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Renewable energy consumption in Sub-Saharan Africa: The role of human capital, foreign direct investment, financial development, and institutional quality

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ABSTRACT

The Sub-Saharan Africa is facing trilemma of energy poverty, climate change hazards, and low economic growth. Lack of access to modern energy is considered as an impediment to the region's wellbeing and development objectives. This study contributes to the energy literature by examining the role of financial development, institutional quality, foreign direct investment, and direct and indirect effects of human capital on the renewable energy consumption of 31 Sub-Saharan African countries over the period 2002–2019. Panel corrected standard error (PCSE) and feasible generalized least square (FGLS) estimation methods are applied for empirical investigation. The findings reveal that complementary effect of both human capital and GDP per capita is a key policy choice for the sample countries. The study also validates a U-shaped GDP-energy consumption nexus. Thus the present work provides a novel and insightful empirical evidence on energy transition and the channels through which it is affected by human capital, financial development, and institutional quality. Therefore, it is recommended that improvement in GDP per capita, capacity enhancement of human capital, and reforms in financial and institutional frameworks entail strategic importance for energy transition.

1. Introduction

Growing global concerns related to the climate change and sustainable development have attracted researchers, regulators, and policy makers towards finding the ways to decouple the energy demand from Green House Gases (GHGs). However, some countries and regions such as Sub-Saharan Africa though not being major contributors to global GHGs, are the most vulnerable to future climate change hazards (Conway and Schipper, 2011). Air pollution causes 490,000 deaths annually in Sub-Saharan Africa (WHO, 2018). Lack of access to modern energy is considered as an impediment to the region's wellbeing and development objectives (Sokona et al., 2012). Moreover, this region is facing negative effects of climate change in the form of food deficits, extreme weather, water stress, and low economic performance (IEA, 2022). IRENA[1] (2018) reports that in the year 2000, out of 1.1 billion people across the world living without electricity, 95% belong to rural Sub-Saharan Africa, which indicates the extreme energy poverty in the region. On the other hand, according to the projections by World Bank (2019), the population of the Sub-Saharan Africa is projected to increase by 100% by 2050. Which will lead to further increase in the energy demand. United Nations Sustainable Development Goal (SDG 7) calls for universal access to clean energy to counter the environmental and rising population. The renewable energy is considered as a viable solution to many socio-economic and environmental problems around the world (Rahman and Sultana, 2022; Nguyen and Kakinaka, 2019; Hua et al., 2016). Hence, transition from conventional and non-renewable energy sources (Coal, Oil, Natural Gas) to renewable energy (Solar, Hydropower, Geothermal, and wind) has become inevitable for sustainable and climate-neutral world. Wang et al. (2022) examined the empirical linkages between energy efficiency and pollution emissions for 30 provinces of China. They found that energy efficiency is negatively associated with sustainability of environment. On the other hand, Wang et al. (2023) analyzed the threshold effects of income inequality in GDP-Environmental quality nexus. This study revealed that the income inequality changes the standard environmental Kuznets curve (EKC) relationship to N-shaped.

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Human capital is considered a significant driver of energy consumption. An increase in human capital is associated with a fall in both clean and dirty energy consumption (Godil et al., 2021; Salim et al., 2017). However, Akintande et al. (2020) identified that human capital is insignificant to enhance renewable energy consumption (REC). Capacity enhancement of the human capital is crucial to achieving clean energy transition targets (Colenbrander et al., 2015). Institutional quality can also play a vital role in energy transition through the channel of policy effectiveness, and regulatory framework (Uzar, 2020). According to Sarkodie and Adams (2018) and Azam et al. (2021), better institutional quality promotes renewable energy. Similarly, Opeyemi et al. (2019) reveal that a strong regulatory framework and control of corruption lead to increased usage of renewable energy. Financing the clean energy project is another crucial indicator of success because the energy transition requires the adoption of green technologies. While the perceived risk of lenders has been an obstacle in the way of clean energy transition (IRENA, 2018). Another factor considered detrimental to energy transition is financial sector, which serves as an intermediary in the transition process (Alsagr and van Hemmen, 2021; Zakaria and Bibi, 2019). In Africa, only 2% of total primary energy demand was comprised of renewables in 2018 (IEA, 2022a). IRENA (2021) identifies seven factors that can accelerate the energy transition in Africa, 1. Cost-reflective tariffs and sustainable service provision, 2. Friendly environment for investment in renewables, 3. Structure and technology for energy efficiency, 4. Strong regulatory framework, 5. Innovative business models, 6. Robust grids, and 7. Neutralizing existing fossil fuel generation capacity. These factors emphasize foreign direct investment (FDI), financial development, institutional quality, and human capital as the determinants of transition towards clean energy. Renewable energy can promote energy security and access, a green environment and sustainable economic development (Oniemola, 2016).

The existing literature provides ample empirical evidence on the relationship between energy consumption, pollution emissions, and economic growth (Rahman et al., 2021, 2022; Rahman, 2020; Rahman and Alam, 2021, 2022; and 2022a, among others) and inconclusive outcomes on the determinants of the renewable energy consumption (Asongu and Odhiambo, 2021; Tao and Wu, 2021; Wang et al., 2016; Yuan et al., 2014; Shafiei and Salim, 2014; Zhang and Lin, 2012;). Yet, the factors affecting the renewable energy consumption need further investigation of the issue to offer more robust policy instruments to meet the SDG 7 goals, particularly in case of Sub-Saharan Africa. This region despite being at the peak of clean energy poverty, and climate change hazards is somehow ignored in terms of comprehensive and empirical analysis on the role of human capital, gross domestic product (GDP), financial and institutional structure on its renewable energy consumption. Unlike the other studies (Saadaoui and Chtourou, 2022; Lei et al., 2022; Lahiani et al., 2021; Raza et al., 2020), the present study fills the gap by extending the literature in three ways. First, to the best of the authors' knowledge, this is the first study in case of the Sub-Saharan African region exploring the impacts of financial development, institutional quality, foreign direct investment (FDI), and direct effects of human capital on the renewable energy consumption. Second, the indirect effect of human capital through the moderating role of GDP is also examined. Third, the analysis also investigates whether the EKC hypothesis hold true in the renewable energy-GDP nexus? This study provides a new policy perspective to view the human capital, financial development, FDI, and institutional quality as decisive factors for energy transition in the region.

Rest of the paper presents the literature review in Section 2, data and methods in Section 3, empirical results, and discussion in Section 4; and finally, Section 5 contains the conclusion and policy recommendations.

2. Literature review

The insightful review of literature covering the four types of relationships to be examined empirically in this study is conducted under the following sub-headings.

2.1. Human capital and renewable energy consumption

Akram et al. (2020) have examined the linkage between human capital and energy consumption in the case of 73 countries classified on income levels, and regions. The empirical analysis is based on the period 1990–2014. The results from Dynamic Ordinary Least Squares (DOLS) reveal that an increase in human capital leads to a decrease in energy consumption. Similar results were found by Salim et al. (2017) in the case of China, Godil et al. (2021) for India, and Kolawole et al. (2017) in the case of Sub-Saharan Africa. However, Yao et al. (2019) evaluated the impact of human capital on both dirty and clean energy consumption. They found that one standard deviation increase in human capital led to a 17.33% fall in dirty energy consumption and an 85.54% rise in environment-friendly energy consumption in OECD economies. Similarly, another study by Khan et al. (2020) maintained that non-renewable energy consumption fell because of an increase in human capital. Whereas renewable energy consumption rose in response to an increase in human capital in G-7 countries. Tinta et al. (2021) and Rahut et al. (2018) also found that an increase in human capital had a positive impact on renewable energy consumption in Sub-Saharan African countries. On the other hand, Akintande et al. (2020) examined the relationship between human capital (proxied as tertiary school enrollment) and renewable energy consumption for the five most populous African countries (Ethiopia, South Africa, DR Congo, Egypt, and Nigeria). The findings showed that improvement in human capital had no significant impact on renewable energy consumption. However, Wang et al. (2023) conducted a study on the relationship between trade, natural resources, human capital and carbon emissions in 208 countries for the period 1990–2018. This study concluded that human capital is momentous for a sustainable environment only after the turning point of EKC. Hence, the literature does not indicate a consensus on how human capital plays its role in sustainable development and energy transition. Moreover, there are very few studies in the case of Sub-Saharan Africa which empirically estimate the renewable energy demand. The present study extends the existing literature by identifying the different channels through which human capital can be vital for energy transition.

2.2. FDI and renewable energy consumption

With the increasing levels of global economic integration, it is crucial to understand the role of FDI inflows in renewable energy consumption to achieve SDG-7. Wang et al. (2022) evaluated the determinants of sustainable development in 134 countries. The empirical findings reveal that rise in urbanization and economic development halts the sustainable development. Similar findings were reported by Li et al. (2021) in the case of 147 countries classified in four income groups. Several other studies have explored the role of FDI in renewable energy consumption. However, a few empirical studies is found in case of Sub-Saharan Africa. Elheddad et al. (2022) examined the impact of FDI on renewable energy consumption in case of Bangladesh. The study found that an increase in FDI causes increase in non-renewable energy and decrease in renewable energy consumption. Whereas Akintande et al. (2020) revealed that increase in FDI inflows had no significant impact on renewable energy consumption in five most populous African countries. Similar results were found by Amoako and Insaidoo (2021). This study concluded that FDI inflows had no significant impact on energy consumption in Ghana. However, Doytch and Narayan (2016) found that increase in FDI inflows caused rise in renewable energy consumption in high-income countries only. Many studies found that increase in FDI inflows were associated with rise in renewable energy consumption through the channel of clean energy technology transfers (Shahbaz et al., 2022b; Doğan et al., 2022; ; Zhang et al., 2021, and Kang et al., 2021). Hence, there is lack of consensus on consensus on the role of FDI in renewable energy consumption in the literature, which requires further examination of the relationship particularly in the case of Sub-Saharan Africa.

2.3. Financial development and renewable energy consumption

As outlined by IRENA (2021), environment-friendly investment requires ease of access to domestic credit. Better financial development promotes investment demand (Schich and Pelgrin, 2002; Benhabib and Spiegel, 2000; Ndikumana, 2005). Similar findings were reported by Koshta et al. (2020), Iorember et al. (2020), and Khoshnevis Yazdi and Ghorchi Beygi (2018). Moreover, researchers have found that financial development has a significant association with environmental performance (Zakaria and Bibi, 2019; Qayyum et al., 2021). Hence, it is important to investigate the impact of financial development on renewable energy consumption. Mukhtarov et al. (2020) have investigated the role of financial development in renewable energy consumption. They concluded that financial development had a strong and positive impact on renewable energy consumption. Anton and Nucu (2020) also claimed that financial development led to an increase in renewable energy consumption. It is further concluded that financial development significantly facilitates the implementation of climate-friendly technologies. Likewise, Eren et al. (2019) analyzed the impact of financial development on renewable energy consumption in the Indian context. They inferred that financial development had an increasing impact on the usage of renewable energy. Similar findings were reported by (Islam et al., 2013; Alsagr and van Hemmen, 2021; Samour et al., 2022; Yu et al., 2022). On the other hand, Raza et al. (2020) revealed that financial development had an asymmetric impact on renewable energy consumption. A similar conclusion was drawn by (Lahiani et al., 2021; Chang, 2015). However, Lei et al. (2022) observed that financial development has no significant impact on renewable energy consumption in China. On the other hand, Saadaoui and Chtourou (2022) found that improvement in financial development led to a fall in renewable energy consumption in Tunisia. The existing literature on the relationship between financial development and renewable energy consumption shows two types of shortcomings. First, there is no concrete agreement on the nature and direction of the relationship. Second, there is almost no empirical work investigating the effects of financial development on renewable energy consumption in the context of Sub-Saharan Africa.

2.4. Institutional quality and renewable energy consumption

Researchers, policymakers, and regulators have been emphasizing the role of reducing poverty and inequality to achieve inclusive and sustainable growth till the 1980's (Anand et al., 2013). However, in the last three decades, environmental-friendly growth has been considered a priority goal in the policy arena (Soytas and Sari, 2006; Grossman and Krueger, 1995). Institutional quality and government policy are regarded as channels through which other economic and social factors promote green and sustainable growth (Uzar, 2020; Siddique et al., 2016; Tamazian and Rao, 2010; and Panayotou, 1997). Sarkodie and Adams (2018) observed that institutional quality affected environmental performance through different economic, social and governance factors in South Africa. The quality of institutions also moderates the effects of energy consumption on environmental pollution (Haldar and Sethi, 2021). However, it is also found that improvement in the rule of law and government effectiveness leads to an increase in both renewable and non-renewable energy consumption. Moreover, political stability causes an increase in renewable energy consumption, and a decrease in non-renewable energy use in South Asia (Mahmood et al., 2021). Whereas Rahman et al. (2022) and Mahalik et al. (2023) have revealed that improvement in the quality of institutions (Corruption control and government effectiveness) ensures an increase in renewable energy consumption. On the other hand, Asongu and Odhiambo (2021) have claimed that institutional quality is inversely related to renewable energy consumption in Sub-Saharan Africa. Therefore, the literature on the linkage between institutional quality and renewable energy consumption shows mixed evidence of the magnitude and significance of the relationship. Table 1 summarizes the selected studies from the literature related to renewable energy consumption.

A comprehensive review of the literature provided above indicates insufficient empirical evidence on the relationship among renewable energy consumption, human capital, financial development FDI, and institutional quality, particularly in the context of Sub-Saharan Africa. Hence, this study aims to explore the channels through which human capital can play a momentous role in energy transition for the said region to fill up this research gap.

3. Methods

3.1. Model and data

This study aims to investigate the impact of FDI, financial development, human capital, and institutional quality on renewable energy consumption in the selected 31 Sub-Saharan African countries. The empirical analysis is based on panel data covering the period 2002–2019 and robust econometric methods. Panel Corrected Standard Errors (PCSE) model is applied to address the issues of cross-sectional dependence, groupwise heteroscedasticity, and autocorrelation. The prevalence of autocorrelation and heteroscedasticity leads to inefficient estimates, hence these issues are appropriately addressed through PCSE. Rahman and Alam (2022a) have also employed this technique to address similar issues. The robustness of the results is confirmed by the Feasible Generalized Least Squares (FGLS) estimation technique. Following da Silva et al. (2018), and Rahman and Sultana (2022), the proposed relationship takes the following form.

$$REC = f(FDev, \mathrm{FDI}, \mathrm{HC}, \mathrm{GE}, \mathrm{RQ}, \mathrm{GDPC}) \quad (1)$$

In the above equation, REC shows renewable energy consumption which is calculated as a percentage of total primary energy consumption. FDev denotes the financial development which is proxied by domestic credit provided to the private sector. This variable is measured as a percentage of gross domestic product (GDP). FDI stands for foreign direct investment (net inflows). It is measured as a percentage of GDP. HC shows the human capital index which is based on return to education and years of schooling. GE and RQ stand for government effectiveness and regulatory quality, respectively. These two variables are used as proxies of institutional quality. Each of these two variables is constructed on a scale of 0–100. Where 0 means worse institutional quality, and 100 represents the best quality of institutions. GDPC denotes GDP per capita measured at constant 2015 US$. Data of REC, FDI, RDE, GE, RQ, and GDPC are collected from the World Bank database[2] Whereas the human capital index is taken from Penn world tables.[3] Table 2 summarizes the main features of the data used in this study.

A strong financial system acts as an intermediary between the surplus and deficit units in any country, hence is expected to promote the energy transition (Yu et al., 2022; Ozdeser et al., 2021; Mukhtarov et al., 2020). However, if the financial system promotes traditional energy sources and cannot afford green energy financing due to multiple uncertainties, it can lead to a fall in renewable energy consumption (Saadaoui and Chtourou, 2022; Godil et al., 2021). Similarly, Ndikumana (2005) claimed that a strong financial sector in a country can facilitate an investment-friendly environment. Moreover, effective and efficient financial intermediation is inevitable for investment growth. Therefore, the expected sign of the relationship between financial development and renewable energy consumption is uncertain in the case of selected countries in this study. FDI can affect renewable energy consumption in multiple ways. If the FDI inflows are bringing green technology into the

[2] See Table 2 to access the database

[3] Can be accessed at https://www.rug.nl/ggdc/productivity/pwt/?lang=en

Table 1
Summary of the recent literature.

Study	Country/Region	Period	Technique	Findings
Shahbaz et al. (2022a)	China	1980–2018	ARDL	Human capital improves the renewable energy consumption (REC)
Opeyemi et al. (2019)	42 Sub-Saharan African countries	2004–2016	System GMM	Institutional quality leads to an increase in REC
da Silva et al. (2018)	Sub-Saharan Africa	1990–2014	Panel ARDL	GDP promotes energy consumption
Uzar (2020)	38 developed and developing countries	1990–2015	MG, PMG	Institutional quality leads to an increase in REC
Asongu and Odhiambo (2021)	44 Sub-Saharan African countries	1996–2019	Tobit regression	Institutional quality causes a fall in REC
Mahmood et al. (2021)	South Asia	1996–2019	Panel cointegration	The rule of law causes a decrease in REC
Koshta et al. (2020)	12 emerging economies	1990–2014	FMOLS	Financial development improves the environmental quality
Saadaoui and Chtourou (2022)	Tunisia	1984–2017	Panel ARDL	GDP and Institutional quality improve REC
Lei et al. (2022)	China	1990–2019	Non-linear ARDL	Financial development has no impact on REC
Raza et al. (2020)	15 top REC countries	1997–2019	Panel smooth transition regression	GDP causes a rise in REC
Lahiani et al. (2021)	USA	1975Q1–2019Q4	Non-linear ARDL	Financial development has an asymmetric impact on REC
Mukhtarov et al. (2020)	Azerbaijan	1993–2015	ARDL	Financial development and GDP cause a rise in REC
Zhang et al. (2021)	BRICS Countries	1997Q1–2018Q4	Non-linear ARDL	FDI positively affects the REC
Kang et al. (2021)	South Asian countries	1990–2019	FMOLS and DOLS	FDI is inversely related to REC
Amoako and Insaidoo (2021)	Ghana	1981–2014	FMOLS	FDI adversely affects energy efficiency
Doytch and Narayan (2016)	74 countries classified on income levels	1985–2012	GMM	The impact of FDI on REC varies with the sector

Table 2
Summary of the Data.

Variable	Acronym	Measurement	Source
Renewable energy consumption	REC	% of total primary energy consumption	World Bank https://databank.worldbank.org/source/world-development-indicators
Human capital	HC	An index	Penn world tables https://www.rug.nl/ggdc/productivity/pwt/?lang=en
Financial development	FDev	Domestic credit to private sector (% of GDP)	World Bank https://databank.worldbank.org/source/world-development-indicators
FDI net inflows	FDI	% of GDP	World Bank https://databank.worldbank.org/source/world-development-indicators
Government effectiveness	GE	An index (0–100)	World Bank https://databank.worldbank.org/source/worldwide-governance-indicators
Regulatory quality	RQ	An index (0–100)	World Bank https://databank.worldbank.org/source/worldwide-governance-indicators
GDP per capita	GDPC	Constant 2015 US$	World Bank https://databank.worldbank.org/source/world-development-indicators

recipient country, its impact on renewable energy consumption will be positive (Shahbaz et al., 2022b). However, if multinational companies discourage renewables, the FDI inflows can be negatively associated with renewable energy consumption (Elheddad et al., 2022). It is also likely that the FDI inflows are not sufficient to influence the energy transition in the recipient country (Akintande et al., 2020). Human capital which represents education can have spillover effects in a society in terms of climate-friendly actions and attitude, and efficiency improvement in the production process (Yao et al., 2019; Churchill et al., 2019). However, Akintande et al. (2020) have found that improvement in human capital cannot contribute to renewable energy transition. This reason can partly be explained by Hancock (2015), who argued that it is the capacity enhancement which can lead to environment-friendly human capital. Therefore, the sign of the impact of the n capital on renewable energy consumption is uncertain. Keeping in view such uncertainty on human capital and renewable energy consumption relationship, the present study analyzes the impact of human capital in two ways. First, the direct effect is captured through its coefficient, which indicates the statistical importance of human capital alone for energy transition while keeping all other explanatory variables constant. Second, in order to better understand the impact of human capital on renewable energy consumption by considering the role of economic development, this study includes the interaction term of human capital and GDP per capita. The rationale behind such indirect effect is three-fold. 1. Skilled and educated workforce can promote technological advancement. These advancements have the potential to lead the cost-effective renewable energy technologies. Moreover, with the increase in GDP, more credit is likely to be supplied for adoption of renewable energy. 2. An educated population is likely to advocate and support the policies pursuing energy transition, and with the rise in GDP more resources can complement the improvements in renewable energy adoption. 3. Economies with high levels of human capital and income levels are often globally competitive, and such economies are more likely to receive renewable energy projects and funding. Institutional quality, such as government effectiveness and regulatory quality represent the capacity and attitude of the regulators to make legislations on green economy and actively participate in international climate treaties. Countries with good institutional quality can perform well in achieving sustainable development goals (Sarkodie and Adams, 2018). Rich economies with advanced technologies can perform better than the poor ones in terms of adopting climate-friendly technology (Rahman and Vu, 2020). Hence it is expected that the GDP has a positive or U-shape relationship with the renewable energy consumption in this study. Fig. 1 provides the graphical representation of the U-shape relationship between REC and GDP per capita.

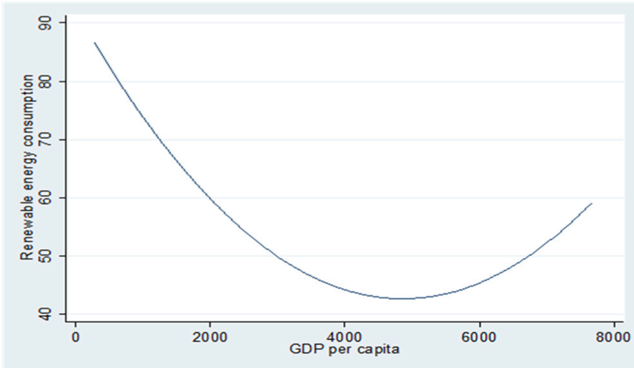

Fig. 1. Average of renewable energy consumption and GDP per capita Source: Constructed by authors (Data source: World Bank).

3.2. Descriptive and Correlation Statistics

The descriptive statistics of the data used in this study are presented in Table 3. The descriptive study of the data is important to capture the potential outliers and better understand the data before the application of inferential statistical techniques so that we can achieve reliable and unbiased estimates of the parameters. Each variable contains 558 observations, where the mean of renewable energy consumption is 68.53%, with minimum and maximum values of 8.94% and 98.27% respectively. Human capital has a mean value of 20.09, and its minimum and maximum values are 0.491 and 142.4 respectively. The mean, minimum and maximum values of GDP per capita are 1815.22, 270.7, and 7662.4, respectively. These values indicate that there are no substantial outliers in the key variables of the model. The correlation matrix is presented in Table 4. The correlation is a standardized variance, which overcomes some issues prevailing in the measure of covariance. Yet the correlation does not imply causation, because of missing variable bias. Hence, it is worthy to examine the relationship through regression analysis (Stock and Watson, 2003). The correlation output indicates that GDP, human capital, indicators of institutional quality, and financial development have a negative correlation with renewable energy consumption. However, FDI has a very low but positive correlation with renewable consumption.

3.3. Econometric approaches

The empirical methodology of this study is carried out in five steps. First, we tested for the potential cross-sectional dependence. Second, panel unit root tests are used to check the order integration of the modelled variables. Third, the modified Wald test (Baum, 2001) and Wooldridge test (Wooldridge, 2010) are applied to test the groupwise heteroscedasticity and autocorrelation, respectively. Fourth, the Panel corrected standard error (PCSE) model is applied to get the estimates of the relationships, and finally, the Feasible Generalized Least Square (FGLS) is employed to check the robustness of the results. This technique is also useful for addressing the issues of cross-sectional dependence, groupwise heteroscedasticity, and autocorrelation (Alonso et al., 2017; Ikpesu et al., 2019; Rahman et al., 2022).

3.3.1. Cross-sectional dependence

The sample countries are almost similar in geographic, economic, and cultural aspects. So, it is likely that the data contain cross-sectional dependence, which may lead to inefficient results (Tugcu, 2018). To avoid this issue, three types of cross-sectional dependence tests are employed in this study; namely, Pesaran (2004) CD test, Friedman (1937) average spearman correlation test, and Frees' test (Frees, 1995, 2004). These tests have different properties and abilities depending on the dimension and size of the data. We preferred the Pesaran (2004) CD test over the Pesaran (2004) scaled LM because the LM statistic's asymptotic property is not properly centred in the case of large cross sections and finite time, which is the case in this study. CD test overcomes this issue, and it provides better results in the case of both small cross-sectional and time units, however, the periods across the cross-sections must be fixed. The null hypothesis of these tests is no cross-sectional dependence (Tugcu, 2018). This study used all these tests to infer the prevalence of the cross-sectional dependence in a better way.

Mathematically, Pesaran (2004) CD test statistic is estimated as follows:

$$CD = \sqrt{2T/(N(N-1)}\ \left(\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\widehat{\rho}_{ij}\right) \tag{2}$$

It shows that CD is normally distributed with $N(0,1)$ for $N\rightarrow\infty$ and T is sufficiently large, with the null hypothesis of no cross-sectional dependence. The mean of the CD statistic is at zero for fixed time values and cross-sections. This property makes this test suitable for panel data models with homogenous, heterogeneous, dynamic, and non-stationary characteristics.

For unbalanced panels, the modified version of (2) is given as follows:

$$CD = \sqrt{2/(N(N-1)}\ \left(\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\sqrt{T_{ij}}\quad\widehat{\rho}_{ij}\right) \tag{3}$$

Where N denotes the number of observations, and ρ indicates the correlation. Friedman (1937) test for cross-sectional dependence is a nonparametric test. It is based on Spearman's rank correlation coefficient. Particularly, if $\{r_{i,1},\ldots\ldots,r_{i,T}\}$ is the rank of $\{u_{i,1},\ldots\ldots,u_{i,T}\}$ and average rank is $(T+1/2)$, the rank correlation coefficient is given below:

$$r_{ij} = r_{ji} = \frac{\sum_{t=1}^{T}\{r_{i,t}-(T+\frac{1}{2})\}\{r_{j,t}-(T+\frac{1}{2})\}}{\sum_{t=1}^{T}\{r_{i,t}-(T+\frac{1}{2})\}^2} \tag{4}$$

The Friedman's test statistic is expressed as follows:

$$R_{ave} = \frac{2}{N(N-1)}\sum_{I=1}^{N-1}\sum_{J=I+1}^{N}\widehat{r}_{ij} \tag{5}$$

The Frees' test statistic is given below:

$$R_{ave}^2 = \frac{2}{N(N-1)}\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\widehat{r}_{ij}^2 \tag{6}$$

When $R_{ave}^2 > (T-1)^{-1} + \frac{Q_q}{N}$, the null hypothesis is rejected. Q_q denotes the quantile of the Q distribution.

3.3.2. Panel unit root tests

We proceed further with testing the unit root by employing Im Pesaran and Shin (CIPS) test (Im et al., 2003) and cross-sectionally augmented dicky fuller (CADF) test (Pesaran, 2007) because these tests can address the issue of cross-sectional dependence. Many researchers have used these tests in the presence of cross-sectional dependence (Syed et al., 2022; Rahman and Sultana, 2022; Kang et al., 2021). In a panel with T time and N cross-sectional units, Pesaran (2007) used a dynamic heterogeneous model as follows:

$$Y_{i,t} = (1-\delta_i)\mu_i + \delta_i Y_{i,t-1} + u_{i,t} \tag{7}$$

Where, $i = 1,\ldots..,N$ and $t = 1,\ldots.,T$.

One-factor disturbance structure with the given initial values is given as:

$$u_{i,t} = \lambda_i f_t + e_{i,t} \tag{8}$$

The f_t is a common factor which is serially uncorrelated with zero mean and constant variance. Further, the Eqs. (7) and (8) can be written

Table 3
Descriptive Statistics.

Variables	Obs	Mean	Std. Dev.	Min	Max	Skew.	Kurt.
REC	558	68.531	22.659	8.94	98.27	-1.069	3.266
FDev	558	20.091	23.73	0.491	142.422	3.308	13.954
HC	558	1.762	0.432	1.088	2.939	0.774	2.851
GDPC	558	1815.22	1735.41	270.737	7662.46	2.131	6.375
FDI	558	4.393	8.788	-11.199	103.337	6.402	57.844
GE	558	27.335	19.81	0.948	81.731	.893	3.017
RQ	558	30.997	18.591	0.49	83.654	.597	2.884

Source: Authors' calculations

Table 4
Matrix of Correlations.

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)
(1) REC	1.000						
(2) FDev	-0.683	1.000					
(3) HC	-0.519	0.479	1.000				
(4) GDPC	-0.611	0.627	0.729	1.000			
(5) FDI	0.084	-0.089	-0.035	-0.082	1.000		
(6) RQ	-0.642	0.593	0.370	0.529	-0.124	1.000	
(7) GE	-0.676	0.607	0.466	0.549	-0.135	0.915	1.000

Source: Authors' estimation

as:

$$\Delta Y_{i,t} = \alpha_i - (1-\delta_i)\lambda_{i,t-1} + \lambda_i f_t + e_{i,t} \quad (9)$$

Where $\alpha_i = ((1-\delta_i)\mu_i$ and $\Delta Y_{Ii,t} = \lambda_{i,t} - Y_{i,t-1}$. The following cross-sectionally augmented dicky fuller (CADF) regression is proposed:

$$\Delta Y_{i,t} = \alpha_i + b_i Y_{i,t-1} + c_i \overline{Y}_{t-1} + d_i \Delta \overline{Y}_t + \epsilon_{i,t} \quad (10)$$

Where $\overline{Y}_t = \frac{1}{N}\sum_{i=1}^{N} Y_{i,t}, \Delta\overline{Y}_t = \frac{1}{N}\sum_{i=1}^{N}\Delta Y_{i,t}$, and $\epsilon_{i,t}$. Cross-sectionally augmented version of the test is given below:

$$CIPS = \frac{1}{N}\sum_{i=1}^{N} CADF_i \quad (11)$$

3.3.3. Testing for heteroscedasticity and autocorrelation

Panel data models provide inefficient results in case of autocorrelation in the errors and if the error process is heteroscedastic within the cross-sections. Therefore, it is important to investigate the presence of these issues. This study used Modified Wald to check the groupwise heteroscedasticity[4] (Baum, 2001). Moreover, the Wooldridge test[5] (Wooldridge, 2010) is employed to check autocorrelation. The Wald test follows Chi-square distribution, whereas the Wooldridge test is based on F-distribution.

The modified Wald test statistic is given as:

$$W = \sum_{i=1}^{N_g} \frac{\widehat{\sigma}_i^{\,2} - \widehat{\sigma}^2}{V_i} \quad (12)$$

Contrary to the Lagrange Multiplier and standard Wald test, the modified Wald test performs better even when the assumption of normality of errors is violated, and follows the asymptotic property (Baum, 2001). The Wooldridge test for autocorrelation also provides robust results in the case of both balanced and unbalanced panel data with no gaps in the time series (Drukker, 2003).

3.3.4. Estimation techniques and robustness

Because of the prevalence of cross-sectional dependence, heteroscedasticity, and autocorrelation in the model, the standard panel data models offer inefficient results. Hence, this study employs a panel-corrected standard error (PCSE) technique. This is an appropriate technique because it can address these problems, particularly in the case of small panels (Marques and Fuinhas, 2012; Bailey and Katz, 2011; Cameron and Trivedi, 2009; Jönsson, 2005). Beck and Katz (1995) proposed a covariance matrix which provides the PCSE. In this matrix, the panel-corrected standard errors are based on the square root of the diagonal terms.

$$COV(b) = (X'X)^{-1}(X'(\Phi \bigotimes I_T)X)(X'X)^{-1} \quad (13)$$

Where, Φ denotes an $N \times N$ matrix withi_{th} andj_{th} term estimated by:

$$\left(\sum_{t=1}^{T} \widehat{e}_{i,t}\widehat{e}_{j,t}\right) \Big/ T \quad (14)$$

The FGLS technique is applied to check the robustness of the results. The logic behind the choice of FGLS is that this technique can tackle the problems of heteroscedasticity, autocorrelation, and cross-sectional dependence (Le and Nguyen, 2019; Cameron and Trivedi, 2009).

4. Empirical results and discussion

The results of cross-sectional dependence are reported in Table 5. The probability (p) value in the CD test is significant at a 10% level, hence the null hypothesis of no cross-sectional dependence is rejected. Similarly, the Frees' test statistic is greater than the critical value, it also indicates that there exists cross-sectional dependence in the data. The results of the order of integration of CIPS and CADF tests are presented in Tables 6 and 7, respectively. The p-values indicate that all the variables except FDI are stationary at first difference. No variable is found to be stationary at the second difference. At this step, we used the modified Wald test and Wooldridge test to know the heteroscedasticity and autocorrelation, respectively (Table 8). The results show that there exists groupwise heteroscedasticity and autocorrelation in the model. To this end, the impact of human capital, FDI, financial development, institutional quality, and GDP per capita on renewable consumption is empirically estimated by employing the PCSE model. The empirical results are reported in Tables 9 and 10. The findings indicate that the level term of GDP per capita is inversely related to renewable consumption. However, the square term of the GDP per capita is positively

Table 5
The Results of cross-sectional dependence tests.

Test	Value of off-diagonal elements	Test statistic	P-value/Critical value
Pesaran CD test	0.408	-1.889	0.059*
Friedman's test	0.406	12.23	0.102
[a]Frees' test	0.408	5.419	0.2763***

[a]The critical value of the Q distribution at 1% level of significance is 0.2763, at 5% it is 0.1888, and at 10% this value is 0.1438
Source: Authors' estimation. Note: *** denotes significance at 99%, ** denotes significance at 95%, and * denotes significance at a 90% confidence interval.

[4] Null hypothesis: H0: No heteroscedasticity
[5] Null hypothesis: H0: No autocorrelation

Table 6
The Results of the CIPS unit root test.

Variable	CIPS Statistic						Decision
	I (0)			I (1)			
	With no constant trend	With constant	With constant and trend	With no constant and trend	With constant	With constant and trend	
REC	-1.36	-1.92	-1.79	-3.30***	-3.11***	-3.26***	I (1)
HC	-0.18	-1.53	-2.11	-1.79***	-1.69	-2.95***	I (1)
FDev	-2.19***	-2.63	-2.54	-3.67***	-3.75***	-4.187***	I (1)
GE	-1.04	-2.00	-2.51	-3.92***	-4.06***	-4.18***	I (1)
RQ	-1.43	-1.61	-2.43	-3.96	-4.12***	-4.06***	I (1)
GDPC	-1.36	-1.59	-1.89	-3.03***	-3.27***	-3.53	I (1)
FDI	-1.52	-2.96**	-3.52***	-5.07***	-5.06***	-5.03***	I (0)

Source: Authors' estimation. Note: *** denotes significance at 99%, and ** denotes significance at 95% confidence interval.

Table 7
The Results of the CADF unit root test.

Variable	CADF P-Value				Decision
	I (0)		I (1)		
	With constant	With constant and trend	With constant	With constant and trend	
REC	0.165	0.781	0.000***	0.001***	I (1)
HC	0.784	0.631	0.000***	0.000***	I (1)
FDev	0.662	0.531	0.000***	0.000***	I (1)
GE	0.492	0.651	0.000***	0.000***	I (1)
RQ	0.676	0.796	0.000***	0.005***	I (1)
GDPC	0.847	0.805	0.000***	0.000***	I (1)
FDI	0.426	0.001***	0.000***	0.005***	I (0)

Source: Authors' estimation. Note: *** denotes significance at a 99% confidence interval.

Table 8
Results of Heteroscedasticity and Autocorrelation.

Test	Test statistic	P-Value	Conclusion
Modified Wald test for group-wise heteroscedasticity	2842	0.000	Heteroscedasticity exists
Wooldridge test for autocorrelation	111.358	0.000	Autocorrelation exists

Source: Authors' estimation.

Table 9
The Results of PCSE and FGLS estimations. The dependent variable is REC.

VARIABLES	(1) PCSE	(2) PCSE	(3) FGLS	(4) FGLS
GDPC	-0.0154***	-0.0154***	-0.0118***	-0.0115***
	(0.000495)	(0.000524)	(0.00150)	(0.00153)
$GDPC^2$	1.98e-06***	2.06e-06***	8.73e-07***	8.39e-07***
	(8.97e-08)	(9.50e-08)	(1.89e-07)	(1.88e-07)
HC	-2.590***	-6.175***	-8.204***	-8.563***
	(0.862)	(0.873)	(2.417)	(2.432)
FDev	-0.305***	-0.305***	-0.144***	-0.133***
	(0.0197)	(0.0158)	(0.0290)	(0.0283)
FDI	-0.0703	-0.0573	-0.00945	-0.00871
	(0.0453)	(0.0448)	(0.0147)	(0.0151)
GE	-0.433***		-0.0820***	
	(0.0512)		(0.0238)	
RQ		-0.450***		-0.0927***
		(0.0383)		(0.0255)
Constant	105.8***	113.8***	106.0***	107.0***
	(1.739)	(2.066)	(3.626)	(3.711)
Observations	558	558	558	558
R-squared	0.599	0.599		
Number of id	31	31	31	31

Source: Authors' estimation. Note: *** denotes significance at 99%, and ** denotes significance at 95% confidence interval. (Standard errors in parentheses)

Table 10
Indirect effect of human capital on renewable energy consumption.

VARIABLES	(1) PCSE	(2) FGLS
GDPC	-0.0136 * **	-0.0103 * **
	(0.00152)	(0.00245)
HC	-16.40 * **	-13.90 * **
	(1.166)	(2.783)
FDev	-0.336 * **	-0.139 * **
	(0.0141)	(0.0296)
FDI	-0.0552	-0.00732
	(0.0537)	(0.0152)
HC*GDPC	0.00550 * **	0.00214 * *
	(0.000666)	(0.000971)
RQ	-0.469 * **	-0.0924 * **
	(0.0419)	(0.0257)
Constant	123.3 * **	112.2 * **
	(2.864)	(4.658)
Observations	558	558
R-squared	0.534	
Number of id	31	31

Source: Authors' estimation. Note: *** denotes significance at 99%, and ** denotes significance at 95% confidence interval. (Standard errors in parentheses)

associated with renewable energy consumption. Contrary to the results from (Saadaoui and Chtourou, 2022; Shahbaz et al., 2022a; Akintande et al., 2020; Ozdeser et al., 2021), this finding is in line with (Elheddad et al., 2022; Raza et al., 2020; Qayyum et al., 2021). This finding also conforms with the environmental-Kuznets curve type hypothesis (Kuznets, 1963), which states that at the initial stages of the development process, pollution (dirty energy, and emissions) rises. But it eventually falls when a country attains a particular level of development. These findings indicate that at the initial stages of economic development, the GDP per capita tends to decrease renewable energy consumption, whereas, after a certain point, it has a positive impact on renewable energy consumption. P-values of both the level and square term of the GDP per capita are significant at a 99% confidence interval. The results are aligned with the empirical findings of Wang and Wang (2020) and Wang and Wang (2022).

The impact of human capital is estimated in two ways. First, direct impact and second indirect impact through GDP per capita. The direct effect of human capital is robust and negative across all the estimated equations. It is also statistically significant with the p-value less than 0.01. This finding indicates that human capital growth retards the energy transition in the Sub-Saharan Africa. A possible explanation of this relationship is that the improvement in human capital is a slow process (Stokey, 2015). Moreover, this result is also supported by Hancock (2015) who argued that African countries are in dire need of enhancing the capacity of their human capital to exploit the advantage of renewable energy. Colenbrander et al. (2015) pointed out the shortcomings in Doctorate programs in renewable energy specialization and recommended that the donor institutions play an effective role in overcoming the deficiencies. Likewise, Haselip et al. (2015) stated that human capital is engaged in areas new to them and they need to enhance their capacities through the learning opportunities from the developed countries. In contrast, the direct effect of human capital on renewable energy consumption is positive in developed countries (Khan et al., 2020; Yao et al., 2019). The coefficient of interaction between human capital and GDP per capita is positive, which shows that human capital can exert a positive impact on renewable energy consumption only through the channel of income (Table 10). Similarly, Churchill et al. (2019) argued that technological progress because of human capital accumulation can lead to efficiency in production processes and energy use. Hence, the substitution effect and technology effect of human capital accumulation are dependent on income growth in Sub-Saharan Africa. In contrast to the inferences of Tinta et al. (2021); Olouch et al., (2021); Yao et al. (2019); Rahut et al. (2018), the findings of the present study are supported by Wang et al. (2022); Akintande et al. (2020). Thus, the inadequate capacity of human capital in the sample countries can be attributed to the fall in the share of renewable energy consumption in the region. Furthermore, as mentioned in Section 3, the positive interaction effect of GDP and human capital can be attributed to technological advancement resulting from a skilled and educated workforce and an increase in income levels. An educated population encourages renewable energy policies which are effectively pursued by those countries which attain higher levels of income. Finally, global competitiveness resulted from a skilled workforce and more renewable energy funding and projects are increased with the rise in income levels.

Financial development has a negative impact on renewable energy consumption in Sub-Saharan Africa. The coefficient indicates that an increase in domestic credit provided to the private sector leads to a fall in renewable energy consumption. This result implies that the financial system in the Sub-Saharan African countries promotes the financing of non-renewable energy consumption. This finding is in line with the findings of (Saadaoui and Chtourou, 2022; Godil et al., 2021) and contradictory to the findings of (Ozdeser et al., 2021; Mukhtarov et al., 2020; Thebuho et al., 2022). The foreign direct investment (net inflows) has no significant role in renewable energy consumption in the sample countries. These findings indicate that neither the scale effect nor the technique and composition effects of foreign direct investment have any considerable impact. Elheddad et al. (2022) argued that Multinational companies do not promote renewable consumption. The results also imply that foreign direct investment inflows in the sample countries are not facilitating the transfer of green technology. The inference of the present study is in line with the results of Amoako and Insaidoo (2021); and Akintande et al. (2020). The indicators of institutional quality (government effectiveness and regulatory quality) also show alarming signs. The coefficients indicate that both government effectiveness and regulatory quality cause a decline in renewable energy consumption. These findings reveal that the institutional quality in the Sub-Saharan African countries is not yet capable of fostering the energy transition in the region. Moreover, the literature on the institutions-growth nexus shows that institutional quality primarily promotes economic growth (Hayat, 2019; Berhane, 2018; Nawaz et al., 2014; Valeriani and Peluso, 2011), which in turn causes an increase in non-renewable energy consumption (Yao et al., 2019; Elheddad et al., 2022).

5. Conclusion and policy implications

There are plentiful studies on the determinants of energy consumption in the literature; however, the role of human capital and income on renewable energy consumption is somewhat ignored, particularly in the case of Sub-Saharan Africa. This region is facing extreme climate change threats and energy poverty, which makes the energy transition inevitable for Sub-Saharan Africa (IRENA, 2018). To fill up this research gap, the present study extends the literature by examining the effects of financial development, FDI, institutional quality, and the direct and indirect role of human capital through the channel of GDP on the renewable energy consumption in 31 Sub-Saharan African countries over the period 2002–2019. Renewable energy consumption is measured as a percentage share of total energy consumption. The empirical findings show that GDP per capita affects renewable energy consumption through a U-shape curve. The U-shape reveals that economic growth initially decreases the share of renewable energy consumption in total energy consumption, however after reaching a certain level of income it leads to an increase in the share of renewable energy. The direct effect of human capital is found to be negative in the selected countries. It indicates that human capital lacks the capacity to pursue a transition from non-renewable to renewable energy (Hancock, 2015). This study introduced an interaction variable of human capital and GDP per capita to explore the indirect impact of human capital through economic growth. The coefficient of the interaction variable is found positive. It indicates that the complementary effect of human capital and GDP per capita on renewable energy consumption is positive. Furthermore, the financial development is inversely related to the renewable energy consumption in the selected countries, which indicates some shortcomings in the financial system in terms of green financing in the sample countries. Moreover, the empirical findings show that institutional quality also fails to improve renewable energy consumption and FDI is found to be insignificant in promoting renewable energy consumption. One of the reasons behind the failure of the financial sector, FDI, and institutional framework could be the perceived risk of lenders associated with the stakeholders of clean energy transition, as argued by IRENA (2018). This research provides a novel and insightful contributions on energy transition in sub-Sahara Africa by demonstrating some empirical findings.

Based on the findings of the present study, a simultaneous increase in human capital and GDP is found to be a significant driver of renewable energy consumption. Hence, the Sub-Saharan African countries should focus on improving both human capital and GDP per capita, simultaneously to foster the transition towards clean energy. This goal can be achieved by promoting international collaborations to promote modern education and imports of energy-efficient technologies to enhance the socio-economic capacity of countries to pursue green energy transition. The idea of international collaboration was put forth by Hancock (2015), particularly in the case of Africa. Likewise, Colenbrander et al. (2015) highlighted the importance of enhancing the capacity of human capital for the transition toward clean energy, which can be ensured by embedding the knowledge of renewable technologies and awareness in academic programs and training along with an increase in per capita income. Nevertheless, there is a need to revamp the present financial and institutional frameworks by effective engagement in international climate treaties to achieve the targets of SDG-7. The governments, private enterprises and financial institutions must coordinate to promote crowdfunding to ensure a renewable energy transition (Bourcet and Bovari, 2020; Rahman et al., 2023; Nawaz and Rahman, 2023). In summary, improving GDP per capita along with capacity enhancement of human capital, and financial sector and institutional reforms are key policy choices for Sub-Saharan Africa for a carbon-neutral future.

Like all other studies, this study has also some limitations. For example, renewable energy consumption also depends on government policy and private initiatives. We could not include these factors due to lack of data. We also could not consider the data period beyond 2002–2019. Subject to data availability, future studies should take care of these factors.

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CRediT authorship contribution statement

Ahmad Nawaz: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Resources, Software, Validation, Visualization, Writing – original draft **Mohammad Mafizur Rahman**: Supervision, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Appendix

Table A.1
List of Sub-Saharan African countries included in the analysis.

Countries	
Benin	Madagascar
Bostwana	Malawi
Burkina Faso	Mali
Burundi	Mauritania
Cameroon	Mozambique
Central African Republic	Niger
Congo Democratic Republic	Nigeria
Congo Republic	Rwanda
Cote d'Ivoire	Senegal
Eswatini	Sierra Leone
Gabon	South Africa
Gambia	Sudan
Ghana	Tanzania
Kenya	Togo
Lesotho	Zimbabwe
Liberia	

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