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

Elvis D. Achuo

University of Dschang, Cameroon
Ministry of Secondary Education, Cameroon
E-mail: elvisachuo21@yahoo.com

Pilag B.C. Kakeu

University of Bamenda, Cameroon
E-mail: pilagbertin@yahoo.com

Simplice A. Asongu

University of Johannesburg, South Africa
E-mail: asongusimplice@yahoo.com

Research Department

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Abstract

Despite the global resolves to curtail fossil fuel consumption 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 on energy consumption. The empirical analysis is based on the System Generalised Method of Moments (SGMM) for a panel of 134 countries from 1996-2019. The SGMM estimates conducted on the basis of three measures of energy consumption, notably fossil fuel, renewable energy as well as total energy consumption, provide divergent results. While financial development significantly reduces fossil fuel consumption, its effect is positive though non-significant with regard to renewable energy consumption. Conversely, financial development has a positive and significant effect on total energy consumption. Moreover, the results reveal that human capital development has an enhancing though non-significant effect on the energy transition process. Additionally, 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.

Key words: Energy transition, Financial development, Fossil fuel, Human capital, Energy consumption, Eco-innovation

1. Introduction

Despite the global resolve to curtail fossil fuel consumption 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; Dominkovi et al., 2018; Li et al., 2020; Bouyghrissi et al., 2022). 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 while 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 & 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 5.7 trillion US Dollars until 2030 (IRENA, 2022).

The World Energy Transitions Outlook (WETO) equally contends that the attainment of the net-zero economy can be catalysed by redirecting about 0.7 trillion US Dollars' 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 (Shahbaz et al., 2021; Anton and Nucu, 2020) and impedes non-renewable energy consumption (Lei et al., 2022), Zhao et al. (2020) argue that financial development heightens both non-renewable and renewable energy consumption.

Besides financial challenges, socio-political factors and poor governance (Painuly, 2001) equally constitute major drawbacks to the energy transition drive. In order 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 fossil fuel consumption, 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 renewable energy consumption. Similarly, Alvarado et al. (2021) contend that human capital decreases non-renewable energy consumption, in the context of OECD (Organization for Economic Cooperation and Development) countries.

Therefore, the importance of human capital in enhancing environmental sustainability through carbon-emission abatement cannot be overemphasised. Moreover, since 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 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 total energy consumption. Moreover, we provide a global comparative analysis with regard 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.

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 while the conclusion and policy implications are contained in section 5.

2. Review of salient literature

This section critically reviews extant studies with regard 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 (ARDL) 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 (VAR) 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 BhaskaraRao (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 GDP (Gross Domestic Product).

Exploring the financial development and renewable energy relationship, Anton and Nucu (2020) argue that financial development enhances renewable energy consumption across European Union (EU) member countries. Likewise, Shahbaz et al. (2021) show that financial development enhances renewable energy consumption 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 United States, Lahiani et al. (2021) conclude that the effects financial development on renewable energy consumption is divergent depending on the measure of financial development. With regard to the financial development and fossil fuel consumption nexus, Zhao et al. (2020) contend that non-renewable energy consumption 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-renewable energy consumption, 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 FDI (foreign direct investment) 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, while 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, since 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 United States (US) between 1975 and 2016, which they attribute to substantial investments in higher education levels in the US. Similarly, Lan et al. (2012) confirmed that energy consumption greatly depends on the level of human capital.

Likewise, Churchill (2022) explores the nexus among human capital and energy consumption in the United Kingdom and reveals the existence of a negative relationship between human capital and energy consumption from both parametric and non-parametric estimations. Additionally, the parametric estimates show that in the long-term, energy consumption is likely to reduce by 4-9 percent following an additional year of schooling. These findings are consistent with the results of Alvarado et al. (2021) who contend that non-renewable energy consumption 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 renewable energy consumption 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 (WDI) and the Worldwide Governance Indicators (WGI), human capital was gotten from the Penn World Tables (PWT Version 10.0). The employed 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

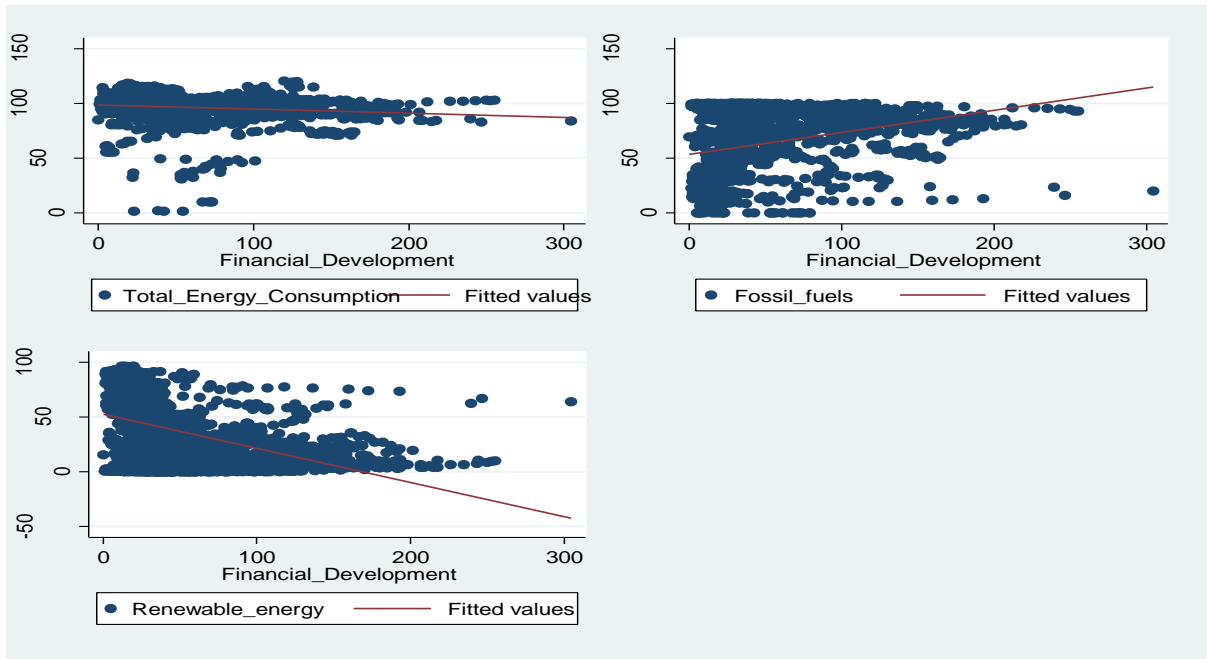
The dependent variable adopted in this study is energy consumption. Unlike most extant studies that limit their analysis of energy consumption either to non-renewable energy consumption (Alvarado et al., 2020) or disaggregate energy consumption into renewable and non-renewable energy (Achuo et al., 2022b), the present study employs the three main measures of energy consumption notably, renewable energy consumption (REC), fossil fuel consumption (FFC), as well as total energy consumption (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 employed 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 regard to FFC.

Figure 2: Correlation between financial development and energy consumption



Another key explanatory variable employed in this study is human capital. Human capital is proxied by the Human Capital Index (HCI), 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-renewable energy consumption and total energy consumption) 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.

3.1.3 Control variables

This study employs several control variables including, foreign direct investment, 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., 2022; 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.

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

Where Y is a vector of three dependent variables that capture energy consumption. The various measures of energy consumption include, renewable energy consumption, fossil fuel consumption and total energy consumption. 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):

$$EC_{it} = \phi_0 + \phi_1 FD_{it} + \phi_2 HC_{it} + \phi_m Z_{it} + \omega_{it} \quad (2)$$

Where EC denotes energy consumption as defined in Equation (1); ϕ_0 is the intercept; ϕ_1 , ϕ_2 and ϕ_j are slope coefficients; ω is the stochastic error term; while the rest of the variables are defined as before, m symbolises the number of control variables included in Z .

3.3 Estimation Procedure

In order to empirically examine the effects of financial development and human capital formation on energy consumption, we make use of the Generalised Method of Moments (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 employs 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), in order 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.

$$EC_{it} = \theta_0 + \phi_1 EC_{i(t-1)} + \phi_2 FD_{it} + \phi_3 HC_{it} + \sum_{j=1}^m \phi_j Z_{j,i(t-1)} + \alpha_i + \beta_t + \omega_{it} \quad (3)$$

$$EC_{it} - EC_{i(t-1)} = \phi_1 (EC_{i(t-1)} - EC_{i(t-2)}) + \phi_2 (FD_{it} - FD_{i(t-1)}) + \phi_3 (HC_{it} - HC_{i(t-1)}) \\ + \sum_{j=1}^m \phi_j (Z_{j,i(t-1)} - Z_{j,i(t-2)}) (\beta_t - \beta_{t-1}) + (\omega_{it} - \omega_{i(t-1)}) \quad (4)$$

Where α represents the country fixed effects; β denotes the time invariant constant; the rest of the variables are defined as before.

Nevertheless, in order to address the problems with regard 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 regard to the effect of financial development and human capital on energy consumption. Then, we provide sensitivity analysis of the baseline results with regard 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 system generalised method of moments (SGMM) estimates conducted on the basis of three measures of energy consumption, notably: fossil fuel, renewable energy as well as total energy consumption, provide divergent results. For instance, while financial development significantly reduces fossil fuel consumption, its effect is positive though insignificant with regard to renewable energy consumption. 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 renewable energy consumption are aggregated into total energy consumption, the effect of financial development is positive and significant. This 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 while a positive change in financial development constrains fossil fuel consumption 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.

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

Variables	(1)	(2)		(3)
	Fossil fuels	Dependent variable		Total Energy Consumption
		Renewable energy		
Financial development	-0.196** (0.0823)	0.0201 (0.0746)		0.0824*** (0.0264)
Internetpenetration	-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	1,185	1,606		1,185
Instruments	21	21		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

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 (Achu 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, 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 foreign direct investment (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 employ 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 Nchofong et al. (2021). The sensitivity analyses of the effects of financial development and human capital on the energy transition process with regard to regional groupings and level of development are highlighted on Tables 2 and 3, while the results highlighting the role of natural resources are outlined on Tables 4 and 5.

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 fossil fuel consumption (Table 2) and renewable energy consumption (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 fossil fuel consumption (Table 2) while curtailing renewable energy consumption (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, since 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 (SSA) 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 fossil fuel consumption 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 regard to fossil fuel and renewable energy consumption 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 regard 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, 2022; Shahbaz et al., 2019) and ensure the attainment of a net-zero global economy.

Table 2. Sensitivity of the System GMM and Driscoll-Kraay estimates across geographical regions and level of development

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Variables	Developed	Developing	EAP	ECA	LAC	MENA	South Asia	SSA
	Dependent variable: Fossil fuel consumption							
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: Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1; 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.

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	1131***	19073***	105.8***	8.707***	9.630***	228.2***	777.3***	223.1***

Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1; Lagged outcome variables are involved in the GMM specifications.

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 fossil fuel consumption (model 1), Table 5 reveals a significantly positive coefficient in the context of renewable energy consumption (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 fossil fuel consumption (Table 4) and raising renewable energy consumption (Table 5), coal rents (model 2) and mineral rents (model 3) constitute impediments to the energy transition process.

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

Variables	(1)	(2)	(3)	(4)	(5)	(6)
	Dependent variable: Fossil fuel consumption					
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***

Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1; Lagged outcome variables are involved in the GMM specifications.

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

Variables	(1)	(2)	(3)	(4)	(5)	(6)
	Dependent variable: Renewable energy consumption					
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	1830***	5661***	9883***	1637***	24222***	243409***

Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1; Lagged outcome variables are involved in the GMM specifications.

5. Conclusion and policy Implications

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 System Generalised Method of Moments (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 total energy consumption, provide divergent results. While financial development significantly reduces fossil fuel consumption, its effect is positive though insignificant with regard to renewable energy consumption. Conversely, when fossil fuel and renewable energy consumption are aggregated into total energy consumption, 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 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 fossil fuel consumption and raising renewable energy consumption, coal rents and mineral rents constitute impediments to the energy transition process.

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.

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 employed in subsequent studies. Equally, future research could consider investigating the indirect channels through which financial development and human capital can impact energy consumption.

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Appendix

Appendix A1: Descriptive Statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
Renewable energy	3078	35.05	30.067	0	96.352
Fossil fuels	2184	65.366	28.351	0	100
Financial development	2671	51.703	45.885	.186	304.575
Internet penetration	3063	28.901	30.087	0	99.701
Urbanisation	3215	56.917	22.74	7.412	100
Human capital	2440	2.447	.684	1.093	4.352
Women empowerment	2919	17.872	11.347	0	63.75
FDI	3176	5.278	17.154	-58.323	449.083
GDP per capita (log)	3181	8.52	1.503	5.386	11.566
Trade	3050	85.811	52.693	.027	437.327
Governance	3215	.035	.939	-1.998	12.768
Resources rents	3186	6.674	10.154	0	66.69
Coal rents	3179	.172	.88	0	25.965
Mineral rents	3186	.703	2.08	0	25.163
Oil rents	3186	3.503	9.243	0	66.564
Gas rents	3179	.381	1.058	0	13.659
Forest rents	3186	1.916	3.958	0	40.408

Appendix A2: Definition and sources of variables

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.

Appendix 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	-0.582	-0.347	-0.386	-0.454	-0.036	-0.151	-0.059	-0.558	-0.058	-0.335	0.196	-0.032	0.048	0.011	-0.002	1.000