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GIS-BASED TREND ANALYSIS ON RENEWAL ENERGY CONSUMPTION AND PRODUCTION IN AFRICA

(Analisis Trend Berasaskan GIS Mengenai Penggunaan dan Pengeluaran Tenaga Boleh Baharu di Afrika)

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ABSTRACT

In Africa, there has been a rise in human activities because of technological advancements and population growth, which have led to the transformation of some African villages into towns and towns into cities, increasing the region's energy demand. Utilization of advanced and appropriate renewable energy technologies stands as a critical solution to address the increasing energy demand in Africa. This study employs GIS-based analysis to examine the evolution and shifts in renewable energy generation and consumption within the region from 1990 to 2020, to enhance awareness of the geospatial aspects of energy dynamics. The analysis detects a shift in both renewable production (REP) and renewable energy consumption (REC) over the past four decades in Africa, which signifies growth in both sections. In many cases, a disparity was observed between the renewable energy consumed and that produced, while REP, REC, and GDP have increased significantly across the continent in recent years. In addition, two models are estimated, and the results found a significant growth relationship between renewable energy production (REP) and GDP, and feedback relationships were confirmed between GDP and CO2_EM. REP improves environmental degradation, and REC has a negative impact on GDP. This study recommends further research and investigation of the data, as GIS statistical analysis still needs more attention to statistics such as the evaluation of neighboring relationships between entities and effects using spatial models.

Keywords: trend-analysis; GIS; renewable energy; model; residual

ABSTRAK

Di Afrika, terdapat peningkatan dalam aktiviti manusia kerana kemajuan teknologi dan pertumbuhan penduduk, yang telah membawa kepada transformasi kampung-kampung Afrika ke bandar-bandar dan bandar-bandar ke bandar-bandar,ini meningkatkan permintaan tenaga rantau ini. Penggunaan teknologi tenaga boleh baharu yang inovatif dan sesuai adalah salah satu penyelesaian yang paling penting untuk permintaan tenaga Afrika yang semakin meningkat. Berdasarkan analisis GIS, kajian ini menyiasat trend dan peralihan pengeluaran dan penggunaan tenaga boleh baharu di Afrika antara tahun 1990 dan 2020 untuk kesedaran geospatial tenaga di rantau ini. Analisis ini mengesan peralihan dalam kedua-dua pengeluaran boleh baharu (REP) dan penggunaan tenaga boleh baharu (REC) sejak empat dekad yang lalu di Afrika, yang menandakan pertumbuhan dalam kedua-dua bahagian. Dalam banyak kes, perbezaan diperhatikan antara tenaga boleh diperbaharui yang digunakan dan yang dihasilkan. manakala REP, REC, dan KDNK telah meningkat dengan ketara di seluruh benua dalam beberapa tahun kebelakangan ini. Di samping itu, dua model telah dianggarkan dan keputusan mendapati hubungan pertumbuhan yang ketara antara pengeluaran tenaga boleh baharu (REP) dan KDNK, dan hubungan maklum balas telah disahkan antara KDNK dan CO2_EM. REP meningkatkan kemerosotan alam sekitar, dan REC mempunyai kesan negatif terhadap KDNK. Kualiti model kereta api dinilai menggunakan ujian yang baik. Kajian ini mengesyorkan penyelidikan dan penyiasatan lanjut mengenai data, kerana analisis statistik GIS masih memerlukan lebih banyak perhatian kepada statistik seperti penilaian hubungan jiran antara entiti dan kesan menggunakan model spatial GIS.

Kata kunci: trend-analisis; GIS; tenaga boleh diperbaharui; model; sisa

1. Introduction

In Africa, where the need for energy is growing quickly, renewable energy is especially important for sustainable development (Asafu-Adjaye *et al*. 2016). Solar, wind, hydro, and geothermal energy are all plentiful renewable energy sources across the continent (IRENA 2019; World Bank Group 2020). The African continent continues to face significant development challenges related to energy access. According to recent estimates, there are at least 600 million individuals who do not have access to electricity. Traditional biomass is used in cooking by more than 700 million people (Yadoo & Cruickshank 2017; Avila *et al*. 2018). Therefore, Sustainable Development Goal 7, which focuses on accessible and clean energy, addresses a very significant difficulty that the African continent, particularly sub-Saharan Africa, is currently facing. However, compared to other parts of the world, Africa still has low levels of renewable energy generation and consumption (MacArthur & Tarhan 2021; Blimpo & Cosgrove-Davies 2019; Mohammed *et al*. 2013;; Tietenberg & Lewis 2018). Policy changes are necessary in this situation to encourage the use of renewable energy sources and boost investment in industry.

Global discussions on sustainable development and reducing climate change now center on renewable energy (Omer 2008). With its abundant resources and rising energy needs, Africa offers a special potential for the development of renewable energy technology (Owusu & Asumadu-Sarkodie 2016). However, advanced analytical methods are needed to fully grasp the dynamics and trends of renewable energy generation and use in Africa (Chu & Majumdar 2012; Liu *et al*. 2015). However, understanding the trends, transitions, and dynamics of renewable energy production and consumption in Africa requires sophisticated analytical tools.

In this paper, trend analysis using econometric models and Geographic Information Systems (GIS) can provide insights into the factors that influence renewable energy production and consumption in Africa. This paper employs GIS-based trend analysis to examine the trends in renewable energy production and consumption in Africa over the past three decades. Renewable energy has gained significant attention globally as a sustainable alternative to fossil fuels. In Africa, where energy access is a major challenge, harnessing renewable energy resources can contribute to economic development and environmental sustainability. Analyzing renewable energy production using GIS-based techniques can provide valuable insights for policymakers, researchers, and investors (Zhang *et al.* 2011). Utilizing renewable energy is necessary to attain Agenda 2063 (which sets goals to achieve in four decades). Governments have committed to increasing the share of renewable energy in overall energy production to 50%. The emphasis is on both the developing risks related to a heavy reliance on nonrenewable energy sources and the advantages that renewable energy sources provide. On the one hand, the creation of new jobs and other opportunities by renewable energy is acknowledged as advantageous to the economic development of Africa (Zakari *et al.* 2022; UNDP 2018). Renewable energy is also seen as a technique to lower greenhouse gas emissions (GHGs), and as a result, it is essential in efforts to combat climate change (Timmons 2017; IPCC 2018). Consequently, this research is to be carried out to gain insight on trends and relationships between renewable energy production and consumption and other related variables in Africa.

2. Background of Study

This portion consisted of the background of the study, and it's divided into two-part renewable energy production and consumption in Africa.

2.1. *Renewable energy production in Africa*

Africa possesses abundant renewable energy resources, including solar, wind, hydro, and biomass (Olanrewaju *et al*. 2019). However, the utilization of these resources remains relatively low due to various challenges such as limited infrastructure, financing constraints, and policy barriers. Understanding the factors influencing renewable energy production is crucial for overcoming these challenges and promoting sustainable energy development in Africa (Bazilian *et al.* 2011). Renewable energy production in Africa refers to the generation of electricity or heat from renewable sources such as solar, wind, hydro, biomass, and geothermal energy. The continent of Africa has significant potential for renewable energy due to its abundant natural resources and increasing energy demand (Elum & Momodu 2017; Ibrahim *et al.* 2021). This topic has gained attention in recent years as countries in Africa strive to diversify their energy mix, reduce dependence on fossil fuels, and mitigate the impacts of climate change.

Africa is endowed with vast solar resources, with many regions receiving high levels of solar radiation throughout the year. Solar power projects have been implemented in various African countries, ranging from small-scale installations for rural electrification to large-scale solar farms (Amankwah-Amoah 2015). These projects utilize photovoltaic (PV) technology to convert sunlight into electricity (Eberhard *et al*. 2016). Additionally, concentrated solar power (CSP) systems are being explored in some regions, which use mirrors or lenses to concentrate sunlight onto a receiver for generating thermal energy.

Global Wind Energy Council (2019) reported that Wind energy is another promising renewable resource in Africa. The continent has substantial wind potential, particularly along its coastlines and in areas with high altitude or narrow valleys. According to studies conducted by organizations like the World Bank and International Renewable Energy Agency (IRENA 2019), Africa has a significant potential for wind energy generation. Countries such as Egypt, Morocco, South Africa, Kenya, and Ethiopia have favorable wind conditions that make them suitable for large-scale wind farm projects. Wind farms have been established in several African countries, harnessing the kinetic energy of the wind to generate electricity through wind turbines for example Egypt is also planning to build wind farm that can generate 2000 kWh per meter-square per year (Bugaje 2006). These projects contribute to the diversification of the energy mix and can provide a stable source of power. While on the other side it was reported that African countries have a huge amount of unrealized potential for renewable energy. The continent possesses a staggering 1000 GW/h of solar energy, 110 GW/h of wind energy, 15 GW/h of geothermal energy, and 350 GW/h of hydroelectric energy, according to estimations from the African Development Bank from 2017. The potential for bioenergy is also significant, with wood supply from surplus forests anticipated to be 520 GWh (IRENA 2015). Due to its various potential and the fact that it may be applied almost everywhere in Africa, solar energy is especially promising in terms of geographical dispersion. Due to the continent's abundance of renewable resources, the potential to generate vast quantities of renewable energy has the potential to transform the prospects of numerous nations. Although hydropower has historically been an option, alternative renewable energy. However, according to the International Renewable Energy Agency (IRENA 2019), Africa has the potential to generate more than 10 terawatts (TW) of solar power, which is equivalent to 40% of the world's total solar potential. Similarly, Africa's wind energy potential is estimated at over 1800 GW, while its hydropower potential exceeds 1,750 TW per year. Despite several reports indicated that renewable energy production in Africa is gaining momentum in Africa as countries strive to meet their growing energy demands sustainably (Olanrewaju *et al.* 2019). Solar, wind, hydro, biomass, and geothermal energy sources are being increasingly utilized to diversify the energy mix and reduce dependence on fossil fuels. However, challenges such as financing, infrastructure development, policy frameworks, and technical expertise need to be addressed to fully harness Africa's renewable energy potential.

2.2. *Renewable energy consumption in Africa*

Renewable energy consumption in Africa refers to the utilization of sustainable and clean sources of energy, such as solar, wind, hydro, geothermal, and biomass, to meet the energy needs of the continent. This subtopic is of great importance as the region (Africa) faces various challenges in terms of energy access, sustainability, and environmental impact as discussed in the renewable energy production part of this paper. However, according to Hoang *et al.* (2021) and Chu *et al.* (2017) Renewable energy consumption in Africa has been steadily increasing over the past decade as countries recognize the importance of transitioning to cleaner and more sustainable sources of power. And one of the main drivers for renewable energy consumption in Africa is the need to address energy poverty and expand access to electricity. According to the International Energy Agency (IEA), around 600 million people in sub-Saharan Africa lack access to electricity (IEA 2020). This has led governments and international organizations to prioritize renewable energy projects to bridge this gap (Amankwah-Amoah 2015; Muazu *et al*. 2023). Despite the progress made in renewable energy consumption, several challenges persist. Limited access to energy remains a significant barrier in Africa (Mohammed *et al*. 2013). The high upfront costs and perceived risks associated with these projects often deter investors. However, initiatives like the African Renewable Energy Initiative (AREI) and the Green Climate Fund aim to mobilize for renewable energy development in the region. This paper is to investigate the renewable energy consumption and production trends in Africa over decades.

3. Theoretical and Empirical Review

This literature review involves gathering information from published academic papers, reports, and other relevant literature sources in order gain insights into previous studies conducted on renewable energy consumption and production in Africa. However, to provide a comprehensive review of the literature on some relevant literature on renewable energy consumption and or production in Africa, we will explore various studies, research papers, and reports related to this topic as summarized in Table 1. The empirical investigation of the relationship between energy produced, used, carbon emission and economic growth is based on four hypotheses: growth, conservation, feedback, and neutrality. Starting with the growth hypothesis, it postulates that energy consumption exerts both direct and indirect influences on economic growth, with energy serving as a direct input into the economy's production process (Maji *et al.* 2019). As a result, higher energy consumption stimulates economic growth. In the industrial process, energy indirectly augments capital and labor inputs, enhancing productivity and economic growth. This hypothesis holds that there is a one-way causal relationship between energy use and economic growth (Azam *et al.* 2021).

Energy conservation regulations have a detrimental influence on economic growth when this occurs. Second hypothesis, economic development is unidirectionally linked to energy used or produced, according to the conservation hypothesis (Hung-Pin 2014) Energy consumption or production according to this theory, may not have a negative impact on economic growth (Ferwerda *et al*. 2015). Finally, the feedback hypothesis proposes a bidirectional causal relationship between energy use and economic growth (Odugbesan & Rjoub 2020). As a result, the two are mutually dependent and beneficial. On the one hand, economic expansion is driven by energy consumption. On the other hand, rising economic expansion drives more energy consumption. Finally, the neutrality theory can explain the connection: That there is no causal association between energy use and economic progress in this exceptional scenario (Alege *et al.* 2018). According to this rationale, energy used or produced contributes so little to overall output that it has little or no effect on economic growth. The summary of the reviewed literature based on Environmental Kuznets Curve theory (non-GIS) are in Table 1:

Table 1: Summary of some non-GIS approaches literature review source from academic database

Author(s)/Year	Data Range	Region(s)	Methodology	Variables	Key Findings
Eggoh *et al*. 2011.	1970-2006.	21 African countries	DOLS & PMG	GDP & TEC	TEC cause GDP.
Maji *et al.* 2019.	1995-2014.	15 African Countries	DOLS, FMOLS & OLS	GDP, REC & BIO	TEC↔GDP
Kouton 2021.	1991-2015.	Sub-Sahara Africa	Cointegration & DOLS	REC & GDP	REC↔ GDP.
Kouton 2021.	1991-2015.	44 sub-Saharan African Countries	DOLS	REC & inclusive GDP	REC↔ inclusive GDP.
Apergis & Payne 2011.	1990-2007.	17 Emerging economies	Cointegration tests & FMOLS	REC, NREC & GDP	REC↔ GDP.
Shahbaz *et al.* 2020.	1980-2018.	South Africa	Non-linear autoregressive		EC→GDP.
Aneja *et al.* 2017	1990-2012.	West African Countries	Distributed lag	PET, ELC & GDP	GDP→ELC
Nyoni & Phiri 2020.	1990-2007.	25 OECD Countries	Causality test	REC, NREC & GDP	REC↔ GDP

Overall, a combination of primary and secondary data collection methods, along with remote sensing techniques, field surveys, and literature reviews, can provide a comprehensive dataset for GIS-based trend analysis on renewable energy consumption and production in Africa. GIS-based trend analysis is a method used in geographic information systems (GIS) to identify and analyze patterns and trends in spatial data. It involves the use of various analytical techniques to uncover relationships and changes in geographical phenomena over time. This approach is widely used in fields such as urban planning, environmental management, transportation, and public health and Sciences. Renewable energy has gained significant attention worldwide due to its potential to mitigate climate change and provide sustainable energy solutions. In Africa, where access to electricity is limited in many regions, renewable energy resources offer a promising alternative. Geographic Information Systems (GIS) have emerged as a valuable tool for analyzing trends in renewable energy consumption and production in Africa. This literature review aims to explore the research conducted on GIS-based trend analysis of renewable energy consumption and production in Africa, focusing on the most authoritative and credible academic journals, and other sources.

3.1. *GIS-based review*

The research review literature on GIS-based trend analysis on renewable energy production and consumption in Africa. This entails analyzing trends in renewable energy generation and consumption across the African continent using Geographic Information System (GIS) technology and the method identifies geographical locations with a high potential for renewable energy development, as well as areas where renewable energy is already created and used. Aly *et al.* (2017) used GIS-based modeling approaches to examine the potential for solar energy generation in Tanzania. According to the report four optimal locations were identified for Concentrated Solar Power (CSP) and Photovoltaic (PV) installations, offering valuable guidance for future renewable energy projects in Tanzania. Ayodele *et al.* (2021) used GIS to assess the potential for wind energy generation in Nigeria. According to the study, various places in the country have considerable wind energy potential. A third study is being conducted. Ayele (2020) conducted a third study that employed GIS to assess the potential for hydropower generation in Ethiopia. The study discovered that the country has 20 potential hydropower project sites, helping energy industry decision-makers optimize renewable energy deployment. The methods given could be applied to Ethiopia's hydropower potential, lowering its fossil fuel dependence. A fourth study by Merem *et al.* (2018) studied maps of renewable energy use and distribution spatially using GIS and descriptive data. Electricity demand and generation capacity change, and GIS mappings illustrate a gradual distribution of renewable energy across the country to increase energy security and access in Ghana. Furthermore, Janke (2010) discovered that GIS-based approach can be utilized to evaluate the potential of renewable energy sources like solar, wind, and hydroelectric power. The author also provided evidence that geographic information systems (GIS) can be used to locate places with high solar radiation and wind speeds, which are favorable for solar and wind power generation, respectively. Furthermore, Mentis *et al.* (2015) optimizes electrification schemes using GIS and least-cost technology planning of renewable energy in Nigeria. The approach determines the best grid extension, mini-grid, and off-grid mix for Nigeria based on population density, infrastructure, economic activity, and technological prices. The analysis reveals that grid extension is the most cost-effective choice for 86% of the newly electrified population by 2030, whereas rural locations with low population densities benefit more from mini-grid or stand-alone solutions using solar, wind, and hydro technologies. Furthermore, Yushchenko *et al.* (2018) investigated the application of GIS in assessing the solar electricity potentials in Africa. According to the findings suggest solar deployment sites in ECOWAS and integrate grid expansion and off-grid electrification initiatives. Finally, Amador and Domínguez (2005) investigated the use of geographic information systems (GIS) in analyzing the influence of renewable energy on rural development. Overall, these studies emphasize the significance of employing GIS-based analysis to discover potential for renewable energy growth. Researchers and policymakers may acquire a more comprehensive understanding of the energy renewable energy landscape and build tailored strategies for supporting sustainable energy development by using the capabilities of GIS technology.

GIS has been used to identify regions with restricted access to electricity and to assess the potential of renewable energy to improve rural livelihoods, according to the above authors. These approaches focused on locating places with significant renewable energy potential as well as limited access to electricity, with no regard for economic and environmental effects, as well as statistical model construction and assessment. The research would focus on both the GIS-based and analytical approaches to have more insight on renewable energy production and consumptions as well as its relationship with environmental and economic effects if any.

4. Data and Methodology

To conduct this study, we used a combination of GIS software and statistical tools to analyze data on renewable energy generation and consumption in Africa. To conduct GIS-based trend analysis on renewable energy consumption and production in Africa, a wide range of data sources of socioeconomic indicators, and energy consumption and production statistics. Open-source programming software such as R and Python were utilized to process and analyze these datasets. The choice of GIS method is to allow the research to get valuable insights into the current trends of renewable energy consumption and production in Africa (Longley *et al.* 2015). One of the key advantages of GIS-based trend analysis is its ability to integrate different types of data, including spatial and attribute data, to provide a comprehensive understanding of trends. By overlaying different layers of data, analysts can identify spatial patterns and relationships that may not be apparent when examining individual datasets separately (Fotheringham 2000; O'Sullivan & Unwin 2010; Longley *et al.* 2015). In addition, Regression analysis is added as a technique to examine the relationship between a dependent variable and one or more independent variables. This would help the research to identify factors that contribute to spatial patterns or trends and the relationships between the economic and environmental variables.

4.1. *Data collection method and research variables*

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4.1 *Data analysis and methods*

The World Bank database, the International Renewable Energy Agency (IRENA), the International Energy Agency (IEA), national energy agencies, the International Hydropower Association (www.hydropower.org), the World Bank - Africa Energy Portal (www.africa-energy-portal.org), the African Development Bank Group (www.afdb.org), and their reports were used to compile data for 54 African countries for the 1990–2020 period. Total Annual Primary Energy Consumption (PEC), Total Annual Primary Energy Production (PEP), Total Annual Carbon Dioxide Emission (CO2_EM), Gross Domestic Product (GDP), Gross Domestic Product Per Capital (GDP_PC), and Total Annual Renewable Energy Consumption (REC) and Production (REP) were the variables. Table 2 summarizes the variables.

Pooled Model used with panel African renewable energy data to examine the relationships between some variables in Table 2. In favor of a solitary focus on interindividual dependencies, it disregards the passage of time and individual qualities (Hurlin 2004; Gonzalez *et al.* 2021). On the other hand, exogeneity is required by simple OLS, which prohibits any correlation between the exogenous variables and any unobserved independent factors (Hurlin 2004; Berry 1994).

To further examine how REP and REC may affect the economy of African countries, the following functions are estimated:

GDP = *f* (REP, REC, HDI, CO2_EM, GDP_PC)

CO2_EM = *f* (REP, REC, GDP, HDI, GDP_PC)

Table 2: Variables summary

Variable	Description	Unit of Measurement
CO2_EM	Total Annual Carbon Dioxide Emission	Tons/year
GDP	Gross Domestic Product	USD/year
GDP_PC	Gross Domestic Product Per Capital	USD/person
PEC	Total Annual Primary Energy Consumption	GW/year
REC	Total Annual Renewable Energy Consumption	GW/year
REP	Total Annual Renewable Energy Production	GW/year
HDI	Human Development Index	Dimensionless index ranging from 0 to 1,
TREP	Total Renewable Energy Production	TW/year
TREC	Total Renewable Energy Consumption	TW/year

5. Discussion of Results

The results of GIS-mapping reveal trend changes and evolution of REP, REC, CO2_EM and GDP over decades are shown in the figures below:

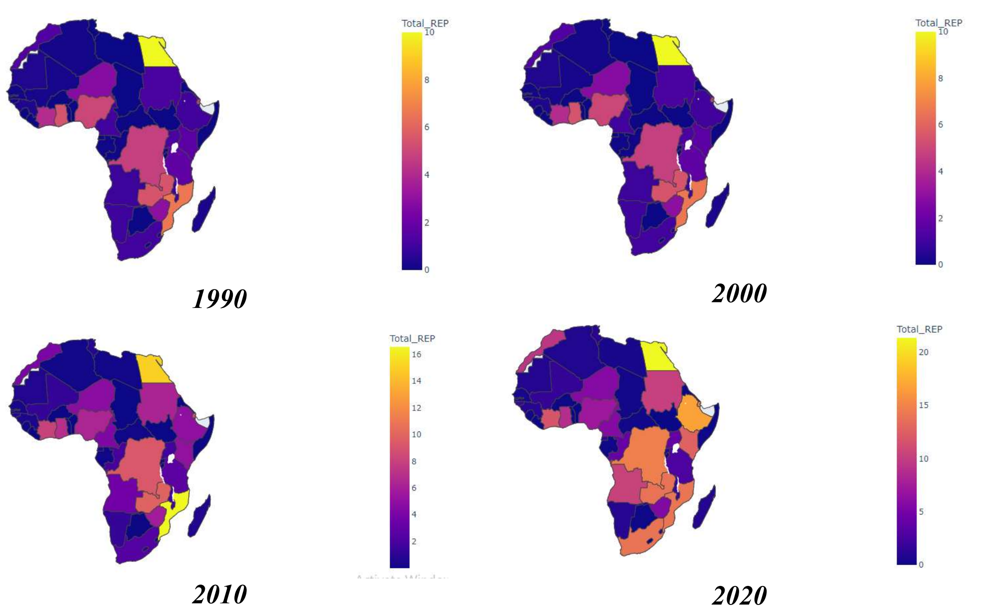

Figure 1: GIS mapping for REP trend 1990-2020

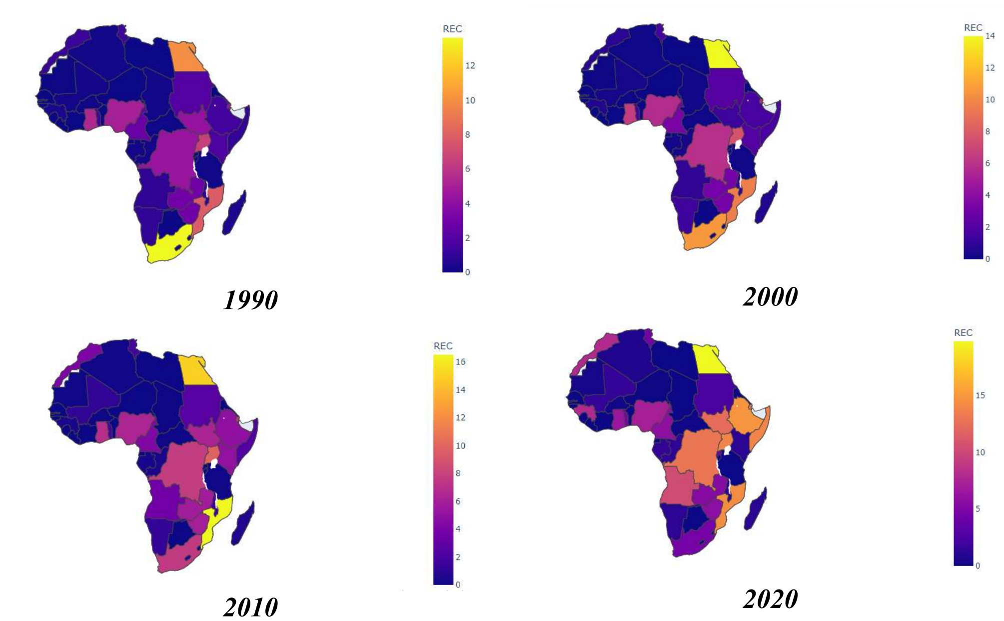

Figure 2: GIS mapping for REC trend 1990-2020

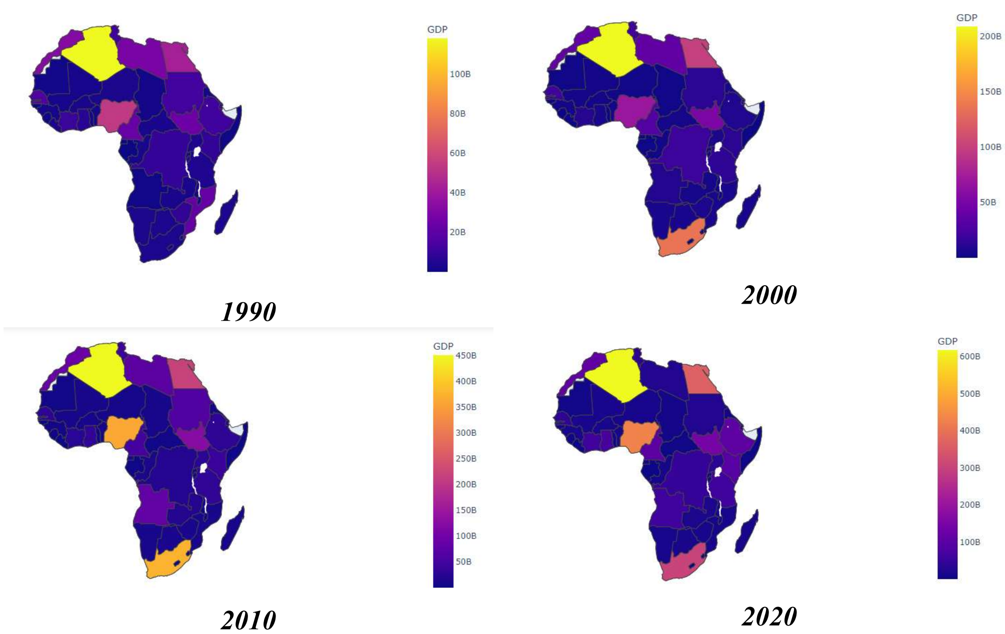

Figure 3: GIS mapping for GDP trend 1990-2020

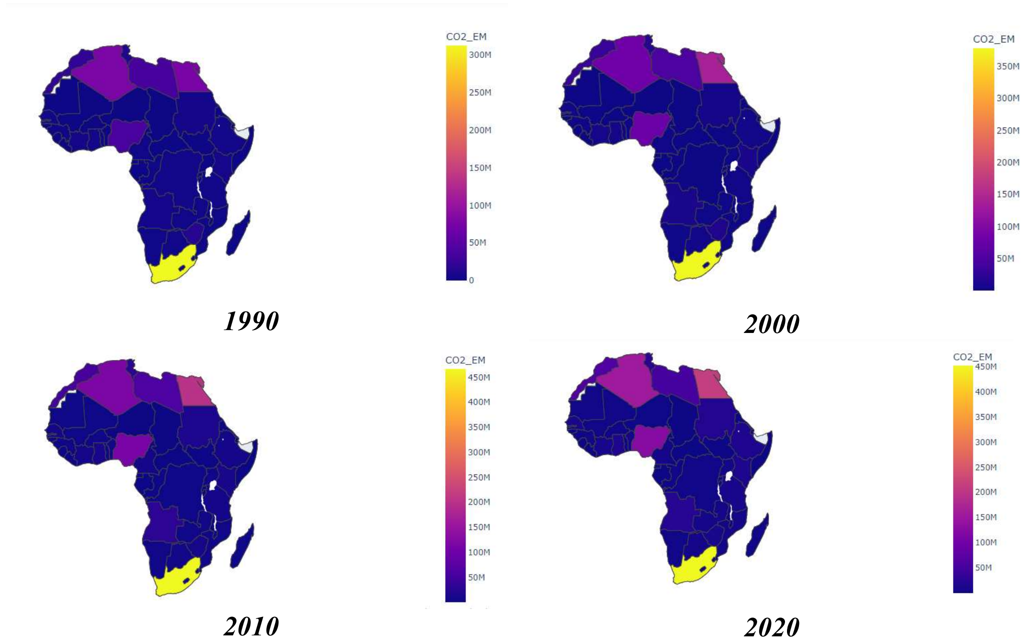

Figure 4: GIS mapping for CO2_EM trend 1990-2020

Figure 1 shows that there is a significant variation in renewable energy production across different countries in Africa over the four decades. In 1990 as a base map, Egypt, South Africa, and Morocco are the leading countries in renewable energy consumption. Egypt, South Africa, and Morocco are the leading countries in renewable energy consumption, while many other countries are still heavily dependent on fossil fuels. Figure 2 show that Countries such as Egypt, Democratic Republic of Congo, Ghana, Kenya, Sudan, Angola, Namibia, Mauritania, Seychelles, Cape Verde, and Gabon are the first fifteen African countries with the higher total REP in 2020. Figure 2 shows map with different shades or colors to represent African REC data values for various specific geographic countries. One can visually depict patterns and variations in data across different locations from the four maps particularly in the recent year 2020. Egypt has the highest REC in 2000, 2010 and 2020 the race of REC in the region. Figure 3 show Algeria maintained the highest GDP in1990, 2000, 2010 and 2020 the race of GDP in the region followed by Nigeria and South Africa and Egypt. Figure 4 shows that South Africa maintained the highest CO2_EM in the area in 1990, 2000, 2010, and 2020, followed by Nigeria, South Africa, and Egypt.

Interpreting maps for trend analysis and analyzing these elements, one can gain valuable insights into trends and variations in the REP, GDP, REC, and CO2_EM represented on the maps. Figure 5 are the dot graphs illustrate the distribution of REP, REC, GDP, and CO2_EM, dated 1990-2020 for African countries. Figure 5 showed that there has been a significant increase in renewable energy generation in Africa over the past decade. Solar and wind energy are the most used sources of renewable energy, with hydroelectric power also being widely used in some countries. The study also revealed that there is a growing trend towards the use of off-grid renewable energy systems in African countries as we can observed from Figure 5 above. Figure 6 and 7 appeared in the appendix indicates the countries with the highest total CO2 EM and Total REP respectively over the period of 1990-2020.

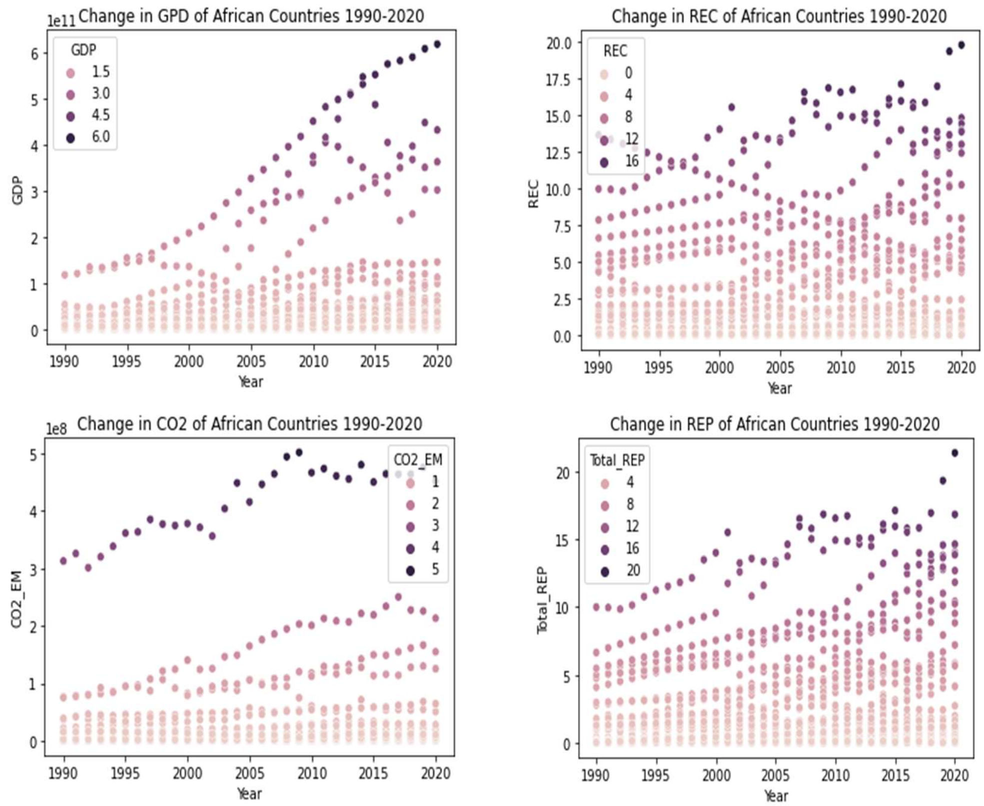

Figure 5: Dot graph for African countries data (REP, REC, GDP & CO2_EM over Years)

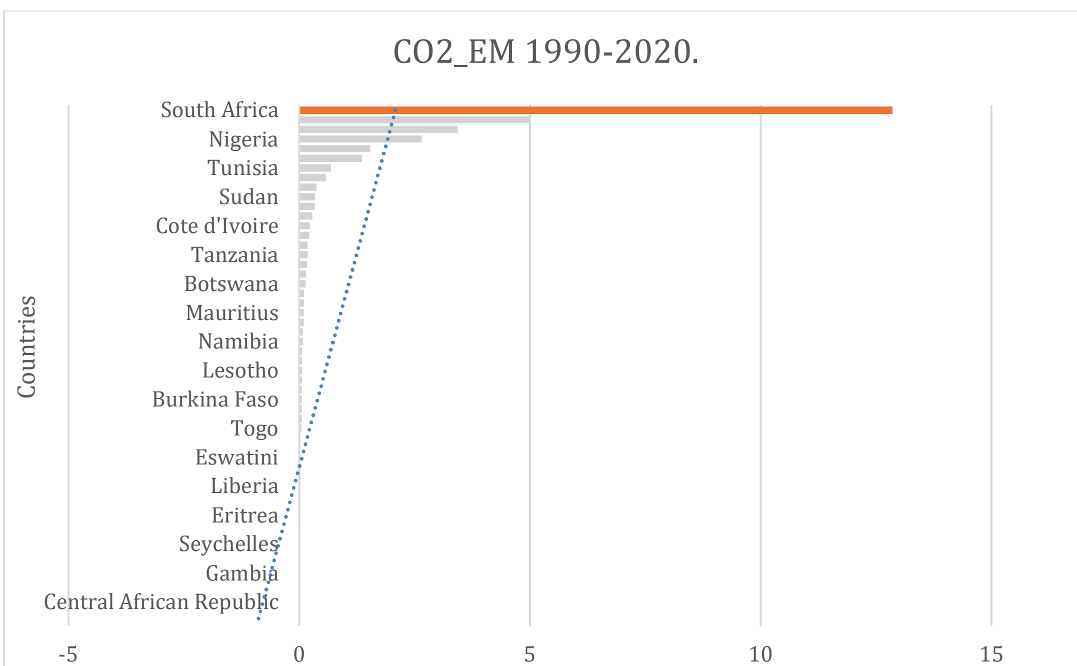

Figure 6: Plots of most highly CO2_EM for African countries

The GIS-based trend analysis using choropleth maps provided oversimplify complex African renewable energy data of 57 African Countries with the study features and this may not provide a complete understanding of underlying factors or causal relationships. Therefore, it is important to complement the maps with additional data sources and analytical methods for a more comprehensive analysis and traditional x,y coordinates visual method for sorting top 20 countries for total CO2_EM and Total REP (TREP) for the period of 1990 to 2020 as in Figure 6 and Figure 7.

Figure 6 show South Africa is the country with highest total CO2_EM followed by Nigeria and then Tunisia in the continent and this in contrary to TREP in Figure 7 that indicated Egypt as the highest country that produced renewable energy within 1990-2020 interval. Zambia is the second highest TREP producer in Africa. Ghana, Zimbabwe, Ethiopia Sudan, South Africa, and Morocco are among the top TREP producers.

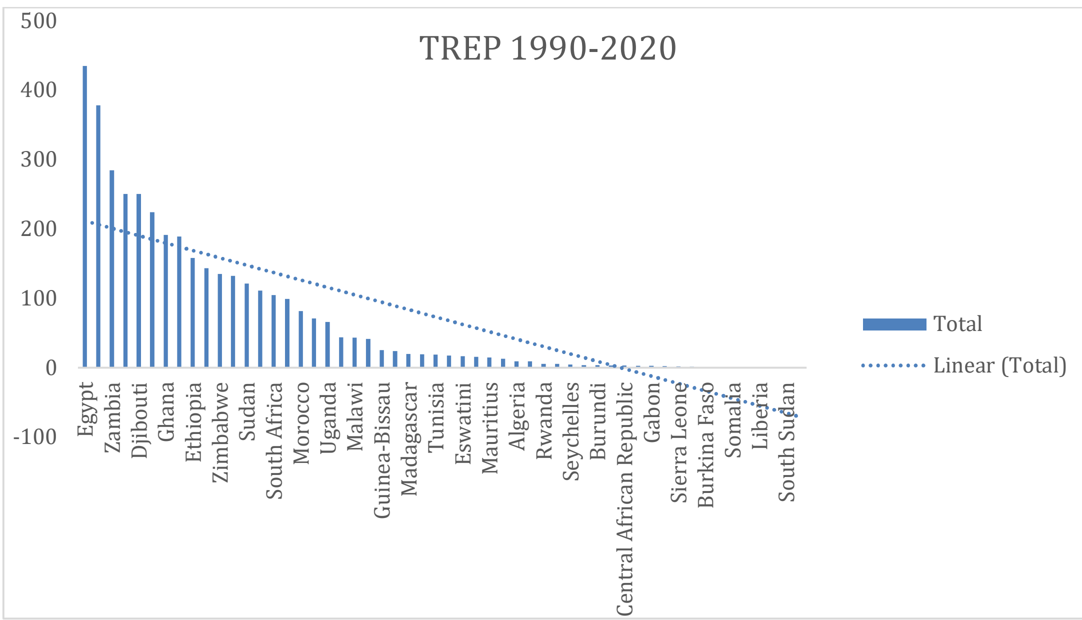

Figure 7: Plots of most highly Total REP for African countries

The study employed Pooled-Ordinary-Least-Square-Regression-Model tag as Pooled-OLSRM to analyses the relationships between the variables involved with special attention to GDP and CO2_EM as dependent Variables in the two main relationships established and the results of the established equations is presented in Table 3:

Table 3: Estimate of model coefficients and p-values

Variable	Dependent variable: GDP		Dependent variable: CO2_EM	
	Coefficient	p-value	Coefficient	p-value
Constant	-2.932e -16	1.0000	-2.374e-17	1.0000
REP	0.1462	0.0000***	-0.1925	0.0000***
REC	-0.0651	0.0260**	0.3491	0.0000***
CO2_EM	0.6799	0.0000***	-	-
HDI	-	-	0.0023	0.8920
GDP	-	-	0.6258	0.0000***
GDP_PC	-	-	0.3491	0.9330

Note: *** for $p < 0.01$, ** for $p < 0.05$, * for $p < 0.1$, respectively. The critical values of the test at 10%, 5% and 1% levels of significance

Table 4: Estimate of models' diagnostics and ICs

Indicator	Dependent variable: GDP	Dependent variable: CO2_EM
R-squared	0.485	0.526
Adj. R-squared:	0.484	0.524
F-statistic	523.2	369.6
Prob (F-statistic)	1.15e-239	5.60e-267
Log-Likelihood	-1820.2	-1750.7
AIC	3648	3513.0
BIC	3670	3546.0
Jarque-Bera (JB):	77874.348	42944.560
Prob (JB)	0.0000	0.000
Cond. No.	3.15	2.91

6. Conclusion

Renewable energy has emerged as a vital solution to the African continent's growing energy demands and environmental issues. This research provides a comprehensive GIS-based trend analysis to ascertain Renewable energy has emerged as a vital solution to the African continent's growing energy demands and environmental issues. This study gives a basic GIS-based trend analysis of renewable energy consumption and production patterns in Africa over three decades. The GIS-based trend analysis provides valuable insights into the status and prospects of renewable energy generation and consumption in Africa. By leveraging GIS technology and statistical tools, policymakers and investors can make informed decisions about renewable energy and contribute to sustainable development in Africa.

The results of this study highlight the importance of investing in renewable energy infrastructure to meet the increasing demand for electricity while also reducing greenhouse gas emissions. There was a mismatch between the renewable energy consumed and that produced in some circumstances. While REP, REC, and GDP have all expanded considerably across the continent in recent years. The researchers also created two models and discovered a significant growth relationship between Renewable Energy Production (REP) and GDP, as well as feedback relationships between GDP and CO2_EM. REC reduces GDP whereas REP reduces environmental deterioration. The quality of the train models was evaluated through a goodness-of-fit assessment. Residual plots confirm the presence of heterogeneity. The study also revealed important trends, regional differences for sustainable energy planning. Examine the trends in renewable energy consumption and production in Africa for sustainable energy planning. We advocate for increased data collection and analysis, as GIS statistical analysis still necessitates a higher focus on statistics, such as the examination of surrounding interactions between entities and effects using spatial models.

This GIS-based trend analysis contributes to the growing body of knowledge on renewable energy utilization in Africa and provides valuable insights for shaping sustainable energy strategies in the continent's pursuit of economic growth and environmental protection. While significant progress has been made in studying renewable energy production using pooled OLSRM and GIS-based analysis in Africa, there are still areas that require further exploration. Especially in statistical model development and quality assessment. Future research could focus on refining models by incorporating additional variables or exploring alternative econometric and statistical approaches. Additionally, spatial analysis by assessing the environmental and economic impacts of renewable energy production and consumption using GIS-based tools can contribute to sustainable development practice in the region.

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