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Research Article

Unlocking Africa's solar and wind energy potential: A panel data analysis on the determinants of the production of electricity through solar and wind energy

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Abstract. With growing global concerns about and attention drawn to climate change, there is a pressing need to transition towards sustainable practices to live more harmoniously with the environment. To mitigate future climate changes, many support and pursue the uptake of renewable energy to slowly shift to a more electricity powered world. Africa, richly endowed with the potential of solar and wind, stands at a pivotal point with the opportunity to develop through electricity generated by renewable. Therefore, this research delves into the complexity of 25 factors influencing the production of solar and wind-powered electricity within the continent. Through a panel data analysis conducted for the years of 2010 till 2019, the study identifies several determinants to have positive and negative effects. Results highlight the intertwined nature of regional challenges and opportunities, emphasizing that political stability, socio-economic dynamics, sound national strategies, and environmental and international commitments play pivotal roles in determining the trajectory of solar and wind energy integration in Africa's electricity mix. Notably the study underscores that a uniform approach across Africa is insufficient, instead tailored national and foreign strategies based on regional specifics found within this study are imperative for maximizing renewable energy adoption.

Keywords: Renewable; Solar & Wind Energy; African continent; Renewable energy development; Africa

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1. Introduction

Global warming has been a pressing issue placing a higher importance of our carbon footprint on the international political agenda. With the negative effects of carbon dioxide emissions on planet earth becoming more apparent, a shift to renewable energy sources has not just become more lucrative, it is now more necessary than ever before. Achieving the 2016 Paris Agreement aspiration to limit the global temperature rise to 1.5 degrees Celsius, would require a substantial increase in solar and wind energy production. Worldwide advancements in solar and wind energy technologies have contributed to a fast decrease in costs, making these sources more available. Nonetheless, energy demands, fossil fuel consumption and the release of carbon emissions continue to rise. With an increasing acknowledgment of renewable energy sources as eco-friendly substitutes for fossil fuels, it has become of high importance to understand the factors that either obstruct or motivate the production of renewable energy. Understanding these endows aid providers and policymakers with essential insights to promote and upscale the renewable sector and establish well formulated forthcoming sustainability policies to reach the various national 2030 emission targets.

Africa, compared to other continents, remains to be most vulnerable to climate change. With increasing natural disasters, low resilience, prevalent poverty rates, high share of undernourished people, sensitive economies, and conflict rates amplifying its vulnerability further undermines made development efforts. Even with intense efforts made to counter global warming, its effects will persistently affect Africa. To avoid the adversities of climate change, building resilience is essential, which is linked to development.

According to the pronounced hypothesis of the Environmental Kuznets Curve (EKC) development comes with a trend that declines the quality of the environment, increasing pollutants, due to the energy needed for this initial development, till a certain level of development has been reached and environmental improvements are made. This theory has however often been disputed for its lack of robustness, as it does not consider other factors that could reduce environmental degradation (Maler, 2001; Stern, 2018). Maler (2001) emphasized that voiced environmental concerns contribute to environmental improvements, regardless of a nation's level of development. With today's availability of renewable technologies, nations are offered the possibility to take a different development trajectory deviating from the global historical reliance on fossil fuels, by using the available renewable resources.

Geographically, Africa's location makes both solar and wind energy an accessible alternative to fossil fuels. Throughout the year, each country is bestowed with a consistent abundance of solar radiation (Hafner *et al*., 2018). This ensures that every African country has a substantial potential for solar energy

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generation (ESMAP, 2020). However, the potential for wind energy generation varies across the continent, as influenced by among others the existing landscape and physical geographic features. For wind energy generated offshore, the coastal regions of southern and eastern Africa, and the Moroccan coast hold the highest potential, while other areas exhibit less favorable conditions (Elsner, 2019). Nonetheless, the coastal areas and the border regions of the Sahara are identified to have the highest potential for onshore wind energy generation (Mentis *et al*., 2015; Janosi *et al*., 2021). Conversely, countries in the central region of Africa such as the Democratic Republic of Congo and the Central African Republic, are perceived to have the lowest potential (Mentis *et al*., 2015). While wind alone could satisfy Africa's energy demand by 250 times (Whittaker, 2020), as of 2018, a mere 1 per cent of the wind energy potential has been harvested (Alemzero *et al.,* 2021). Moreover, the prospects of both solar and wind energy are predicted to increase as a result of global warming (Sawadogo *et al.,* 2020).

With the world slowly transitioning to a less carbon intensive way of life to tackle climate change, electricity consumption is predicted to grow, replacing old energy systems as can be seen from the rise in electric transportation (Luderer *et al.,* 2022). Solar and wind energy are expected to have a large role in this transition. However due to both being an intermittent source of energy, concerns are often raised about their dependability as the sole source for electricity. This can be resolved by relying on a mix of sources that complement each other, which is often argued to increase the stability of electricity, either by combining solar and wind or other sources, preferably renewable (Jurasz et al., 2020). It is believed that continuous advancements will address other issues such as the resources needed for production (Huber & Steininger, 2022), cost, physical space and environmental implications, some of which can already be mitigated (Evans *et al*., 2009; Levenda *et al.,* 2021). Additionally, many recent technological and research advances have presented numerous solutions to facilitate the incorporation of solar and wind energy in the existing systems and even show that a combination of these renewable sources can provide a constant electricity load in hybrid systems (Jurasz et al., 2020; Luderer *et al.,* 2022; Ostergaard *et al*., 2020).

Therefore, given the considerable potential in solar and wind energy, coupled with the advancements of modern technologies, Africa stands in a favorable position to boost its renewable energy production. By doing so, nations can contribute to their development, expand access to electricity, improve energy security, improve public health, and above all enhance its resilience. Simultaneously, contributing to the global wellbeing of the environment, Africa can challenge the prevailing belief that links development with both environmental degradation and the release of polluting emissions. To do so, it is crucial to acquire an informed understanding of the factors influencing the generation of these renewable sources to navigate their adoption efficiently. Therefore, this paper explores the different factors and sectors affecting the generation of solar and wind energy for electrical use in Africa.

The paper seeks to fill gaps and build upon the existing literature, that is discussed in section 2, by investigating new and in other regions already established determinants of solar and wind energy generated electricity. While other renewable energy resources, such as bioenergy, marine energy, geothermal energy and hydropower, are often included in the existing literature, this paper excludes them to provide an in depth understanding on determinants of electricity produced exclusively form solar and wind energy in Africa. The methodology and data used are elaborated upon in section 3. Section 4 discusses the analysis and results. Followed by section 5 that presents the conclusion and the study's suggested recommendations.

2. Literature review

2.1 Conducted studies

Over the past couple of decades, a noticeable increase in interest in constructing renewable energy and a growing recognition of its potential is evident through the expanding available literature on this subject. Conducted studies are using different scales and criteria, yet according to Bourcet (2020), there remains to be a lack of research on developing nations. However, research on developing nations has to a certain extent been conducted. On a global scale, Pfeiffer & Mulder (2013) conducted a study spanning from 1980 for a 30-year period, covering 108 countries. Despite their findings indicating that economic indicators and political stability positively affect renewable energy, a considerable 71 per cent of their data contains zero values, casting a shadow over the reliability of their results. On a regional scale, studies are often conducted either by considering membership affiliations, often centered on developed nations including on G-20 countries (Lee, 2019) and OPEC countries (Romano & Scandurra, 2014), or through geographical classification. This study follows the latter, taking a geographical approach. For studies taking a geographic approach, an often referred to regional study for developed nations focuses on EU member countries by Marques *et al.* (2010). For the case of Africa, there have been a handful of conducted studies on specific sectors. Nyiwul (2017), for instance, delved into the Sub-Saharan region spanning from 1980 to 2011, and established the influential role of environmental factors in renewable energy consumption, while economic variables were discovered to have a minimal role. These findings are in consistency with Ben Aissa *et al.* (2014), who respectively noted no recognizable impact on trade in certain African nations. Similarly, Ergun *et al.* (2019) constituted that among the analyzed social and economic factors, only Foreign Direct Investments (FDI) positive influences the use of renewable energy. Nonetheless, the literature indicates inconsistencies on found results. Contrary to other studies, Akintande *et al. (*2020) identified, albeit from a limited pool of populous African nations, a positive influence of institutional, macroeconomic, and socioeconomic factors.

The existing body of literature presents results that remain to be inconsistent, revealing an understudied scope in the range of nations analyzed and the depth of variables explored. To the best of our knowledge, there is an absence of studies that fully encompass the whole African continent and integrate a diverse range of variables spanning from economic, social, national, institutional to environmental and international categories. This study sets out to mend the discovered gap by integrating a diverse set of variables from these six categories, to provide a comprehensive overview of influences on Africa's adoption of solar and wind energy resources for electrical use.

2.2 Determinants of solar and wind energy for electrical use

Similar to previous studies by for example Marques *et al.* (2010) on the EU and Aguirre *et al.* (2014) on a global scale, this study investigates factors from six categories that affect the use of solar and wind energy for the generation of electricity. Namely, those that were categorized under political, economic, social, national, environmental, and international.

2.2.1 Political factors

A stable government portrayed by rule of law, effective good governance, control of corruption, and accountability is known to foster development and economic growth. This particularly boosts the production of renewable energy as detailed in this and section 2.2.2 (Akingyemi, 2019). Given this, it's expected that studies, like the study by Amoah *et al.* (2022) focusing on Africa, reveal a negative correlation between corruption and renewable energy developments. Not only does corruption impede overall development, but it can also hamper progress in the renewable energy sector in several ways. Countries with significant levels of corruption may be confronted with firms employing unsustainable methods due to easily obtained licenses from corrupt officials. Furthermore, elevated costs for both construction and material import due to the demand for bribes can create a barrier for the uptake of renewables.

However, while stable governance plays a significant role, it does not necessarily equate to increased efforts in promoting renewable energy. When politicians back unsustainable policies and practices, even indicators of political stability can inversely relate to renewable energy development. This inverse relation was identified by Asongu & Adhimabo (2021) regarding factors like: rule of law, voice and accountability, control of corruption, and political stability. Yet they maintained their stance that good governance generally enhances renewable energy. Given that their research focused solely on Africa, they argued that these values might be skewed due to the values being standardized based on a global sample, suggesting the values must be interpreted differently. Although the values are skewed, this reasoning appears to be weak. The findings stem from discrepancies in the models, meaning the relationships illustrated by the coefficients persist, regardless of standardization. Therefore, while acknowledging the potential for regional variances, this study maintains the stance that there's generally a positive link between political factors and electricity generation from solar and wind energy.

2.2.2 Economic factors

One of the biggest economic indicators used throughout the existing literature is GDP, reflecting a country's financial capacity to overcome financial barriers. The availability of funds contributes to technological advancements and the procurement of essential materials for the construction of, for example, wind turbines or solar panels. Though many studies affirm the positive relation between GDP and renewable energy production (Aguirre & Ibikunle, 2014), a threshold is evident. Numerous studies focusing on Europe have identified adverse effects (Bourcet, 2020). These found negative influences are attributed to the rise in energy demands that arise from growth which at present cannot be addressed solely by renewable sources (Cadoret & Padovano, 2016).

Furthermore, in Africa, persistent unemployment and financial constraints prevent households from making investments in renewable solutions. In Kenya, a study revealed that households with electrical connections to the grid favor monthly payments over a hefty one-time installation cost for solar panels, mainly because of the challenge of affording such a substantial initial investment (Abdullah & Jeanty, 2011). Similarly, the majority of rural households can't afford a large one-time payment for either wind turbines or off-grid solar panels. The influence of both GDP and unemployment on the use of solar and wind energy will therefore depend on whether recent technological breakthroughs have substantially reduced these financial barriers.

There are alternative economic avenues that can stimulate and amplify the electricity generation from solar and wind sources. Over time, besides facilitating the movement of materials, Free Trade Agreements (FTAs) have evolved to embed environmental considerations. By incorporating environmental provisions, FTAs pave the way for a global market that endorses renewable energy development (Cima, 2018 & Dent, 2021). The European Union's Green Deal and Carbon Border Adjustment Mechanism (CBAM) serves as an example of an initiative that incorporates environmental provisions into import regulations, motivating non-EU countries to transition towards greener energy sources to benefit from more favorable trade conditions.

While FTAs facilitate the movement of materials, the exchange of knowledge and technologies is facilitated through the inflow of foreign direct investments (FDI). Despite relevance of FDI's frequently acknowledged within the literature, a consistent significant influence hasn't been established (Bourcet, 2020). For instance, Ergun (2019) identified there to be a positive influence, while Pfeiffer & Mulder (2013) noted a negative one. Meanwhile the literature largely overlooks the potential influence of FDI outflows, which could clarify these inconsistent findings.

Beyond (non-)governmental organizations (as discussed in section 2.2.6), businesses and other economic avenues play a crucial role in developing, enhancing, and executing renewable energy initiatives (MacLean & Brass, 2015). Countries that provide conducive settings for new businesses to establish and flourish will benefit from the emergence of new enterprises that contribute to the development of and increased accessibility to solar and wind sources. This study therefore anticipates that factors related to the promotion of material transfers, business activities, and that indicate financial capabilities to fund renewable energy initiatives will show to have a positive influence on the generation of electricity from solar and wind sources.

2.2.3 National factors

Throughout history, nations have employed sanctions as a political tool to retaliate against others. While sanctions do not necessarily have to limit trade in fuels it has been most recently used in 2022 on a global scale, obstructing the export of fossil fuels affected countries heavily dependent on fossil fuel imports to suffice demand. This highlights the issue of energy vulnerability. A nation predominantly dependent on fuel imports for energy is exposed to potential supply disruptions, price volatility, and abrupt discontinuations (Gnansounou, 2008). To mitigate such risks, nations can turn towards renewable energy to produce their own electricity, thereby reducing their dependence on imports and decreasing their vulnerability to sudden exogenous shocks. Numerous studies, focused on developed nations (Bourcet, 2020), support the theory that those experiencing energy vulnerability are driven to achieve self-reliance by developing renewable energy sources. Yet Marques et al.'s (2010) study implies that the incentive to substitute import with renewable energy production becomes insufficient once a nation already produces renewable energy or has a low dependency on fuel imports.

Many nations within Africa already rely on their own sources to produce electricity. Once a nation already harvests a resource, it can be hard to transition. This creates a certain natural resource trap as described by Collier (2007) that can be hard to get out of as the whole nation puts a focus on an abundant available natural resource. As a result, nations that have naturally access to fossil fuels, hydropower or constructed nuclear power plants will be less likely to adopt (other)

renewable energy sources (Nyiwul, 2017; Bourcet, 2020). Although hydropower is considered a renewable energy source, worldwide opposition to it has grown due to its negative impacts on the ecosystem and agriculture, besides the possible displacement of communities living near connected rivers. Additionally, climate change attributes to a disruption in the production of hydropower, causing shortages due to more frequently occurring droughts and changes in rainfall patterns (Hafner *et al*., 2018). Similarly, the availability of non-renewable resources is limited and can run out. While Africa remains to have a large untapped potential in resources, future diminishes in the availability of resources are expected to worsen. These anticipated future developments might reverse the adverse effects of fossil fuels and hydropower on the adoption of solar and wind energy, as nations will be forced to diversify their energy portfolios and expand the production from alternative energy sources to address potential shortfalls.

Another vulnerability caused by a nation's geographic location, besides dependency on natural resources, is being landlocked. Collier (2007) described a nation that does not directly border the sea as inherently disadvantaged. Because of the dependence of landlocked nations on adjacent nations for economic overspill and access to the sea, the establishment of roads and electricity grids is crucial. Although plans for a continental electrical grid were made, these are yet to be fully implemented. This leaves landlocked nations to either become self-reliant for the generation of energy, or to use the existing underdeveloped infrastructure to import from abroad. Because of the disadvantageous position that landlocked nations are in, Collier (2007) gave the recommendation to prioritize rural development, as rapid industrialization is deemed not feasible. With a considerable proportion of a landlocked nation's population residing in rural areas the study expects that off grid solutions are brought to bring development to rural areas, which enhances the contribution of solar and wind energy to the nation's total electricity generation.

2.2.4 Social factors

A sustainable development goal related to social issues that renewable energy can address is provision of electricity to all. Incorporating clean fuel sources for cooking forms an integral sub-goal, that can contribute to the resolution of many outstanding issues such as indoor pollution, deforestation and enlarged inequalities towards women. With women often taking charge of cooking, they are most prone to the negative consequences of inhaling particles that are released from using solid or fossil fuels when cooking, exacerbating gender disparities (Rosenthal *et al*., 2018).

To address this issue, cleaner cooking fuels like LPG or electricity are introduced within societies. LPG in particular, has gained popularity by proving to be successful in reducing deforestation and emissions compared to firewood or charcoal usage. However, LPG remains to be a fossil fuel despite it being frequently portrayed as more environmentally friendly. Consequently, a rising demand for LPG brings forth concerns about the sustainability of supply and possible environmental implications. Yet, a transition is hampered by existing barriers including limited accessibility to electricity and concerns over increased costs, as found within studies in Ecuador and India (Banerjee *et al*., 2016; Gould *et al.* ,2020).

Africa faces similar challenges, with a significant portion of its population dependent on LPG or solid fuels for cooking. Yet the global trend towards LPG usage suggests communities are making effort towards the adoption of cleaner fuels. Taking Nepal as an example, Bhandari & Pandit (2018) found that a transition from LPG to renewable electricity is more cost beneficial, primarily because of the country's reliance on imports to meet LPG demands. To continue Africa's shift towards renewable energy, which addresses environmental, health and equality concerns, it is essential to ensure widespread access to renewable electricity. Off-grid renewable solutions like small wind turbines and solar panels provide a financially viable alternative, particularly when compared with the options of either extending the current grid or supplying distant rural areas with LPG (Elliot & Cook, 2018). Therefore, this study expects that the motivation to address social development concerns, influenced by factors like the percentage of access to clean cooking fuels, electricity, and those residing in rural areas, or number of deaths caused by indoor pollution, to encourage an increase in the national adoption of renewable solutions.

2.2.5 Environmental factors

The previous sections touched upon vulnerabilities caused by a dependency on import or resources. This section turns towards vulnerabilities caused by changes in the climate that create changes to the ecosystem that many lives depend on or cause an increase in natural disasters.

To enhance resilience and mitigate future effects of climate change, many nations are now focusing on renewable energy production. A 2021 study by Hao & Shao found that nations more susceptible to climate change effects tend to prioritize the integration of renewable energy within their national energy mix. This sentiment was expressed during COP22, with 47 vulnerable nations pledging a commitment to aim for 100 per cent renewable energy consumption. Currently, given that a majority of African countries can be classified as vulnerable states, this study expects that this vulnerability motivates a shift towards the use of renewable sources.

Carbon dioxide emissions are widely recognized as a major contributor to global warming and thus indirectly cause increased vulnerabilities. In response, many nations have implemented policies and standards to promote the use of renewable energy and consequently reduce carbon emissions. An example of this is the carbon tax on imports to incentivize nations to adopt more sustainable production methods. Studies have held a belief that the escalating concerns over environmental issues stemming from the rising carbon dioxide emission levels are a driving force to an increase in the production of renewable energy (Aguirre & Ibikunle, 2014; Nyiwul , 2017; Akintande *et al.,* 2020). However, the strength of this relationship varies based on the metric used for measuring carbon emissions (Bourcet, 2020). With Africa being one of the continents with the lowest emissions and least contribution to the release of polluting gases, the influence of carbon emissions on electricity produced by solar and wind sources is anticipated to be minimal.

Another strategy of mitigating the impacts of carbon emissions is through reforestation. Given the crucial role forests hold in lowering emissions, the promotion of reforestation is, besides increasing the use of renewable energy, gaining momentum. To counter forest degradation, 18 African countries have become part of the REDD+ program established by the United Nations Framework Convention on Climate Change. Forest degradation forms an urgent transboundary concern in Africa, stemming from climate change, fires, overexploitation, labor activities and other factors that have led to a swift decrease in forest coverage. An estimated average of 22 per cent was lost in the 20th century (Aleman *et al*., 2017), with even higher losses of 83 to 93 per cent in the western and eastern regions of the continent. As a result, although proper forest management and reforestation can diminish carbon emissions,

it might also reduce the urgency to transition to renewable energy. Especially countries with significant deforestation rates, such as Zambia, may prioritize reforestation efforts over the adoption of renewable energy.

2.2.6 International factors

Climate change, being a global concern, necessitates collective global efforts. Without international environmental agreements and external pressure, a nation might not see the purpose in allocating resources for environmental preservation, especially if it believes other nations won't. On a global scale, environmental concerns have grown to influence the attention paid to renewable energy. These concerns are reflected through the 1992 Kyoto Protocol, a historically recognized steppingstone for the reduction of emissions. Consequently, studies such as that of Popp *et al.* (2011) established the positive impact of ratifying the Kyoto Protocol on investments made within the renewable energy sector. This suggests that while countries might already recognize the urgency of climate change, international agreements can provide added incentives through the pressure to meet the set standards. Therefore, international agreements established due to environmental concerns that build further onto and refine the Kyoto Protocol, such as The Paris Agreement, are expected to have a similar positive impact on the national share of electricity generated from solar and wind resources.

Beyond international agreements and their enforcement, global climate concerns also shape aid distribution. While funding constraints remain a significant barrier to renewable energy development in numerous developing countries (as discussed under economic factors in section 2.2.2), donor-led development projects have introduced local communities across Africa to renewable energy solutions. Moreover, aid can act as a catalyst, encouraging the redirection of local resources, that local governments would otherwise allocate to different sectors, towards renewable energy (MacLean & Brass, 2015).

However, there are limitations to the contribution aid has on the advancements of renewable energy. Collier (2007) noted that aid can lose its efficacy when it surpasses 16 per cent of a country's GDP. Additionally, there is often a partial diversion of funds into sectors where it is used for unintended purposes, therewith compromising its effectiveness (Pfeiffer & Mulder, 2013). This is further supported by Wang *et al.* (2021), that established, for the Sub-Saharan region, that aid no longer contributes to the development of renewable energy once a nation moves past the initial stages of development, indicated by urbanization and carbon dioxide emissions. Even though these argumentations are overall valid, the studies took the total amount of aid received into account and did not look specifically into aid given to the area of renewable energy. Additionally, while differences in development can impact the effect of aid, due to the categorization of many nations within Africa as Least Developed Countries (LDCs) this study expects aid towards the renewable energy sector to have an overall positive influence.

3. Methodology

3.1 Theoretical framework

To examine the determinants of the share of electricity produced through solar and wind energy sources in Africa, this study employs a panel data analysis to capture both the cross-sectional and temporal variations in the data, as well as control for unobserved heterogeneity across countries. The general model specification is as follows:

$$Y_{it} = \gamma + \beta X'_{it} + \alpha_i + \varepsilon_{it} \quad (1)$$

Where Y represents solar or wind electricity production in country *i* at time *t*, X' is the vector of the variables of the study's interest, β represents the coefficients to be estimated, α_i is the country specific-effect and ε_{it} is the idiosyncratic error term.

A standard regression technique, such as the Ordinary Least Squares (OLS), ignores the panel structure of the data and may lead to inconsistent estimates. It was furthermore deemed inappropriate for this research through the Breusch-Pagan Lagrange multiplier test. Instead, equation (1) is estimated using both a Fixed Effect (FE) and a Random Effect (RE) model. The RE model is more efficient when country-specific effects are not correlated with the explanatory variables and permits the inclusion of time-invariant variables. However, if there is a correlation between country-specific effects and the explanatory variables, the FE model offers more consistency. The Hausman test was used to test the appropriateness of RE and FE. However, according to Schmidheiny (2021) the Hausman test holds validity only under the condition of homoscedasticity. To assess whether this condition was met in the conducted regressions, the Modified Wald test for group-wise heteroscedasticity was applied to the FE regressions. The outcomes revealed heteroscedasticity to be present. Consequently, clustered standard errors were employed in the regressions. This approach, however, rules out the utilization of the Hausman test. Therefore, a robust Hausmant test was employed as an alternative to evaluate the appropriateness of using an RE regression.

Furthermore, explanatory variables underwent testing using Pearson correlations, and these variables were lagged to eliminate influences the regressand might potentially have on them. Lastly, to incorporate the landlocked dummy variable into the FE model, which based on the robust Hausman test were often deemed more reliable, an interaction indicator involving time and a nation's landlocked status was generated. (Results for lagged variables and additional regressions, not shown in this paper, can be found in the appendix.)

3.2 Data source

The study gathered data for 54 countries within Africa and a 10-year timeframe, from 2010 to 2019 (South Sudan forms an exception, due to its 2011 declaration of independence). Data for 25 explanatory variables were obtained from publicly

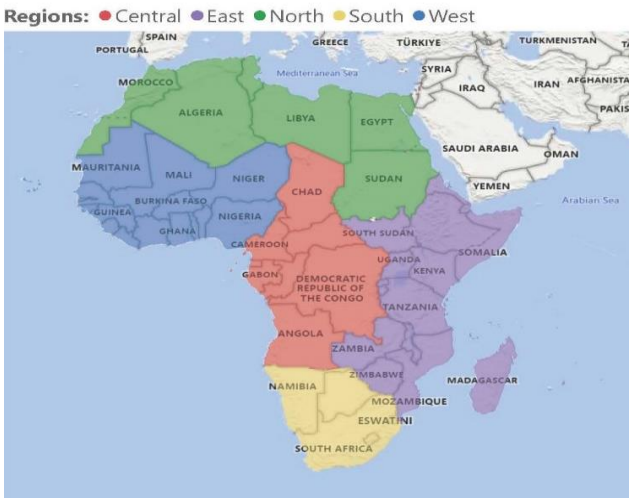

Fig 1 The geographic grouping of countries used for this research in accordance with M49 Standards of the United Nations Statistics Division.

available sources: The Energy statistics database of the United Nations Statistics Division, the World Bank, WTO Regional Trade Agreements database, International Labour Organization (ILOSTAT), IHME Global Burden of Disease, International Energy Agency (IEA), the Food and Agricultural Organization, the ND-GAIN Notre Dame Global Adaptation Initiative, United Nations Treaty Collection, and OECD's CRS statistics. To limit the impact of missing observations only variables with at least 75 per cent of data available were used and additional regressions were performed with a sample of 51 countries to examine the validity of the results.

To address the detected multicollinearity, the study refined its approach opting for three separate regressions that each include two study sectors, rather than a single regression containing all variables. Besides overall regressions on the whole continent, the study conducted regressions based on geographic location. Herewith dividing the continent into 5 regions, as portrayed in Figure 1. Furthermore, a separate subcategory was established for all landlocked nations within Africa.

The following nations were considered part of the northern region: Algeria, Egypt, Libya, Morocco, Sudan and Tunisia. The eastern region: Burundi, Comoros, Djibouti, Eritrea, Ethiopia, Kenya, Madagascar, Malawi, Mauritius, Mozambique, Rwanda, Seychelles, Somalia, South Sudan, Tanzania, Uganda, Zambia & Zimbabwe. For the western region: Benin, Burkina Faso, Cabo Verde, Cote d'Ivoire, Gambia, Ghana, Guinea, Guinea-Bissau, Liberia, Mali, Mauritania, Niger, Nigeria, Senegal, Sierra Leone & Togo. The central region: Angola, Cameroon, Central African Republic, Chad, Democratic Republic of Congo, Equatorial Guinea, Gabon, Republic of the Congo & Sao Tome and Principe. The southern region: Botswana, Eswatini, Lesotho, Namibia & South Africa.

3.3 Variable statistics

This study's dependent variable is defined as the percentage of electricity generated from solar and wind resources. Regional variations in annual averages are displayed in Figure 2. Even though the averages are small, the figure depicts a general upward trend across all regions. Herewith the figure affirms that

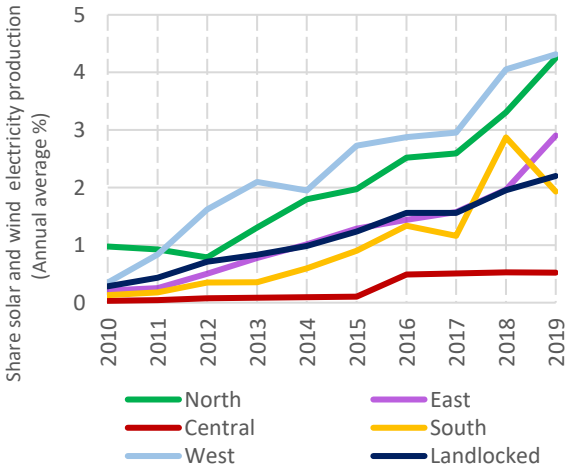

Fig 2 Annual share of electricity produced through both solar and wind electricity per region.

Table 1
Variable statistic summary (2010-2019)

Variable	Unit	Observations	Mean	Maximum	Minimum	Std. Dev.
Share of electricity produced by Solar and Wind energy (annual)	%	536	1.46	20.8	0	3.23
Carbon Dioxide emissions (annual)	kt	538	23636.2	447980	100	67755.5
GDP growth (annual)	%	519	3.973	123.14	-62.076	7.940
Free Trade Agreements	FTA count	539	2.35	9	0	1.9
Foreign direct investment net outflows	USD	421	2.35e+08	7.692e+09	-2.4e+09	8.3e+08
Starting a business score	Score: 0 - 100	514	68.65	94.5	4.3	17.7
Unemployment	% of labour force	529	8.55	28.47	0.32	6.5
Control of corruption	Score: -2.5 to 2.5	539	-0.66	1.03	-1.82	0.64
Rule of law	Score: -2.5 to 2.5	539	-0.712	0.97	-2.42	0.636
Government effectiveness	Score: -2.5 to 2.5	539	-0.799	1.06	-2.48	0.655
Voice and accountability	Score: -2.5 to 2.5	539	-0.64	0.98	-2.22	0.755
Access to clean cooking fuels and technologies	%	539	27.1	100	0	33.6
Deaths due to indoor air pollution	Annual number per 100,000 people	539	119.5	297	0.13	73.4
Access to electricity	%	538	47.5	100	2.7	28.5
Rural population	%	531	55.6	89.5	10.2	18.4
Landlocked nation	Dummy	539	0.295	1	0	0.456
Fuels imported (belonging to SITC section 3)	%	410	16.15	50.6	0.1	8.5
Electricity generated using fossil fuels (Coal, Oil, Natural gas)	Gwh	539	11275	243637	0	38058
Electricity generated using hydropower	Gwh	537	2304.8	17092	0	3812
Forest coverage	% of land area	539	28.2	91.78	0.045	24.66
Mineral resource depletion	% of GNI	518	7.8	57.9	0	9.2
Vulnerability index	Score: 0.000 to 1.000	539	0.53	0.688	0.379	0.074
ND- GAIN country index	Score: 0 to 100	530	39.12	56.66	26.989	6.31
Aid disbursements to sector 232	Million USD	467	21.77	637.17	0.002	51.48
Paris Agreement ratification	Dummy	539	0.33	1	0	0.47
UN International year - 2012	Dummy	539	0.8	1	0	0.4

renewable sources for electricity are progressively replacing other energy sources within the electricity mix. With half of the landlocked nations located in the East, there is a large similarity between both trend lines. In addition to the dependent variable, Table 1 provides a comprehensive list of explanatory variables used for this study. Overall, the statistics showcase a notable variance in values, as indicated by the standard deviations, which supports the appropriateness for conducting regression analyses. Furthermore, it indicates the average political, economic, national, social, and environmental situation in Africa.

4. Results and discussion

4.1 Economic and political variables

For the whole continent of Africa, results indicate that the relation of both political and economic variables on the generation of electricity through renewables is positive. Yet overall political variable results are insignificant and regionally the relation differs. Therefore, the study results suggest that the effects of political and economic factors are dependent on the region and the stance of the ruling national parties (Table 2 shows partially the found results for these variables).

Political variables highlight distinct regional variations. In the Southern and Western regions, that have statistically better political conditions compared to other African regions (Figure 3), the results are positive. In particular, factors like the rule of law, control of corruption, and accountability are found to have a significant positive influence. This aligns with theories from Amoah *et al.* (2022) and Akingyemi (2019), asserting that political stability and anti-corruption measures encourage the adoption of renewable energy. This is also proven to be the case in other regions, such as by Pata *et al.* (2022) on South Asia.

Conversely, results for the Northern and Eastern region, that have statistically unfavorable political conditions, reveal that increases in governmental effectiveness can be disadvantageous to the adoption of electricity produced by solar and wind energy. Additionally, for the Central region a negative relation was found, yet variables like governmental effectiveness and accountability were found insignificant. Nonetheless, these results suggest that regions with weaker political stability may gravitate towards non-renewable practices, a notion supported by Pan *et al.* (2022) for the whole of Africa. Other potential barriers to renewable resource uptake caused through political instability encompass inadequate policies and implementation challenges (Barbier and Burgess, 2020), regulatory instability for the promotion of renewable sources (Boute (2020) & Fabrizio (2012)), and uncertainties for investors (Fabrizio, (2012) & Adebayo *et al.* (2022)). This study's

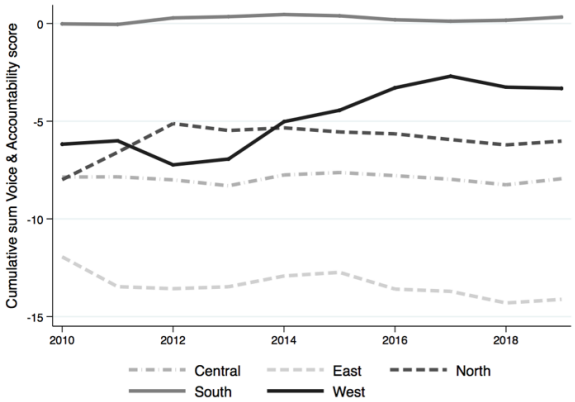

Fig 3 Cumulative sum per region of country scores for voice and accountability. Country scores range from -2.5 to 2.5.

Table 2
Regressions on Political and Economic variables across regions and overall Africa

Political and Economic Variables	Overall	North	West	South	East	Central	Landlocked
	SW-Per (1) FE	SW-Per (2) RE	SW-Per (3) RE	SW-Per (4) RE	SW-Per (5) RE	SW-Per (6) RE	SW-Per (7) RE
GDP growth in (annual)	-	0.051***	0.003	-0.033	0.029	-0.0127	-0.004
		(0.005)	(0.019)	(0.027)	(0.018)	(0.0137)	(0.015)
Starting a business score	0.052*	0.830***	0.053*	-0.146***	0.0537**	0.0108	0.057***
	(0.028)	(0.17)	(0.031)	(0.036)	(0.0209)	(0.0106)	(0.012)
Free Trade Agreements	0.537*	-0.715***	-1.645**	0.837***	-0.101	-0.230	-0.151
	(0.282)	(0.255)	(0.809)	(0.249)	(0.212)	(0.260)	(0.082)
Unemployment	-	-	0.331	0.105*	-0.078	-	-0.112***
			(0.334)	(0.073)	(0.098)		(0.032)
Foreign direct investment net outflows	2.4e-10*	2.2e-09***	-	-	-	-	-
	(1.3e-10)	(8.5e-10)					
Control of corruption	0.777	-	-	-	-	-0.592	-
	(1.306)					(0.664)	
Rule of law	-	-	3.364**	-	-	-	-
			(1.520)				
Government effectiveness	-	-1.205**	-	-	-0.966**	-	-
		(0.616)			(0.413)		
Voice and accountability	-	-	-	1.489***	-	-	-
				(0.229)			
Constant	-3.174	-61.66***	1.736	5.765**	-2.752	-0.733	-1.333**
	(2.137)	(13.075)	(2.858)	(2.509)	(1.765)	(0.824)	(0.680)
Observations	394	49	156	50	145	80	153
R-squared	0.106	0.810	0.426	0.589	0.017	0.030	0.258

Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1
FE = Fixed effect regressions. RE= Random effect regressions.
SW-Per= Solar and wind energy as percentage of the annual electricity produced.
The lagged variables were introduced to the regressions but are not shown in this table.

results for economic variables reinforce these observations, emphasizing that less political fragility favors the uptake of solar and wind resources.

For all fixed effect regression models, there is overall a positive relationship present between economic variables and electricity produced from solar and wind energy. Lagged economic variables such as FTAs, FDI outflows, and the starting a business score were found to be significant. This suggests that a robust, outward-oriented economy with a favorable business and trade environment can positively influence electricity generated through these renewables. Interviews conducted by MacLean and Brass (2015) point out that the ease of conducting business is one of the main factors for businesses when selecting their location. This implies that businesses in the sectors of either solar or wind energy prioritize not only the presence of a market but also a conducive business environment. Given the global shift towards sustainable solutions, regions with a significant number of its population residing in rural communities that lack grid electricity access and have an untapped renewable energy potential, coupled with a favorable business environment, as indicated by the starting a business score, could be on the forefront of investment and innovation from renewable energy enterprises.

However, random effect regressions reveal regional disparities for FTAs and annual GDP growth. Both the Northern and Southern regions have a high average of FTAs per country compared to the other regions, but the relationship differs across model regressions. As noted by Dent (2021) and Cima (2018), an increase in FTAs can open doors to sustainable practices, yet the results show it could simultaneously pave the way for unsustainable practices. Nevertheless, within country models support the notion that an increase in the number of FTAs can contribute to a higher proportion of solar and wind energy used for electricity.

While economic growth, expressed through GDP, was anticipated to have a beneficial influence, it does not significantly impact the generation of electricity through these renewables, particularly in Sub-Saharan regions, consistent with the findings of Nyiwul (2017). Nonetheless large regional differences were found. Regional positive coefficients suggest that GDP growth could lower the financial barriers to renewable options. Conversely, negative coefficients indicate that economic growth is accompanied by a growing energy demand that cannot be met through renewable sources. Furthermore, unemployment, though mostly not significant, indicates that for landlocked nations financial constraints do hinder investment in renewable energy sources. This interplay where economic growth alleviates financial barriers, while renewable energy is unable to satisfy an increasing energy demand that comes fort from economic growth, causes the overall neutrality of GDP on the share of electricity produced from solar and wind energy across Africa.

4.2 National and social variables

Improvements to integral human rights, such as access to electricity and clean sources for cooking, exhibit regional disparities in their effects on the use of renewables for electricity (Table 3 shows partially the found results). The results imply that the studies taken social factors have a positive influence for regions such as the west, east and central Africa. With an exception for death due to indoor pollution, that indicates a negative effect. Indicating that with an increase in access to clean cooking resources electricity, and a decrease in death due to indoor pollution, the use of renewables increases. These are regions that have on average statistically lower scores for these social variables. Indicating that the need to develop in these social aspects is favorable for a rise in the share of renewables.

Table 3
Regressions on Social and National variables across regions and overall Africa

Social and National Variables	Overall	North	West	South	East	Central	Landlocked
	SW-Per (1) FE	SW-Per (2) RE	SW-Per (3) RE	SW-Per (4) RE	SW-Per (5) RE	SW-Per (6) RE	SW-Per (7) FE
CO2 log (annual)	-0.246***	-1.783	-0.608	-0.562	0.726***	-0.0544***	3.319***
	(0.048)	(1.330)	(0.755)	(0.576)	(0.349)	(0.0129)	(1.01)
Landlocked	-	-	3.449**	-2.159*	0.854	0.203***	-
			(1.711)	(1.113)	(0.661)	(0.0449)	
Gross electricity generated using hydropower	-1.08e-05	0.000184	-0.0006*	0.000337	-	1.15e-05*	0.00012*
	(0.00012)	(0.000177)	(0.0003)	(0.0008)		(6.44e-06)	(0.00006)
Gross electricity generated using fossil fuels	-	-	-	-	-0.00041***	-	-
					(0.000179)		
Fuels imported	-0.0011	-0.0701	-0.0298	-0.0350	-	0.00255	-0.021*
	(0.0007)	(0.186)	(0.022)	(0.0502)		(0.00168)	(0.01)
Access to clean cooking fuels and technologies	-	-1.950***	-	-	-	0.006***	-
		(0.602)				(0.0008)	
Access to electricity	-	-	-	-	0.0318***	-	-
					(0.00807)		
Deaths due to indoor air pollution	-	-	-0.0840***	-	-	-	-0.02
			(0.023)				(0.11)
Rural population	-0.015***	-	-	-0.0338	-	-	0.37**
	(0.0033)			(0.0307)			(0.15)
Constant	6.940***	216.1***	19.91***	9.099	-5.678**	0.356***	-47.44**
	(0.936)	(74.86)	(5.517)	(5.557)	(2.484)	(0.082)	(15.61)
Observations	484	35	114	45	160	49	123
R-squared	0.015	0.336	0.613	0.402	0.026	0.350	0.369

Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1
FE = Fixed effect regressions. RE= Random effect regressions.
SW-Per= Solar and wind energy as percentage of the annual electricity produced.
The lagged variables were introduced to the regressions but are not shown in this table.

Koengkan *et al.* (2022) and Khavari *et al.* (2023) substantiate that advocacy through policies for renewables contribute to better access to clean cooking and a decrease in death. Awareness on smaller scale is as important, Zahno *et al.* (2020) and Paudel *et al.* (2023) proved that awareness of health benefits attributed to a higher uptake of and willingness to pay for clean cooking solutions by households. With greater awareness on social benefits of renewables, regions within Africa recognize the opportunity to embark on a development path different from the traditional reliance on fossil fuels, there appears to be a tilt towards renewable energy to improve integral social aspects of life. However, this does not remove the remaining barriers that require cooperation of various actors.

To ensure access to electricity in rural communities, off-grid renewable solutions were expected to form a financially lucrative solution compared to the costs of connecting to the existing grid. Nevertheless, households remain concerned about monthly expenses, forming a large barrier to the uptake of renewables (Adenle, 2020; Paudel *et al.*, 2023). Which also indicates a continuous lack of financial systems to relief user costs and support uptake (Mohammed *et al.*, 2013; Boamah, 2020). A significant share of the population living in rural communities implies less economic development than is usually found with urbanization. Therefore, nations with a larger share of its population residing in rural areas will find it even harder to finance these renewable solutions. Contrarily, the study found that landlocked nations form an exception. Supporting Collier's (2007) theory that these nations should focus on rural development due to their natural disadvantage.

In the Southern region, where there's better access to clean cooking sources, electricity and less death due to indoor pollution, a similar relation is found for these variables that however does not significantly affect electricity generated through renewable energy. The Northern region, on the other hand, presents a reversed situation. Death due to indoor pollution, while much lower compared to other African regions, is found to have a positive influence. Meaning that to reduce death, electricity from other sources than renewable is preferred in this region. Furthermore, the already prevalent access to both electricity and clean resources for cooking in this region disadvantageously impacts the uptake of renewables. Thus, in this region, as suggested by Bourcet (2020) to be possible, the existing reliance on fossil fuels offsets the incentive for renewable solutions.

Having a dependency on fossil fuels carries risks of eventual shortage and environmental damage. It is expected that a nation will look for alternatives due to future scarcity in availability of their resources (Romano & Scandurra, 2014). Nonetheless, findings suggest that neither does this future scarcity nor environmental concerns surrounding fossil fuels incentivize the use of renewable sources yet. While the environmental risks are gaining global attention, many countries remain to rely on fossil fuel imports to meet the difference between domestic production and consumption needs. However, besides the continuous rise in energy demands, this heavy reliance on imports exposes countries to risks of global shortages, price fluctuations and sanctions (Gnansounou, 2008). It is thus of no surprise that Kao *et al.* (2021), in the case of Lesotho, highlights the benefit of reduced energy imports from an increase in domestically generated renewable energy. Nonetheless, imports have a significant negative effect that is found for landlocked nations. Furthermore, with fossil fuel imports insinuating a dependency on fossil fuels, in line with global results found by Aguirre & Ibikunle (2014,) this study's overall results suggest a hesitancy to switch to alternatives. Marques *et al.* (2010) argues, the incentive to substitute import with

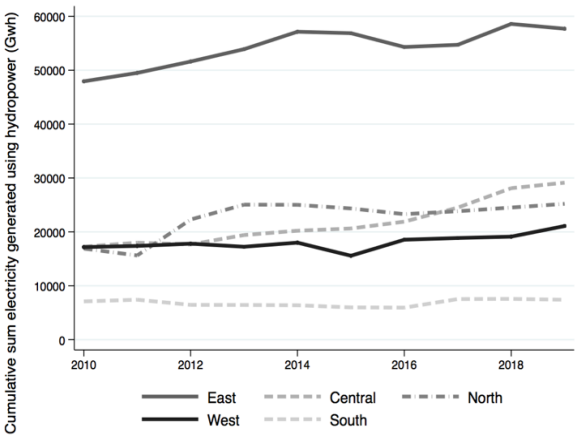

Fig 4 Cumulative sum per region of gross electricity generated (Gwh) using hydropower.

renewable energy production can be insufficient when the dependency on import is not high enough. Therefore, as energy demands grow, an increase in imports might eventually catalyze to be an incentive. Yet, with Africa's average fossil fuel imports standing at 16% during the study's taken years, the continent's dependence on imports is seemingly not substantial enough to drive this shift to renewables.

Findings on the influence of the use of hydropower for electricity imply that possible effects on the use of solar or wind energy are overall not too evident yet. The eastern region that has a large dependency on hydropower (Figure 4) forms the only exception, where for within country models a consistent significant positive effect is found. For many nations that have a large dependency on hydropower, energy outages caused by a decrease in the availability of water due to climate change form a large concern (Hafner *et al.,* 2018). Therefore, due to concerns surrounding future availability, nations are looking into diversification of their energy mix. Suggesting that nations in the east are adapting to climate change impacts by stabilizing their electricity supply through the uptake of other renewable sources. Through this strategy, a nation can rely more on solar and wind energy during periods of drought when hydropower provides less (Jurasz et al., 2020).

While results for other regions are not consistent nor show there to be a clear effect, there appears to be a significant negative effect in the western region, contrary to the east, although not perceivably consistent nor large. A possible clause for these results could be, as Marques *et al.* (2010) suggests, that nations that already produce renewable energy domestically will be less sensitized to construct access to other renewable sources. In the case of Ghana, a nation in the west that's highly reliant on hydropower for its production of electricity, fossil fuels are used to address electricity availability gaps (Gyamfi *et al.,* 2015). Although Ghana has implemented various policies promoting renewable energy throughout the years, the adoption of renewable sources other than hydropower are yet to measurably increase (Nyasapoh *et al.*, 2022). This and the inconsistencies found for other regions implies that while water scarcity could impact the uptake of solar and wind energy, obstacles remain and differences in preferences balance out the found effects.

4.3 Environmental and international variables

Given Africa's substantial untapped resource potential, it is of no surprise that, similar to the utilization of fossil fuels, their

Table 4
Regressions on Environmental and International variables across regions and overall Africa

Environmental and International Variables	Overall	North	West	South	East	Central	Landlocked
	SW-Per (1) FE	SW-Per (2) RE	SW-Per (3) RE	SW-Per (4) RE	SW-Per (5) RE	SW-Per (6) RE	SW-Per (7) RE
CO2 per Cap (annual)	-	-	10.77**	-	0.224	-	-
			(5.244)		(0.0743)		
Forest coverage	0.517**	0.298***	-0.0445*	-0.0514	-0.0182*	-0.00743**	-0.0279*
	(0.214)	(0.0520)	(0.0248)	(0.0558)	(0.00781)	(0.00353)	(0.0163)
Mineral resource depletion	-	0.0311	-0.202	-	0.00438	-	-
		(0.0316)	(0.180)		(0.0251)		
Vulnerability index	-7.661	-	20.08	-14.1**	3.489	1.389	2.816
	(8.797)		(24.49)	(6.809)	(3.492)	(1.653)	(4.812)
ND- GAIN country index	-	0.192***	-	-	-	-	-
		(0.0360)					
Aid disbursements to sector 232	0.005 **	0.011***	-0.0043	-0.00024	0.0012	-0.0019**	0.018***
	(0.0023)	(0.00096)	(0.035)	(0.0031)	(0.0024)	(0.0008)	(0.0066)
Paris Agreement ratification dummy	1.38 ***	1.293	0.797*	1.618**	0.784***	0.371	0.547***
	(0.348)	(1.202)	(0.329)	(0.813)	(0.230)	(0.340)	(0.214)
UN International year of sustainable energy for all dummy	1.307**	-	-	0.447	-	0.087***	0.837***
	(0.537)			(0.295)		(0.029)	(0.249)
Constant	-10.087	-9.588***	-10.27	7.819***	-0.855	-0.296	-0.939
	(9.488)	(2.123)	(14.61)	(2.596)	(1.903)	(1.009)	(2.952)
Observations	464	42	130	40	136	65	142
R-squared	0.196	0.800	0.325	0.307	0.213	0.290	0.338

Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1
FE = Fixed effect regressions. RE= Random effect regressions.
SW-Per= Solar and wind energy as percentage of the annual electricity produced.
The lagged variables were introduced to the regressions but are not shown in this table.

depletion of reserves doesn't have a notable influence yet on the share of wind and solar energy used in the electricity mix. However, environmental concerns are overarching, covering the study's considered national, environmental and international factors. As a result, within Africa, overall forest coverage and international factors exert a significant influence on the utilization of renewable energy (Table 4 shows partially the found results for these variables). Nonetheless a nation's vulnerability that could have resulted in greater environmental concerns, has no direct effect on the usage of these sources. Contrarily, to Hao & Shao's (2021) findings that the most vulnerable nations are more likely to increase renewable energy production, lagged values were proven to be insignificant implying that the relationship is reversed. Meaning renewable sources do have an influence on a nation's vulnerability score, while reversed scores do not directly influence the sources used for electricity.

Environmental concerns that come from an increase in emissions prompt nations to investigate mitigating solutions (Aguirre & Ibikunle, 2014; Nyiwul, 2017; Akintande *et al.,* 2020). According to regional findings, carbon emissions can favorably influence the proportion of solar and wind energy utilized for electricity. Nevertheless, these results are not always consistent and results, depending on the unit taken, and with reforestation forming another solution to address an increase in emissions (Raihan & Tuspekova, 2022; Waheed *et al*., 2018), forest coverage shows to have a negative effect. Across country model results indicate that those with a higher percentage of forest coverage will be less inclined to expand the proportion of solar and wind energy utilized. Yet, within nation models give promising results. Overall, the results imply that within country reforestation has a positive effect. Thus, a nation would not necessarily choose only one approach to address environmental concerns.

The global agenda plays a large role in addressing environmental concerns, which is endorsed by results found for the UN year 2012 of sustainable energy for all and the Paris Agreement. While a year dedicated to development has a positive influence, its strength is somewhat subdued regionally. The results for the Paris Agreement indicate that ratification of an agreement positively influences the share of electricity produced through solar and wind energy. These results are in line with what could be seen in the existing literature for the Kyoto protocol influencing the energy transition (Dogan et al. 2022), increasing renewable technology patent applications (Miyamoto & Takeuchi, 2019), and growth in renewable energy capacities (Popp et al., 2011).

With nations seeking strategies to address their environmental concerns across borders, financial assistance from donor countries often reflects their own concerns. The study's findings indicate that aid given to the renewable sector mostly does have a positive influence. While aid can serve as a catalyst to reroute local resources towards renewable energy projects (MacLean & Brass, 2015), a focus must be placed on the sustainability of renewable projects as it requires a continuous national involvement once foreign support is removed (Adenle, 2020) a nation's political situation.

Furthermore, aid targeted towards the most undeveloped and often fragile nations can be dispersed towards different purposes (Pfeiffer & Mulder, 2013). With the earlier political results implying a statistically worse political landscape for the central region, the effect of aid found for this region implies that the received funding is indeed, at least partially, dispersed to other areas than renewable energy. However, this does not take away the importance of aid. Findings for landlocked nations indicate that in the certain instance shown in table 4, an increase of 1 mil USD could lead to a 0.02 per cent rise in the contribution of solar and wind energy to the electricity mix. Taking in mind the proportion of renewable energy (solar and wind) in the electricity mix between 2010 to 2019, portrayed in Figure 2, such an increase could be considered large.

5. Conclusion

The integration and growth of renewable energy in Africa's electricity mix is deeply intertwined with regional challenges and opportunities. This study explored this intricate relation between several factors and regional circumstances, that influence the share of electricity produced through solar and wind energy in Africa.

The political situation evidently plays a crucial role in achieving progress in the energy transition. The study's findings emphasize the need for political stability to encourage regional cooperation, promote governance reforms, and to enhance national strategies to integrate goals for the use of renewable energy. Concurrently, there is a need to increase social awareness on the benefits of cleaner energy sources. Especially in regions that are still grappling with issues like access to clean cooking, indoor air pollution, and access to electricity, heightened awareness could drastically boost the uptake of solar and wind energy.

On the economic scene, an outward oriented economy fosters conditions conducive to the growth of the renewable energy sector, but it can also support unsustainable practices. This accentuates the important role that the political sector plays in the uptake of renewable sources, highlighting the found regional differences and stances towards a transition to solar and wind energy. Financial constraints, especially in regions with a large rural population, rising energy demands, and a continued reliance on fossil fuels necessitate sound national strategies and financial mechanisms to support the uptake of renewables. While official development assistance could alleviate at least partially financial constraints, it requires national cooperation and interest for project sustainability. Furthermore, regional nuances must be considered as political intricate landscapes and other factors studied in this study can determine the effectiveness of aid.

To tackle demand and dependency challenges, a gradual shift to solar and wind energy by integrating it in the electricity mix appears beneficial. For hydropower, findings show difference in regions whereby some diversify its electricity mix with renewables, driven largely due to concerns on the impact of climate change on water reserves, while for other regions a different trajectory is taken where established dependencies on hydropower and fossil fuels hinder the adoption of new renewable energy sources. Interestingly, the study found that the current levels of fossil fuel usage, resource depletion, and imports do not spur a continent-wide shift to renewables. Yet as energy demands continue to rise, decreasing non-renewable resources, this trajectory could change in the near future.

Lastly, Africa's environmental concerns are apparent, through the found influence of forest coverage, carbon emissions and international commitments. Even though Africa is the smallest contributor to emissions, environmental concerns stemming from emissions seem to contribute to the uptake of solar and wind energy. These environmental concerns could have been addressed through, for example, reforestation or other decarbonizing solutions. Nonetheless, rather than diverting resources from renewable energy adoption efforts, these endeavors demonstrate a nation's commitment to decarbonization. Therefore, national increases in forest coverage can encourage the use of renewables, indicating that energy strategies are harmonized with broader environmental goals. Additionally, international commitments like the Paris Agreement further push for the integration of these energy sources in the electricity mix.

Africa's journey towards the integration of renewable energy in the electricity mix is neither straightforward nor uniform across the continent. Factors such as regional differences, environmental urgencies, international commitments and socio-economic-political dynamics collectively shape Africa's renewable energy narrative. Although the potential of solar and wind energy is large and the need urgent, the continent's diverse challenges require tailored national strategies. The findings of this study highlight recent trends and identify barriers, emphasizing that a "one size fits all" approach is inadequate. Instead, there's a need for country specific, forward-looking strategies based on regional results. Further research is therefore encouraged to build on these findings, to offer regional technological solutions that align with the distinct factors for each specific sector that were identified to influence the uptake of solar and wind energy for the production of electricity.

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References

Abdullah, S., & Jeanty, P.W. (2011). Willingness to pay for renewable energy: Evidence from a contingent valuation survey in Kenya. *Renewable and Sustainable Energy Reviews,* 15(6), 2974-2983. https://doi.org/10.1016/j.rser.2011.03.016

Adebayo, T.S., Akadiri, S.S., Uhunamure, S.E., Altuntas, M., & Shale, K. (2022). Does political stability contribute to environmental sustainability? Evidence from the most pollitically stable economies. *Heliyon,* 8. https://doi.org/10.1016/j.heliyon.2022.e12479

Adenle, A.A. (2020). Assessment of solar energy technologies in Africa-opportunities and challenges in meeting the 2030 agenda and sustainable development goals. *Energy Policy,* 137. https://doi.org/10.1016/j.enpol.2019.111180

Aguirre, M., & Ibikunle, G. (2014). Determinants of renewable energy growth: A global sample analysis. *Energy Policy,* 69, 374-384. https://doi.org/10.1016/j.enpol.2014.02.036

Akintande, O.J., Olubusoye, O.E., Adenikinju, A.F., & Olanrewaju, B.T. (2020). Modeling the determinants of renewable energy consumption: Evidence from the five most populous nations in Africa. *Energy,* 206, 117992. https://doi.org/10.1016/j.energy.2020.117992

Akinyemi, O., Efobi, U., Asongu, S., & Osabuohien, E.S. (2019). Renewable energy, trade performance and the conditional role of finance and institutional capacity of Sub-Sahara African countries. *SSRN Electronic Journal*. https://doi.org/10.2139/ssrn.3400247

Aleman, J.C., Jarzyna, M.A., & Staver, A.C. (2017). Forest extent and deforestation in tropical Africa since 1900. *Nature Ecology & Evolution,* 2(1), 26-33. https://doi.org/10.1038/j.renene.2021.07.021

Alemzero, D., Acheampon, T., & Huaping, S. (2021). Prospects of wind energy deployment in Africa: Technical and economic analysis. *Renewable Energy,*179,652-666. https://doi.org/10.1016/j.renene.2021.07.021

Amoah, A., Asiama, R.H., Korle, K., & Kwablah, E. (2022). Corruption: Is it a Bane to renewable energy consumption in Africa? *Energy Policy*, 163, 112854. https://doi.org/10.1016/j.enpol.2022.112854

Asongu, S., & Odhiambo, N. (2021). Governance and renewable energy consumption in sub-Saharan Africa. *SSRN Electronic Journal*. https://doi.org/10.2139/ssrn.384750

Banerjee. M., Prasad, R., Rehman, I.H., & Gill, B. (2016). Induction stoves as an option for clean cooking in rural India. *Energy Policy,* 88, 159-167. https://doi.org/10.1016/j.enpol.2015.10.021

Barbier, E.B., & Burgess, J.C. (2020). Sustainability and development after COVID-19. *World Development*, 135, 105082. https://doi.org/10.1016/j.worlddev.2020.105082

Ben Aissa, M.S., Ben Jebli, M., & Ben Youssef, S. (2014). Output, renewable energy consumption and trade in Africa. *Energy Policy*, 66, 11-18. https://doi.org/10.1016/j.enpol.2013.11.023

Bhandari, R., & Pandit, S. (2018). Electricity as a cooking means in Nepal – a modelling tool approach. *Sustainability*, 10(8), 2841. https://doi.org/10.3390/su10082841

Boamah, F. (2020). Desirable or debatable? Putting Africa's decentralised solar energy future in context. *Energy Research & Social Science*, 62. https://doi.org/10.1016/j.erss.2019.101390

Bourcet, C. (2020). Empirical determinants of Renewable Energy Deployment: A Systematic Literature Review. *Energy Economics*, 85, 104563. https://doi.org/10.1016/j.eneco.2019.104563

Boute, A. (2020). Regulatory stability and renewable energy investment: The case of Kazakhstan. *Renewable and Sustainable Energy Reviews*, 121. https://doi.org/10.1016/j.rser.2019.109673

Cadoret, I., & Padovano, F. (2016). The political drivers of renewable energies policies. *Energy Economics,* 56, 261-269. https://doi.org/10.1016/j.eneco.2016.03.003

Cima, E. (2018). Promoting renewable energy through ftas? The legal implications of a new generation of trade agreements. *Journal of World Trade,* 52 (4), 663-695. https://doi.org/10.54648/trad2018029

Collier, P. (2007) *The Bottom Billion: Why the poorest countries are failing and what can be done about it.* Oxford University Press

Dent, C.M. (2021). Trade, climate and energy: A new study on Climate action through free trade agreements. *Energies*, 14(14), 4363. https://doi.org/103390/en14144363

Dogan, E., Chishti, M.Z., Alavijeh, N.K., Tzeremes, P. (2022). The roles of technology and Kyoto Protocol in energy transition towards COP26 targets: Evidence from the novel GMM-PVAR approach for G-7 countries. *Technological Forecasting and Social Change*, 181. https://doi.org/10.1016/j.techfore.2022.121756

Elliot, D., & Cook. T. (2018). Renewable Energy: From Europe to Africa, *Springer Nature,* Chapter 3. https://doi.org/10.1007/978-3-319-74787-3

Elsner, P. (2019). Continental-scale assessment of the African Offshore Wind Energy Potential: Spatial analysis of an under-appreciated Renewable Energy Resource. *Renewable and Sustainable Energy Reviews,*104, 394-407. https://doi.org/10.1016/j.rser.2019.01.034

Ergun, S. J., Owusu, P.A., & Rivas, M.F. (2019). Determinants of renewable energy consumption in Africa, *Environmental Science and Pollution Research,* 26(15), 15390-15405. https://doi.org/10.1007/s11356-019-04567-7

ESMAP (2020). Global Photovoltaic Power Potential by Country. Washington. World Bank

Evans, A., Strezov, V., & Evans, T.J. (2009). Assessment of sustainability indicators for renewable energy technologies. *Renewable and Sustainable Energy Reviews*, 13, 5, 1082-1088. https://doi.org/10.1016/j.rser.2008.03.008

Fabrizio, K.R. (2012). The effect of regulatory uncertainty on investment: Evidence from renewable energy generation. *The Journal of Law, Economics, and Organization,* 29(4), 765-798. https://doi.org/10.1093/jleo/ews007

Gnansounou, E. (2008). Assessing the energy vulnerability: Case of industrialised countries. *Energy Policy*, 36(10), 3734-3744. https://doi.org/10.1016/j.enpol.2008.07004

Gould, C.F., Schlesinger, S.B., Molina, E., Bejarno, M.L., Valarezo, A., & Jack, D.W. (2020). Household fuel mixes in peri-urban and rural Ecuador: Explaining the context of LPG, patterns of continued firewood use, and the challenges of induction cooking. *Energy Policy*, 136, 111053. https://doi.org/10.1016/j.enpol.2019.111053

Gyanfi, S., Modjinou, M., & Djordjevic, S. (2015). Improving electricity supply security in Ghana – The potential of renewable energy. *Renewable and Sustainable Energy Reviews*, 43, 1035-1045. https://doi.org/10.1016/j.rser.2014.11.102

Hafner, M., Tagliapietra, S., & Strasser, L.D. (2018). Energy in Africa: Challenges and opportunities. Springer Open.

Hao, F., & Shao, W. (2021). What really drives the deployment of renewable energy? A global assessment of 118 countries. *Energy Research & Social Science*, 72, 101880. https://doi.org/10.1016/j.erss.2020.101880

Huber, S.T., & Steininger, K.W. (2022). Critical sustainability issues in the production of wind and solar electricity generation as well as storage facilities and possible solutions. *Journal of Cleaner Production*, 339. https://doi.org/10.1016/j.jclepro.2022.130720

Janosi, I.M., Medjdoub, K., & Vincze, M. (2021). Combined wind-solar electricity production potential over north-western Africa. *Renewable and Sustainable Energy Reviews,* 151. https://doi.org/10.1016/j.rser.2021.111558

Jurasz, J., Canales, F.A., Kies, A., Guezgouz, M., & Beluco, A. (2020). A review on the complementarity of renewable energy sources: Concept, metrics, application and future research direction. *Solar Energy*, 195, 703-724. https://doi.org/10.1016/j.solener.2019.11.087

Kao, M., Mokeke, S., Mothala, M., & Thamae, L. Z. (2021). Meeting electricity demand and generating revenue from production of solar and wind energy. *2021 International Conference on Electrical, Computer and Energy Technologies (ICECET)*, 1-6, https://doi.org/10.1109/ICECET52533.2021.9698494

Khavari, B., Ramirez, C., Jeuland, M., & Nerini, F.F. (2023). A geospatial approach to understanding clean cooking challenges in sub-Saharan Africa. *Nature Sustainability*, 6, 447–457. https://doi.org/10.1038/s41893-022-01039-8

Koengkan, M., Fuinhas, J.A., Kazemzadeh, E., Alavijeh, N.K., & de Araujo, S.J. (2022). The impact of renewable energy policies on deaths from outdoor and indoor air pollution: Empirical evidence from Latin American and Caribbean countries. *Energy*, 245. https://doi.org/10.1016/j.energy.2022.123209

Lee, T. (2019). Financial investment for the development of Renewable Energy Capacity. *Energy & Environment*, 32(6), 1103-1116. https://doi.org/10.1177/0958305x19882403

Levenda, A.M., Behrsin, I., & Disano, F. (2021). Renewable energy for whom? A global systematic review of the environmental justice implications of renewable energy technologies. *Energy Research & Social Science*, 71. https://doi.org/10.1016/j.erss.2020.101837

Luderer, G., Madeddu, S., Merfort, L., Ueckerdt, F., Pehl, M., Pietzcker, R., Rottoli, M., Schreyer, F., Bauer, N., Baumstark, L., Bertram, C., Dirnaichner, A., Humpenoder, F., Levesque, A., Popp, A., Rodrigues, R., Strefler, J., & Kriegler, E. (2022). Impact of declining renewable energy costs on electrification in low-emission scenarios. *Nature Energy*, 7, 32-42. https://doi.org/10.1038/s41560-021-00937-z

MacLean, L.M. & Brass, J.N. (2015). Foreign aid, NGOs and the private sector: New forms of hybridity in renewable energy provision in Kenya and Uganda. *Africa Today*, 62(1), 57. https://doi.org/10.2979/africatoday.62.1.57

Maler, K.G. (2011). Economic Growth and the Environment. *Encyclopedia of Biodiversity*, 277-284. https://doi.org/10.1016/B0-12-226865-2/00084-5

Marques, A.C., Fuinhas, J.A., & Manso, J.P. (2010). A quantile approach to identify factors promoting renewable energy in European countries. *Environmental and Resource Economics*, 49(3), 351-366. https://doi.org/10.1007/s10640-010-9436-8

Mentis, D., Herman, S., Howells, M., Welsch, M., & Sival, S.H. (2015). Assessing the technical wind energy potential in Africa a GIS-based approach. *Renewable Energy,* 83, 110-125. https://doi.org/10.1016/j.renene.2015.03.072

Miyamoto, M., & Takeuchi, K. (2019). Climate agreement and technology diffusion: Impact of the Kyoto Protocol on international patent applications for renewable energy

technologies. *Energy Policy*, 129, 1331-1338. https://doi.org/10.1016/j.enpol.2019.02.053
Mohammed, Y.S., Mustafa, M.W., & Bashir, N. (2013). Status of renewable energy consumption and developmental challenges in Sub-Sahara Africa. *Renewable and Sustainable Energy Reviews*, 27, 453-463. https://doi.org/10.1016/j.rser.2013.06.044
Nyasapoh, M.A., Elorm, M.D., & Derkyi, N.S.A. (2022). The role of renewable energies in sustainable development of Ghana. *Scientific African*, 16. https://doi.org/10.1016/j.sciaf.2022.e01199
Nyiwul, L. (2017). Economic performance, environmental concerns, and renewable energy consumption: Drivers of renewable energy development in Sub-Sahara Africa. *Clean Technologies and Environmental Policy*, 19(2), 437-450. https://doi.org/10.1007/s10098-016-1229-5
Ostergaard, P.A., Duic, N., Noorollahi, Y., Mikulcic, H., & Kalogirou, S. (2020). Sustainable development using renewable energy technology. *Renewable Energy*, 146, 2430-2437. https://doi.org/10.1016/j.renene.2019.08.094
Pan, X., Dossou, T.A.M., Berhe, M.W., & Kambaye, E.N. (2022). Towards efforts to promote renewable energy development in Africa: Does governance quality matter? *Energy & Environment. https:/*/doi.org/10.1177/0958305X221120259
Pata, U.K., Yilanci, V., Hussain, B., & Naqvi, S.A.A. (2022). Analyzing the role of income inequality and political stability in environmental degradation: Evidence from South Asia. *Gondwana Research,* 107, 13-29. https://doi.org/10.1016/j.gr.2022.02.009
Paudel, J., Sharifi, A., Khan, G.D. (2023). What are the drivers of sustainable energy transition? Insights from an empirical analysis of household preferences for electric induction cooking in Nepal. *Journal of Cleaner Production*, 417. https://doi.org/10.1016/j.jclepro.2023.138021
Pfeiffer, B., & Mulder, P. (2013). Explaining the diffusion of renewable energy technology in developing countries. Energy Economics, 40, 285-296. https://doi.org/10.1016/j.eneco.2013.07.005
Popp, D., Hascic, I., & Medhi, N. (2011). Technology and the diffusion of renewable energy. *Energy Economics*, 33(4), 648-662. https://doi.org/10.1016/j.eneco.2010.08.007
Raihan, A., & Tuspekova, A. (2022). Toward a sustainable environment: Nexus between economic growth, renewable energy use, forested area, and carbon emissions in Malaysia. *Resources, Conservation & Recycling Advaances,* 15. https://doi.org.10.1016/j.rcradv.2022.200096
Romano, A., & Scandurra, G. (2014). Investments in renewable energy sources in OPEC members. *Advances in Methodology and Statistics*, 11(2). https://doi.org/10.51936/jjuz8754
Rosenthal, J., Quinn, A., Grieshop, A.P., Pillarisetti, A., & Glass, R.I. (2018). Clean cooking and the SDGS: Integrated analytical approaches to guide energy interventions for health and environment goals. *Energy for Sustainable Development*, 42, 152-159. https://doi.org/10.1016/j.esd.2017.11.003
Sawadogo, W., Reboita, M.S., Faye, A., da Rocha, R.P., Odoulami, R.C., Olusefun, C.F., Adeniyi, M.O., Aboidun, B.J., Sylla, M.B., Diallo, I., Coppola, E., & Giorgi, F. (2020). Current and future potential of solar and wind energy over Africa using the regcm4 CORDEX-core ensemble. *Climate Dynamics*. https://doi.org/10.1007/s00382-020-05377-1
Schmidheiny, K. (2021). *Short Guides to Microeconometrics: Panel Data: Fixed and Random Effects*. University of Basel
Stern, D.I. (2018). The Environmental Kuznets Curve. *Reference Module in Earth Systems and Environmental Sciences*. https://doi.org/10.1016/B978-0-12-409548-9.09278-2
Waheed, R., Chang, D., Sarwar, S., & Chen, W. (2018). Forest, agriculture, renewable energy and CO2 emission. *Journal of Cleaner Production,* 172, 4231-4238. https://doi.org/10.1016/j.jclepro.2017.10.287
Wang, Q., Guo, J., & Dong, Z. (2021). The positive impact of Official Development Assistance (ODA) on renewable energy development: Evidence from 34 sub-saharan africa countries. *Sustainable Production and Consumption*, 28, 532-542. https://doi.org/10.1016/j.spc.2021.06.007
Whittaker, S. (2020). Exploring Africa's Untapped Wind Potential. International Finance Corporation
Zahno, M., Michaeloewa, K., Dasgupta, P., & Sachedva, I. (2020). Health awareness and the transition towards clean cooking fuels: Evidence from Rajasthan. *PLOS ONE*, 15(4). https://doi.org/10.1371/journal.pone.0231931