Economic and Geopolitical Drivers of Renewable Energy in Sub-Saharan Africa: A Panel Data Analysis

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Highlights

- We explore gaps in renewable energy research in Sub-Saharan Africa, focusing on geopolitical risks and economic policy instruments.
- Our study highlights the significant progress made by African countries in enhancing renewable energy capacity and examines the role of government effectiveness and electricity access in urban areas.
- Findings reveal that higher government effectiveness and improved electricity access are positively associated with increased renewable energy production.
- We emphasize the importance of robust frameworks and policy instruments to catalyze private investments and foster sustainable growth in the renewable energy sector.

Abstract

This paper aims to explore the gaps in previous research on renewable energy development in Sub-Saharan Africa by examining the impact of geopolitical risks and specific economic policy instruments. The study focuses on the multifaceted factors influencing renewable energy expansion, highlighting the significant progress made by African countries in enhancing their renewable energy capacity. The research employs panel data analysis to investigate the detailed geopolitical and financial factors affecting renewable energy development to understand their impact on the maturity of SSA renewable energy markets. We also examine the role of government effectiveness, financial management, and electricity access in urban areas in promoting renewable energy production. Our findings reveal that higher government effectiveness and improved electricity access in urban areas are positively associated with increased renewable energy production. The positive impact of the gross debt ratio underscores the crucial role of government spending in supporting renewable energy projects. Conversely, lower political stability and regulatory quality are linked to decreased renewable energy production, emphasizing the need for a stable and well-regulated environment. The negative impact of electricity access highlights the necessity for targeted policies to improve energy distribution networks and support renewable energy initiatives. The study concludes by underscoring the importance of robust frameworks and a broad range of policy instruments to catalyze private investments and foster sustainable growth in the renewable energy sector.

Economic Policy; Panel Data Analysis; Renewable Energy; Sub-Saharan Africa; Geopolitical Risks

1 Introduction

Many countries, particularly those with advanced economies, have led the development of renewable energy development. While these nations are investing significant amounts of money in modernizing their energy ecosystems for greater development, less affluent countries are struggling to keep pace. The advancement of renewable energy could help these countries achieve greater energy sovereignty and higher levels of electricity access due to the decentralized nature of renewable energy.

Of the countries struggling to keep pace, Sub-Saharan African (SSA) ones are uniquely positioned to benefit from renewable resources as a means to meet the growing demand for energy (Sweerts et al., 2019). The region faces numerous energy challenges, such as low electricity access rates, deteriorating infrastructure, harmful cooking practices, and dependence on wood, leading to deforestation (Hancock, 2015). While the abundance of fossil fuels in Africa has long been studied, social scientists have only recently begun to study renewable energy in Africa (Hancock, 2015).

As Hancock, 2015 states its abundance of natural resources that could be used for energy (oil, natural gas, coal, sun, wind, waves, crops, and water), SSA remains the region of the world with the lowest access to electricity, leaving 621 million Africans without it, 32% of the region's population. The worst rates are recorded in rural areas, where a large percentage of Africans live.

The need to boost Africans' access to electricity, along with concerns about climate change and the growth of the renewable energy sector, has led to a concomitant increase in academic literature on renewable energy in the developing world. However, most of the published research on renewable energy has focused on technical and economic aspects, and social scientists have been slow to conduct and publish research in this area. Furthermore, of all the regions of the world, Africa is the least represented in the renewable energy literature.

Modern renewable energies, such as those obtained from the sun and wind, represent a tremendous opportunity for SSA. In addition to the electricity sector, renewable energy can be a fundamental part of Africa's structural economic transformation; it will play a crucial role as green industries with immense potential develop, reducing dependencies in various forms, including structural, technological, and single-commodity trade dependencies. Modern renewable energy can also play a central role in managing the environmental impacts of population and economic growth, especially through reduced reliance on fossil fuel-based and traditional biomass (firewood and charcoal) energy generation for heating and cooking.

SSA has particularly great potential for solar energy generation. The continent receives an average annual solar irradiation of 2,119 kilowatt-hours per square meter per year ($kWh/m/year$), and most countries in West and Southern Africa receive more than 2,100 ($kWh/m/year$) on average (IRENA, 2024). This abundance of renewable resources, along with the wide availability of land, shows a clear path for the continent's successful transition from conventional to renewable energy sources.

Figure 1: SSA Renewable share of production (%) evolution

However, the difficulty in attracting sufficient investment is a significant obstacle to the deployment of renewable energy in developing countries. Public financing in the region is insufficient to provide basic energy services and respond to the projected increase in demand, which correlates with population growth in the coming decades (Sweerts et al., 2019).

As a result, much of the African population continues to rely on unsustainable energy solutions from captive hydrocarbons for industrial applications and biofuels for domestic use. The lack of infrastructure remains one of the causes of Africa's low socioeconomic development.

For energy transitions in SSA to be successful, modern energy systems will need to include communities, farms, or public facilities that are most likely to be left behind. Energy transitions in SSA will therefore depend on international partnerships, including reliable climate financing to boost the regional use of sustainable and modern renewable energy. Understanding the main factors that hinder the development of renewable policies is key to easen development. In this paper we will study SSA as this region has particularities that make it different to other regions in the world and it is, from an energy requirement point of view, one of the regions in the world where the energy needs will grow more in all the world (doubling the needs in 2030 IRENA, 2015, FACT in 2050).

It is also true that it is a region where the main solar/wind resources are located, with a great potential for generation. But it also has big issues that have to be addressed: corruption, regulatory difficulty and above all, conflict. Therefore, and due to the particularities mentioned and the great economic potential, a specific analysis is required to understand why countries that have developed renewable energy have succeeded whilst others have failed.

In order to understand the effect of the main economic and geopolitical factors, a panel data model has been developed. Panel data analysis is used to understand on individual behavior for each of the countries in the data set, and is used widely in econometrics to analyze effects such as income dynamics, currency exchange rates or GDP evolution in different countries. In this paper, we will analyze the evolution of the share of renewable energy in the countries energy pool. Even though the nexus between development and renewable energy has been established (Wang et al., 2022), SSA countries have not been studied intensively. When they have been studied, geopolitical factors are not generally included in the analysis, leaving out main driving forces that alter these countries. This paper studies the renewable energy development in 37 SSA countries for the period 2002 to 2020.

2 Literature review

Current state-of-the-art research have used panel data to study the development of renewable energies in SSA and the interconnection with non-renewable evolution. As an example Vural, 2020 studies the relation between growth and the development of both and Inglesi-Lotz and Dogan, 2018 to the CO2 emissions. From a more economic perspective, Barkat et al., 2023 study the effects of remittances on energy poverty with a wider population of developing countries which includes SSA countries, and prove that enhanced financial development improves energy access in low income countries. Building on the existing research, Elabbas et al., 2023 highlights the role of regional power pools in Africa as crucial development tools, despite their unrepresentative and under-researched dynamics in evolution and market design. The development of five African power pools aims to integrate the continent into a single electricity market, enhancing energy access and reliability. Additionally, Mukoro et al., 2021 provides a comprehensive literature review on the life cycle assessments of renewable energy in Africa, offering an in-depth analysis of environmental issues specific to the continent's renewable energy sector. This study systematically evaluates the state-of-the-art, environmental impacts, methodological choices, and compares findings with other regions. Furthermore, Brinkerink et al., 2024 introduces a global electricity transmission database, which is essential for energy system modeling, facilitating better planning and integration of renewable energy sources into the global grid. We will now explore the economic and geopolitical factors influencing renewable energy development and assess their alignment with existing literature.

2.0.1 Economic factors and renewable energy

The relationship between renewable energy production and economic factors is multifaceted and influenced by various elements, as highlighted in several studies. Private investment in renewables in Africa is crucial for advancing sustainable energy solutions, as discussed by Baumli and Jamasb, 2020. Sweerts et al., 2019 emphasize the significant impact of financial conditions on the cost of electricity generation across different technologies in 46 African countries, revealing that current financial practices often disadvantage renewables. By lowering financing costs, the deployment of renewable energy can be significantly increased. Ngouhouo and Nchofoung, 2021 and Cheng et al., 2024 explore economic resilience, with Ngouhouo Ngouhouo and Nchofoung, 2021 on SSA and Cheng et al., 2024 examining China's economic zones, both highlighting the importance of economic stability for renewable energy adoption. Zeqiraj et al., 2020 underscores the role of renewable energy production in enhancing the low-carbon economy (LCE), noting that while stock market development may hinder LCE in the long run, renewable energy consumption and production are vital for a sustainable future. Wu and Broadstock, 2015 further supports this by demonstrating that both income and financial development in emerging markets promote renewable energy consumption, with long-term financial development having a greater impact than short-term measures. Collectively, these studies illustrate the critical interplay between economic factors and the advancement of renewable energy production, underscoring the need for supportive financial and economic policies to foster a sustainable energy transition. Sahlian et al., 2021 analyzed the EU-28 and found that renewable energy positively influences economic growth measured as **GDP** by reducing greenhouse gas emissions and maintaining economic stability. In contrast, Szustak et al., 2021 observed that the correlation between energy production and GDP is inconsistent across European countries, suggesting that the relationship may be random. Akintande et al., 2020 focused on Africa's most populous nations and identified key determinants of renewable energy consumption, emphasizing the role of economic and environmental factors. Tudor and Sova, 2021 provided a global perspective, highlighting that GDP per capita and carbon intensity impact renewable energy consumption, with notable differences across income levels. These studies collectively underscore the complex and multifaceted nature of the relationship between GDP and renewable energy development, influenced by regional, economic, and environmental factors. According to Obuobi et al., 2022, renewable energy demand positively impacts **revenue** in West African economies, while financial reforms and foreign direct investments also play significant roles in enhancing environmental quality. Mohsin et al., 2022 highlight the importance of technological progress and renewable energy deployment in driving green economic growth. Furthermore, Nyantakyi et al., 2023 emphasize the role of economic growth, environmental taxes, and financial development in shaping renewable energy consumption patterns, noting that economic growth and environmental taxes positively influence renewable energy adoption, whereas financial development has a negative effect. These studies collectively suggest that a combination of economic growth, financial reforms, technological advancements, and environmental policies are crucial for promoting renewable energy development and achieving sustainable economic growth. Enders, 2022 discusses how energy subsidies can act as debt generators, destabilizing the countries **primary balance**, implying that fiscal policies supporting renewable energy must be carefully designed to avoid exacerbating fiscal imbalances. Burger, 2024 examines the sustainability of South African fiscal policy, underscoring the importance of aligning public debt management strategies with fiscal sustainability goals, which is crucial for supporting long-term investments in renewable energy. Woldu and Kanó, 2024 analyze the fiscal sustainability in SSA countries, highlighting that fiscal policy follows a debt-stabilizing rule at low to moderate debt levels but weakens when the debt-to-GDP ratio exceeds 55%. This suggests that primary surplus alone is insufficient to contain debt beyond this threshold, emphasizing the need for prudent fiscal management and targeted investments. Together, these studies suggest that while primary balance is a critical component of fiscal health, effective renewable development requires integrated fiscal and energy policies that promote sustainable investments without compromising fiscal stability. Onuoha et al., 2023a explore the impact of public **gross debt** on renewable energy consumption in Sub-Saharan Africa, revealing that high levels of public debt can either burden or boost sustainability efforts depending on the governance quality and fiscal policies in place. Okere et al., 2023 further investigate this dynamic, emphasizing that public debt plays a crucial role in addressing energy poverty, with effective debt management being essential for fostering renewable energy adoption. Akam et al., 2021 provide insights into how external debt influences environmental sustainability, showing that while economic growth driven by debt can increase emissions, renewable energy can mitigate these effects. Finally, Onuoha et al., 2023a highlight the importance of governance quality in managing public debt to support the green transition, suggesting that well-structured fiscal policies are vital for balancing debt levels and promoting renewable energy consumption. Together, these studies underscore the need for integrated fiscal and energy policies to ensure that public debt supports rather than hinders renewable development.

2.0.2 Geopolitical risks and renewable energy

Several scholars have explored the connection between geopolitical risks and renewable energies. Conflict is a particularly important driving force in SSA, and various studies have examined its relation to renewable energy production from different perspectives. For instance, Thiak and Hira, 2024 investigate the development of electricity grids, key for renewable development, in post-conflict countries, using South Sudan as a case study. In South Sudan war has ravaged electric grids and the issues around security and policy are central to project execution. Similarly, Matallah et al., 2024 focus on Yemen to study the effects of conflict on renewable energy access, finding a positive correlation driven mainly by foreign aid. Conversely, Lomax et al., 2023 examine the risks of conflict escalation due to new renewable energy projects, highlighting the impact of foreign aid on local communities. From a econometric perspective, Ren et al., 2024 using geospatial analysis techniques found geopolitical risk is negatively associated with the conditional spatial β convergence of the renewable energy consumption, being oil price fluctuations the underlying force. Employing a nonlinear panel threshold model Ben Cheikh and Ben Zaied, 2023 found that negative geopolitical events affect the development of renewable energy based on the development level of the countries. In line with previously mentioned papers, Cai and Wu, 2021 use a time-varying parameter Bayesian vector auto regressive model to reveal that geopolitical risk increases renewable energy consumption, while renewable energy growth reduces geopolitical risk. In the study by Akintande et al., 2020 , the determinants of renewable energy consumption in Africa's five most populous nations are modeled, highlighting the importance of **political stability** factors in shaping energy policies. S. Asongu and Odhiambo, 2022 further explore this nexus in Sub-Saharan Africa, revealing that political and institutional governance negatively impact renewable energy consumption, suggesting that political stability and effective governance are crucial for fostering renewable energy adoption. Adebayo, 2022 demonstrates that political stability attracts foreign investment, which in turn compels the government to address climate issues more seriously, thereby promoting renewable energy use and mitigating environmental degradation. These studies collectively underscore that political stability not only influences the implementation of renewable energy policies but also attracts necessary investments, thereby playing a pivotal role in achieving sustainable development goals. The relationship between **liberal democracy** and renewable development is multifaceted and deeply interconnected. Vanegas Cantarero, 2020 emphasizes the importance of energy democracy in accelerating the energy transition in developing countries, highlighting that sustainable development can be achieved through inclusive and participatory energy policies. Ambole et al., 2021 further explore this concept by examining energy communities in sub-Saharan Africa, arguing that co-design and stakeholder engagement are crucial for fostering energy democracy and achieving equity and energy justice. Yang and Park, 2020) discuss the effectiveness of renewable energy aid in the context of democratic governance, suggesting that financial incentives and democratic institutions play a significant role in enhancing renewable energy outcomes. Finally, Cheng et al., 2024 identify democratic institutions as key determinants of renewable energy consumption, underscoring the importance of political structures in promoting sustainable energy practices. Together, these studies illustrate that liberal democracy not only supports the implementation of renewable energy initiatives but also ensures their effectiveness and sustainability through inclusive governance and community participation. The relationship between the **rule of law** index and renewable development is multifaceted and influenced by various factors. Muhammad and Long, 2021 highlight that stronger rule of law in Belt and Road Initiative (BRI) countries correlates with lower CO2 emissions, suggesting that effective governance can enhance environmental policies and enforcement. Similarly, Amoah et al., 2020 emphasize the role of economic well-being and economic freedom in promoting renewable energy consumption in Africa, indicating that robust legal frameworks and economic policies are crucial for sustainable energy transitions. Liu and Feng, 2023 further support this by demonstrating that national energy legislation significantly boosts renewable energy development, underscoring the importance of legal structures in facilitating green energy initiatives. Additionally, Sarkodie et al., 2020 argue that good governance, including the rule of law, is essential for attracting foreign direct investment in renewable energy, which is vital for climate change mitigation. The relationship between **electricity access** and renewable energy development is multifaceted and deeply interconnected. Sievert and Steinbuks, 2020 explore the willingness to pay for electricity access in extreme poverty in sub-Saharan Africa, highlighting the economic constraints and the potential for renewable energy solutions to bridge the gap in electricity access. Sterl et al., 2020 discuss the implementation of smart renewable electricity portfolios in West Africa, emphasizing the role of innovative energy solutions in enhancing electricity access and promoting sustainable development. Mutezo and Mulopo, 2021 review Africa's transition from fossil fuels to renewable energy, using circular economy principles to underline the importance of sustainable practices in achieving energy security and economic growth. Sarkodie and Adams, 2020 analyze the impact of electricity access on income inequality in South Africa, demonstrating how improved access to electricity can reduce economic disparities and foster inclusive growth. Together, these studies illustrate the critical role of renewable energy in improving electricity access and driving economic development in Africa. The relationship between **urban electricity access** and renewable energy development presents unique challenges and opportunities compared to general electricity access. Aboagye et al., 2021 examine the status of renewable energy resources for electricity supply in Ghana, highlighting the potential for urban areas to leverage these resources for sustainable energy solutions. Dagnachew et al., 2020 discuss the actors and governance structures involved in the transition toward universal electricity access in Sub-Saharan Africa, emphasizing the need for tailored approaches in urban settings to address specific infrastructural and policy challenges. Booysen et al., 2022 explore the pairing of electric vehicles with solar energy for sustainable informal public transport in Uganda, showcasing how urban areas can integrate renewable energy solutions to enhance mobility and reduce emissions. Blimpo et al., 2020 investigate the low household electricity uptake in Sub-Saharan Africa, noting that urban areas face distinct barriers such as higher population density and greater demand for reliable electricity. These studies collectively underscore the importance of addressing the unique factors influencing urban electricity access to effectively harness renewable energy for sustainable urban development.

As it has been previously reviewed the relationship between the development of renewable energies and economic and geopolitical factors has been studied in prior research. However, and to the best of our knowledge, few studies have integrated together economic and geopolitical factors together, missing the holistic risk perspective it can provide on renewable energy development in SSA. Consequently, in the following sections, we will examine the significance of the selected token factors, which simplify the complex array of factors influence a country's energy strategy and its transition from a fossil fuel-based economy to a renewable one.

3 Material & methods

3.1 Data

As stated in section 2 renewable development depends on a great number of factors. We have selected a set of those established in the reviewed literature to have direct correlation to renewable development.

While models, as stated by Burnham and Anderson, 2004 are simplifications of reality with various degrees of usefulness, we must strive to capture in the most comprehensive possible way the factors that might affect the renewable development. For this paper, a panel of 31 SSA countries has been selected, between the years 2002 and 2022. Regarding SSA data, datasets from African countries often lack data over certain periods, disqualifying them for panel data analysis. Consequently, economic factors have been sourced from reliable sources such as the IMF and from the World bank data project for the economic and geopolitical factors to ensure their quality. The factors are described in table 1 together with the data source for each of them. We will now examine each of the factors individually and the papers that prove their correlation to renewable energy production:

3.1.1 Descriptive analysis

This section provides a comprehensive overview of the socio-economic indicators used in the paper across the countries by first analyzing the values for the average of each of the factors and studying after their evolution. One of the key observations from 2 is the significant variation in GDP per capita, which ranges from as low as \$208 in Burundi to as high as \$12,862 in Seychelles. This disparity highlights the diverse economic landscapes and different development levels within the region. Political stability and rule of law also show considerable differences. For instance, countries like Cabo Verde and Mauritius exhibit positive scores in political stability and rule of law, indicating a relatively stable and well-governed environment throughout the analysis period. In contrast, nations such as Sudan and the Central African Republic have negative scores, reflecting permanent political instability and governance challenges. Another important aspect is the renewable energy share (RS), which varies widely among the countries. Eswatini and Namibia have high renewable energy shares, suggesting a strong commitment to sustainable energy practices and a developed infrastructure, mainly with regards to hydro power. On the other hand, countries like Chad and Nigeria have very low renewable energy shares, indicating a reliance on non-renewable energy sources. Table 2 also reveals insights into the economic performance and fiscal health of these countries. For example, Angola and Congo, Rep. have relatively high primary balances as a percentage of GDP, suggesting better fiscal management. However, countries like Burundi and Mozambique show negative primary balances, indicating fiscal deficits. Overall, the data underscores the diverse geopolitical and economic conditions across the region, with significant variations in economic performance, political stability, governance, and energy practices. These differences highlight the unique challenges and opportunities each country faces in its development journey.

The evolution of each of the countries in the panel data is precisely what can be observed in 2, where the variables have been normalized in order to be able to see their evolution. This normalization allows a comprehensive review of the variations and helps understand whether the countries are experiencing an increase or decrease their renewable share production, rule of law, political instabilities, etc. Furthermore, this approach also allows us to identify specific shocks in the data that can be traced to world events. While it is not feasible to comment on all the countries in the table, as an example, the increase in revenue in Niger in 2007 could be attributed to the signature of a US\$5 billion agreement for oil extraction in the Agadem block with China's National Petroleum Corporation. The political stability index also helps understand the conflict environment, as a dramatic decrease is observed in 2009 in Saint Tome and Principe, where a military coup d'etat was given and in 2012 in Mali, following a coup against Amadou Toumani Touré. With regards to the renewable share production, following the soaring energy needs in SSA, investment in renewable energy has also increased notably from 2012 to today. Analyzing the investments and their correlation to the renewable energy production share by region:

- In Southern Africa, 90% of investment is in South Africa, accounting most investments for solar (36%) followed by wind (34%). While overall percentage has remained low, its renewable energy pool is composed mainly of solar (58%) and wind (32%), contrasting with other hydro dependent countries.
- In Western Africa investments are more distributed, with Nigeria receiving the highest investment (21% of the total of the region), followed by Senegal (14%). Nigeria, a country with abundant renewable energy resources is annually increasing its investments to meet the growing demand of its population.

Variable	Definition	Source	Relation of factors to renewable energy
Renewable electricity output (% of total electricity output) (RS)	Share of electrity generated by renewable power plants in total electricity generated by all types of plants	World Development Indicators	
Political Stability Index (PS)	Political Stability and Absence of Violence/Terrorism measures perceptions of the likelihood of political instability and/or politically-motivated violence, including terrorism. Estimate gives the country's score on the aggregate indicator.	V-Dem Core	Akintande et al., 2020;S. Asongu and Odhiambo, 2022;Adebayo, 2022
Liberal Democracy Index (LD)	This index includes assessments of the rule of law, checks and balances, and civil liberties, in addition to the elements evaluated in the electoral democracy index.	V-Dem Core	Vanegas Cantarero, 2020; Ambole et al., 2021; Yang and Park, 2020; Chen et al., 2021
Rule of Law Index (RL)	It captures the extent to which the government complies with the law, courts are independent, laws transparent, justice accessible, corruption absent, and the bureaucracy is impartial.	V-Dem Core	Muhammad and Long, 2021;Amoah et al., 2020; Liu and Feng, 2023;Sarkodie et al., 2020
GDP (current USD)	Gross domestic product (GDP) at prices of the current reporting period, expressed in terms of current prices in USD.	WDI	Sahlian et al., 2021;Szustak et al., 2021;Akintande et al., 2020;Tudor and Sova, 2021
Electricity Access	Percentage of population with access to electricity.	WDI	Sievert and Steinbuks, 2020; Sterl et al., 2020; Mutezo and Mulopo, 2021; Sarkodie and Adams, 2020
Urban Electricty Access	Percentage of urban population with access to electricity.	WDI	Aboagye et al., 2021; Dagnachew et al., 2020; Booysen et al., 2022; Blimpo et al., 2020
Revenue (as share of GDP) (RE)	Total income that a government collects from various sources, such as taxes, social contributions, and other revenues, measured as a proportion of the country's Gross Domestic Product (GDP). This ratio helps to understand the scale of government revenue relative to the overall economic output of the country.	WDI	Obuobi et al., 2022; Mohsin et al., 2022; Nyantakyi et al., 2023
Primary Balance (as share of GDP)	Difference between the government's revenue (excluding interest payments on debt) and its non-interest expenditures, expressed as a percentage of the country's Gross Domestic Product (GDP).	WDI	Burger, 2024; Enders, 2022; Woldu and Kanó, 2024
Gross Debt (as share of GDP)	Ratio of a country's public debt to its gross domestic product	WDI	Onuoha et al., 2023b;Okere et al., 2023; Akam et al., 2021;Onuoha et al., 2023a;Dimnwobi et al., 2023

Table 1: Factors

Country	RS	PS	Lib_Dem	RL	GDP	EACC	Elec_Acc_Urban
Angola	70.485710	-0.57476190	0.12828571	-1.221904762	2850.7000	37.638095	64.13810
Burundi	87.395923	-1.64904762	0.11585714	-1.248095238	208.2510	6.547619	54.34286
Cabo Verde	11.715382	0.82285714	0.69657143	0.450952381	3158.0662	80.333333	89.71905
Cameroon	73.304895	-0.81761905	0.14990476	-1.106190476	1386.5962	55.385714	86.92381
Central African Republic	90.451150	-1.93238095	0.18561905	-1.560952381	398.3295	10.990476	25.34286
Chad	2.693326	-1.44619048	0.08890476	-1.396666667	731.7571	7.566667	25.90952
Congo, Rep.	56.445178	-0.59380952	0.09752381	-1.187142857	2439.0095	41.071429	58.26190
Côte d'Ivoire	28.323218	-1.34761905	0.30776190	-1.016666667	1806.0643	60.966667	89.32857
Equatorial Guinea	23.070803	-0.03476190	0.05500000	-1.190000000	10922.7548	65.838095	92.13810
Eswatini	94.974899	-0.23476190	0.09914286	-0.530000000	3447.5290	54.628571	75.41905
Gabon	47.110112	0.15238095	0.21252381	-0.570476190	7590.2010	85.828571	95.60000
Ghana	58.373323	0.02142857	0.62838095	0.001428571	1475.9429	67.028571	86.11905
Guinea	65.547675	-1.19809524	0.12000000	-1.319523810	742.6276	31.223810	75.19048
Kenya	79.047283	-1.20095238	0.37561905	-0.710476190	1254.1843	41.190476	72.56667
Madagascar	52.531944	-0.34476190	0.21909524	-0.687619048	450.0743	21.823810	61.25238
Mali	40.893849	-0.98714286	0.33685714	-0.552380952	686.0100	31.571429	71.31429
Mauritius	22.653011	0.89095238	0.60790476	0.866666667	8353.3500	99.409524	99.59524
Mozambique	93.357622	-0.23666667	0.28804762	-0.794761905	515.0581	20.528571	54.85238
Namibia	96.718048	0.71476190	0.54438095	0.260476190	4609.8229	46.461905	73.43333
Niger	2.116397	-0.95952381	0.40885714	-0.593333333	461.7005	14.133333	55.07143
Nigeria	25.152056	-1.91952381	0.34323810	-1.104285714	2029.6919	52.757143	84.61905
Rwanda	51.102632	-0.36142857	0.12366667	-0.290476190	604.5771	21.957143	63.36667
Senegal	12.343835	-0.17000000	0.54880952	-0.208095238	1279.2910	55.933333	85.90000
Seychelles	2.823054	0.74380952	0.43280952	0.294285714	12862.1605	98.166667	99.45714
Sierra Leone	56.907488	-0.26523810	0.34200000	-0.938095238	447.6705	17.604762	41.12381
South Africa	2.658788	-0.17952381	0.63590476	0.013809524	6422.7624	83.614286	86.67143
Sudan	56.135296	-2.12476190	0.06009524	-1.306666667	1422.5129	42.061905	71.31429
São Tomé and Principe	12.321171	0.32000000	0.55533333	-0.601904762	1332.4519	64.447619	71.47143
Tanzania	48.541102	-0.35571429	0.37890476	-0.449047619	799.8124	22.704762	53.12857
Uganda	89.176783	-0.96666667	0.23628571	-0.406190476	667.0524	22.152381	55.16190
Mean	48.5	-0.541	0.311	-0.637	2712.0	45.4	70.6
SD	33.1	0.901	0.198	0.628	3473.0	28.1	21.6
Min	0.0	-2.7	0.035	-1.85	114.0	2.7	11.9
Max	100.0	1.2	0.716	1.02	19850.0	100.0	100.0
Q1	20.0	-1.26	0.126	-1.14	568.0	18.8	56.0
Q2	47.8	-0.375	0.295	-0.7	1267.0	44.5	73.6
Q3	76.8	0.07	0.442	-0.25	3270.0	65.4	87.9

Table 2: Country data table

- In East Africa, investments between 2010 and 2020 were concentrated in countries such as Kenya (60%) and Uganda (7%). Despite their significant population growths (from 35 million in 2005 to 47 million in 2019 for Kenya, and from 27 million to 47 million for Uganda) these countries have increased their renewable energy production share in a slower pace.
- Central Africa is one of the regions which has seen less investment in renewable energy as stated by IRENA, 2024. In this region, Gabon is the country that has received the most investment (28%) in the region, followed by Angola (26%). In this two countries, even if the percentage of the energy mix hasn't changed significantly, the amount of renewable energy in terajoules (TJ) has increased from 56,000 to 60,000.

3.2 Methodology

3.2.1 Estimation methodology

To explore the research question, various reduced form equations that connect the proportion of renewable energy output in a countrys energy production pool to the various economic and geopolitical

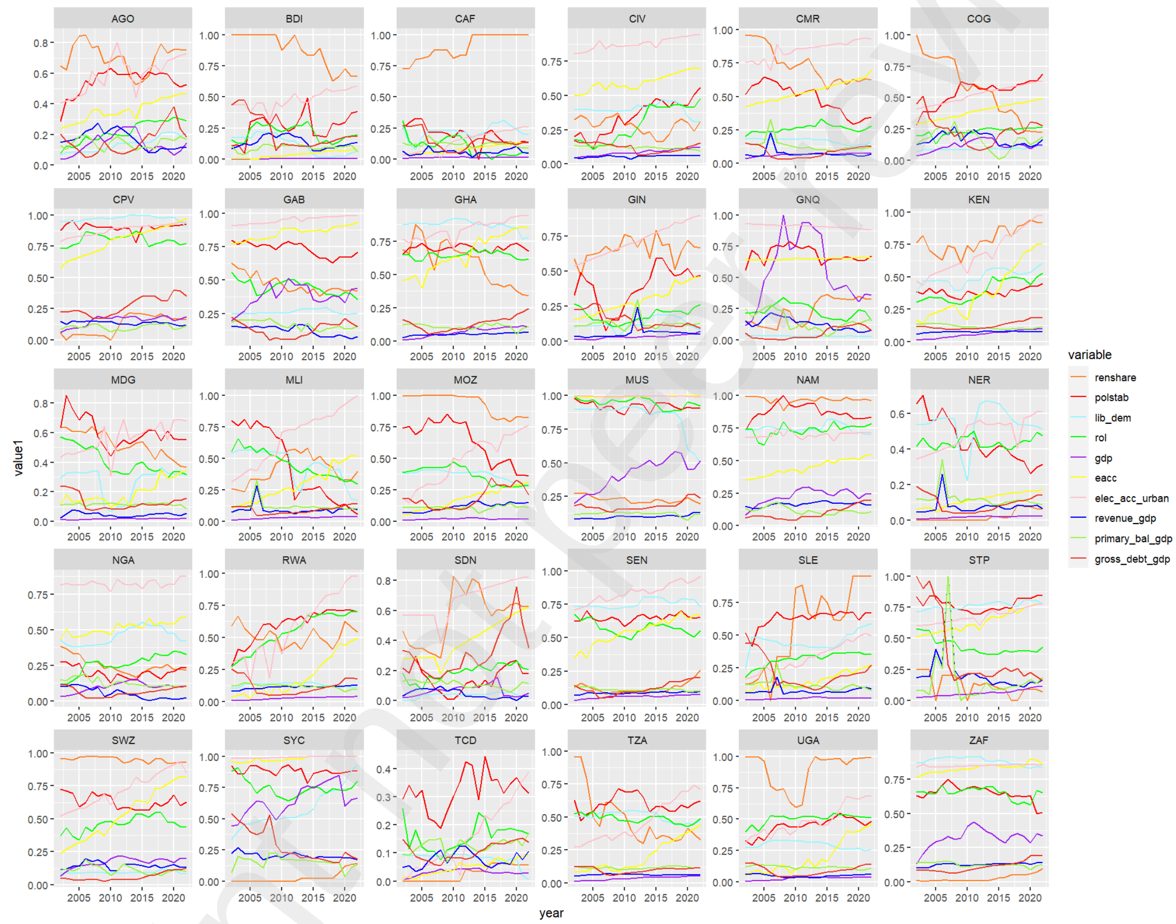

Figure 2: Evolution of the variables

factors previously described have been estimated using the approach established by Pesaran et al., 1999. In addition, following Grossman and Krueger, 1995 these equations include current or lagged GDP per capita, consequently following the model:

$$RS = f(GDP + EAC + ... + GDB + EXP)$$

The objective of using the panel data approach is finding the relationship between the factors and how each of them affect to renewable production. This will lead us to the estimation of the impact of each of the factors.

The methodology comprises several steps. Firstly, we have to identify if any cross-sectional dependence or correlation exists between the variables. In order to do so, the Pesaran, 2014 Cross-Sectional Dependence test is used. This test is a statistical method used to detect cross-sectional dependence in panel data models. This dependence occurs when the errors (residuals) of different cross-sectional units, such as countries or firms, are correlated due to common shocks or unobserved factors affecting multiple units simultaneously. In order to reject the null hypothesis the p-value must be above the common significance levels (i.e. 0.1), indicating that there is no evidence of cross-sectional dependence between the factors in the model. Following Pesaran, 2014, the following equation can be used for testing the cross-dependence hypothesis:

$$CD_{lm} = \sqrt{\frac{1}{N(N-1)}} \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} (T\rho_{ij}^2 - 1)$$

Once the cross-sectional dependence has been analyzed, the statistical Cross-sectional Im-Pesaran-Shin (CIPS) test will be applied to the data to determine whether the variables are stationary or contain a unit root, which would imply they are not stationary (Pesaran, 2014). This approach extends the traditional Im-Pesharan-Shin (IPS) test, incorporating cross-sectional averages of the dependent variable and the lagged differences to account for the cross-sectional dependence. The inclusion of fixed effects in the CIPS test helps to control for unobserved heterogeneity across cross-sections, ensuring that the results are not biased by omitted variables that are constant over time. Additionally, trend effects are incorporated to account for deterministic trends within the data, which can influence the stationarity properties of the variables. By addressing both fixed and trend effects, the CIPS test provides a more robust framework for analyzing panel data. Fixed effects, which is modeled as:

$$\triangle y_{it} = a_i + b_i y_{i,t-1} + c_i \overline{y}_{t-i} + \sum_{j=0}^{p} d_{ij} \triangle \overline{y}_{t-j} + \sum_{j=1}^{p} \delta_{ij} \triangle y_{i,t-j} + u_{it}, i = 1, ..., N; t = 1, ..., T$$

And individual time trend and fixed effects:

$$\triangle y_{it} = a_{0i} + a_{1i} t + b_i y_{i,t-1} + \sum_{j=0}^{p} d_{ij} \triangle \overline{y}_{t-j} + \sum_{j=1}^{p} \delta_{ij} \triangle y_{i,t-j} + u_{it}, i = 1, ..., N; t = 1, ..., T$$

y_{it} being the renewable generation share, t is the time trend; d_{ij} and δ_{ij} being parameters, ϵ_{it} the error term for the i cross section for time t, $\triangle$ the difference operator and $\overline{y}_t = N^{-1} \sum_{j=1}^{p} y_{jt}$.In this way the method is more reliable with panels where cross-sectional units are correlated. If the variables are found to be significant in the first level this indicates that all the variables are non-stationary in their levels but become stationary after first differencing. This transformation would suggest that the variables exhibit a unit root, implying that they follow a stochastic trend. This commonality indicates variables have a significant cointegration relationship, meaning that despite shorter term fluctuations, in the long run the variables move together:

$$CIPS(N, T) = t - bar = N^{-1} \sum_{i=1}^{N} t_i(N, T)$$

where $t_i(N, T)$ corresponds to the cross-sectionally augmented Dickey–Fuller (CADF) statistic for the i-th cross-sectional unit, given by the t-ratio of the coefficient of $y_{i,t-1}$ in the CADF regression.

Having obtained the result of the root test the existence of co-integration has to be analysed. In order to do so a panel co-integration test is used, which is a statistical method employed to determine whether a long-run equilibrium relationship exists among non-stationary time series variables in panel data. Panel data, which combines cross-sectional and time-series data, might exibit non-stationarity, meaning the variables properties change over time. The Durbin-Hausman method (Westerlund, 2007) specifically addresses the issue of endogeneity in the variables and the potential bias in estimators by comparing the consistency of different estimators. This method tests the null hypothesis that the estimators are consistent under the assumption of no cointegration against the alternative hypothesis that they are inconsistent due to the presence of cointegration.

The Durbin-Hausman test is particularly useful in panel data analysis as it allows to account for individual heterogeneity and cross-sectional dependence, which are common in economic data. By including both fixed and random effects models, this test evaluates whether the random effects or fixed effects model is appropriate. This distinction is relevant for accurate inference and policy recommendations, as it ensures that the long-run relationships among the variables are correctly identified and estimated. The related Durbin-Hausman test statistics is modeled as:

$$DH_g = \sum_{i=1}^{n} \hat{S}_i(\tilde{\phi}_i - \hat{\phi}_i)^2 \sum_{t=2}^{T} \hat{e}_{it-1}^2 \quad \text{and} \quad DH_p = \hat{S}_n(\tilde{\phi} - \hat{\phi})^2 \sum_{i=1}^{n} \sum_{t=2}^{T} \hat{e}_{it-1}^2$$

Where the two variance ratios are:

$$\hat{w}_n^2 = \frac{1}{n} \sum_{i=1}^{n} \hat{w}_i^2 \quad \text{and} \quad \hat{\sigma}_n^2 = \frac{1}{n} \sum_{i=1}^{n} \hat{\sigma}_i^2$$

Where σ^2 is the variance estimate, and S^2 are the variance ratios. DH_p, is the panel statistic and DH_g the group mean statistic. In this context, ϕ_{2i} represents the OLS estimator of ϕ_i, while ϕ_2 denotes its pooled counterpart. The corresponding and pooled instrumental variable estimators of ϕ_i, denoted as ϕ_{1i} and ϕ_1 respectively, are obtained from $\hat{e}_{it-1}$ joined with $\hat{e}_{it}$. For the panel test DH_p, the null and alternative hypotheses are expressed as $H_0 : \phi_i = \phi$ for all $i = 1, \ldots, N$ versus $H_{1p} : \phi_i = \phi$ and $\phi < 1$ for all i. Thus, in this scenario, we assume a common value for the autoregressive parameter under both the null and alternative hypotheses. Conversely, for the mean group (DH_g) test, the null hypothesis H_0 is tested against the alternative hypothesis $H_{1g} : \phi_i < 1$ for i. Here, the heterogeneous autoregressive parameter is assumed to vary across cross-sectional units. Consequently, we assume a common value for the autoregressive parameter under both the null and alternative hypotheses. Therefore, if this assumption holds true, rejecting the null hypothesis should be interpreted as evidence supporting cointegration for all n units. Finally, in order to understand the relation between the factors used to analyze the renewable share production, the Dumitrescu-Hurlin causality test (Dumitrescu and Hurlin, 2012) is used to determine if one time series can predict another. This statistic test is an extension of the Granger causality test, adapted for panel data, which consists of multiple cross-sectional units observed over time. One of the key features of the Dumitrescu-Hurlin test is its ability to handle heterogeneity across cross-sectional units. This means it allows for differences in the causal relationships between different units in the panel. Additionally, the test can manage cross-sectional dependence, which occurs when the entities in the panel are not entirely independent of each other. This is crucial for accurate analysis in real-world data where such dependencies are common.

4 Results and discussion

Following the process outlined in the methodology section we will describe the results obtained to investigate the effects of economic and geopolitical variables on the renewable energy production.

4.0.1 Correlation matrix

Additionally, we computed the correlation matrix for all variables to examine the linear relationships between them. The correlation coefficients, which range from -1 to 1, indicate the strength and direction of the linear relationship between pairs of variables. A value close to 1 or -1 signifies a strong positive or negative correlation, respectively, while a value near 0 indicates no linear relationship.

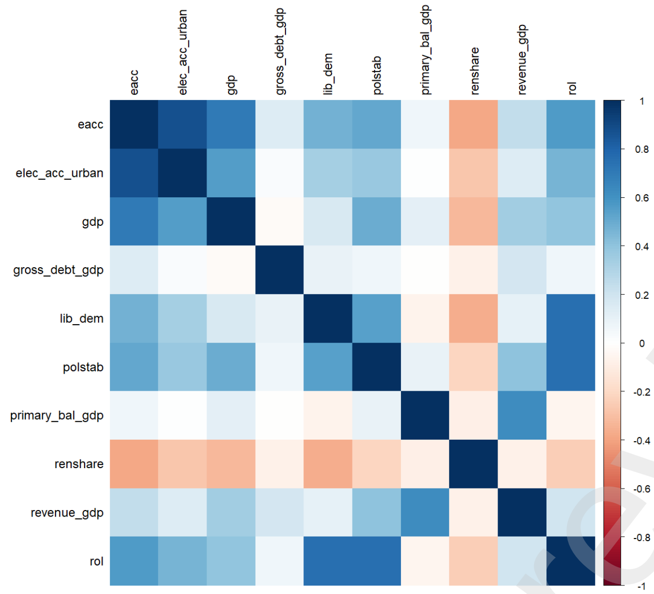

Figure 3: Enter Caption

In our analysis, we observed that electricity access and electricity access in urban environments have a correlation close to 1. This high correlation suggests that these two variables are similar in their variation across the dataset. Despite this, we included both variables in our analysis to explore if they yield different results in the panel data context of renewable production share. This approach allows us to capture any subtle differences that might exist between general electricity access and access specifically in urban areas, which could have distinct implications for renewable energy policies.

Furthermore, the variable "rule of law" is found to be highly correlated with both the liberal democracy index and the political stability index. This high correlation indicates that countries with strong rule of law tend to also have higher levels of liberal democracy and political stability. This interrelationship is crucial as it underscores the importance of a stable and democratic governance framework in fostering an environment conducive to renewable energy development.

Also, GDP shows a strong positive correlation with both electricity access and political stability. This suggests that wealthier countries tend to have better electricity access and more stable political environments. These factors are likely to create favorable conditions for the adoption and expansion of renewable energy sources. The strong correlation between GDP and electricity access highlights the role of economic development in ensuring widespread access to electricity, which is a critical component for the integration of renewable energy into the grid. This high correlations observed between certain variables reassure the interconnected nature of economic, political, and infrastructural factors in influencing renewable production share.

4.0.2 Cross-section dependency

In the model, which includes variables like political stability, liberal democracy, rule of law, GDP, and others described in section 3.1, the obtained test statistic value is -0.6604, and the p-value is 0.509. The null hypothesis for this test is that there is no cross-sectional dependence, while the alternative hypothesis is that there is cross-sectional dependence. Given the high p-value, which is above the common significance levels (0.05), our data fails to reject the null hypothesis. This indicates that there is no significant evidence of cross-sectional dependence in the panel data model. Therefore, the residuals of the model are not significantly correlated across the different cross-sectional units, suggesting that the model does not suffer from cross-sectional dependence.

4.0.3 Dumitrescu-Hurlin causality test

The Dumitrescu-Hurlin test was conducted to examine the causal relationship between renewable production share (RS) and the factors described in 3.1, in a panel dataset. The null hypothesis of the

Data	Values
Model	$log(RS)\ PS + LD + RL + lag(GDP, 1) + EA + EAU + RE + lag(PB, 1) + log(GD)$
z	-0.6604
p-value	0.509
Alternative Hypothesis	Cross-sectional dependence

Table 3: Pesaran CD Test for Cross-Sectional Dependence

test states that there is no Granger causality from (RS) to factors for any of the cross-sectional units in the panel, while the alternative hypothesis suggests that there is Granger causality for at least one cross-sectional unit.

The results indicate that there is sufficient evidence to conclude that RS Granger-causes one of the factors or vice-versa for at least one cross-sectional unit in the panel. In other words, past values of RS provide useful information for predicting future values of the factors. If the p-value had been greater than 0.05, we would not have rejected the null hypothesis, implying no evidence of Granger causality from RS to the factors in the panel data. These findings suggest that past values of RS provide useful information for predicting future values of these factors and vice versa, underscoring the interconnectedness between renewable production and these economic and political variables.

Factors	**Z-bar**	**P-Value**	**Alternative**
RS PS	1.0344663	3.009182e-01	Granger causality for at least one individual
PS RS	3.2196824	1.283327e-03	Granger causality for at least one individual
RS LD	0.3481548	7.277239e-01	Granger causality for at least one individual
LD RS	7.6128915	2.680308e-14	Granger causality for at least one individual
RS RL	3.8329676	1.266066e-04	Granger causality for at least one individual
RL RS	2.9073932	3.644548e-03	Granger causality for at least one individual
RS GDP	5.6584060	1.527854e-08	Granger causality for at least one individual
GDP RS	1.1443508	2.524782e-01	Granger causality for at least one individual
RS EA	7.6843246	1.538063e-14	Granger causality for at least one individual
EA RS	2.6282862	8.581628e-03	Granger causality for at least one individual
RS EAU	6.6869673	2.278428e-11	Granger causality for at least one individual
EAU RS	12.8845897	5.496707e-38	Granger causality for at least one individual
RS RE	1.2906606	1.968214e-01	Granger causality for at least one individual
RE RS	3.8567779	1.148915e-04	Granger causality for at least one individual
RS PB	5.8777695	4.158313e-09	Granger causality for at least one individual
PB RS	6.1842752	6.238845e-10	Granger causality for at least one individual
RS GD	4.0314542	5.543281e-05	Granger causality for at least one individual
GD RS	9.0637409	1.260516e-19	Granger causality for at least one individual

Table 4: Granger causality test results

4.0.4 CIPS

We now analyze the results of the CIPS test for the panel data used. The results from Table 5, which shows the CIPS test for unit roots across various variables, indicate mixed stationarity properties. All the factors analyzed fail to reject the null hypothesis of unit roots, suggesting they are stationary.

The results of the Pesaran CIPS Panel unit root test indicate that all the variables examined, are non-stationary at their levels but become stationary after first differencing. This suggests that these variables are integrated of order 1, $I(1)$, meaning they require differencing to achieve stationarity. The test statistics for the first differences, both with and without a trend, provide strong evidence against the null hypothesis of a unit root, confirming the stationarity of the differenced series. These findings are crucial for subsequent analyses and modeling, as they highlight the need to transform the data to ensure accurate and reliable results.

Variable	Level_Constant	Level_Constant_Trend	First_Diff_Constant	First_Diff_Constant_Trend
RS	-1.211104	-2.264973	-3.294538	-3.549453
PS	-2.236749	-2.491512	-3.289114	-3.471821
LD	-1.354236	-1.983211	-2.619152	-2.980638
RL	-1.947957	-2.075031	-2.897457	-3.219065
GDP	-1.433195	-2.461370	-2.943958	-3.093331
EA	-2.056807	-3.309476	-4.182910	-4.147596
EAU	-2.767338	-2.644607	-4.270480	-4.244675
RE	-2.015686	-2.645920	-4.154651	-4.224467
PB	-2.591268	-2.947741	-4.148712	-4.221053
GD	-1.742143	-2.703907	-3.123655	-3.137496
Integration Order: I (1)				

Table 5: Pesaran CIPS Panel unit root test results

4.0.5 Westerlund test

Consequently, we conducted the Westerlund ECM panel cointegration tests to determine the number of cointegrating relationships among the variables. The results indicate that there is no evidence of cointegration among the variables in the panel data. The tests were conducted with an average AIC-selected lag length of 0.63 and lead length of 0. The test statistics (Gt, Ga, Pt, and Pa) all have P-values of 1.000, which means that the null hypothesis of no cointegration cannot be rejected at any conventional significance level. This suggests that the variables do not share a long-term equilibrium relationship and move independently over time.

Statistic	Value	Z-value	P-value
Gt	-0.567	7.517	1.000
Ga	-1.185	6.696	1.000
Pt	-3.801	3.989	1.000
Pa	-0.735	4.030	1.000

Results for H0: no cointegration with 30 series.
Average AIC selected lag length: 0.63.
Average AIC selected lead length: 0.

After conducting the Westerlund cointegration test to identify long-term equilibrium relationships among our panel, we now determine the most appropriate model for our data. This involves deciding between a fixed effects model and a random effects model, which have been modelled in the 3.2 section.

4.0.6 Fixed effects

The fixed effects model accounts for time-invariant characteristics of the entities being studied, which in this case could be countries or regions. This model shows that several variables significantly impact renewable energy production. For instance, political stability (PS) has a negative and significant effect, indicating that higher political stability might be associated with lower renewable energy share. This could be due to stable political environments favoring established energy sectors over newer, renewable alternatives.

Liberal democracy (LD) on the other hand, has a strong positive effect, suggesting that more democratic regimes are more likely to invest in renewable energy. This aligns with the idea that democratic governments might be more responsive to public demand for sustainable energy solutions.

Electricity Access (EA) and urban electricity access (EAU) also show significant positive impacts, highlighting the importance of economic development and infrastructure in promoting renewable energy. Interestingly, Gross Domestic Product (GDP) lagged by one period has a positive effect, indicating that economic growth can lead to increased renewable energy investment, albeit with a delay.

Variable	Estimate	Std. Error	t-value	$Pr(>\|t\|)$
Political Stability	-5.2434e-01	1.7435e-01	-3.0074	0.0027532 **
Liberal Democracy	7.3959e+00	1.2964e+00	5.7050	1.884e-08 ***
Rule of Law	5.9324e-01	3.4916e-01	1.6990	0.0898674 .
GDP	1.4630e-04	4.0937e-05	3.5738	0.0003821 ***
Electricity Access	-3.5356e-02	1.0995e-02	-3.2158	0.0013757 **
Urban Electricity Access	4.3464e-02	1.0341e-02	4.2030	3.065e-05 ***
Revenue	6.8838e-04	7.1398e-03	0.0964	0.9232265
Primary Balance	1.7239e-02	7.2643e-03	2.3731	0.0179731 *
Gross Debt	3.4090e-01	1.1555e-01	2.9501	0.0033094 **
*Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1*				

Table 6: Resultados del modelo

4.0.7 Random effects

The random effects model, which assumes that individual entity characteristics are random and uncorrelated with the predictors, provides a slightly different perspective. Here, the intercept is not significant, suggesting that the baseline level of renewable energy share does not vary much across entities when accounting for the included variables.

The significance of political stability (PS) and liberal democracy (LD) remains, reinforcing their roles in influencing renewable energy production. However, the rule of law (ROL) is not significant in this model, which could imply that its impact is more nuanced and possibly intertwined with other factors not captured in this model.

The economic activity (EA) and urban electricity access (EAU) continue to show strong positive effects, consistent with the fixed effects model. This consistency underscores the robustness of these variables in promoting renewable energy.

Variable	Estimate	Std. Error	z-value	$Pr(>\|t\|)$
(Intercept)	-1.0375e+00	8.8238e-01	-1.1758	0.2396795
Political Stability	-4.2509e-01	1.7114e-01	-2.4839	0.0129962 *
Liberal Democracy	4.1097e+00	1.1198e+00	3.6701	0.0002425 ***
Rule of Law	3.1057e-01	3.3705e-01	0.9214	0.3568253
GDP	1.2730e-04	4.0128e-05	3.1723	0.0015125 **
Electricity Access	-4.0811e-02	1.0579e-02	-3.8579	0.0001144 ***
Urban Electricity Access	4.5281e-02	1.0173e-02	4.4510	8.547e-06 ***
Revenue	-1.9296e-03	7.1961e-03	-0.2681	0.7885878
Primary Balance	1.4339e-02	7.3843e-03	1.9418	0.0521607 .
Gross Debt	3.0901e-01	1.1595e-01	2.6651	0.0076966 **
*Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1*				

Table 7: Random Effects results

4.0.8 Durbin Hausman cointegration

Having tested both , we use the Durbin–Wu–Hausman test to check the consistency of our model. The test gave us a Chi-square value of 9.2154 with 9 degrees of freedom and a p-value of 0.4176. Since the p-value is above 0.1, we do not reject the null hypothesis. This means there is no significant evidence to suggest that one of the models is inconsistent. Therefore, both models appear to be consistent with the data, supporting the robustness of our model and the fact that the intercept in the random effects model is not significant.

The results of the Hausman test indicate that both the Fixed Effects and Random Effects models are equally suitable for our data. This suggests that either approach can be used, as both account for

Data	Values
Model	$log(RS)\ PS + libdem + ROL + lag(GDP, 1) + EA + elecaccurban + revenueGDP + lag(pri$
Chisq	9.2154
df	9
p-value	0.4176
Alternative Hypothesis	One model is inconsistent

Table 8: Statistical Model Summary

the correlation between the individual-specific effects and the regressor, providing an accurate representation of the underlying relationships. From the economic Sub-Saharan African analysis point of view the fixed effects model is particularly relevant. This is because it effectively controls for time-invariant characteristics specific to each entity, such as economic policies and institutional frameworks. This control ensures that the observed effects of the variables are not biased by unobserved heterogeneity, leading to more accurate and reliable estimations. Therefore, the following analyses are conducted using the fixed effects model to provide a robust understanding of the economic dynamics in the region.

4.0.9 Coeff parameters

We now visualize the coefficient parameters in the regression model with their standard error to understand the impact of each factor on renewable energy production. The regression coefficients shown in 4 provide insights into the magnitude and direction of the relationship between the dependent variable and each independent variable (factor).

Notably, as expected per the papers reviewed in the 2 section (Akintande et al., 2020 and Adebayo, 2022) variables Political Stability and Electricity Access have the most negative coefficients. This indicates that lower political stability and electricity access are associated with a decrease in renewable production share. This findings are also consistent with Dong et al., 2024, Annamalaisamy and Vepur Jayaraman, 2022 and S. A. Asongu et al., 2019.

Conversely, Liberal Democracy and Urban Electricity Access have the most positive coefficients, suggesting that higher levels of liberal democracy and urban electricity access are linked to an increase in renewable production share, as identified by Cheng et al., 2024. Although in a smaller scale, this findings match what was observed by Ambole et al., 2021 in SSA rural communities.

Primary Balance as a share of GDP has a slight positive value, indicating that a slight surplus in the government's revenue, excluding interest payments, could be due to increased public spending or reduced tax revenues, which in turn may positively impact the renewable production share. On the other hand, Gross Debt shows a significant positive value, suggesting that higher gross debt is associated with an increase in renewable production share, as stated by Enders, 2022.

Interestingly, GDP and Revenue have values close to zero, indicating that these variables do not have a significant direct impact on the renewable production share in our model. This could be because the relationship between renewable production and these factors is more complex and influenced by other mediating variables. As it was noted in the 2 section Szustak et al., 2021 observed inconsistencies for GDP relation to RS across European countries and Tudor and Sova, 2021 pointed to notable differences in correlation across different income levels.

Therefore, while primary balance and gross debt provide some insights into the fiscal conditions affecting renewable energy production, GDP and revenue may require further investigation to understand their indirect effects on renewable production share.

5 Discussion

Despite significant advancements in renewable energy development in Sub-Saharan Africa (SSA), previous research has often overlooked the impact of geopolitical risks and specific economic policy instruments. Our analysis aims to fill these gaps by examining the multifaceted factors influencing renewable energy expansion in SSA.

Our analysis highlights the remarkable progress African countries have made in expanding their renewable energy capacity. Driven by increased financial management and government effectiveness,

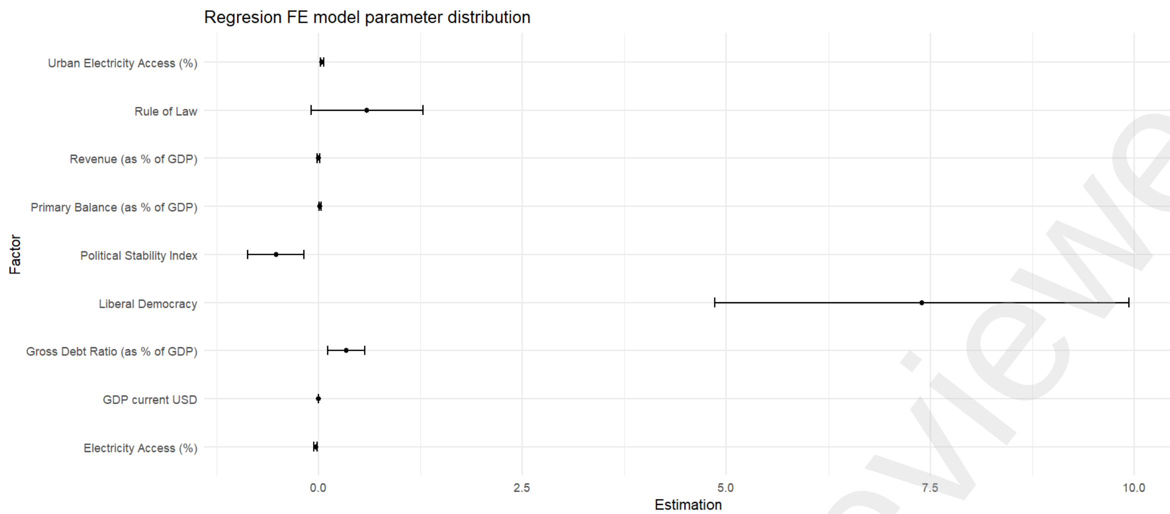

Figure 4: Enter Caption

countries have been able to meet national energy plans and announced targets. The adoption of various renewable energy policies, such as fiscal incentives, public investments, loans, grants, and regulatory policies like auctions, underscores the growing maturity of SSA renewable energy markets.

The results obtained via the panel data analysis provide valuable insights into the detailed geopolitical and financial factors influencing renewable energy development. Higher government effectiveness and improved electricity access in urban areas are positively associated with increased renewable energy production. Additionally, the positive impact of the gross debt ratio highlights the crucial role of government spending in supporting the financial resources that allow renewable energy projects. Conversely, lower political stability and regulatory quality are linked to decreased renewable energy production, emphasizing the need for a stable and well-regulated environment. The negative impact of electricity access further underscores the necessity for targeted policies to improve energy distribution networks and support renewable energy initiatives.

The regression coefficients obtained provide additional insights into the magnitude and direction of the relationship between Renewable Production Share and each factor. Notably, the variables Political Stability and Electricity Access have the most negative coefficients, indicating that lower political stability and electricity access are associated with a lower renewable production share.

Conversely, Liberal Democracy and Urban Electricity Access have the most positive coefficients, suggesting that higher levels of liberal democracy and urban electricity access are linked to an increase in renewable production share. Interestingly, GDP and Revenue have values close to zero, indicating that these variables do not have a significant direct impact on the renewable production share in our model. This could be because the relationship between renewable production and these factors is more complex and influenced by other mediating variables.

While our analysis offers significant insights, the following limitations must be noted. The study primarily relies on available data, which may not capture all nuances of the renewable energy landscape in Africa. Additionally, the dynamic nature of geopolitical risks and economic conditions can influence the outcomes, necessitating continuous monitoring and adaptation of policies.

Future research could explore the long-term impacts of renewable energy policies on socio-economic development and environmental sustainability. Investigating the effectiveness of specific policy instruments in different African contexts can provide deeper insights into best practices. Moreover, examining the role of technological innovations and private sector involvement in scaling up renewable energy projects will be key for future studies.

In conclusion, our analysis underscores it is imperative for governments, policymakers, and regulators to establish robust frameworks that catalyze private investments. Effective deployment policies should be complemented by a broad range of policy instruments designed to maximize socio-economic benefits.

Attracting both domestic and foreign investors requires targeted investment promotion measures and raising awareness among local financial institutions about the renewable energy market. Public financing can play a crucial role in reducing risk perceptions, while public-private partnerships can help share investment costs and risks. Additionally, addressing geopolitical risks through diplomatic efforts and regional cooperation is essential for creating a conducive environment for renewable energy development. Government effectiveness in managing these risks and ensuring political stability can significantly enhance the attractiveness of renewable energy projects and foster sustainable growth in the sector.

Regional cooperation will be essential for facilitating large-scale renewable energy deployment and creating economies of scale. We hope this holistic approach will contribute to a more sustainable and resilient energy future for Africa.

6 Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work the author(s) used Copilot in order to improve the readability and language of the manuscript . After using this tool/service, the authors reviewed and edited the content as needed and take full responsibility for the content of the published article.

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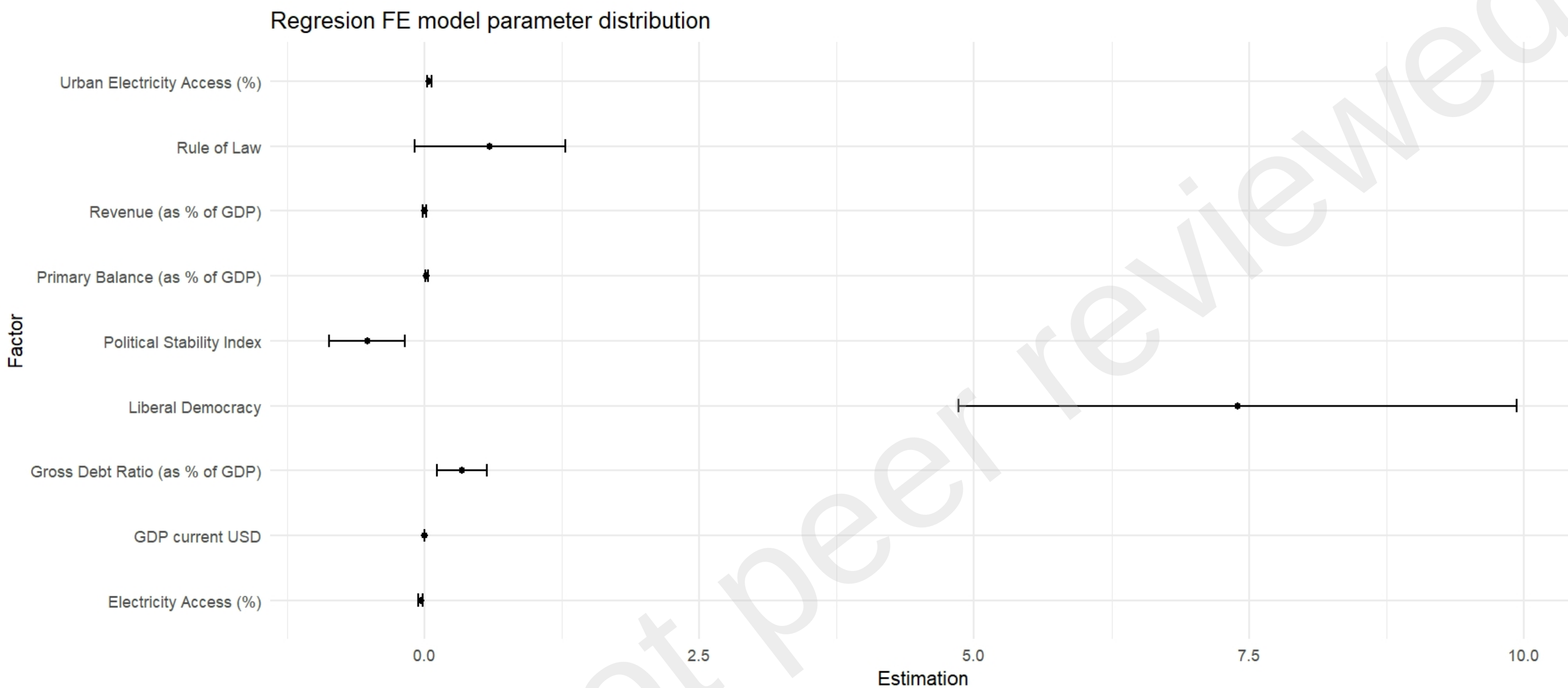
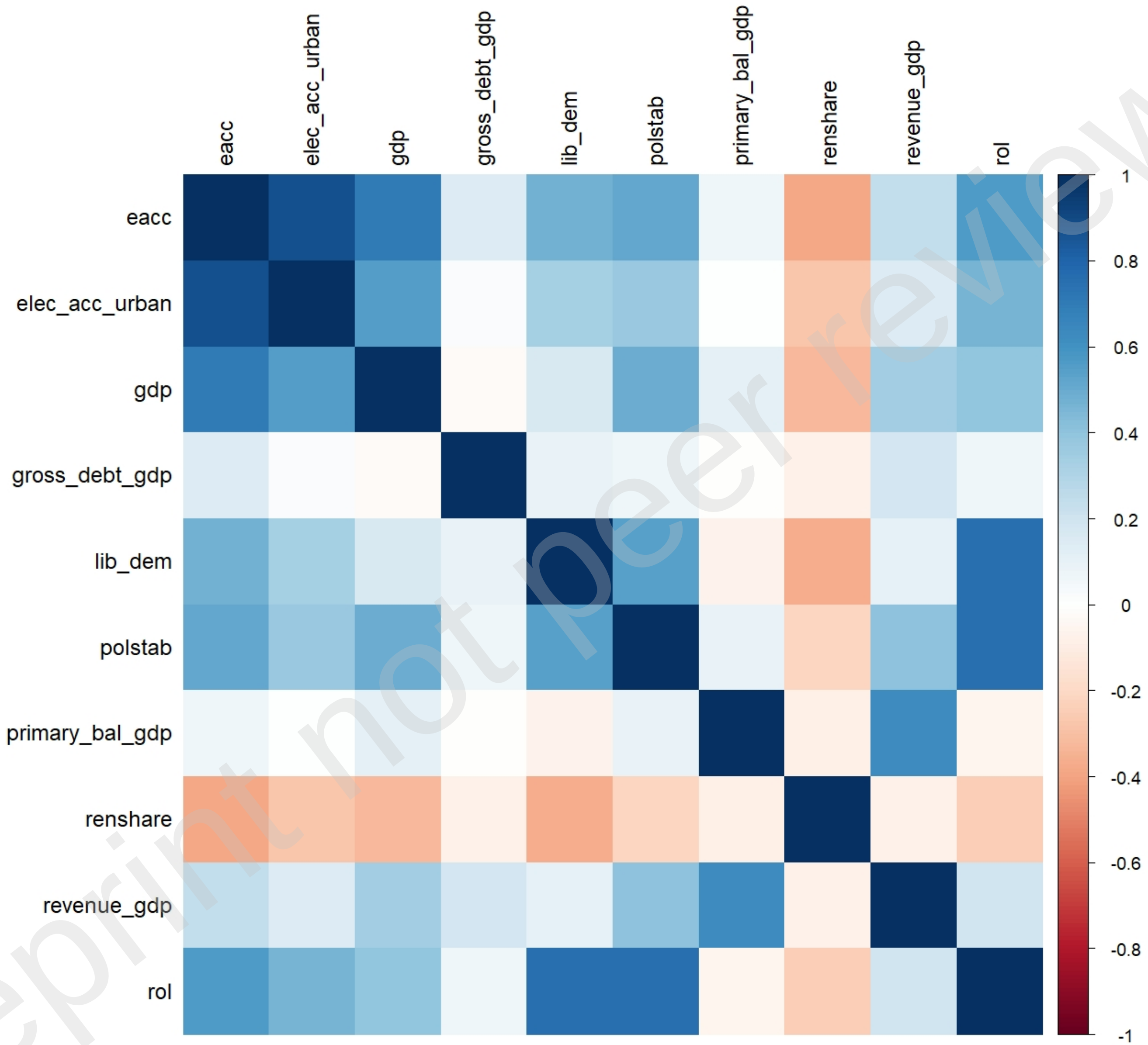

Regresion FE model parameter distribution
Urban Electricity Access (%)
Rule of Law
Revenue (as % of GDP)
Primary Balance (as % of GDP)
Political Stability Index
Liberal Democracy
Gross Debt Ratio (as % of GDP)
GDP current USD
Electricity Access (%)
Factor
0.0
2.5
5.0
7.5
10.0
Estimation



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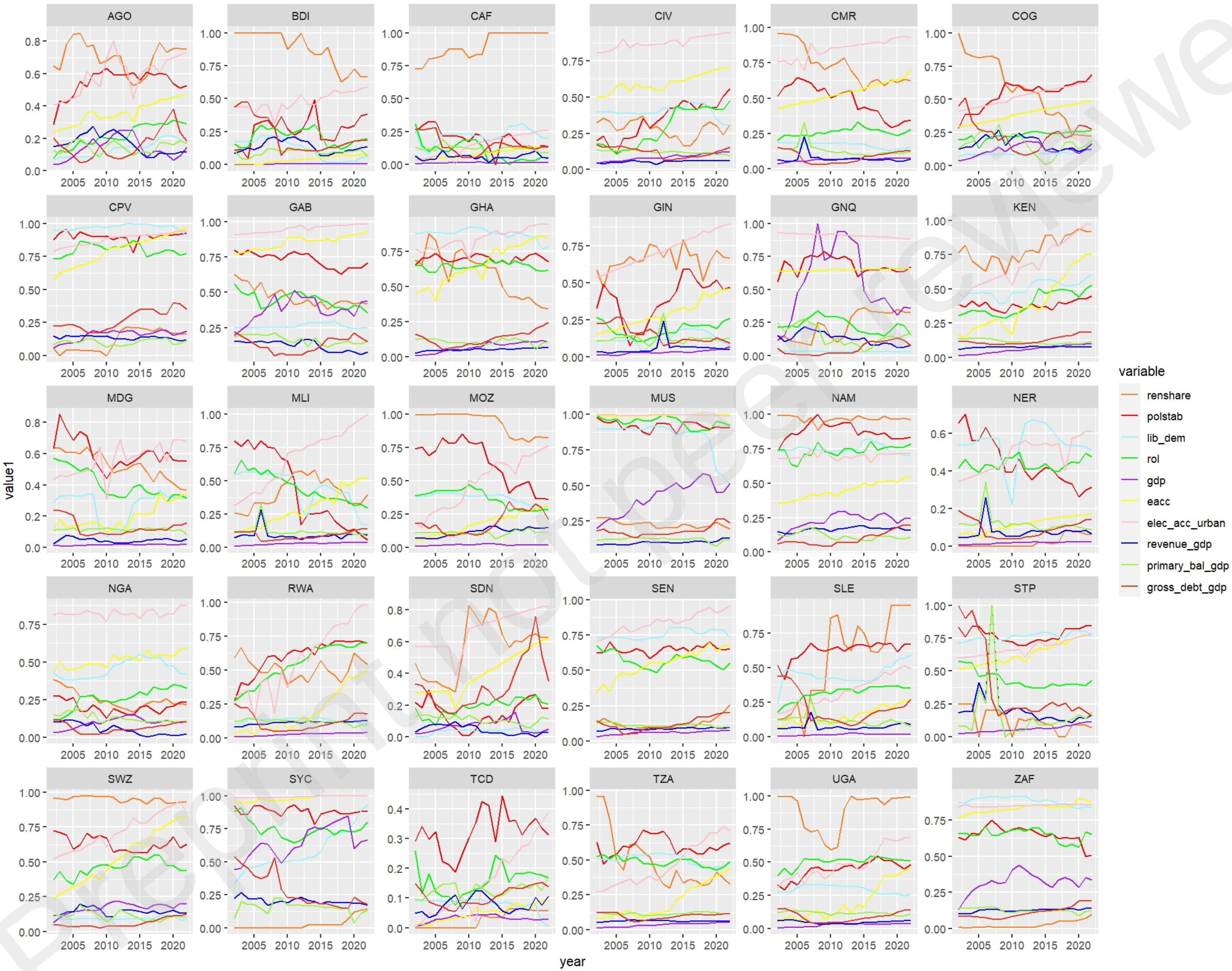
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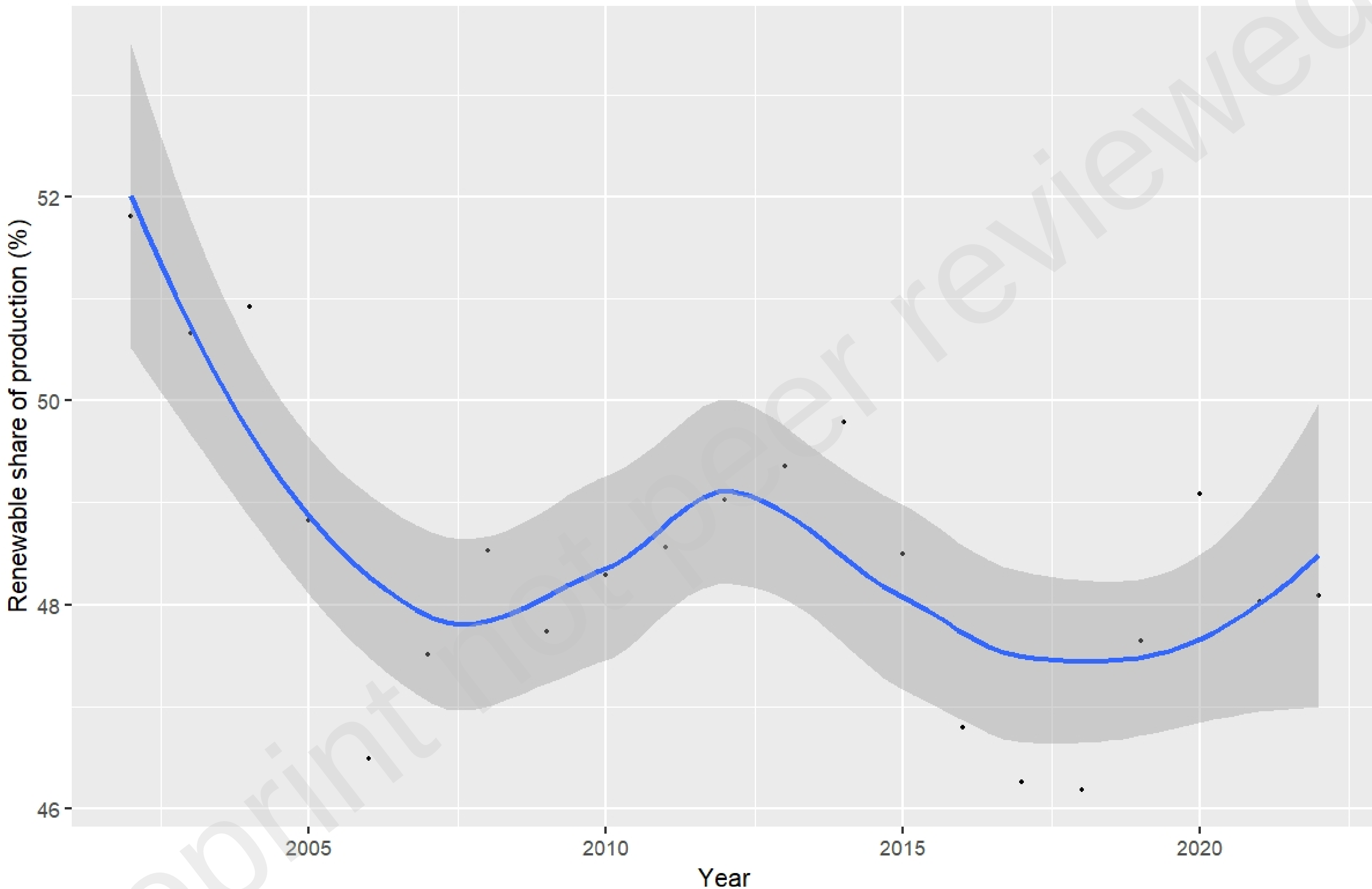

Renewable share of production (%)
52
50
48
46
2005
2010
2015
2020
Year