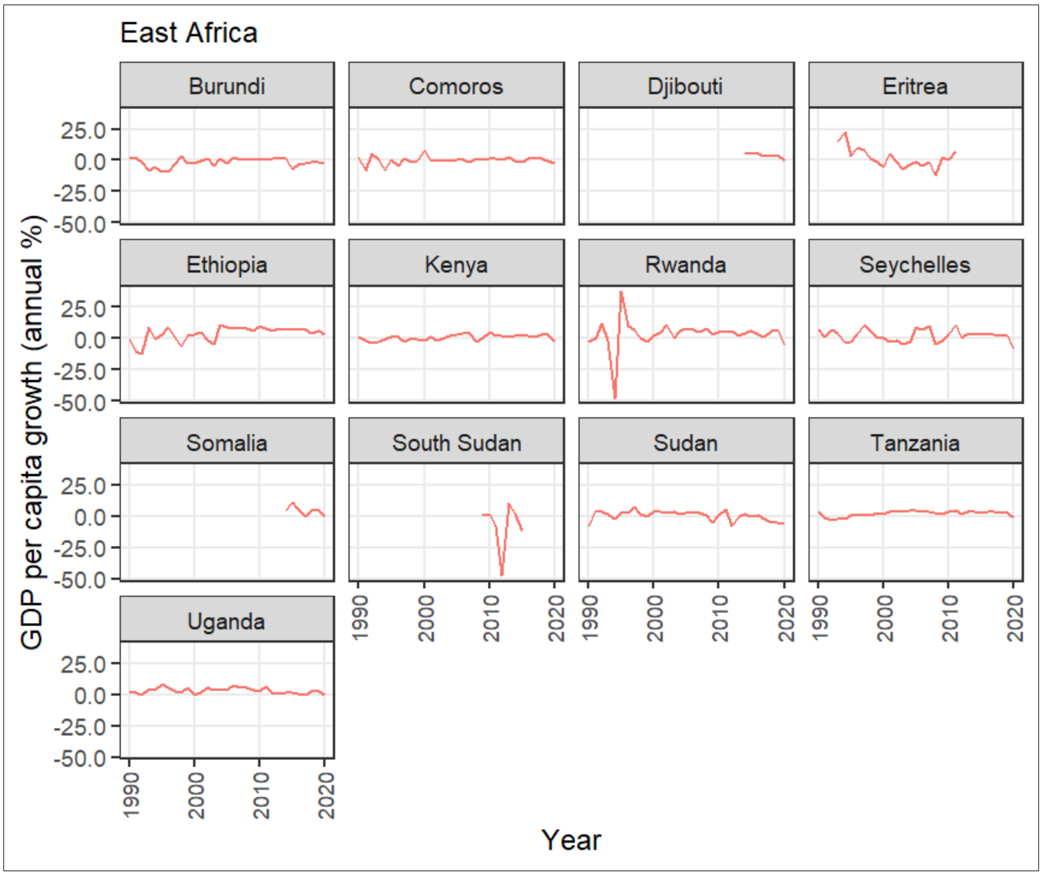


Figure 15 GDP per capita growth (annual %) (Source Author)

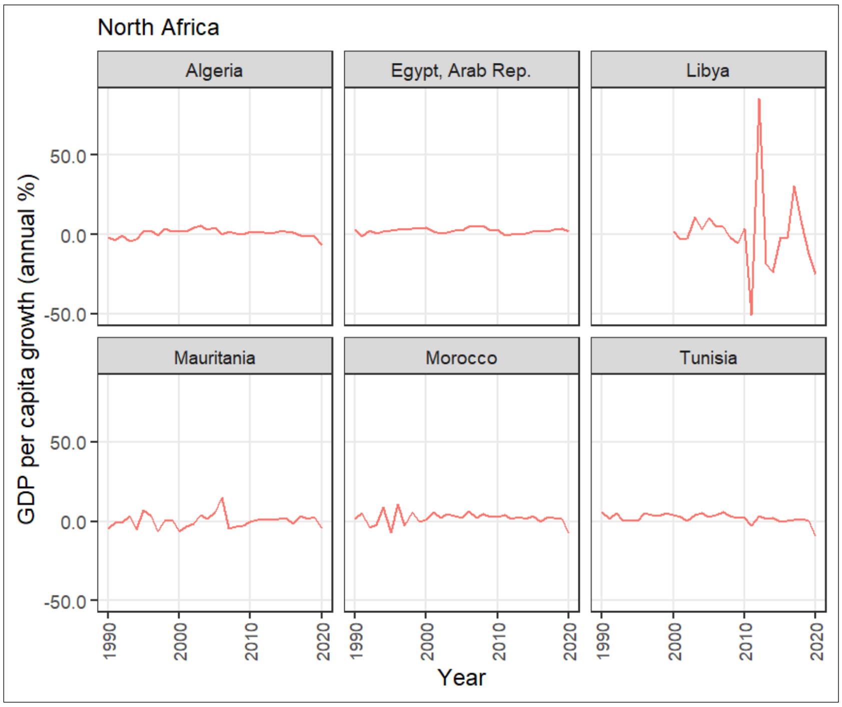


Figure 16 GDP per capita growth (annual %) (Source Author)

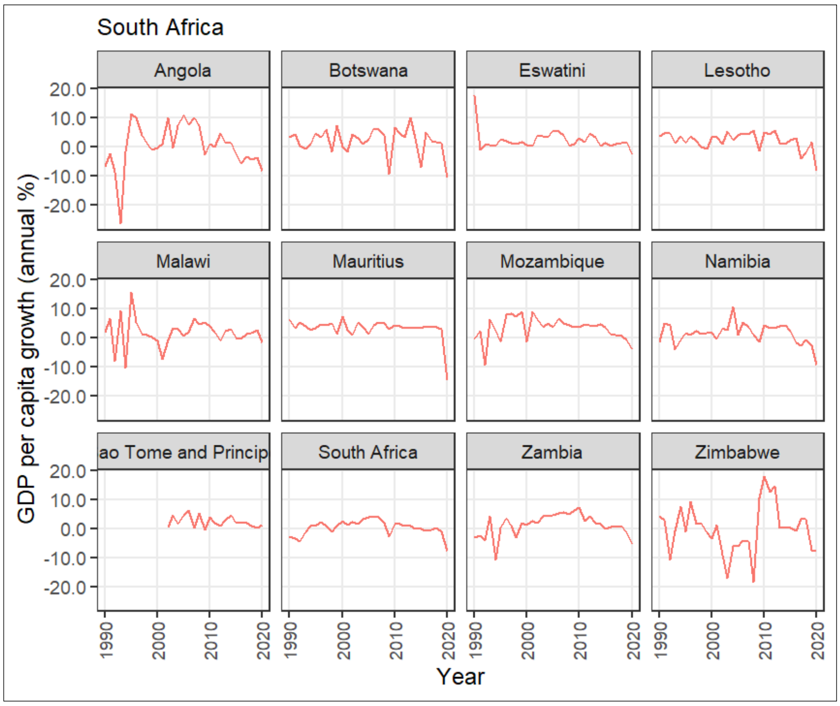


Figure 17 GDP per capita growth (annual %) (Source Author)

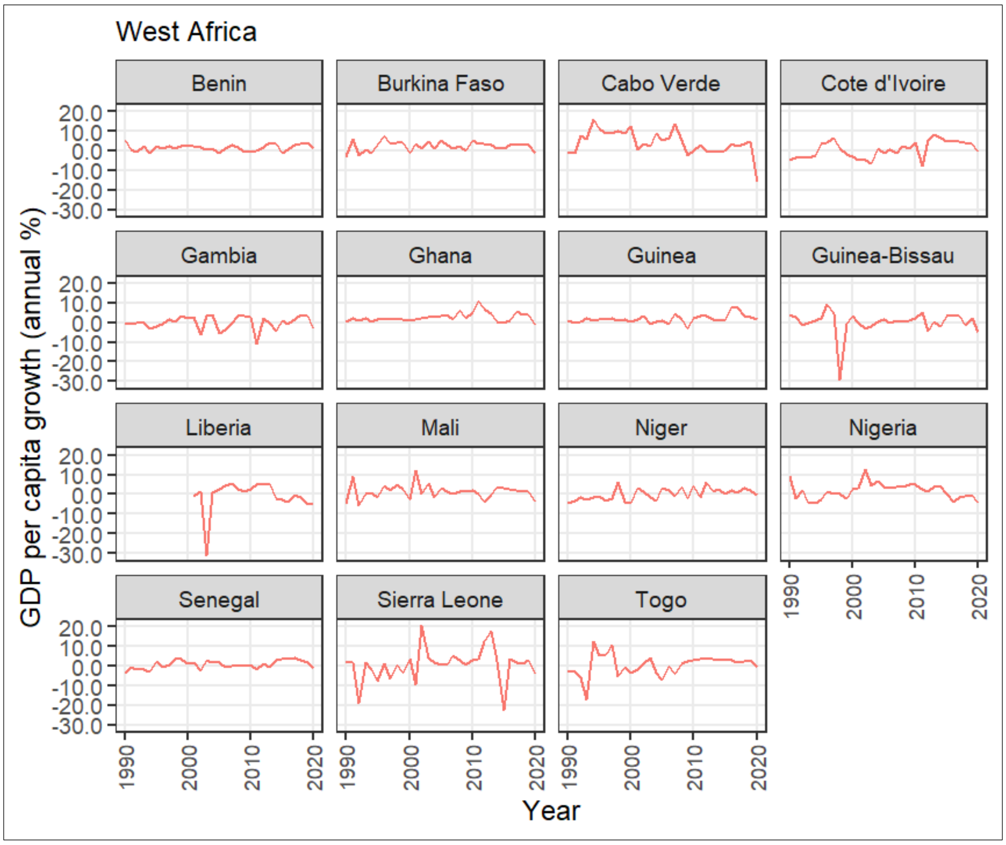


Figure 18 GDP per capita growth (annual %) (Source Author)

5.15 To assess the differences and Similarities

Using data from 18 African countries based on complete data availability, clusters were created using the nine aggregate principal components. A cross-section of data was created using average scores across the principal components extracted from PCA results. Each component was computed by equally weighted variables in that cluster. The data was then aggregated across the years to obtain cross-section data of countries only with measures of the nine optimal clusters. Among the selected 97 variables, 14 were in Cluster 1, 11, 2, 12, 3, 9, 4, and 13 in 5, 7, Cluster 6, 17, Cluster 7, 11, Cluster 8, and 3 in Cluster 9. Thus, the scaled data of each of the 97 variables were averaged respectively to compute each of the 9 PCs.

Using the nine PCs, countries were

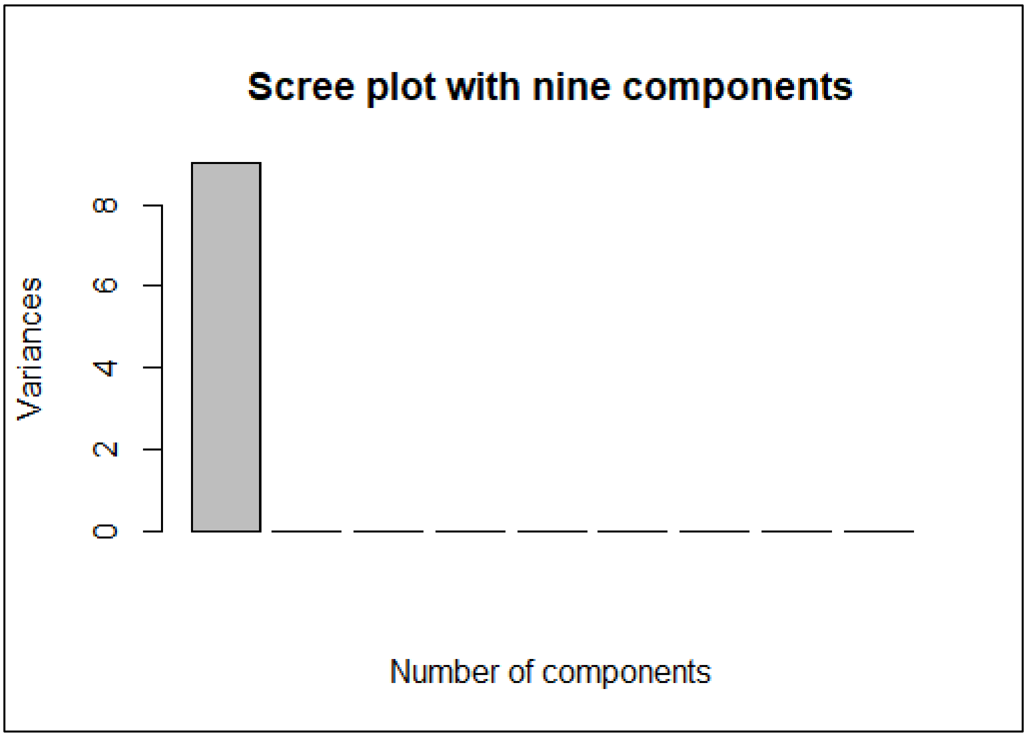


Figure 19: Scree plot with nine components(Source Author)

Thus, due to the small sample size, the PC might not sufficiently classify countries independently. As indicated in Figure 20, one component explains 100% of the variance. The finding is primarily attributed to significant missing cases, which constrained the analysis to rely on a few countries. The ultimate countries collected comprised 18 countries: Algeria, Cameroon, Congo, Rep, Egypt, Arab Rep, Gabon, Ghana, Kenya, Madagascar, Mauritius, Morocco, Mozambique, Nigeria, Rwanda, South Africa, Tanzania, Tunisia, Uganda, and Zimbabwe.

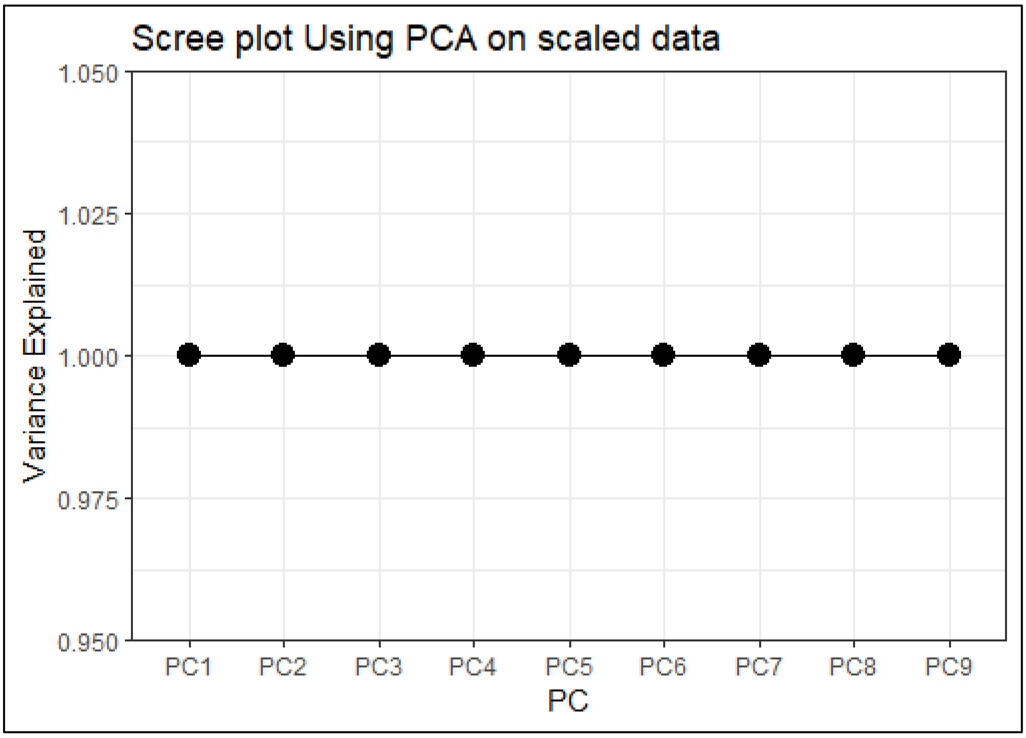


Figure 20: Variances explained by the PC

The implication of the above variance is zero Euclidean distances between countries. Thus, the initial 97 indicators were used to cluster the aggregate data, a data frame of 18 versus 124 variables.

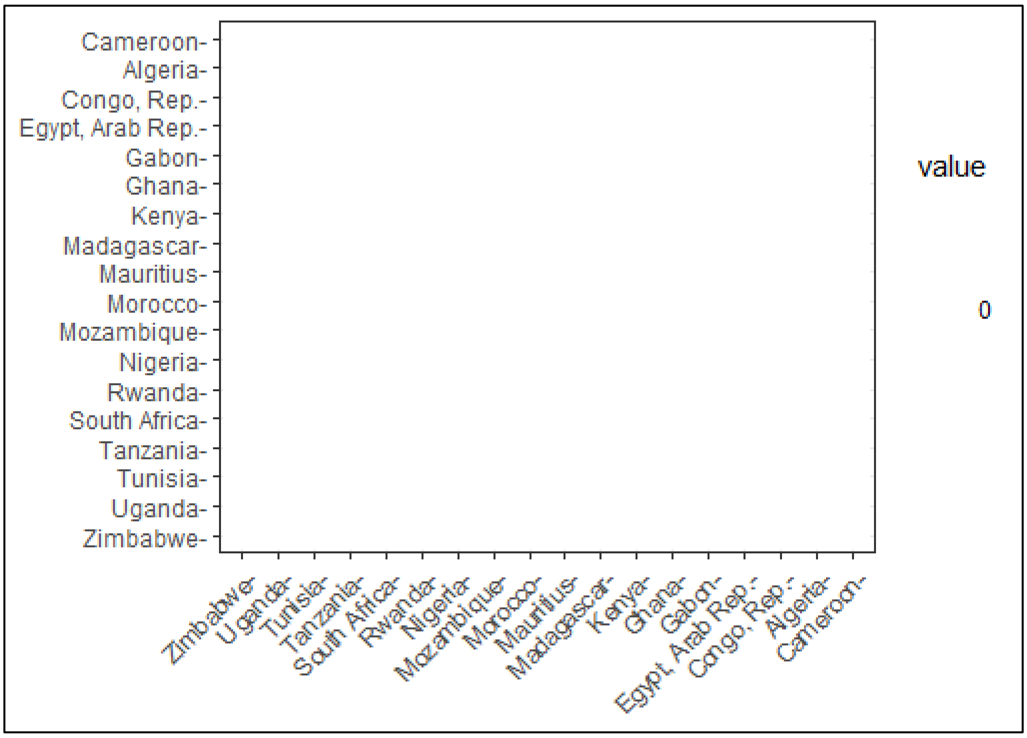


Figure 21: Output of R Studio (Source: Author)

5.16 Biplot of variables with country labels

Variables with moderate to strong positive correlation with PC1 are access to electricity remittances. Countries like Kenya, Madagascar, Nigeria, Rwanda, Tanzania, and Uganda lie close to and near the centre, with moderate outcomes. Ghana is isolated at the top centre, which has relatively higher forest rents with respect to the average of all the countries, a low value of oil rents, service rates, mortality rates, employment from agriculture, and low urban population growth. Zimbabwe stands alone on the left with a low representation of women in governance, a low value of oil rents, service rates, mortality rates, employment from Agriculture and low urban population growth. Other countries have moderate outcomes (Figure 22)

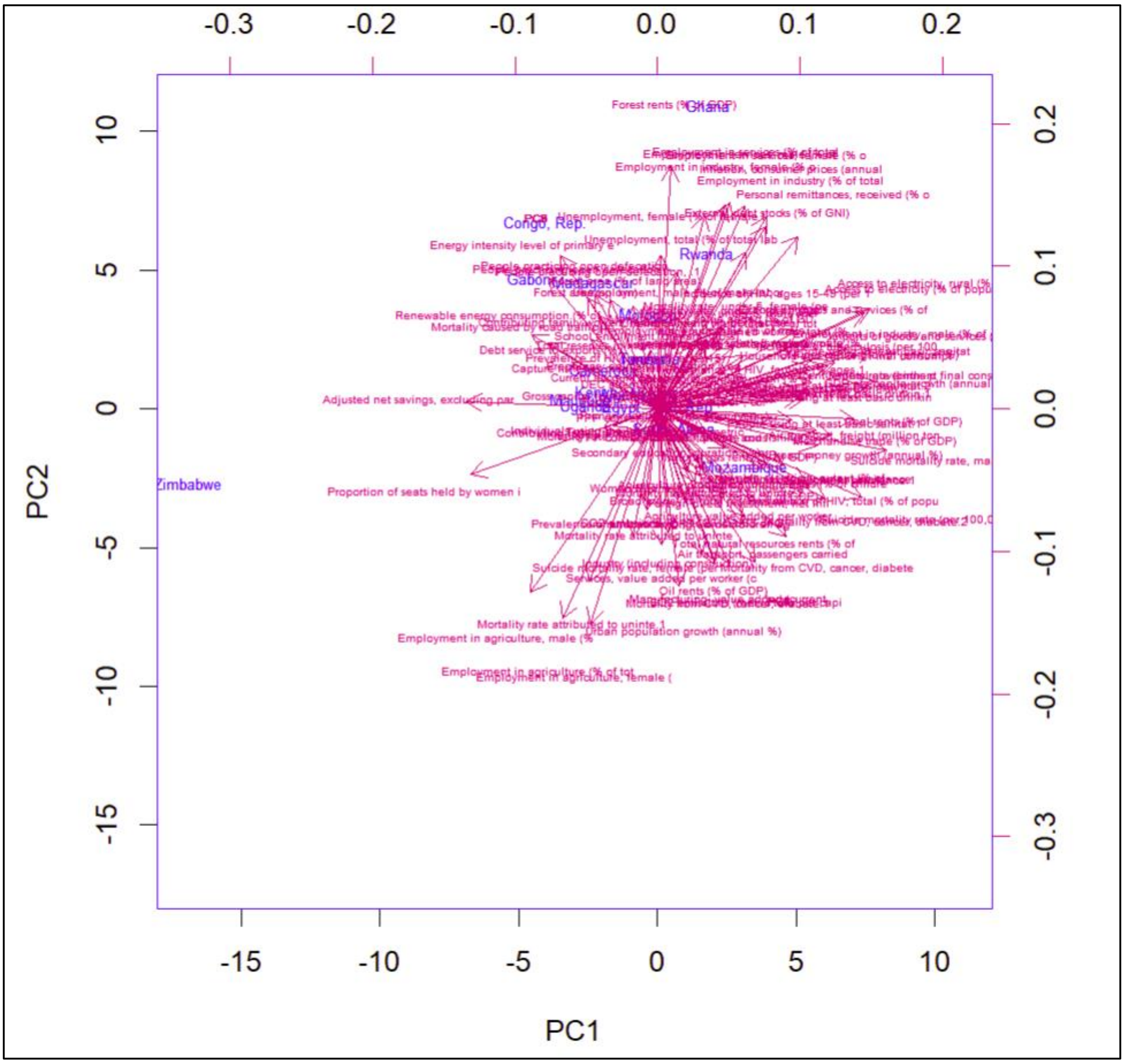


Figure 22: Biplot graph (Source: Author)

5.17 Euclidean distances

The Euclidean distance between countries is visualized in Figure 23. The plot is an 18-picture with colour pixels representing the distance between two countries. The bluer the color, the higher the dissimilarity. This picture is symmetric concerning the diagonal with the zero distances. Similar countries belong to the same cluster.

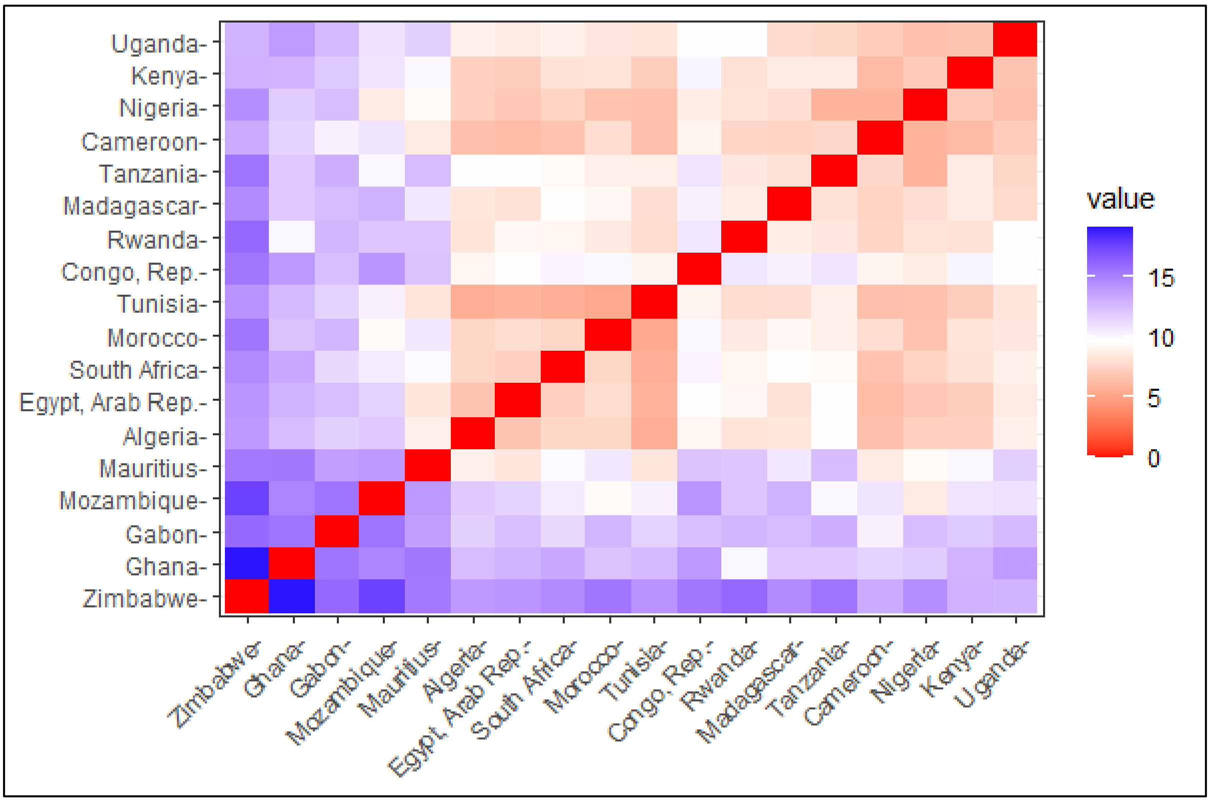
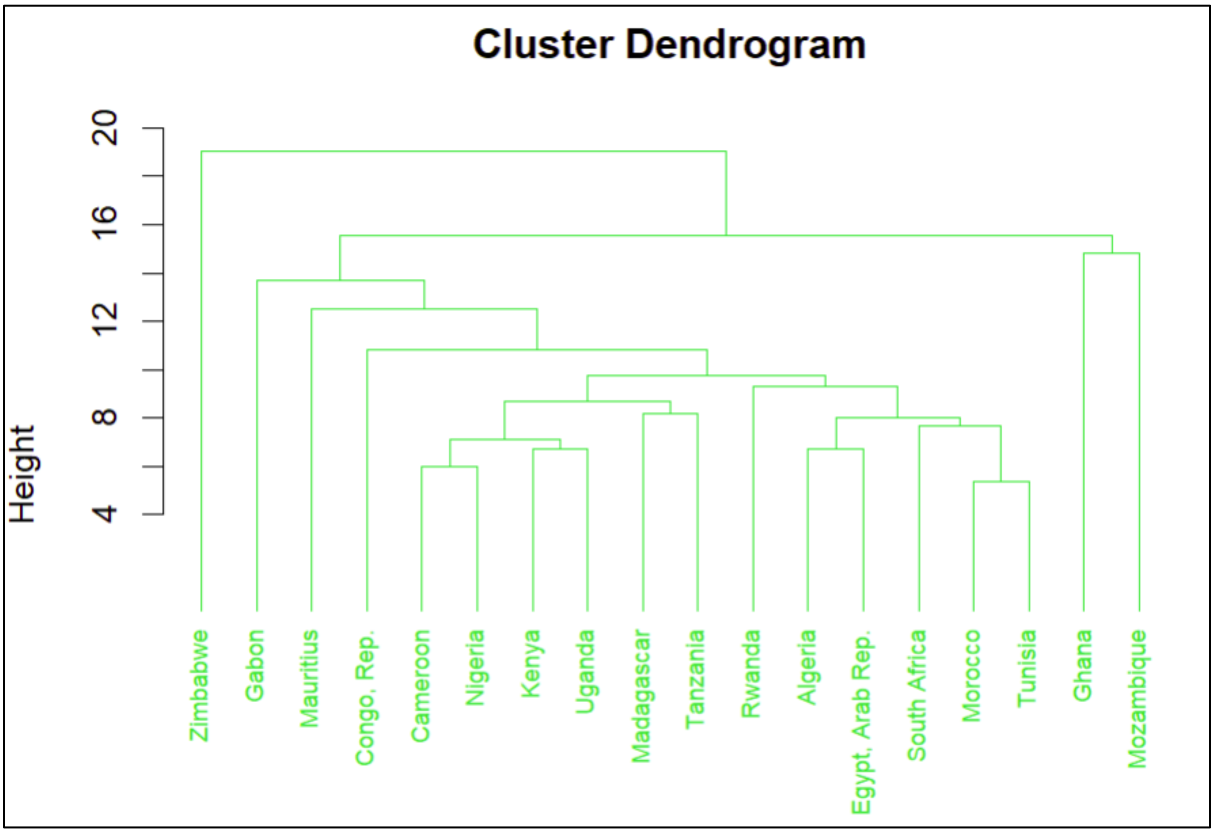


Figure 23: Euclidean distances

5.18 Hierarchical clustering

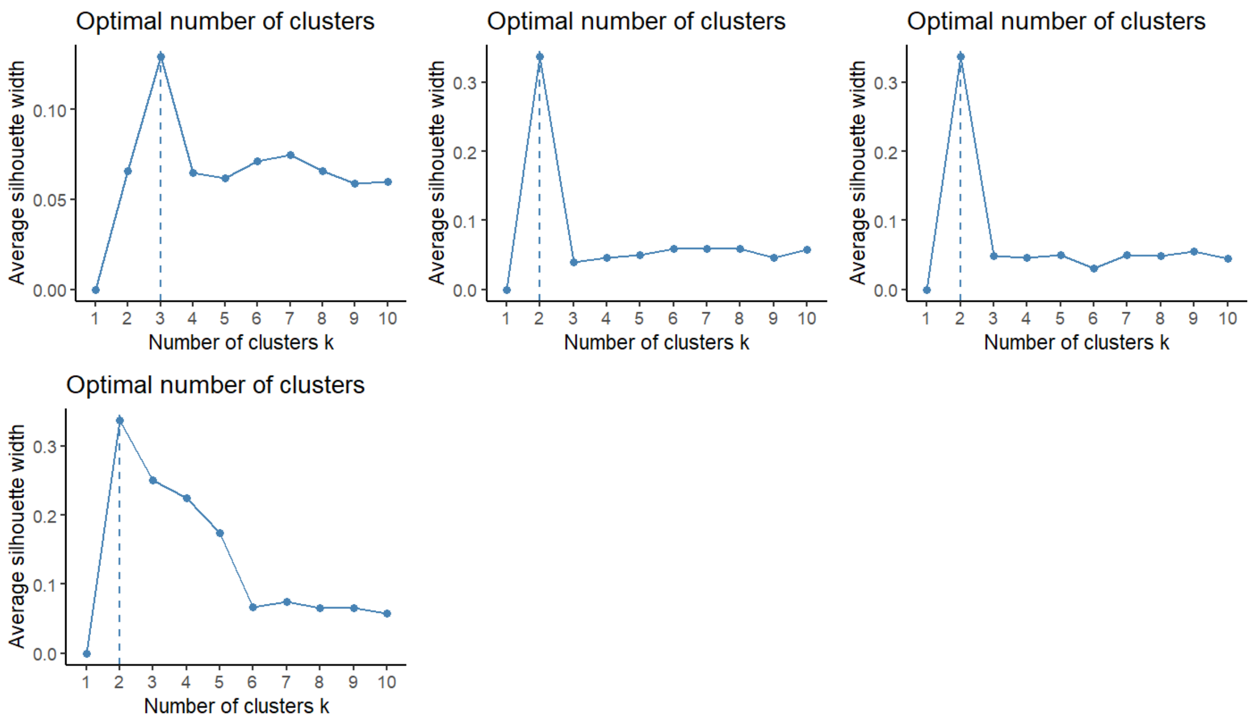


Considering the visual plot, six clusters can outlined as follows

Cluster 1	2	3	4	5	6
Cameroon, Congo, Rep, Kenya, Madagascar, Nigeria, Rwanda, Tanzania, Uganda,	Algeria, Egypt, Arab Rep., Mauritius, Morocco, South Africa, Tunisia	Gabon	Mozambique	Zimbabwe	Ghana

Cameroon, Congo, Rep, Kenya, Madagascar, Nigeria, Rwanda, Tanzania, Uganda are clustered together since are on the upper left plane on the biplot in 15. These countries have moderate to high performance on energy consumption and intensity, have low prevalence of communicable diseases such as measles and have low mortality from cardiovascular diseases and cancer. Ghana's uniqueness is high forest rents whereas Zimbabwe have low women representation of women in leadership positions in parliament.

5.18.1 Optimal clusters



The optimal clusters are such that Zimbabwe stands on one cluster alone while others are grouped into another.

6. SMMARY AND CONCLUSION

The study explored the SDGs in Africa and their interlinkages. The preliminary analysis SDGs were classified into three major domains. The first dimension was environmental degradation indicators with nine themes namely; Atmosphere, Natural hazards, Land, Oceans, seas and coasts, Freshwater, Biodiversity, Consumption and production patterns. The second dimension was sustainability proxied by two sub-domains. The first is social inclusion, which looks at digital connectivity and age dependency ratio, health and safety of employees, digitalization, job creation, and industrialization. The second sub-domains are gender equity which can be addressed by enhancing female education and women representation in leadership. By addressing identity-based exclusion, leveraging digital technologies, and focusing on youth empowerment, the African continent can move toward a more inclusive and equitable future. The third domain was on macroeconomic variables such as GDP, inflation, and unemployment which are commonly and widely examined across Africa.

There is a general substantial interlinkage with sustainability indicators environmental within a given domain. The findings also indicated land degradation and desertification are critical environmental issues that have a profound impact on food security and biodiversity. The impact is also interlinked with other sustainability measures. For instance, land degradation and desertification significantly undermine food security by diminishing the productivity of arable land, leading to reduced agricultural yields and threatening food insecurity and contributes to rising poverty levels due loss of potential income. The scarcity of water resources, which is both a cause and consequence of desertification, further exacerbates this issue, as water is essential for maintaining agricultural practices and supporting life. Moreover, these processes disrupt vital ecosystem functions, negatively affect biodiversity, and contribute to the loss of plant and animal species, which are crucial for ecological balance and the provision of ecosystem services. Efforts to mitigate the effects of land degradation include afforestation, reforestation, terracing, crop rotation, mixed cropping, irrigation schemes and traditional soil conservations (Megerssa & Bekere, 2019).

The success of the implementation of the SDGs has attracted wide empirical research in Africa. While studying 48 African countries, Bartniczak and Raszkowsk (2018) established a significant heterogeneity in terms of the success of the implementation of the SDGs. The authors established that Cape Verde and Ghana are among the countries recording the best results regarding the level of implementation of the sustainable development concept in the 2002–2016 period. The least-performing countries include the Democratic Republic of the Congo, Liberia, Chad, Central African Republic, and Eritrea. Plausibly, several confounders contribute to the success of the implementation of SDGs in Africa.

Gabrah *et al.* (2023) established that limited control of resources, over-dependence on foreign aid, poverty heightened by income inequality, demographic pressures, poor governance and corruption, environmental degradation, and lack of data and information are key barriers affecting SDGs and their implementation. Thus, it is important to realize the potential confounders that can influence the implementation of SDGs. Reliance on external sources of financing, such as overseas development assistance (ODA) and foreign direct investments

(FDIs), may hinder their ability to pursue their development agendas and priorities and may create a vicious cycle of dependency and underdevelopment (Gabrah *et al.*, 2023). Besides, conflict and instability are major threats to peace and security in Africa and have negative consequences for human rights, governance, and development. Conflict and instability may disrupt the implementation and monitoring of the SDGs and divert resources and attention away from the development goals to address humanitarian and security needs (Li et al., 2015). All these challenges rely on government policies to harness the potential of foreign aid in achieving other SDGs while maintaining an internal thriving business environment that enables individuals to act in their interest and, in turn, contributes towards achieving SDGs.

Conclusion

Africa is still constrained to achieve most of the SDGs such as zero hunger and zero net emissions. In this study, the interlinkages between the SDGs which conflicting outcomes are part of the challenges that has inhibited Africa to achieve SDG. For instance, expanding agricultural crop lands to sustain food insecurity comes along with unprecedented carbon loss and loss of water sheds which are crucial for reducing carbon emissions and supply of clean water for domestic and farming use. Thus, Africa should fully optimize on technological innovations that will increase the marginal product of capital (cropland cover) and increasing its food productivity by adopting technology such as use of improved seed varieties and mechanization (Wu et al., 2018). Technological advances to compart unprecedented environmental consequences of the inefficient use of fertilizer such water and air pollution, soil degradation, and greenhouse gas emissions, and loss biodiversity include promoting sustainable practices such as micro-topographical and field-specific fertilizer application based on the soil nutrients characteristics across SSA (Tsujimoto *et al*., 2019).

Generally, inclusive development requires African countries to harness the demographic heterogeneity through investment in family planning and gender parity to enhance female labour force participation rate, enhance digitalization through increased internet usage and access, industrialization, and job creation. Thef findings further revealed that Africa has implemented significant reforms promoting gender equality and social inclusion in employment and digital space through a raft of measures including enhancing female education and increasing women representation in leadership positions, and increasing internet connectivity. However, their uneven developments as some countries lag due to civic, ethnic, and religions marginalization.

5.1.1 Limitation

Despite the study's robust techniques triangulating both qualitative and quantitative methods, the study is not without limitations. The lack of data was a major challenge that limited the scale of the study. Many African countries face challenges in collecting, managing, and disseminating reliable and timely data and information on the SDGs, due to limited institutional and technical capacities, inadequate funding, and poor coordination among stakeholders (Erin & Bamigboye, 2021; Gabrah *et al* 2023)

Out of the potential 403 indicators, only 112 were used in PCA due to missing data with severely affects the proportion of missing cases. Variables with large missing cases were dropped to optimize the complete data. This limits the study's scope of examining the intercorrelation between SDG indicators wholly. Thus, dissemination of the data should be enhanced in Africa to help track the success and the intercorrelation between SDG indicators. Data and information are essential for measuring and tracking the progress and performance of the SDGs, and for informing evidence-based policies and interventions.

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7 List of pictures, tables, Graphs and Abbreviations

7.1 List of tables

7.2 List of graphs

7.3 List of abbreviations

SDG:	Sustainable Development Goals
UNEP:	United Nations Environment Programme
PCA:	Principal Component Analysis
PAT:	Principal Axis Technique
SVD:	Singular Value Decomposition
EVD:	Eigenvalue decomposition
ADF:	Augmented Dickey-Fuller
KPSS:	KPSS Kwiatkowski-Phillips-Schmidt-Shin

CSD:	Commission on sustainable development
STAMP:	Sustainability Assessment and Measurement Principles
FDI:	Foreign Direct Investment
UAE:	United Arab Emirates
EFP:	Environmental footprint
MFP:	Material Flow Analysis
SDI:	Sustainable Development Index
ESI:	Environmental Sustainability Indicators
EPA:	Environmental Protection Agency
GHG:	Greenhouse Gas
GNI:	Gross National Income
GDP:	Gross Domestic Product
LCU:	Local Currency Unit
ILO:	International Labour Organization