# Financial development, human capital and energy transition: a global comparative analysis

Elvis Achuo
*University of Dschang, Dschang, Cameroon*

Pilag Kakeu
*University of Bamenda, Bambili, Cameroon, and*

Simplice Asongu
*School of Economics, University of Johannesburg, Johannesburg, South Africa and Department of Economic and Data Science, New Uzbekistan University, Tashkent, Uzbekistan*

Received 4 November 2023
Revised 14 January 2024
Accepted 30 January 2024

## Abstract

**Purpose** – Despite the global resolves to curtail fossil fuel consumption (FFC) in favour of clean energies, several countries continue to rely on carbon-intensive sources in meeting their energy demands. Financial constraints and limited knowledge with regards to green energy sources constitute major setbacks to the energy transition process. This study therefore aims to examine the effects of financial development and human capital on energy consumption.

**Design/methodology/approach** – The empirical analysis is based on the system generalised method of moments (SGMM) for a panel of 134 countries from 1996 to 2019. The SGMM estimates conducted on the basis of three measures of energy consumption, notably fossil fuel, renewable energy as well as total energy consumption (TEC), provide divergent results.

**Findings** – While financial development significantly reduces FFC, its effect is positive though non-significant with regards to renewable energy consumption. Conversely, financial development has a positive and significant effect on TEC. Moreover, the results reveal that human capital development has an enhancing though non-significant effect on the energy transition process. In addition, the results reveal that resource rents have an enhancing effect on the energy transition process. However, when natural resources rents are disaggregated into various components (oil, coal, mineral, natural gas and forest rents), the effects on energy transition are divergent. Although our findings are consistent when the global panel is split into developed and developing economies, the results are divergent across geographical regions. Contingent on these findings, actionable policy implications are discussed.

**Originality/value** – The study complements extant literature by assessing nexuses between financial development, human capital and energy transition from a global perspective.

**Keywords** Energy transition, Financial development, Fossil fuel, Human capital, Energy consumption, Eco-innovation

**Paper type** Research paper



The authors are indebted to the editor and reviewers for constructive comments.

International Journal of Energy Sector Management
Emerald Publishing Limited
1750-6220
DOI 10.1108/IJESM-11-2023-0004

## 1. Introduction

Despite the global resolve to curtail fossil fuel consumption (FFC) in favour of clean energies (United Nations, 2015), several countries continue to rely on carbon-intensive sources in meeting their energy demands. The continuous reliance on fossil fuels undermines the attainment of the 7th and 13th sustainable development goals (SDGs) relating to universal access to clean energy and the dampening of the undesirable environmental impacts of climate change, which are believed to heighten with the increasing use of non-renewable energy (İnal *et al.*, 2022; Achuo, 2022; Shafiei and Salim, 2014). Nevertheless, the problem of energy transition has attracted unparalleled interest in the recent past. Thus, the growing interest shown by academics and policymakers as regards energy transition is indicative of the fact that the world is increasingly gaining awareness on the need to substitute fossil fuels with renewable energies.

The energy transition concept has been growing in academic and political circles for more than three decades; first in developed and then in developing countries, giving rise to both theoretical and empirical debates (Leach, 1992; Solomon and Krishna, 2011; Dominković *et al.*, 2018; Li *et al.*, 2020; Jangam *et al.*, 2020; Bouyghrissi *et al.*, 2022; Akram *et al.*, 2023). Addressing the issue of energy transition is central to the achievement of the SDGs, notably SDG-7. Basically, energy transition is the process of replacing fossil fuels with low-carbon energy sources (Jiang and O'Neill, 2004; Araújo, 2014). Specifically, energy transition is a significant structural change in an energy system with respect to the supply and consumption of increasingly environment-friendly energy. Indeed, throughout the process of civilisation and urbanisation (Zhang *et al.*, 2017), people have turned decisively from fossil fuels to more eco-friendly sources of energy to meet their basic needs for cooking, heating and travel.

Though it is natural to switch from one energy source to another depending on local resources, convenience, pollution, technical innovation, cost, energy quality, storage and other factors (Solomon and Krishna, 2011), several studies have questioned the factors that may hinder people from switching energy sources if better options become available. Solomon and Krishna (2011) argued that several interrelated factors can drive energy transition, for instance, the cost of a particular source of energy such as wood may increase, whereas the cost of another source of energy such as coal decreases. Recent decades have been characterised by growing concerns regarding the adverse socioeconomic and environmental impacts resulting from the excessive consumption of non-renewable energy.

However, the global resolve to curtail energy consumption from fossil fuel sources has been hindered to a greater extent by financial constraints (Alsagr and van Hemmen, 2021). Although energy transition investment has witnessed a remarkable increase in recent years, several investors and capital providers around the world remain sceptical as they fear that the pursuit of a net-zero economy may render them non-competitive (White and Case, 2022). Though there is hope of business expansion in new technologies and renewable energy sources, several capital providers still find it difficult to completely divert investments from the traditional carbon-intensive energy sources.

Thus, the slow pace of energy transition across the globe in general and developing countries in particular may be blamed partly on the enormous financial and physical capital requirements associated with the energy transition path. Consequently, Gielen *et al.* (2021) opine that the dream of achieving a net-zero economy by 2050 could remain futile if the global clean energy investment is not more than tripled. Accordingly, the International Renewable Energy Agency (IRENA) asserts that the attainment of the 1.5°C emission scenario outlined in the 2015 Paris Agreement will require yearly investments of US$5.7tn until 2030 (IRENA, 2022).

The World Energy Transitions Outlook equally contends that the attainment of the net-zero economy can be catalysed by redirecting about US$0.7tn worth of annual investments in non-renewable energies towards green technologies. On average, between now and 2050, energy transition investment will have to increase by 4.4 trillion every year (Gielen *et al.*, 2021). While several contemporary studies contend that financial development, respectively, enhances renewable energy consumption (REC) (Shahbaz *et al.*, 2021; Anton and Nucu, 2020) and impedes non-REC (Lei *et al.*, 2022), Zhao *et al.* (2020) argue that financial development heightens both non-renewable and REC.

Besides financial challenges, sociopolitical factors and poor governance (Painuly, 2001) equally constitute major drawbacks to the energy transition drive. To curtail these challenges, stakeholders in the energy sector are encouraged to adopt good governance practices by ensuring a high degree of transparency and accountability in the energy sector. Moreover, Nalan *et al.* (2009) opine that renewable energy development is hindered because policymakers lack the appropriate knowledge as regards clean energy technologies.

Thus, with the hope that increased knowledge development could propel policymakers to take more informed and decisive actions aimed at mitigating the adverse developmental effects of FFC, recent studies have endeavoured to incorporate human capital to energy transition analysis. For instance, in a recent study for G-7 countries, Khan *et al.* (2020) argue that human capital enhances REC. Similarly, Alvarado *et al.* (2021) contend that human capital decreases non-REC, in the context of Organization for Economic Cooperation and Development (OECD) countries.

Therefore, the importance of human capital in enhancing environmental sustainability through carbon-emission abatement cannot be overemphasised. Moreover, as the early works of Becker (1964), human capital development has been shown to have immense importance in the development drive of countries. Thus, from the point of view of human capital theory, investment in education is very important since it enhances future productivity (Psacharopoulos and Patrinos, 2018).

Thus, this study sets out to examine the effects of financial development and human capital on energy consumption. The empirical analyses are based on a global panel of 134 countries, encompassing both developed and developing economies.

The contributions of this study are multifold. Firstly, unlike several extant studies that focus their analysis on either total energy consumption (TEC) or a particular component of energy consumption, this study comprehensively examines the effects of financial development and human capital on both the disaggregated components of energy consumption (renewable and non-renewable) as well as TEC. Moreover, we provide a global comparative analysis with regards to the level of development, geographical region and income level. Finally, we incorporate resource rents into our empirical model as a major determinant of energy transition. This is because of the general conviction that price is a key determining factor for the demand of a commodity. Therefore, questioning the role of resource rents in the energy transition drive is of great importance.

Furthermore, the importance of this study cannot be overemphasised as the results are suggestive of the need for the formulation of appropriate policies aimed at fostering the sustainable use of eco-innovation and green technologies in the financial sector. Moreover, the results make a clarion call on governments to increase investments in human capital development in the fields of eco-innovation.

Our empirical analysis is based on the system generalised method of moments (SGMM) for a panel of 134 countries from 1996 to 2019. The SGMM estimates conducted on the basis of three measures of energy consumption, notably fossil fuel, renewable energy as well as TEC, provide divergent results. Our study finds that while financial development significantly reduces FFC, its effect is positive though non-significant with regards to REC. Conversely, financial development has a positive and significant effect on TEC. Moreover, the results reveal that human capital development has an enhancing though non-significant effect on the energy transition process. In addition, the results reveal that resource rents have an enhancing effect on the energy transition process. However, when natural resources rents are disaggregated into various components (oil, coal, mineral, natural gas and forest rents), the effects on energy transition are divergent. Although our findings are consistent when the global panel is split into developed and developing economies, the results are divergent across geographical regions.

The remainder of the paper is structured as follows. While Section 2 reviews extant literature, Section 3 provides the methodological strategy. The empirical results are presented and discussed in Section 4, whereas the conclusion and policy implications are contained in Section 5.

## 2. Review of salient literature

This section critically reviews extant studies with regards to two strands of literature. While the first strand of literature focuses on the relationship between financial development and energy consumption, the second lays emphasis on the nexus between human capital development and energy consumption.

### *2.1 Financial development and energy consumption*

Although there are several studies on the relationship between financial development and energy consumption, no consensus has been reached (Yue *et al.*, 2019). Results on the link between financial development and energy consumption vary across countries, financial development indicators and methodologies. For instance, employing the autoregressive distributed lag method, Islam *et al.* (2013) found that financial development has a significant and positive impact on energy consumption in the short and long terms in Malaysia. The same approach was adopted by Bekhet *et al.* (2017) and the results show that financial development boosts energy consumption in some Gulf Cooperation Council countries. In a related study, Gómez and Rodríguez (2019) find a negative relationship between financial development and energy consumption. These results are consistent with those of Ouyang and Li (2018), who reported that the comprehensive financial development indicator effectively reduces energy consumption in a panel vector autoregressive model across Chinese provinces. Similarly, Shahbaz *et al.* (2013) found a negative relationship between financial development and energy consumption in the context of South Africa.

In addition, several studies have examined the relationship between financial development and energy consumption in energy transition countries. Tamazian and Rao (2010) suggest that financial development can help improve environmental quality by reducing carbon dioxide emissions. Using China as an example, Zhang (2011) found that financial development has become a major driver of carbon emissions, through increased energy consumption. Nevertheless, Jalil and Feridun (2011) provide clear evidence that financial development in China will reduce energy consumption in the long run. However, this depends on the methodological approach, as the relationship between energy consumption and financial development appears very complex. Other studies have shown that the relationship varies according to indicators of financial development. For example, Sadorsky (2011) finds a positive relationship between financial development and energy consumption when financial development is measured by banking variables such as the ratio of depository bank assets to gross domestic product (GDP).

Exploring the financial development and renewable energy relationship, Anton and Nucu (2020) argue that financial development enhances REC across European Union member countries. Likewise, Shahbaz *et al.* (2021) show that financial development enhances REC across developing countries. Similar results have equally been reported for India (Eren *et al.*, 2019) and China (Zhao *et al.*, 2020). Conversely, in a recent study focussing on the USA, Lahiani *et al.* (2021) conclude that the effects financial development on REC is divergent depending on the measure of financial development. With regards to the financial development and FFC nexus, Zhao *et al.* (2020) contend that non- REC heightens with improvements in financial development. These findings are inconsistent with the results obtained by Lei *et al.* (2022), who argue that while a positive change in financial development constrains non-REC, a negative change in financial development results to increased consumption of fossil fuels in the long run.

Although empirical evidence suggests a significant impact of financial development on energy consumption, Yue *et al.* (2019) conclude on the existence of a non-significant linear relationship between financial development and energy consumption. The authors also show that the effects of financial development on energy consumption are divergent depending on the indicators of financial development. For example, they report that the indicator of stock market development led to a decrease in energy consumption in China and Poland, whereas the development of financial openness reduces energy consumption, except in Georgia and the Kyrgyz Republic.

Furthermore, by examining the link between energy consumption and financial development, Ma and Fu (2020) find that overall financial development has a significant positive impact on energy consumption from a global perspective, and that its two components (financial institution and financial market) have the same effect. Sadorsky (2010) contends that financial development significantly boosts energy consumption when financial development indicators such as market capitalisation to GDP and stock market turnover ratio are used. Riti *et al.* (2017) chose money supply as an indicator of financial development and found that financial development plays an important role in decreasing energy consumption. Zhang (2011) used foreign direct investment (FDI) as one of the indicators of financial development, and the empirical results indicate that financial development has a positive but small influence on energy consumption. Also, adopting FDI as an indicator of financial development, Tamazian and Rao (2010) show that increasing FDI inflows can definitely reduce energy consumption.

Moreover, Chang (2015) applied a traditional panel threshold model to explore the non-linear relationship between financial development and energy consumption. The results show that financial development indicators representing the level of the banking market will increase energy consumption in low-income countries, whereas financial development indicators reflecting the stock market will decrease energy consumption. These results are in contrast to those of Ma and Fu (2020), according to which financial development has a positive impact on energy consumption in developing countries, but no clear effect in developed countries.

Conversely, Leach (1992) examines the substitution of traditional biomass fuels by modern energy sources in the household sector of developing countries and contends that the energy transition process is highly dependent on the size of cities and, within cities, on household income, as the main constraints to the energy transition process are poor access to modern fuels and the high cost of appliances. Similarly, Jiang and O'Neill (2004) conclude that energy transition in China varies greatly from one geographical region to another due to differences in access to different energy sources, prices, climate, income and level of urbanisation. The authors also find that energy use patterns based on people's net income are more consistent with the energy transition model in rural China. Similarly, improvements in the efficiency of existing economic activity can accelerate the substitution of energy sources and lead to further cost reductions in the energy transition process (Solomon and Krishna, 2011). However, given that access to renewable energy is expensive, the energy transition process requires significant financial development to ensure energy efficiency, the use of renewable energy and the development of innovative carbon capture and sequestration techniques to better address environmental issues (Yue et al, 2019; Bayar *et al.*, 2020; Dong *et al.*, 2022; Ahmad *et al.*, 2022).

In view of this literature, it is still very difficult to conclude that financial development cannot be used to limit the increase in energy consumption from a global perspective.

### *2.2 Human capital and energy consumption*

A relatively substantial body of literature exists on the link between human capital and energy consumption (Salim *et al.*, 2017; Akram *et al.*, 2018; Yao *et al.*, 2019) with more or less divergent results. For example, Salim *et al.* (2017) used panel data from the Chinese provinces from 1990 to 2010 to test this relationship and found that human capital has a negative impact on energy consumption. In a related study for India, Akram *et al.* (2018) conclude that human capital reduces energy consumption. In the context of developed countries, Shahbaz *et al.* (2019) report that human capital was found to reduce energy consumption in the USA between 1975 and 2016, which they attribute to substantial investments in higher education levels in the USA. Similarly, Lan *et al.* (2012) confirmed that energy consumption greatly depends on the level of human capital.

Likewise, Churchill *et al.* (2022) explore the nexus among human capital and energy consumption in the UK and reveal the existence of a negative relationship between human capital and energy consumption from both parametric and non-parametric estimations. In addition, the parametric estimates show that in the long term, energy consumption is likely to reduce by 4%–9% following an additional year of schooling. These findings are consistent with the results of Alvarado *et al.* (2021) who contend that non-REC decreases with improvements in human capital in the context of OECD countries. Examining the effect of human capital on energy consumption for a panel of OECD economies over the period 1965–2014, Yao *et al.* (2019) suggest that a one standard deviation increase in human capital reduces overall energy consumption by 15.36%. Separating clean energy consumption from dirty energy consumption, the authors find that a one standard deviation increase in human capital is associated with a 17.33% decrease in dirty energy consumption and an 85.54% increase in clean energy consumption.

Assessing the link between human capital, energy consumption and economic growth, Shahbaz *et al.* (2022) show that human capital development has a negative and statistically significant effect on energy consumption. The results also show a unidirectional causal effect of human capital on all forms of energy consumption. However, the association between economic growth, dirty energy use and clean energy use remains interdependent, indicating a feedback effect.

In a related study, Ahmad *et al.* (2022) examine the effect of financial development, human capital and institutional quality on environmental sustainability in emerging economies and contend that financial development promotes environmental sustainability through human capital. The authors also find that institutional quality reduces the negative environmental impacts of financial development. Equally, Bouyghrissi *et al.* (2022) conclude that REC interacts with financial development and FDI inflows to jointly reduce carbon dioxide emissions in Morocco. Consequently, policymakers should encourage eco-sustainable economic growth by greening the financial sector and reviewing financial globalisation policies, as well as promoting human capital development.

Despite the existence of a relatively vast body of literature examining the relationship between energy transition and socio-economic factors, no consensus has been reached and the links between financial development, human capital and energy transition remain an open debate. This study therefore fills an important gap in literature by providing global comparative evidence of the linkages between financial development, human capital development and energy consumption.

## 3. Empirical strategy

### *3.1 Data and description of variables*

The data used in this study is gotten from varied sources. While most of the variables were essentially sourced from the World Bank database, specifically the World Development Indicators and the Worldwide Governance Indicators, human capital was gotten from the Penn World Tables (PWT Version 10.0). The used data spans from 1996 to 2019 and involves 134 countries, encompassing both developed and developing economies. This time frame and number of countries was largely limited by the availability of data for the variables of interest.

*3.1.1 Dependent variable.* The dependent variable adopted in this study is energy consumption. Unlike most extant studies that limit their analysis of energy consumption either to non-REC (Alvarado *et al.*, 2021) or disaggregate energy consumption into renewable and non-renewable energy (Achuo *et al.*, 2022b), the present study uses the three main measures of energy consumption notably, REC, FFC as well as TEC. While REC is the share of renewable energy in TEC and includes energy from wind, solar, geothermal and tide, FFC is the share of fossil fuel in TEC and includes energy from coal, natural gas, petroleum, gasoline, kerosene, diesel and fuel oil. TEC aggregates energy consumption from both non-renewable and renewable sources. However, similar computations for energy consumption have been used by Khan *et al.* (2020).

*3.1.2 Independent variables.* The principal independent variable used in this study is financial development, captured by domestic credit to the private sector (%GDP). The use of this measure is consistent with Achuo *et al.* (2022b). While Sadorsky (2010) posits that financial development significantly boosts energy consumption, Riti *et al.* (2017) contend that financial development decreases energy consumption. However, Yue *et al.* (2019) argue that the effects of financial development on energy consumption are divergent depending on the indicators of financial development as well as the measure of energy consumption. Consequently, a positive or negative relation is expected in this study.

The apparent correlations between financial development and the various measures of energy consumption are highlighted in Figure 1. While TEC and REC are seen to decrease with financial development, the relation is shown to be positive with regards to FFC.

Another key explanatory variable used in this study is human capital. Human capital is proxied by the human capital index, which captures changes in human capital development across countries and time. Hence, this index, which is adjusted with expected returns to education, varies across countries on the basis of different qualification levels. A similar measure of human capital has been adopted by competent contemporary studies (Khan *et al.*, 2020; Alvarado *et al.*, 2021). Khan *et al.* (2020) found a negative relationship between human capital and energy consumption (notably, non-REC and TEC) across G-7 countries. Similar results have been reported by Alvarado *et al.* (2021) in the context of OECD countries. Thus, consistent with extant studies, a negative or positive relationship is expected between human capital and energy consumption.

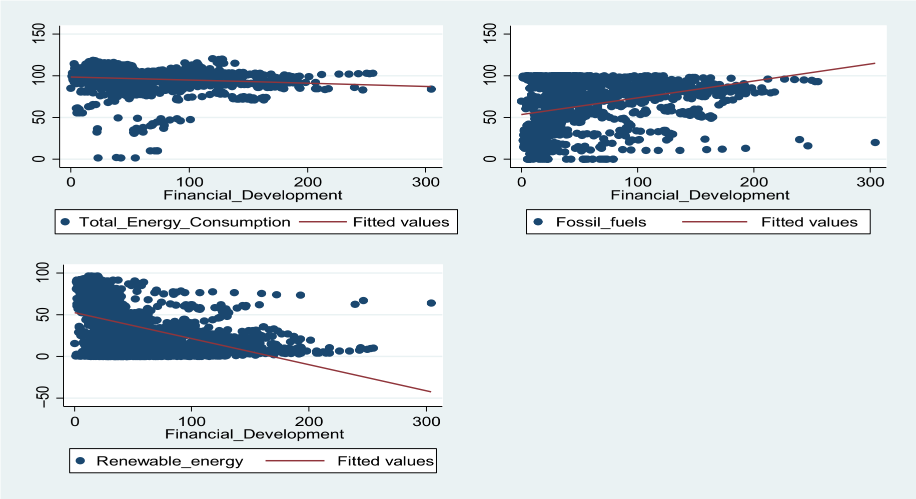


**Figure 1.**
Correlation between financial development and energy consumption

**Source:** Authors' own creation

*3.1.3 Control variables.* This study uses several control variables including, FDI, internet penetration, women empowerment, governance, trade openness, GDP per capita, urbanisation and resources rents. The inclusion of these variables in the empirical model is consistent with contemporary literature (Asongu *et al.*, 2020, 2019, 2018; Miamo and Achuo, 2022; Nchofoung *et al.*, 2022). The complete definition, measurement, descriptive statistics and correlation analysis of all the modelled variables are presented in the Appendix.

### *3.2 Model specification*

Inspired by the human capital augmented neoclassical growth model and consistent with contemporary extant studies (Khan *et al.*, 2021; Fang and Chang, 2016; Sadorsky, 2010), we specify the following functional model in which energy consumption is primarily explained by financial development and human capital:

$$Y_{it} = f(FD_{it},\ HC_{it}, Z_{it}) \tag{1}$$

where $Y$ is a vector of three dependent variables that capture energy consumption. The various measures of energy consumption include, REC, FFC and TEC. The subscripts $i$ and $t$ denote the cross-sections and time periods, respectively. While $FD$ represents financial development, $HC$ implies human capital development and $Z$ is a vector of control variables.

Consistent with Fang and Chang (2016), equation (1) can be written explicitly as follows or equation (2):

$$EC_{it} = \varnothing_0 + \varnothing_1 FD_{it} + \varnothing_2 HC_{it} + \varnothing_m Z_{it} + \omega_{it} \tag{2}$$

where $EC$ denotes energy consumption as defined in equation (1); $\varnothing_0$ is the intercept; $\varnothing_1$, $\varnothing_2$ and $\varnothing_j$ are slope coefficients; $\omega$ is the stochastic error term; whereas the rest of the variables are defined as before, $m$ symbolises the number of control variables included in $Z$.

*3.3 Estimation procedure*

To empirically examine the effects of financial development and human capital formation on energy consumption, we make use of the GMM estimation procedure developed by Arellano and Bover (1995). This modelling approach is suitable when the cross sections (*N*) exceed the number of time periods (*T*), as evidenced in this study. Moreover, the GMM method uses internal instruments and controls for unobserved heterogeneity and double causality.

However, in addition to the strengths of the GMM estimator, the study adopts the system GMM estimation technique propounded by Roodman (2009), to account for the inherent problem of cross-sectional dependence in panel data series. This is consistent with Achuo *et al.* (2022a) who contend that the system GMM controls for cross-sectional dependence and instrument proliferation.

Moreover, this approach is robust because of its ability to incorporate both a level equation or equation (3) and a difference equation or equation (4). Thus, consistent with Asongu and Odhiambo (2019), the following standard system GMM procedure is specified. It is dynamic because the lagged outcome variable is included in the equation:

$$EC_{it} = \theta_0 + \varnothing_1 EC_{i(t-1)} + \varnothing_2 FD_{it} + \varnothing_3 HC_{it} + \sum_{j=1}^{m} \varnothing_j Z_{j,i(t-1)} + \alpha_i + \beta_t + \omega_{it} \tag{3}$$

$$\begin{aligned} EC_{it} - EC_{i(t-1)} = {} & \varnothing_1 \left(EC_{i(t-1)} - EC_{i(t-2)}\right) + \varnothing_2 \left(FD_{it} - FD_{i(t-1)}\right) + \varnothing_3 \left(HC_{it} - HC_{i(t-1)}\right) \\ & + \sum_{j=1}^{m} \varnothing_j \left(Z_{j,i(t-1)} - Z_{j,i(t-2)}\right) \ (\beta_t - \beta_{t-1}) + \left(\omega_{it} - \omega_{i(t-1)}\right) \end{aligned} \tag{4}$$

where $\alpha$ represents the country fixed effects; $\beta$ denotes the time invariant constant; the rest of the variables are defined as before.

Nevertheless, to address the problems with regards to identification, simultaneity and restriction of modelled variables, the study treats all the explanatory variables included in the estimated model as endogenous variables, in accordance with Nchofoung *et al.* (2022).

## 4. Empirical results

This section provides a critical discussion of the empirical findings of the study. Firstly, we discuss the baseline findings with regards to the effect of financial development and human capital on energy consumption. Then, we provide sensitivity analysis of the baseline results with regards to regional groupings and level of development. Finally, we investigate the sensitivity of the baseline findings in the presence of natural resources.

*4.1 Baseline results*

The results relating to the effects of financial development and human capital formation on energy consumption are presented on Table 1. The SGMM estimates conducted on the basis of three measures of energy consumption, notably, fossil fuel, renewable energy as well as TEC, provide divergent results. For instance, while financial development significantly reduces FFC, its effect is positive though insignificant with regards to REC. The insignificant effect of financial development on energy consumption is in congruence with Yue *et al.* (2019), who opine that the effects of financial development on energy consumption vary depending on the indicators of financial development adopted. Conversely, when fossil fuel and REC are aggregated into TEC, the effect of financial development is positive and significant. This

| Variables | (1) Fossil fuels | (2) Dependent variable Renewable energy | (3) Total energy consumption |
|---|---|---|---|
| Financial development | −0.196** (0.0823) | 0.0201 (0.0746) | 0.0824*** (0.0264) |
| Internetpenetartion | −1.451*** (0.287) | 1.697*** (0.252) | 0.232 (0.142) |
| Urbanisation | 0.715*** (0.174) | −0.280*** (0.0867) | 0.00949 (0.119) |
| Human capital | 0.471 (1.985) | 0.563 (1.951) | 0.491 (1.140) |
| Women empowerment | 0.494* (0.252) | −1.095*** (0.162) | −0.512*** (0.0844) |
| FDI | −1.263*** (0.379) | 2.031*** (0.248) | 0.400*** (0.0782) |
| GDP per capita (log) | 30.82*** (7.019) | −36.48*** (3.332) | −9.022*** (3.054) |
| Trade | 0.179* (0.0862) | −0.229*** (0.0601) | −0.137*** (0.0249) |
| Governance | −2.780 (4.582) | 8.614* (4.250) | 0.447 (2.817) |
| Constant | −237.7*** (53.41) | 338.6*** (25.81) | 184.8*** (22.52) |
| Observations Instruments | 1,185 21 | 1,606 21 | 1,185 21 |
| AR(1)_Prob | 0.00109 | 0.0105 | 0.00213 |
| AR(2)_Prob | 0.486 | 0.555 | 0.698 |
| Hansen_Prob | 0.164 | 0.128 | 0.608 |
| Fisher | 489.3*** | 759.7*** | 85.29*** |

**Notes:** Standard errors in parentheses; lagged outcome variables are involved in the GMM specifications. ***$p < 0.01$; ** $p < 0.05$; * $p < 0.1$
**Source:** Authors' own creation

**Table 1.**
System GMM results of the effect financial development and human capital on energy consumption

implies that financial development leads to an increase in overall energy consumption. Although these results corroborate the earlier findings of Ma and Fu (2020), they however contradict the findings of Ouyang and Li (2018), who conclude that financial development effectively reduces energy consumption. Overall, our results are largely consistent with Lei *et al.* (2022) who argue that in the long run, a negative change in financial development increases dirty fuel consumption, whereas a positive change in financial development constrains FFC in favour of clean energy. This finding has policy implications as it is indicative of the urgent need for the formulation of appropriate policies aimed at fostering the sustainable use of eco-innovation and green technologies in the financial sector.

As concerns the role of human capital on energy consumption, its effect is positive but non-significant for various measures of energy consumption. The insignificant effect is suggestive of the fact that more still needs to be done in terms of human capital development in the field of clean energy. Therefore, it is imperative for governments to increase investments in human capital formation, especially in the fields of eco-innovation. Policymakers have to step up efforts aimed at sensitising people on the importance of clean energy consumption in the present dispensation characterised by growing environmental pollution orchestrated by increasing dependence of humanity on dirty energy consumption (Achuo *et al.*, 2022b). However, the role of human capital on energy consumption as revealed in this study is inconsistent with the findings of Shahbaz *et al.* (2022) who found a statistically negative and significant effect of human capital on all measures of energy consumption in China. Notwithstanding, several studies (Churchill *et al.*, 2022; Shahbaz *et al.*, 2019; Akram *et al.*, 2018; Salim *et al.*, 2017) have demonstrated the importance of human capital in enhancing the energy transition process in the context of developed economies.

Likewise, Table 1 reveals that other control variables like internet penetration and FDI have an enhancing effect on the energy transition process. This finding, particularly for FDI, is consistent with extant studies by Tamazian and Rao (2010) and Zhang (2011). These authors use FDI as a proxy for financial development and conclude that increasing FDI inflows definitely inhibit dirty energy consumption.

*4.2 Robustness checks*

In checking for the robustness of the baseline findings presented on Table 1, we first disaggregate the global panel of 134 countries into developed and developing economies, and then into different geographical regions, before considering the role of natural resources. This is consistent with Nchofoung *et al.* (2021). The sensitivity analyses of the effects of financial development and human capital on the energy transition process with regards to regional groupings and level of development are highlighted on Tables 2 and 3, whereas the results highlighting the role of natural resources are outlined on Tables 4 and 5. The sensitivity analyses are also designed to take into account comparative dynamics to improve room for policy implications.

The results reveal that financial development has an enhancing effect on the energy transition process in the context of developed economies, as evidenced by the respective significant negative and positive coefficients as regards FFC (Table 2) and REC (Table 3). Conversely, financial development seems to be an impediment to the energy transition process in the context of developing economies. This is because increased financial development rather exacerbates FFC (Table 2) while curtailing REC (Table 3). This disturbing situation in the context of developing countries may however be justified by the fact that several developing countries are yet less concerned with energy transition given that most of these countries are still in dire need of basic energy needs like electrification. This is further justified by the financial constraints that characterise developing countries, as the energy transition process requires huge financial and physical capital (Alsagr and van Hemmen, 2021).

The results in Tables 2 and 3 further reveal that financial development impedes the energy transition process in the context of sub-Saharan African countries as well as the East Asia and Pacific region. The results show that financial development engenders an expansion in the consumption of fossil fuels. The increase in FFC is likely to exacerbate environmental pollution, thereby undermining global efforts towards pollution mitigation. However, these results corroborate the findings of Qudrat-Ullah and Nevo (2021) who posit that environmental sustainability does not seem to be a priority of developing countries (particularly African economies) towards the attainment of the global SDGs.

Moreover, although the effect of human capital on energy consumption is insignificant, the respective negative (Table 2) and positive (Table 3) coefficients with regards to fossil fuel and REC both in the context of developed and developing countries is indicative of the importance of human capital in the energy transition process. The insignificant effect may simply point to the inefficacy of the efforts expended so far by policymakers in sensitising people on the importance of green technologies. This therefore calls for more synergy between national and international bodies with regards to the design and implementation of policies aimed at encouraging the use of clean energy. These policies must be accompanied by increased funding for the exponentiation of training opportunities on energy transition. Indeed, human capital development is likely to enhance the energy transition process (Churchill *et al.*, 2022; Shahbaz *et al.*, 2019) and ensure the attainment of a net-zero global economy.

Looking at the role of natural resources on the energy transition process, Tables 4 and 5 reveal that the effects of natural resources on energy consumption are divergent depending on the type of resource and measure of energy consumption. Generally, total resource rents have an enhancing effect on the energy transition process. For instance, while Table 4 shows that there exists a significantly negative relationship between total resource rents and FFC

**Table 2.**
Sensitivity of the system GMM and Driscoll–Kraay estimates across geographical regions and level of development

| | Dependent variable: fossil fuel consumption | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Variables | (1) Developed | (2) Developing | (3) EAP | (4) ECA | (5) LAC | (6) MENA | (7) South Asia | (8) SSA |
| Financial development | −0.0533* (0.0288) | 0.255*** (0.0181) | 0.299*** (0.0850) | −0.0239 (0.0611) | −0.194 (0.286) | −0.0495* (0.0243) | 0.111 (0.220) | 0.320*** (0.107) |
| Internet penetration | −0.790*** (0.0955) | −0.570*** (0.109) | −0.164* (0.0857) | −0.777*** (0.212) | 0.333 (0.242) | −0.0856* (0.0395) | −2.142*** (0.314) | −0.221 (0.203) |
| Urbanisation | 0.440*** (0.0563) | 0.503*** (0.0584) | 2.083*** (0.626) | 0.0874 (0.271) | 1.085** (0.419) | 0.0518 (0.0466) | 2.816*** (0.270) | 0.0668 (0.213) |
| Human capital | −3.050 (2.639) | −1.205 (1.425) | −2.556 (1.723) | −0.932 (0.916) | −0.466 (0.906) | −0.380** (0.168) | 1.124** (0.262) | 0.293 (1.268) |
| Women empowerment | −1.316*** (0.133) | 0.0506 (0.0927) | 1.410** (0.577) | −0.558 (0.353) | 0.546 (0.478) | −0.237*** (0.0556) | −0.0999 (0.196) | −0.111 (0.340) |
| FDI | 0.343*** (0.117) | −0.429*** (0.110) | −0.276 (0.295) | 0.0680 (0.0718) | −0.533 (0.994) | 0.0126* (0.00670) | −0.515 (1.910) | −0.231 (0.290) |
| GDPpercapita (log) | 13.99*** (2.793) | 13.57*** (2.591) | −22.14 (14.06) | 11.06*** (3.912) | −2.899 (10.46) | 2.312 (1.431) | 21.83*** (2.949) | 6.865 (4.399) |
| Trade | −0.160*** (0.0285) | −0.131*** (0.0137) | 0.000803 (0.0319) | 0.00503 (0.0381) | 0.281 (0.203) | 0.0228 (0.0140) | −0.477*** (0.0539) | −0.00968 (0.0521) |
| Governance | 9.751*** (2.100) | −3.152* (1.592) | −8.619 (8.360) | 3.892** (1.643) | −6.866 (5.349) | −1.996 (1.945) | 6.353 (6.178) | 15.17*** (3.415) |
| Constant | −30.46 (19.87) | −80.82*** (19.60) | 110.5 (82.05) | 10.60 (20.58) | −12.41 (65.73) | 77.29*** (11.91) | −140.9*** (25.65) | −17.07 (27.83) |
| Observations | 380 | 805 | 164 | 443 | 266 | 154 | 62 | 278 |
| Instruments | 21 | 21 | | | | | | |
| AR(1)_Prob | 0.000533 | 0.000165 | | | | | | |
| AR(2)_Prob | 0.655 | 0.672 | | | | | | |
| Hansen_Prob | 0.228 | 0.176 | | | | | | |
| Adj. $R$-squared | | | | 0.353 | 0.481 | 0.668 | | 0.778 |
| Fisher | 1002*** | 3494*** | 35.87*** | 11.57*** | 11.25*** | 288.1*** | 354.0*** | 368.5*** |

**Notes:** EAP = East Asia and Pacific; ECA = Europe and Central Asia; LAC = Latin America and the Caribbean; MENA = Middle East and North Africa; South Asia = 6; SSA = Sub-Saharan Africa Lagged outcome variables are involved in the GMM specifications. Standard errors in parentheses ***$p < 0.01$; ** $p < 0.05$; * $p < 0.1$
**Source:** Authors' own creation

**Table 3.** Sensitivity of the system GMM and Driscoll–Kraay estimates across geographical regions and level of development

| Variables | (1) Developed | (2) Developing | (3) EAP | (4) ECA | (5) LAC | (6) MENA | (7) South Asia | (8) SSA |
|---|---|---|---|---|---|---|---|---|
| | Dependent variable: renewable energy consumption | | | | | | | |
| Financial development | 0.116*** (0.0380) | −0.222*** (0.0160) | −0.351*** (0.0567) | 0.0200 (0.0475) | −0.0325 (0.236) | 0.0635*** (0.0206) | 0.0908 (0.111) | −0.319*** (0.0785) |
| Internet penetration | 1.282*** (0.146) | 0.182** (0.0632) | 0.412*** (0.0617) | 0.537*** (0.176) | −0.305* (0.167) | −0.00930 (0.00891) | 2.084*** (0.130) | −0.181 (0.151) |
| Urbanisation | −0.510*** (0.162) | −0.435*** (0.0510) | −2.171*** (0.377) | −0.413 (0.270) | 0.0549 (0.214) | −0.157*** (0.0478) | −2.087*** (0.0467) | −0.113 (0.108) |
| Human capital | 9.070 (6.416) | 1.907 (2.776) | 0.216 (0.645) | −0.0180 (0.491) | −0.172 (0.958) | 0.216 (0.180) | −0.422 (0.511) | −0.375 (0.691) |
| Women empowerment | 0.0517 (0.147) | 0.125** (0.0527) | −0.967*** (0.301) | 0.648** (0.245) | −0.782* (0.406) | 0.246*** (0.0527) | 0.362** (0.103) | 0.144 (0.182) |
| FDI | −0.497*** (0.110) | 0.0955 (0.205) | 0.484*** (0.110) | −0.0226 (0.0496) | −0.300 (0.544) | −0.0152** (0.00580) | −1.192 (0.619) | 0.132*** (0.0414) |
| GDPpercapita (log) | −29.72*** (3.304) | −9.680*** (1.575) | 27.97** (11.01) | −5.713 (4.405) | −14.63*** (5.003) | −0.866 (1.215) | −15.31*** (2.438) | −3.844 (4.843) |
| Trade | −0.00927 (0.0179) | −0.0573*** (0.0153) | 0.0104 (0.0280) | −0.0686** (0.0287) | −0.101 (0.118) | −0.0306*** (0.00935) | 0.216** (0.0512) | −0.0799* (0.0394) |
| Governance | −1.578 (7.532) | 0.509 (1.060) | −5.936 (10.43) | −3.075*** (0.969) | 6.168 (5.918) | 4.940** (1.860) | −4.353 (3.597) | −14.83*** (3.317) |
| Constant | 247.3*** (35.69) | 0 (0) | −61.03 (74.91) | 69.29*** (22.07) | 184.7*** (33.36) | 21.64* (10.38) | 190.6*** (15.77) | 103.5*** (34.23) |
| Observations | 444 | 1,162 | 180 | 443 | 293 | 171 | 62 | 436 |
| Instruments | 21 | 31 | | | | | | |
| AR(1)_Prob | 0.000631 | 0.000108 | | | | | | |
| AR(2)_Prob | 0.738 | 0.761 | | | | | | |
| Hansen_Prob | 0.212 | 0.615 | | | | | | |
| Adj. $R$-squared | | | 0.887 | 0.395 | 0.463 | | 0.976 | |
| Fisher | 1,131*** | 19,073*** | 105.8*** | 8.707*** | 9.630*** | 228.2*** | 777.3*** | 223.1*** |

**Notes:** Standard errors in parentheses ***$p < 0.01$; **$p < 0.05$; *$p < 0.1$ Lagged outcome variables are involved in the GMM specifications
**Source:** Authors' own creation

**Table 4.** System GMM estimates on the role of natural resources on the energy transition process

| | Dependent variable: fossil fuel consumption | | | | | |
|---|---|---|---|---|---|---|
| Variables | (1) | (2) | (3) | (4) | (5) | (6) |
| Financial development | 0.0204 (0.0363) | −0.000853 (0.0574) | 0.0812** (0.0335) | −0.0194 (0.0200) | −0.0426 (0.0941) | −0.211** (0.0850) |
| Internet penetration | −0.557* (0.298) | −0.285 (0.216) | −0.647*** (0.0723) | −0.579* (0.275) | −1.226*** (0.370) | −1.447*** (0.276) |
| Urbanisation | 0.687** (0.253) | 0.414** (0.155) | 0.384* (0.204) | 0.647** (0.252) | 0.364 (0.218) | 0.298 (0.182) |
| Human capital | 0.453 (1.734) | 5.550 (10.77) | 0.491 (1.358) | −0.647 (1.753) | −1.016 (2.339) | 0.134 (1.823) |
| Women empowerment | −0.181 (0.196) | −0.268* (0.136) | 0.930*** (0.192) | 0.0139 (0.144) | 0.0756 (0.259) | 0.508* (0.247) |
| FDI | −0.447** (0.190) | 0.0437** (0.0201) | 0.538** (0.249) | −0.252 (0.189) | −1.395** (0.517) | −1.070*** (0.347) |
| GDP per capita (log) | 15.06* (7.580) | 12.37** (5.548) | 18.73*** (2.543) | 16.22** (6.978) | 28.50** (10.31) | 32.26*** (6.495) |
| Trade | −0.0197 (0.0369) | −0.0557* (0.0269) | −0.228*** (0.0421) | −0.0674 (0.0427) | 0.0524 (0.0975) | 0.152** (0.0598) |
| governance | −10.61* (5.735) | −3.472 (4.345) | −10.53*** (2.751) | −8.476* (4.847) | −0.478 (6.499) | 1.839 (3.736) |
| Resources rents | −0.737*** (0.142) | | | | | |
| Coal rents | | 13.63*** (3.077) | | | | |
| Mineral rents | | | 6.656*** (0.974) | | | |
| Oil rents | | | | −0.658*** (0.0911) | | |
| Gas rents | | | | | 0.187 (4.349) | |
| Forest rents | | | | | | −5.314** (1.985) |
| Constant | −106.3** (47.77) | 0 (0) | −140.2*** (25.75) | −115.1** (42.94) | −190.2** (77.87) | −216.6*** (51.11) |
| Observations | 1,185 | 1,185 | 753 | 1,185 | 1,182 | 1,185 |
| Instruments | 23 | 34 | 23 | 23 | 23 | 23 |
| AR(1)_Prob | 9.51e-05 | 0.0110 | 0.00260 | 0.000132 | 0.00251 | 0.000498 |
| AR(2)_Prob | 0.507 | 0.104 | 0.124 | 0.278 | 0.130 | 0.172 |
| Hansen_Prob | 0.208 | 0.869 | 0.182 | 0.255 | 0.202 | 0.236 |
| Fisher | 147.0*** | 3336*** | 289.8*** | 165.8*** | 250.0*** | 581.3*** |

**Notes:** Standard errors in parentheses *** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$; Lagged outcome variables are involved in the GMM specifications
**Source:** Authors' own creation

**Table 5.** System GMM estimates on the role of natural resources on the energy transition process

| Variables | Dependent variable: renewable energy consumption (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| Financial development | −0.129*** (0.0350) | −0.0716*** (0.0183) | −0.0883*** (0.0154) | −0.269*** (0.0520) | −0.0871*** (0.0167) | −0.0717*** (0.0108) |
| Internet penetration | 0.486*** (0.156) | 0.319*** (0.108) | 0.266*** (0.0600) | 1.986*** (0.294) | 0.440*** (0.0716) | 0.514*** (0.0851) |
| Urbanisation | −0.371*** (0.0845) | −0.333*** (0.0964) | −0.317*** (0.0811) | −0.410*** (0.0924) | −0.318*** (0.0626) | −0.258*** (0.0296) |
| Human capital | 0.670 (3.684) | 10.46 (10.03) | 1.485 (4.404) | 1.666 (11.58) | 0.0638 (0.947) | −0.678 (1.014) |
| Women empowerment | 0.190*** (0.0436) | 0.111** (0.0406) | 0.309*** (0.0398) | −0.334 (0.212) | 0.263*** (0.0414) | 0.176*** (0.0340) |
| FDI | 0.0564*** (0.0128) | 0.0554*** (0.0149) | 0.0890*** (0.0158) | 0.753*** (0.165) | 0.0822*** (0.0266) | 0.0607*** (0.0165) |
| GDP per capita (log) | −12.30*** (1.917) | −12.52*** (1.741) | −13.31*** (3.510) | −30.26*** (3.657) | −14.97*** (1.918) | −15.29*** (1.750) |
| Trade | −0.0482*** (0.0108) | −0.0363*** (0.00298) | −0.0793*** (0.00565) | −0.130* (0.0705) | −0.0827*** (0.00562) | −0.0825*** (0.00499) |
| Governance | 1.034 (0.653) | 0.956 (0.681) | 2.460 (3.029) | 0.714 (3.579) | 1.302 (1.663) | 0.366 (1.363) |
| Resources rents | 0.336** (0.128) | | | | | |
| Coal rents | | −3.063* (1.587) | | | | |
| Mineral rents | | | −0.810* (0.456) | | | |
| Oil rents | | | | 0.864*** (0.241) | | |
| Gas rents | | | | | −1.468 (1.761) | |
| Forest rents | | | | | | 1.342*** (0.205) |
| Constant | 158.2*** (16.25) | 137.0*** (20.28) | 0 (0) | 284.8*** (45.31) | 174.0*** (11.72) | 172.8*** (14.65) |
| Observations | 1,606 | 1,606 | 1,606 | 1,606 | 1,603 | 1,606 |
| Instruments | 45 | 45 | 34 | 23 | 23 | 23 |
| AR(1)_Prob | 7.75e-05 | 0.000123 | 0.000149 | 0.000484 | 0.000119 | 9.22e-05 |
| AR(2)_Prob | 0.341 | 0.0999 | 0.145 | 0.973 | 0.159 | 0.368 |
| Hansen_Prob | 0.995 | 0.996 | 0.781 | 0.122 | 0.112 | 0.128 |
| Fisher | 1,830*** | 5,661*** | 9,883*** | 1,637*** | 24,222*** | 243,409*** |

**Notes:** Standard errors in parentheses *** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$. Lagged outcome variables are involved in the GMM specifications
**Source:** Authors' own creation

(Model 1), Table 5 reveals a significantly positive coefficient in the context of REC (Model 1). However, when natural resources rents are disaggregated into various components (oil, coal, mineral, natural gas and forest rents), the effects are divergent. Moreover, while oil rents (Model 4) and forest rents (Model 6) contribute to the enhancement of energy transition by, respectively, reducing FFC (Table 4) and raising REC (Table 5), coal rents (Model 2) and mineral rents (Model 3) constitute impediments to the energy transition process.

## 5. Conclusion and policy implications

### *5.1 Conclusion*

Despite the resolve of world leaders to curtail global consumption of fossil fuels in favour of clean energies, several countries continue to rely on carbon-intensive sources in meeting their energy demands. Financial constraints and limited knowledge with regard to green energy sources constitute major setbacks to the energy transition process. This study therefore examines the effects of financial development and human capital formation on energy consumption. The empirical analysis is based on the SGMM for a global panel of 134 countries over the 1996–2019 period.

The SGMM estimates conducted on the basis of three measures of energy consumption, notably fossil fuel, renewable energy as well as TEC, provide divergent results. While financial development significantly reduces FFC, its effect is positive though insignificant with regards to REC. Conversely, when fossil fuel and REC are aggregated into TEC, the effect of financial development is positive and significant. Moreover, the results reveal that human capital development has an enhancing though non-significant effect on the energy transition process. These findings are consistent irrespective of the country's status as developed or developing. The non-significance of human capital can be traceable to the perspective that irrespective of countries, the level of education qualification of individuals does not significantly influence their decisions about the energy transition process. Hence, formal education may not be the exclusive factor of human capital eliciting energy transition and thus, informal education measures could also be worthwhile, though data on informal education are not currently available. The results equally reveal that resource rents have an enhancing effect on the energy transition process. However, when natural resources rents are disaggregated into various components (oil, coal, mineral, natural gas and forest rents), the effects on energy transition are divergent. While oil rents and forest rents contribute to the enhancement of energy transition by respectively reducing FFC and raising REC, coal rents and mineral rents constitute impediments to the energy transition process.

### *5.2 Policy implications*

Contingent on the findings of this study, it is imperative for various governments to increase investments in human capital formation especially in the fields of ecological(eco)-innovation. Moreover, appropriate policies aimed at fostering the sustainable use of eco-innovation and green technologies should be formulated and valorised in the financial sector. Thus, policymakers are advised to step-up efforts aimed at financing and sensitising people on the importance of clean energy consumption. Therefore, there is need for more synergy between national and international bodies with regard to the design and implementation of policies aimed at encouraging the use of eco-innovation and green technologies. These policies must be accompanied by increased funding for the exponentiation of training opportunities on energy transition. Indeed, increased financial resources to fund sensitisation campaigns will create more awareness and ensure an adequate development of human capital in clean energy-related technologies.

*5.3 Future research directions*

Given that the current study focuses on a global panel of 134 countries, it will be worthwhile for future research to investigate the role of financial development on country-specific basis for more inclusive policies to be designed in with regard to country specificities. Moreover, other indicators of financial development could be used in subsequent studies. Equally, future research could consider investigating the indirect channels through which financial development and human capital can impact energy consumption.

**References**

Achuo, E.D. (2022), "The nexus between crude oil price shocks and environmental quality: empirical evidence from sub-Saharan Africa", *SN Business and Economics*, Vol. 2 No. 7, pp. 1-15, doi: 10.1007/s43546-022-00264-9.

Achuo, E.D., Asongu, A.S. and Tchamyou, V.S. (2022a), "Women empowerment and environmental sustainability in Africa", *Association for Promoting Women in Research and Development in Africa, ASPROWORDA WP 22/003*.

Achuo, E.D., Miamo, C.W. and Nchofoung, T.N. (2022b), "Energy consumption and environmental sustainability: what lessons for posterity?" *Energy Reports*, Vol. 8, pp. 12491-12502.

Ahmad, M., Ahmed, Z., Yang, X., Hussain, N. and Sinha, A. (2022), "Financial development and environmental degradation: do human capital and institutional quality make a difference?" *Gondwana Research*, Vol. 105, pp. 299-310.

Akram, V., Jangam, B.P. and Rath, B.N. (2018), "Does human capital matter for reduction in energy consumption in India?" *International Journal of Energy Sector Management*, Vol. 13 No. 2, pp. 359-376, doi: 10.1108/IJESM-07-2018-0009.

Akram, V., Rath, B.N. and Sahoo, P.K. (2023), "Club convergence in per capita carbon dioxide emissions across Indian states", *Environment, Development and Sustainability*, pp. 1-28, doi: 10.1007/s10668-023-03443-2.

Alsagr, N. and van Hemmen, S. (2021), "The impact of financial development and geopolitical risk on renewable energy consumption: evidence from emerging markets", *Environmental Science and Pollution Research*, Vol. 28 No. 20, pp. 25906-25919.

Alvarado, R., Deng, Q., Tillaguango, B., Méndez, P., Bravo, D., Chamba, J., . . . Ahmad, M. (2021), "Do economic development and human capital decrease non-renewable energy consumption? Evidence for OECD countries", *Energy*, Vol. 215, p. 119147, doi: 10.1016/j.energy.2020.119147.

Anton, S.G. and Nucu, A.E.A. (2020), "The effect of financial development on renewable energy consumption. A panel data approach", *Renewable Energy*, Vol. 147, pp. 330-338.

Araújo, K. (2014), "The emerging field of energy transitions: progress, challenges, and opportunities", *Energy Research and Social Science*, Vol. 1, pp. 112-121.

Arellano, M. and Bover, O. (1995), "Another look at the instrumental variable estimation of error-components models", *Journal of Econometrics*, Vol. 68 No. 1, pp. 29-51.

Asongu, S.A. and Odhiambo, N.M. (2019), "Environmental degradation and inclusive human development in sub-Saharan Africa", *Sustainable Development*, Vol. 27 No. 1, pp. 25-34.

Asongu, S.A., Le Roux, S. and Biekpe, N. (2018), "Enhancing ICT for environmental sustainability in sub-Saharan Africa", *Technological Forecasting and Social Change*, Vol. 127, pp. 209-216.

Asongu, S.A., Iheonu, C.O. and Odo, K.O. (2019), "The conditional relationship between renewable energy and environmental quality in sub-Saharan Africa", *Environmental Science and Pollution Research*, Vol. 26 No. 36, pp. 36993-37000.

Asongu, S.A., Agboola, M.O., Alola, A.A. and Bekun, F.V. (2020), "The criticality of growth, urbanization, electricity and fossil fuel consumption to environment sustainability in Africa", *Science of the Total Environment*, Vol. 712, p. 136376.

Bayar, Y., Diaconu, L. and Maxim, A. (2020), "Financial development and CO2 emissions in post-transition European Union countries", *Sustainability*, Vol. 12 No. 7, p. 2640, doi: 10.3390/su12072640.

Becker, G. (1964), *Human Capital: A Theoretical and Empirical Analysis with Special Reference to Education*, National Bureau of Economic Research, Inc.

Bekhet, H.A., Matar, A. and Yasmin, T. (2017), "$CO_2$ emissions, energy consumption, economic growth, and financial development in GCC countries: dynamic simultaneous equation models", *Renewable and Sustainable Energy Reviews*, Vol. 70, pp. 117-132.

Bouyghrissi, S., Murshed, M., Jindal, A., Berjaoui, A., Mahmood, H. and Khanniba, M. (2022), "The importance of facilitating renewable energy transition for abating $CO_2$ emissions in Morocco", *Environmental Science and Pollution Research*, Vol. 29 No. 14, pp. 20752-20767.

Chang, S.C. (2015), "Effects of financial developments and income on energy consumption", *International Review of Economics and Finance*, Vol. 35, pp. 28-44.

Churchill, S.A., Inekwe, J., Ivanovski, K. and Smyth, R. (2022), "Human capital and energy consumption: six centuries of evidence from the United Kingdom", *Energy Economics*, Vol. 117, p. 106465, doi: 10.1016/j.eneco.2022.106465.

Dominković, D.F., Bačeković, I., Pedersen, A.S. and Krajačić, G. (2018), "The future of transportation in sustainable energy systems: opportunities and barriers in a clean energy transition", *Renewable and Sustainable Energy Reviews*, Vol. 82, pp. 1823-1838.

Dong, F., Li, Y., Gao, Y., Zhu, J., Qin, C. and Zhang, X. (2022), "Energy transition and carbon neutrality: exploring the non-linear impact of renewable energy development on carbon emission efficiency in developed countries", *Resources, Conservation and Recycling*, Vol. 177, p. 106002, doi: 10.1016/j.resconrec.2021.106002.

Eren, B.M., Taspinar, N. and Gokmenoglu, K.K. (2019), "The impact of financial development and economic growth on renewable energy consumption: empirical analysis of India", *Science of the Total Environment*, Vol. 663, pp. 189-197.

Fang, Z. and Chang, Y. (2016), "Energy, human capital and economic growth in Asia Pacific countries—evidence from a panel cointegration and causality analysis", *Energy Economics*, Vol. 56, pp. 177-184.

Gielen, D., Gorini, R., Leme, R., Prakash, G., Wagner, N., Janeiro, L., . . . Saygin, D. (2021), "World energy transitions outlook: 1.5° C pathway".

Gómez, M. and Rodríguez, J.C. (2019), "Energy consumption and financial development in NAFTA countries, 1971–2015", *Applied Sciences*, Vol. 9 No. 2, p. 302, doi: 10.3390/app9020302.

İnal, V., Addi, H.M., Çakmak, E.E., Torusdağ, M. and Çalışkan, M. (2022), "The nexus between renewable energy, $CO_2$ emissions, and economic growth: empirical evidence from African oil-producing countries", *Energy Reports*, Vol. 8, pp. 1634-1643.

IRENA(International Renewable Energy Agency) (2022), "World energy transitions outlook: 1.5°C pathway", available at: www.irena.org/Publications/2022/Mar/World-Energy-Transitions-Outlook-2022

Islam, F., Shahbaz, M., Ahmed, A.U. and Alam, M.M. (2013), "Financial development and energy consumption nexus in Malaysia: a multivariate time series analysis", *Economic Modelling*, Vol. 30, pp. 435-441.

Jalil, A. and Feridun, M. (2011), "The impact of growth, energy and financial development on the environment in China: a cointegration analysis", *Energy Economics*, Vol. 33 No. 2, pp. 284-291.

Jangam, B.P., Sahoo, P.K. and Akram, V. (2020), "Convergence in electricity consumption across Indian states: a disaggregated analysis", *International Journal of Energy Sector Management*, Vol. 14 No. 3, pp. 624-637, doi: 10.1108/IJESM-03-2019-0009.

Jiang, L. and O'Neill, B.C. (2004), "The energy transition in rural China", *International Journal of Global Energy Issues*, Vol. 21 Nos 1/2, pp. 2-26.

Khan, A., Chenggang, Y., Hussain, J. and Kui, Z. (2021), "Impact of technological innovation, financial development and foreign direct investment on renewable energy, non-renewable energy and the environment in belt and road initiative countries", *Renewable Energy*, Vol. 171, pp. 479-491.

Khan, Z., Malik, M.Y., Latif, K. and Jiao, Z. (2020), "Heterogeneous effect of eco-innovation and human capital on renewable and non-renewable energy consumption: disaggregate analysis for G-7 countries", *Energy*, Vol. 209, p. 118405, doi: 10.1016/j.energy.2020.118405.

Lahiani, A., Mefteh-Wali, S., Shahbaz, M. and Vo, X.V. (2021), "Does financial development influence renewable energy consumption to achieve carbon neutrality in the USA?" *Energy Policy*, Vol. 158, p. 112524, doi: 10.1016/j.enpol.2021.112524.

Lan, J., Kakinaka, M. and Huang, X. (2012), "Foreign direct investment, human capital and environmental pollution in China", *Environmental and Resource Economics*, Vol. 51 No. 2, pp. 255-275.

Leach, G. (1992), "The energy transition", *Energy Policy*, Vol. 20 No. 2, pp. 116-123.

Lei, W., Ozturk, I., Muhammad, H. and Ullah, S. (2022), "On the asymmetric effects of financial deepening on renewable and non-renewable energy consumption: insights from China", *Economic Research-Ekonomska Istraživanja*, Vol. 35 No. 1, pp. 3961-3978.

Li, H.X., Edwards, D.J., Hosseini, M.R. and Costin, G.P. (2020), "A review on renewable energy transition in Australia: an updated depiction", *Journal of Cleaner Production*, Vol. 242, p. 118475.

Ma, X. and Fu, Q. (2020), "The influence of financial development on energy consumption: worldwide evidence", *International Journal of Environmental Research and Public Health*, Vol. 17 No. 4, p. 1428.

Miamo, C.W. and Achuo, E.D. (2022), "Can the resource curse be avoided? An empirical examination of the nexus between crude oil price and economic growth", *SN Business and Economics*, Vol. 2 No. 1, pp. 1-23.

Nalan, Ç.B., Murat, Ö. and Nuri, Ö. (2009), "Renewable energy market conditions and barriers in Turkey", *Renewable and Sustainable Energy Reviews*, Vol. 13 Nos 6/7, pp. 1428-1436.

Nchofoung, T.N., Achuo, E.D. and Asongu, S.A. (2021), "Resource rents and inclusive human development in developing countries", *Resources Policy*, Vol. 74 No. 4, p. 102382, doi: 10.1016/j.resourpol.2021.102382.

Nchofoung, T.N., Asongu, S.A., NjamenKengdo, A.A. and Achuo, E.D. (2022), "Linear and non-linear effects of infrastructures on inclusive human development in Africa", *African Development Review*, Vol. 34 No. 1, pp. 81-96.

Ouyang, Y. and Li, P. (2018), "On the nexus of financial development, economic growth, and energy consumption in China: new perspective from a GMM panel VAR approach", *Energy Economics*, Vol. 71, pp. 238-252.

Painuly, J.P. (2001), "Barriers to renewable energy penetration; a framework for analysis", *Renewable Energy*, Vol. 24 No. 1, pp. 73-89.

Psacharopoulos, G. and Patrinos, H.A. (2018), "Returns to investment in education: a decennial review of the global literature", *Education Economics*, Vol. 26 No. 5, pp. 445-458.

Riti, J.S., Shu, Y., Song, D. and Kamah, M. (2017), "The contribution of energy use and financial development by source in climate change mitigation process: a global empirical perspective", *Journal of Cleaner Production*, Vol. 148, pp. 882-894.

Roodman, D. (2009), "How to do xtabond2: an introduction to difference and system GMM in Stata", *The Stata Journal: Promoting Communications on Statistics and Stata*, Vol. 9 No. 1, pp. 86-136.

Sadorsky, P. (2010), "The impact of financial development on energy consumption in emerging economies", *Energy Policy*, Vol. 38 No. 5, pp. 2528-2535.

Sadorsky, P. (2011), "Financial development and energy consumption in central and eastern European frontier economies", *Energy Policy*, Vol. 39 No. 2, pp. 999-1006.

Salim, R., Yao, Y. and Chen, G.S. (2017), "Does human capital matter for energy consumption in China?" *Energy Economics*, Vol. 67, pp. 49-59.

Shafiei, S. and Salim, R.A. (2014), "Non-renewable and renewable energy consumption and $CO_2$ emissions in OECD countries: a comparative analysis", *Energy Policy*, Vol. 66, pp. 547-556.

Shahbaz, M., Khan, S. and Tahir, M.I. (2013), "The dynamic links between energy consumption, economic growth, financial development and trade in China: fresh evidence from multivariate framework analysis", *Energy Economics*, Vol. 40, pp. 8-21.

Shahbaz, M., Gozgor, G., Adom, P.K. and Hammoudeh, S. (2019), "The technical decomposition of carbon emissions and the concerns about FDI and trade openness effects in the United States", *International Economics*, Vol. 159, pp. 56-73.

Shahbaz, M., Topcu, B.A., Sarıgül, S.S. and Vo, X.V. (2021), "The effect of financial development on renewable energy demand: the case of developing countries", *Renewable Energy*, Vol. 178, pp. 1370-1380.

Shahbaz, M., Song, M., Ahmad, S. and Vo, X.V. (2022), "Does economic growth stimulate energy consumption? The role of human capital and R&D expenditures in China", *Energy Economics*, Vol. 105, p. 105662, doi: 10.1016/j.eneco.2021.105662.

Solomon, B.D. and Krishna, K. (2011), "The coming sustainable energy transition: history, strategies, and outlook", *Energy Policy*, Vol. 39 No. 11, pp. 7422-7431.

Tamazian, A. and Rao, B.B. (2010), "Do economic, financial and institutional developments matter for environmental degradation? Evidence from transitional economies", *Energy Economics*, Vol. 32 No. 1, pp. 137-145.

United Nations (2015), Transforming our world: the 2030 agenda for sustainable development, available at: https://sustainabledevelopment.un.org/post2015/transformingourworld/publication

White and Case (2022), "Scaling up energy transition", available at: www.whitecase.com/sites/default/files/2022-11/Scaling_up_the_energy_transition.pdf

Yao, Y., Ivanovski, K., Inekwe, J. and Smyth, R. (2019), "Human capital and energy consumption: evidence from OECD countries", *Energy Economics*, Vol. 84, p. 104534, doi: 10.1016/j.eneco.2019.104534.

Yue, S., Lu, R., Shen, Y. and Chen, H. (2019), "How does financial development affect energy consumption? Evidence from 21 transitional countries", *Energy Policy*, Vol. 130, pp. 253-262.

Zhang, N., Yu, K. and Chen, Z. (2017), "How does urbanization affect carbon dioxide emissions? A cross-country panel data analysis", *Energy Policy*, Vol. 107, pp. 678-687.

Zhang, Y.J. (2011), "The impact of financial development on carbon emissions: an empirical analysis in China", *Energy Policy*, Vol. 39 No. 4, pp. 2197-2203.

Zhao, P., Lu, Z., Fang, J., Paramati, S.R. and Jiang, K. (2020), "Determinants of renewable and non-renewable energy demand in China", *Structural Change and Economic Dynamics*, Vol. 54, pp. 202-209.

## Further reading

Carley, S. and Konisky, D.M. (2020), "The justice and equity implications of the clean energy transition", *Nature Energy*, Vol. 5 No. 8, pp. 569-577.

Psacharopoulos, G. (1994), "Returns to investment in education: a global update", *World Development*, Vol. 22 No. 9, pp. 1325-1343.

Tamazian, A., Chousa, J.P. and Vadlamannati, K.C. (2009), "Does higher economic and financial development lead to environmental degradation: evidence from BRIC countries", *Energy Policy*, Vol. 37 No. 1, pp. 246-253.

Wang, J., Zhang, S. and Zhang, Q. (2021), "The relationship of renewable energy consumption to financial development and economic growth in China", *Renewable Energy*, Vol. 170, pp. 897-904.

**Corresponding author**
Simplice Asongu can be contacted at: asongusimplice@yahoo.com

## Appendix

| Variable | Obs | Mean | SD | Min | Max |
|---|---|---|---|---|---|
| Renewable energy | 3,078 | 35.05 | 30.067 | 0 | 96.352 |
| Fossil fuels | 2,184 | 65.366 | 28.351 | 0 | 100 |
| Financial development | 2,671 | 51.703 | 45.885 | 0.186 | 304.575 |
| Internet penetration | 3,063 | 28.901 | 30.087 | 0 | 99.701 |
| Urbanisation | 3,215 | 56.917 | 22.74 | 7.412 | 100 |
| Human capital | 2,440 | 2.447 | 0.684 | 1.093 | 4.352 |
| Women empowerment | 2,919 | 17.872 | 11.347 | 0 | 63.75 |
| FDI | 3,176 | 5.278 | 17.154 | −58.323 | 449.083 |
| GDP per capita (log) | 3,181 | 8.52 | 1.503 | 5.386 | 11.566 |
| Trade | 3,050 | 85.811 | 52.693 | 0.027 | 437.327 |
| Governance | 3,215 | 0.035 | 0.939 | −1.998 | 12.768 |
| Resources rents | 3,186 | 6.674 | 10.154 | 0 | 66.69 |
| Coal rents | 3,179 | 0.172 | 0.88 | 0 | 25.965 |
| Mineral rents | 3,186 | 0.703 | 2.08 | 0 | 25.163 |
| Oil rents | 3,186 | 3.503 | 9.243 | 0 | 66.564 |
| Gas rents | 3,179 | 0.381 | 1.058 | 0 | 13.659 |
| Forest rents | 3,186 | 1.916 | 3.958 | 0 | 40.408 |

**Source:** Authors' own creation

**Table A1.** Descriptive statistics

| Variable | Definition | Source |
|---|---|---|
| Fossil fuel | Fossil fuel energy consumption (% of total) | WDI |
| Renewable energy consumption | Renewable energy consumption (% of total final energy consumption) | WDI |
| Total energy consumption | It is the sum of energy consumption from both renewable and non-renewable sources | WDI |
| Financial development | Domestic credit to private sector (% of GDP) | WDI |
| Human capital | Human Capital Index (HCI), which captures changes in human capital development across countries and time. It is adjusted with expected returns to education and varies across countries on the basis of different qualification levels | PWT10 |
| Internet penetration | Individuals using the Internet (% of population) | WDI |
| Women empowerment | Proportion of seats held by women in national parliaments (%) | WDI |
| FDI | Foreign direct investment, net inflows (% of GDP) | WDI |
| Trade openness | Trade (% of GDP) | WDI |
| Urbanisation | Urban population (% of total population) | WDI |
| Governance | It is a composite governance index, which is the average of the six governance indicators | WGI |
| GDP per capita | GDP per capita, PPP (constant 2017 international $) | WDI |
| Resource rents | Total natural resources rents (% of GDP) | WDI |
| Forest rents | Forest rents (% of GDP) | WDI |
| Mineral rents | Mineral rents (% of GDP) | WDI |
| Coal rents | | WGI |
| Gas rents | Natural gas rents (% of GDP) | WDI |
| Forest rents | Forest rents (% of GDP) | WDI |

**Notes:** WDI = World Development Indicators; WGI = World Governance Indicators; PWT10 = Penn World Tables, version 10.0; GDP = Gross Domestic Product; FDI = Foreign Direct Investments
**Source:** Authors' own creation

**Table A2.** Definition and sources of variables

**Table A3.** Matrix of correlations

| Variables | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) | (11) | (12) | (13) | (14) | (15) | (16) | (17) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (1) Renewable energy | 1.000 | | | | | | | | | | | | | | | | |
| (2) Fossil fuels | −0.914 | 1.000 | | | | | | | | | | | | | | | |
| (3) Financial development | −0.443 | 0.373 | 1.000 | | | | | | | | | | | | | | |
| (4) Internet | −0.424 | 0.308 | 0.367 | 1.000 | | | | | | | | | | | | | |
| (5) Urbanisation | −0.596 | 0.539 | 0.441 | 0.404 | 1.000 | | | | | | | | | | | | |
| (6) Human capital | −0.021 | 0.017 | 0.021 | 0.008 | 0.014 | 1.000 | | | | | | | | | | | |
| (7) Women empowerment | −0.107 | 0.036 | 0.352 | 0.528 | 0.283 | −0.009 | 1.000 | | | | | | | | | | |
| (8) FDI | −0.130 | 0.122 | 0.191 | 0.126 | 0.137 | −0.048 | −0.003 | 1.000 | | | | | | | | | |
| (9) GDP per capita (log) | −0.623 | 0.518 | 0.483 | 0.400 | 0.413 | 0.012 | 0.391 | 0.128 | 1.000 | | | | | | | | |
| (10) Trade | −0.272 | 0.196 | 0.180 | 0.306 | 0.226 | −0.028 | 0.056 | 0.293 | 0.273 | 1.000 | | | | | | | |
| (11) Governance | −0.446 | 0.330 | 0.430 | 0.391 | 0.484 | 0.005 | 0.430 | 0.145 | 0.793 | 0.287 | 1.000 | | | | | | |
| (12) Resources rents | 0.043 | 0.030 | −0.265 | −0.203 | 0.069 | 0.020 | −0.234 | −0.057 | −0.128 | −0.047 | −0.347 | 1.000 | | | | | |
| (13) Coal rents | −0.095 | 0.118 | 0.040 | −0.054 | −0.031 | −0.008 | 0.000 | 0.035 | −0.067 | −0.007 | −0.049 | 0.145 | 1.000 | | | | |
| (14) Mineral rents | −0.028 | 0.068 | −0.063 | −0.067 | 0.025 | −0.006 | −0.030 | 0.005 | −0.132 | −0.034 | −0.071 | 0.167 | 0.432 | 1.000 | | | |
| (15) Oil rents | −0.044 | 0.099 | −0.205 | −0.125 | 0.154 | 0.033 | −0.210 | −0.052 | 0.004 | −0.030 | −0.276 | 0.945 | −0.047 | −0.082 | 1.000 | | |
| (16) Gas rents | −0.146 | 0.210 | −0.036 | 0.043 | 0.079 | −0.030 | −0.053 | −0.035 | 0.016 | −0.027 | −0.116 | 0.389 | −0.030 | −0.035 | 0.346 | 1.000 | |
| (17) Forest rents | 0.623 | v0.582 | −0.347 | −0.386 | −0.454 | −0.036 | −0.151 | v0.059 | −0.558 | −0.058 | −0.335 | 0.196 | −0.032 | 0.048 | 0.011 | −0.002 | 1.000 |

**Source:** Authors' own creation