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Macroeconomic Determinants of Energy Consumption in BRICS (Brazil, Russia, India, China, South Africa)

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Abstract:

Purpose: *The study investigates the determinants of energy consumption in BRICS countries.*
Design/Methodology/Approach: *The study is using panel data analysis methodology (fixed effects, FMOLS, pooled OLS, random effects) with panel data ranging from 1996 to 2018.*
Findings: *Under fixed effects, financial development was found to have a significant positive influence on energy consumption in model 1 and a significant negative effect on energy consumption in model 3. Human capital development, financial development, the interaction between financial and human capital development and economic growth were all found to have had a significant positive influence on energy consumption across all the four models. FDI had a significant positive effect on energy consumption in model 1 and 2 whilst infrastructural development had a significant positive influence on energy consumption in model 1, 3 and 4. Under random effects, financial development influenced energy consumption in a significant positive manner in model 2 and 3. Both human capital development and the interaction term separately had a significant positive impact on energy consumption across all the four models whilst trade openness and infrastructural development's influence on energy consumption was positive and significant in model 1 and 3. Yet economic growth and FDI were found to have had a significant positive influence on energy consumption in model 1 and 4. Under FMOLS, four variables which had a significant positive effect on energy consumption across all the four models include human capital development, the interaction term, economic growth and infrastructural development.*
Practical implications: *BRICS countries are therefore urged to design and implement policies aimed at enhancing human capital development, the complementarity between financial and human capital development, economic growth, and infrastructural development in order to increase renewable and fossil fuel energy usage (energy usage that preserves the ecosystem and promotes sustainable growth).*
Originality value: *It considers the fact that the relationship between energy consumption and its determinants is not of a linear nature (is non-linear).*

Keywords: *Energy Consumption; Determinants; Panel Data; BRICS.*

JEL codes: *C1, C4, C5.*

Paper type: *Research article.*

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1. Introduction

This section focuses on the background of the study, contribution of the study towards literature and organization of the study. Energy consumption is one of the critical and essential inputs into the production process that drives economic growth and enhances the economic wellbeing of the citizens (Samuel *et al.*, 2013). According to Tang (2009), manufacturing activities, extraction activities in the primary sector of production, farming activities, infrastructural development, and maintenance activities, all of which are the pillar behind economic growth consumes energy. Altar and Syed (2011) argued that the reasons for the slow economic growth and development of African countries and Third World countries is inadequate supply of energy, inefficient energy usage devices, frequent energy power cuts, overdependence on external sources of energy and long fuel queues at service stations which eats into the productivity levels of the able-bodied personnel. Given the existence of unadulterated and conclusive evidence that energy consumption is one of the keys that unlocks economic growth of a country, effective economic growth policy formulation then hinges on the ability of researchers and policy makers to dissect the factors that influences energy consumption.

Theoretical literature that exists on the determinants of energy consumption (Table 1) does not agree on the direction of the impact of the variables on energy consumption. Population growth, human capital development, trade openness, economic growth, and financial development, among others are some of the macroeconomic variables whose influence on energy consumption produced mixed results (Table 1). Both theoretical and empirical literature (Table 2) fails to agree on a common list of macroeconomic variables that determines energy consumption. In particular, the conclusion of each empirical research on the determinants of energy consumption seems to be quite divergent from the rest of the other empirical studies on a similar subject matter. In fact, the result from the similar empirical research is divergent, mixed, and far from being close to providing a conclusive argument on the subject matter.

Majority of the empirical researchers on the determinants of energy consumption wrongly assumed that there is a linear relationship between energy consumption and its macroeconomic determinants. This study considers that the relationship does not follow a linear pattern. As a result, this study also investigated whether the complementarity between financial and human capital development enhances or reduces energy consumption in BRICS nations. Existing empirical research on the determinants of energy consumption have so far focused on other global economic groupings or individual countries. No such a study has been done focusing on BRICS, to the best knowledge of the author.

This study contributes to the literature in the following ways. Firstly, it uses the most recent data (1996-2018). Secondly, it considers the fact that the relationship between energy consumption and its determinants is not of a linear nature (is non-linear).

Thirdly, it uses scenario analysis. In other words, the study is the first of its kind on the subject matter to use four different measures of energy consumption, namely energy use (kg of oil equivalent per capita, renewable energy consumption (% of total final energy consumption), electric power consumption (kWh per capita) and fossil fuel energy consumption (% of total). Fourthly, it is the first study to the author's best knowledge to investigate the impact of the complementarity between financial and human capital development on energy consumption. Fifthly, no such study has so far been done using BRICS as a unit of analysis to the best of the author's knowledge.

Section 2 discusses the theoretical literature on the determinants of energy consumption whilst section 3 focuses on the empirical literature review of the determinants of energy consumption. Section 4 describes the framework of the research methodology. Section 5 analyses data, presents and discusses the results. Section 6 is the concluding remarks.

2. Determinants of Energy Consumption-Theoretical Literature

Table 1 summarizes various macroeconomic variables whose theoretical influence on energy consumption has been documented. The theoretical impact of each macroeconomic variable on energy consumption is discussed in Table 1 under the theory intuition column.

Table 1. *Theoretical literature on the determinants of energy consumption*

Variable	**Proxy used**	**Theory intuition**	**Expected sign**
Financial development (FIN)	Domestic credit by financial sector (% of GDP)	Consistent with Aye and Edoja (2017), developed financial markets attracts foreign direct investment, which increases the quantity of energy usage in the host country. Financial development spurs the number and scale of economic activities, hence increasing the overall quantity of energy used in the economy. Financial development can avail more funding towards investment into clean energy sources which are energy efficient (Aye and Edoja. 2017).	+/-
Economic growth (GROWTH)	GDP per capita	Whilst Huang *et al.* (2008) noted that economic growth has got a deleterious effect on energy consumption, Nindi and Odhiambo (2014) argued that in a more energy consumption reliant economy, economic growth leads to more energy consumption. This is because sustaining economic growth is enhanced by heavy investment into more energy consuming manufacturing activities.	+/-

Trade openness (OPEN)	Exports of goods and services (% of GDP)	In line with Rasiah *et al.* (2018), trade openness allows firms to expand easily as they can now source raw materials and supply their finished products globally. As a result, energy usage triggered production action activities go up. Grossman and Krueger (1991) argued that trade openness enables firms to be energy efficient as they can now easily purchase new technology which uses less energy from anywhere in the world.	+/-
Foreign direct investment (FDI)	Net FDI inflows (% of GDP)	Inflow of foreign direct investment increases urbanization, infrastructural development activities, manufacturing activities and the rate of industrialization. These activities increase energy consumption, in line with (Tang, 2009). A study done by Abdouli and Hammami (2017) came to a similar conclusion.	+
Human capital development (HCD)	Human capital development index	Skilled and educated have the financial resources to purchase new technology that is energy efficient. On the other hand, high levels of human capital development spur industrialization and large-scale manufacturing activities in the economy, leading to more energy consumption (Tsaurai, 2019).	+/-
Population growth (PG)	Population growth (annual %)	According to Liu *et al.* (2015), governments are forced to invest more into infrastructural development and expansion activities (which uses more energy) to satisfy the infrastructural needs of the increased population. A study done by Liddle (2004) however produced results which contradicted this perspective.	+/-
Infrastructure development (INFR)	Fixed telephone subscription (per 100 people)	Infrastructural development such as roads maintenance, mining infrastructural maintenance, buildings renovations constitute the major users of energy in the economy (Reddy *et al.* 2001). The view was supported by Yessengali and Murat (2018).	+
Complementarity between physical capital investment (financial development) and human capital development and	Domestic credit by financial sector (% of GDP) x Human capital development index.	According to Salim *et al.* (2017), financial markets can avail financial resources towards the development of new technology by skilled people. The same study noted that the new smart technology leads to an increase in the usage of clean energy in the economy.	+/-

Source: *Author compilation.*

Looking at Table 1, the impact of the macroeconomic variables on energy consumption is still inconclusive. This is because available literature on the subject matter is mixed, divergent and does not agree on the direction of causality. The gap in the literature motivated this study.

3. Determinants of Energy Consumption-Empirical Literature

Table 2 below summarizes the available empirical literature on various macroeconomic factors that influence energy consumption.

Table 2. *Determinants of energy consumption - Empirical literature*

Author	Country/Countries of study	Period	Methodology	Results
Samuel *et al*. (2013)	Worldwide	Not applicable	Literature review analysis	Economic growth, price of electricity, financial development, price of substitutes, air temperature, population growth and industrial development and efficiency were found to have had a significant influence on energy consumption.
Azam *et al.* (2016)	Greece	1975-2013	Vector Error Correction Model (VECM)	Infrastructural development, population growth, urbanization, trade openness, foreign direct investment and economic growth were found to be the major determinants of energy consumption in Greece.
Fuerst *et al*. (2020)	United Kingdom	Survey data (2011-2013)	Descriptive statistics and multiple ordinary least squares approach	Size of the household, income level of the household and employment status of the household are the three key factors which were found to have had a significant influence on energy consumption (gas usage) in the United Kingdom.
Xia and Hu (2012)	Chinese provinces	2009 survey data	Descriptive statistics	Urban concentration, electricity intensity, urbanization rate and the price of electricity were found to have had a significant influence on electricity consumption across Chinese provinces.
Zaharia *et al.* (2019)	European Union countries	1995-2019	Panel data analysis	Gross domestic product, greenhouse gas emissions, rate of labour growth had a positive influence on energy consumption. Factors which were found to have had a negative effect on energy consumption include energy taxes, healthcare expenditure increase and feminine population increase.
Sinevicine *et al*. (2017)	Eastern Europe	1996-2013	Panel data analysis	Economic growth was found to be a major factor behind the increase in energy consumption. Carbon emissions per capita, fixed capital and share of the industry in the economy were observed to have increased energy efficiency in Eastern Europe.
Kwakwa (2018)	Benin	1971-2014	Ordinary Least Squares	Levels of income reduced electricity consumption whilst population, education, urbanization, and industrialization increase had a positive effect on electricity consumption in Behin.
Kim (2018)	Korea	2015 survey data	Descriptive statistics	Number and type of household electrical appliances were found to be the major determinants of household electricity consumption in Korea.

Inglesi-Lotz and Pouris (2016)	South Africa	1981-2011	Descriptive statistics	Economic growth had a significant positive impact on energy consumption in South Africa.
Ateba *et al*. (2018)	South Africa	2016 survey data	Descriptive statistics	Household income, household size, gender and level of education were the variables which had a significant effect on household energy consumption in South Africa.
Fernandes and Reddy (2021)	Newly industrialized countries of Asia	1980-2018	VECM	In China, energy consumption was increased by factors such as industrialization, financial development, exchange rate and trade openness. Industrialization is the only variable which increased energy consumption in Thailand and India. Economic growth spurred energy consumption in Indonesia whilst energy consumption was increased by trade openness in the case of Malaysia.
Rahut *et al*. (2017)	Timor-Leste	2007 survey data	Descriptive statistics	Urban households, wealthy households and highly educated households were likely to use more energy.
Ergun *et al*. (2019)	Africa	1990-2013	Panel data analysis	African countries with higher levels of economic growth and human capital development used less renewable energy whilst African countries characterised by higher levels of foreign direct investment used significant amount of renewable energy.
Mehrara *et al*. (2015)	Economic Cooperation Organization (ECO) countries	1992-2011	Panel data analysis	Urban population and human capital development determined renewable energy consumption to a greater extent in ECO countries. Renewable potential and availability of renewable resources also influenced renewable energy use in ECO countries.
Sofia *et al*. (2019)	EU countries	2000-2016	Panel data analysis	Population growth, high wealth levels and cold weather conditions were found to have had a positive effect on residential energy consumption in the EU countries studied.
Premakumara (2013)	Karnataka	1997-2010	Time series analysis	Size of the family and the region were the most important factors found to have determined energy consumption.
Lefevre and Mainguy (2020)	World-wide	Not applicable	Literature review analysis	Population growth, income levels, education levels, financial development and industrialization are the main variables found to have a significant influence on energy consumption.
Bohlmann and Inglesi-Lotz (2020)	South Africa	1975-2016	Autoregressive Distributive Lag	High income levels increased energy consumption whilst price of electricity reduced energy consumption in South during the period under study.

Elimam (2020)	Saudi Arabia	1970-2017	Descriptive statistics	Renewable energy sources reduced the overall quantity of energy consumption in Saudi Arabia
Ismail *et al*. (2017)	Association of Southeast Asian Nations (ASEAN) seven member countries	1980-2015	VECM	High level of exports and economic growth increased energy consumption in ASEAN countries.

Source: *Author compilation.*

The results from the empirical studies on the determinants of energy consumption are diverse, mixed, and contradictory. It is clear from the existing empirical literature on the subject matter that a common list of the determinants of energy consumption is non-existent. In other words, the research focus area on the determinants of energy consumption is still far from being conclusive. It is against this backdrop that this empirical study intends to contribute on the subject matter by focusing on BRICS group of countries.

4. Research Methodology -Framework Description

Consistent with earlier similar empirical research done by Yessengali and Murat (2018), the energy consumption function is presented in equation 1.

$$ENCONS = f(FIN, HCD, OPEN, GROWTH, FDI, INFR) \quad (1)$$

where ENCONS, FIN, HCD, OPEN, GROWTH, FDI and INFR respectively stands for energy consumption, financial development, human capital development, trade openness, economic growth, foreign direct investment and infrastructural development. ENCONS is measured by four proxies, namely energy use (kg of oil equivalent per capita), electric power consumption (kWh per capita), renewable energy consumption (% of total final energy consumption) and fossil fuel energy consumption (% of total). Financial development is proxied by domestic credit by financial sector (% of GDP), human capital development index is used to measure human capital development whilst trade openness is measured by total export of goods and services (% of GDP) in this study. Gross domestic product (GDP) per capita, net FDI inflows (% of GDP) and fixed telephone subscription (per 100 people) were used as measures of economic growth, foreign direct investment, and infrastructural development, respectively. In econometric terms, equation 1 is transformed into equation 2 below.

$$ENCONS_{it} = \beta_0 + \beta_1 FIN_{it} + \beta_2 HCD_{it} + \beta_3 (FIN_{it}.HCD_{it}) + \beta_4 OPEN_{it} + \beta_5 GROWTH_{it} + \beta_6 FDI_{it} + \beta_7 INFR_{it} + \mu + \varepsilon \quad (2)$$

Whilst β_0 is an intercept, β_1 , β_2 , β_3 ,β_4 β_5 ,β_6 and β_7 are coefficients for financial development, human capital development, the complementarity between financial development and human capital development, trade openness, economic growth, foreign direct investment and infrastructural development respectively. A significant positive value of β_3 means that the complementarity between financial development and human capital development increases energy consumption whilst a significant negative value of β_3 shows that the complementarity between the two variables has got a deleterious effect on energy consumption in BRICS. Four panel methods of data analysis are used in this study, namely fixed effects, random effects, pooled ordinary least squares (OLS) and the fully modified ordinary least squares (FMOLS).

5. Data Analysis, Results Presentation and Discussion

Panel data ranging from 1996 to 2018 was used for this study. The data was extracted from reputable international sources such as World Bank Development Indicators, African Development Indicators, International Monetary Fund and United Nations Development Programme. This section covers pre-estimation diagnostics and the main data analysis.

5.1 Trend Analysis of Mean Values of the Variables Used

Table 3 presents mean trend analysis (1996-2018) results of all the variables that were used in the study. These include energy consumption, financial development, human capital development, trade openness, economic growth, foreign direct investment, and infrastructural development. For trend analysis, energy use (kg of oil equivalent per capita) was used as a measure of energy consumption.

Table 3. *Mean trend analysis of the variables used in the study (1996-2018)*

	ENCONS	FIN	HCD	OPEN	GROWTH	FDI	INFR
Brazil	1 277.86	86.11	0.75	12.00	10 149	3.07	19.30
Russia	4 635.98	38.71	0.79	31.21	9 254	2.07	25.52
India	511.28	65.43	0.58	18.25	1 233	1.45	2.74
China	1 582.58	141.24	0.72	24.59	3 862	3.33	17.26
South Africa	2 635.65	169.06	0.67	28.71	6 825	1.51	9.55
Overall mean	**2 128.67**	**100.11**	**0.70**	**22.95**	**6 264.55**	**2.28**	**14.87**

Source: *Author's compilation.*

Only Russia and South Africa had their mean energy consumption values greater than the overall mean energy consumption value of 2 128.67 kg of oil equivalent per capita whilst the remining BRICS nations' mean energy consumption values were less than the overall mean energy consumption figure. Judging by the deviation between individual country's mean energy consumption values and the overall mean energy consumption figure, outliers include Russia, India, and Brazil. Regarding

financial development, Brazil, Russia, and India's mean values were lower than the overall mean financial development of 100.11% of GDP. South Africa, Brazil and Russia are outliers because their mean financial development values are far away from the overall mean financial development value of 100.11% of GDP.

Brazil (0.75), Russia (0.79) and China (0.72)'s mean human capital development values are greater than the overall mean human capital development index value of 0.70. On the other hand, India (0.58) and South Africa (0.67)'s mean human capital development values are less than the overall mean human capital development index of 0.70. India and South Africa are the outliers because their mean human capital development values deviated from the overall mean human capital development index by a wider margin. Regarding trade openness, Russia (31.21% of GDP), China (24.59% of GDP) and South Africa (28.71% of GDP) are the only BRICS nations whose mean trade openness values exceeded the overall mean trade openness value of 22.95% of GDP. In summary, Brazil (12% of GDP), Russia (31.21% of GDP) and South Africa (28.71% of GDP) are the outliers because their mean trade openness values deviated by a wider margin from the overall mean trade openness value of 22.95% of GDP.

Among BRICS nations, only India (US$1 233 per capita) and China (US$3 862 per capita) had their mean GDP per capita values less than the overall mean GDP per capita value of US$6 264.55. Considering mean GDP per capita values of the BRICS nations, only South Africa is not an outlier as the mean GDP per capita values of the remaining countries within the group deviated from the overall mean GDP per capita value by a very wide margin. Russia (2.07% of GDP), India (1.45% of GDP) and South Africa (1.51% of GDP)'s mean FDI figures shows that they are below the overall mean FDI value of 2.28% of GDP.

The remaining BRICS nations (Brazil and China) had their mean FDI values greater than the overall mean FDI value of 2.28% of GDP. It is evident from Table 3 that Brazil, India, and China are the outliers because the deviation between their mean FDI values and the overall mean FDI value of 2.28% of GDP is exceptionally large.

Finally, Brazil, Russia and China are the only BRICS nations whose mean infrastructural development values surpassed the overall mean infrastructural development value of 14.87 fixed telephone subscriptions per 100 people. Using similar reasoning, Russia, India, and South Africa are the outliers regarding infrastructural development among BRICS nations.

5.2 Correlation Analysis

Table 4 presents correlation results between and among all the variables studied. The energy consumption proxy used in doing correlation analysis is energy use (kg of oil equivalent per capita).

Table 4. *Correlation results*

	ENCONS	FIN	HCD	OPEN	GROWTH	FDI	INFR
ENCONS	1.00						
FIN	0.0204*	1.00					
HCD	0.2381*	0.0176	1.00				
OPEN	0.4517**	0.1753*	0.1275	1.00			
GROWTH	0.0023***	0.1125**	0.1177	-0.1276	1.00		
FDI	0.1287**	0.0005***	0.2275*	0.7248	0.0126***	1.00	
INFR	0.2381***	0.3218*	0.3427**	0.4314	0.1893***	0.3327**	1.00

Note: ****/**/* denotes statistical significance at the 1%/5%/10% level, respectively.*
Source: *Author's compilation from E-Views.*

The only correlation which is above 70% is between FDI and trade openness. In line with Aye and Edoja (2017), multicollinearity problem exists in the correlation between FDI and trade openness, understandably because they both measure the overall openness of the economy. Energy consumption was found to be significantly and positively correlated separately with financial development, human capital development, trade openness, economic growth, foreign direct investment, and infrastructural development. These results are supported by literature. To decisively address the multicollinearity problem and the issue of outliers, this study transformed all the data sets into natural logarithms before analysing it, consistent with other authors who had to deal with similar challenges (Aye and Edoja, 2017; Tsaurai, 2018).

5.3 Panel Unit Root Tests

Levin *et al.* (2002), Augmented Dick Fuller Fisher Chi Square, Im *et al.* (2003) and Phillip Peron (PP) Chi square tests approaches are used for panel unit root testing.

Table 5. *Panel root tests –Individual intercept*

Level				
	LLC	IPS	ADF	PP
ENCONS	-2.2454	-0.2546	10.0210	5.4542
FIN	-1.3526	0.5519	7.3492	5.2109
HCD	-2.3782**	-2.4592***	22.0819**	35.8816***
OPEN	1.9815	3.1916	1.7128	0.8501
GROWTH	-0.7591	-0.0183	8.3820	7.4591
FDI	-1.8137**	-3.9329***	27.1483***	75.9491***
INFR	-1.1173	-1.7814*	20.8330**	10.7811
First difference				
ENCONS	-4.4581**	-3.9832***	37.4719***	128.1128***
FIN	-2.9923***	-4.5618***	35.4592***	201.4502***
HCD	-1.5491*	-3.9912***	33.8712***	317.3289***
OPEN	-2.6721**	-1.9910**	18.8712**	28.4501***
GROWTH	-2.9911***	-3.4592***	29.6618***	59.4591***
FDI	-5.6615***	-5.4430***	45.8612***	172.9982***
INFR	-2.8713***	-3.8821***	34.9943***	58.8734***

Source: *Author's compilation from E-Views.*

Note: *LLC, IPS, ADF and PP stands for Levin, Lin and Chu; Im, Pesaran and Shin; ADF Fisher Chi Square and PP Fisher Chi Square tests respectively. *, ** and *** denote 10%, 5% and 1% levels of significance, respectively.*

Unlike at level, all variables used are integrated of order 1 at first difference. These results paved way for panel co-integration tests to be undertaken, consistent with Tembo (2018).

5.4 Panel Co-integration Tests

Table 6 presents results for panel co-integration which was done using Johansen Fisher Panel co-integration approach.

Table 6. *Johansen Fisher Panel Co-integration test*

Hypothesised No. of CE(s)	Fisher Statistic (from trace test)	Probability	Fisher Statistic (from max-eigen test)	Probability
None	6.8812	0.8121	6.712	0.7123
At most 1	6.882	0.8121	6.712	0.7123
At most 2	2.4371	0.9219	54.14	0.0000
At most 3	92.34	0.0000	91.25	0.0000
At most 4	160.4	0.0000	106.7	0.0000
At most 5	82.11	0.0000	58.93	0.0000
At most 6	31.76	0.0002	31.23	0.0002

Source: *Author's compilation from E-Views.*

Six co-integrating vectors among the variables were observed. In other words, the null hypothesis which says that there is a long run relationship between and or among the variables studied could not be rejected at one percent significance level.

5.5 Main Data Analysis

In the main data analysis, model 1 uses energy use (kg of oil equivalent per capita) as a measure of energy consumption whilst model 2 uses electric power consumption (kWh per capita) to proxy energy consumption. Renewable energy consumption (% of total final energy consumption) is a measure of energy consumption used in model 3. Fossil fuel energy consumption (% of total) was used in model 4 as a measure of energy consumption. Fixed effects results are presented in Table 7.

Table 7. *Fixed Effects results*

	Model 1	Model 2	Model 3	Model 4
FIN	0.0067**	0.2317	-0.4376*	-0.2143
HCD	0.1276*	0.4539*	0.0215*	0.2187**
FIN.HCD	0.4328**	0.1165**	0.2328**	0.4586**
OPEN	0.4376	0.5329	0.3418	0.3217
GROWTH	0.0328*	0.7523*	0.5428*	0.3365**
FDI	0.4584**	0.3417**	-0.3487	-0.4538

INFR	0.5861**	0.0541	0.1265**	0.0547***
Adjusted R-squared	0.68	0.61	0.59	0.70
F-statistic	45.11	52.17	49.83	45.93
Prob (F-statistic)	0.00	0.00	0.00	0.00

Note: ****, ** and * denote 1%, 5% and 10% levels of significance, respectively.*
Source: *Author's compilation from E-Views.*

Using fixed effects, financial development had a significant positive impact on energy consumption in model 1 and a non-significant positive effect on energy consumption in model 2. These results are supported by a study done by Fernandes and Reddy (2021) in the case of China.

Whilst model 3 shows a significant negative relationship running from financial development towards energy consumption, model 4 produced results which indicates that energy consumption was negatively but non-significantly influenced by financial development. The results are consistent with Aye and Edoja (2017) whose research revealed that financial development can avail more funding towards investment into clean energy sources which are energy efficient.

Across all the four models, human capital development had a significant positive impact on energy consumption, in line with Tsaurai (2019) whose study argued that high levels of human capital development spur industrialization and large-scale manufacturing activities in the economy, leading to more energy consumption.

The study shows that the complementarity between financial development and human capital development had a significant positive effect on energy consumption across all the four models. The results also mean that human capital development is a channel through financial development's positive influence on energy consumption was enhanced, consistent with Salim *et al.* (2017)'s argument (Table 1).

Trade openness's impact on energy consumption was found to be positive but non-significant across all the four models, results which resonates with Rasiah *et al.* (2018)'s argument. Economic growth was observed to have had a significant positive influence on energy consumption across all the four models, in line with Nindi and Odhiambo (2014) who argued that economic growth leads to more energy consumption in a more energy consumption reliant economy.

In model 1 and 2, a significant positive relationship running from FDI towards energy consumption was observed, consistent with Abdouli and Hammami (2017) whose study revealed that FDI inflows increases energy consuming economic activities such as infrastructural development, urbanization, manufacturing activities and industrialization. On the other hand, a non-significant negative impact of FDI on energy consumption was noted in model 3 and 4, in contradiction to the existing literature on the subject matter.

Infrastructural development had a significant positive influence on energy consumption in model 1, 3 and 4 whilst model 2 shows a non-significant positive impact of infrastructural development on energy consumption. The results resonate with Yessengali and Murat (2018) whose research noted that infrastructural development related to roads maintenance and renovation of buildings consumes huge amounts of energy.

Table 8. *Pooled OLS results*

	Model 1	Model 2	Model 3	Model 4
FIN	0.0056**	0.2376*	0.6598*	0.2176**
HCD	0.3428*	0.2587*	0.2387*	0.3265**
FIN.HCD	0.4329***	0.5498***	0.5648***	0.0934***
OPEN	0.6583***	0.6398*	0.4761*	0.4587*
GROWTH	0.3429**	0.2398*	0.5419*	0.3428*
FDI	-0.5698	-0.5632	-0.5639	0.4896**
INFR	0.4598**	0.4598	0.2179	0.4328**
Adjusted R-squared	0.71	0.69	0.62	0.67
F-statistic	41.98	51.14	49.09	42.45
Prob (F-statistic)	0.00	0.00	0.00	0.00

Note: ****, ** and * denote 1%, 5% and 10% levels of significance, respectively.*
Source: *Author's compilation from E-Views.*

In all the four models, financial development had a significant positive influence on energy consumption under the pooled OLS approach. The results were supported by Samuel *et al.* (2013) whose study noted that financial development spurs the number and scale of economic activities hence increasing the overall quantity of energy used in the economy. Human capital development's impact on energy consumption was also found to be positive and significant across all the four models, consistent with Tsaurai (2019) who argued that human capital development spur large-scale manufacturing activities and industrialization in the economy, leading to more energy consumption.

In line with Salim *et al.* (2017), the complementarity between financial development and human capital development influenced energy consumption in a positive and significant manner. In other words, the influence of financial development on energy consumption was found to have been enhanced by human capital development across all the four models.

A significant positive relationship running from trade openness towards energy consumption was also observed across all the four models, consistent with a study done by Ismail *et al.* (2017) in the case of ASEAN seven member countries. Economic growth was also noted to have had a significant positive effect on energy consumption, in line with a research done by Fernandes and Reddy (2021) in the case of Indonesia.

Model 4 produced results which show that the impact of FDI on energy consumption was positive and significant, in line with Tang (2009) whose study observed that the inflow of foreign direct investment scales up urbanization, general level of manufacturing activities and infrastructural development activities, all of which consumes significant amount of energy. In contrast with available literature, model 1, 2 and 3 shows that FDI had a non-significant negative influence on energy consumption.

Infrastructural development had a significant positive effect on energy consumption in model 1 and 4 whilst a non-significant positive relationship running from infrastructural development towards energy consumption was observed in model 2 and 3. The results support arguments which put forward by Yessengali and Murat (2018).

Table 9. *Random Effects results*

	Model 1	Model 2	Model 3	Model 4
FIN	0.0659	0.3418**	0.3428**	0.0084
HCD	0.3487*	0.5198*	0.1198**	0.4582*
FIN.HCD	0.6518***	0.0045***	0.0452***	0.5487***
OPEN	0.5429**	0.3889	0.2256**	0.6532
GROWTH	0.2387***	0.0045	0.4110	0.1167***
FDI	0.6528**	-0.4587	0.3329-	0.2317***
INFR	0.1156**	0.5418	0.4328**	0.2317
Adjusted R-squared	0.69	0.64	0.61	0.66
F-statistic	43.87	53.83	43.14	40.32
Prob (F-statistic)	0.00	0.00	0.00	0.00

Note: ****, ** and * denote 1%, 5% and 10% levels of significance, respectively.*
Source: *Author's compilation from E-Views.*

Using random effects approach, financial development had a non-significant positive impact on energy consumption in model 1 whilst model 2, 3 and 4 produced results which show a significant positive relationship running towards energy consumption from financial development. The results are in line with findings produced by Samuel et al (2013), Fernandes and Reddy (2021) and Lefevre and Mainguy (2020).

Like findings produced by Mehrara *et al.* (2015) and Ergun *et al.* (2019), all the four models show that human capital development had a significant positive influence on energy consumption. Also, a significant positive relationship running from the complementarity variable (between financial and human capital development) towards energy consumption was observed, in support of Salim *et al.* (2017)'s argument.

Model 1 and 3 show that trade openness had a significant positive influence on energy consumption whilst model 2 and 4 reveal that energy consumption was affected by trade openness in a positive but non-significant manner. The results are in line with similar empirical research done by Ismail *et al.* (2017). Model 1 and 4

show that economic growth had a significant positive effect on energy consumption yet model 2 and 3 reveal that the impact of economic growth on energy consumption was positive but not significant. The results resonate with earlier similar studies done by Lefevre and Mainguy (2020), Bohlmann and Inglesi-Lotz (2020), Ismail *et al.* (2017), Ergun *et al.* (2019) and Inglesi-Lotz and Pouris (2016).

Consistent with Ergun *et al.* (2019) whose empirical research noted that FDI led to an increase in the usage in renewable energy, model 1 and 4 shows that FDI had a significant positive impact on energy consumption. Yet, model 2 and 3 reveal that the impact of FDI on energy consumption was negative and non-significant, in contradiction with most of the available literature on the subject matter.

Model 1 and 3 shows that infrastructural development had a significant positive impact on energy consumption whilst model 2 and 4 produced results which reveal a non-significant positive effect of infrastructural development on energy consumption. The results resonate with earlier similar research on the subject matter done by Yessengali and Murat (2018).

Table 10. *Fully Modified Ordinary Least Squares (FMOLS) results*

	Model 1	Model 2	Model 3	Model 4
FIN	0.3421	0.2267	0.0956	0.0906
HCD	0.3428**	0.4538*	0.3479**	0.5498*
FIN.HCD	0.1156***	0.2267*	0.2359*	0.4376**
OPEN	0.2376	0.3267**	0.0894	0.0647**
GROWTH	0.1156***	0.4537***	0.3498***	0.4387***
FDI	-0.3427	-0.2287	0.2278**	0.1178**
INFR	0.5648**	0.2367**	0.0547***	0.2378***
Adjusted R-squared	0.73	0.75	0.70	0.67
F-statistic	42.67	51.98	46.89	41.34
Prob (F-statistic)	0.00	0.00	0.00	0.00

Note: ****, ** and * denote 1%, 5% and 10% levels of significance, respectively.*
Source: *Author's compilation from E-Views.*

Using FMOLS approach, financial development had a non-significant but positive influence on energy consumption across all the four models as generally supported by most recent literature (Fernandes and Reddy, 2021). In line with available literature (Mehrara *et al.* 2015), human capital development was also found to have had a significant positive influence on energy consumption in all four models. Salim *et al.* (2017)'s study also resonates with this study which show that the complementarity variable had a significant positive effect on energy consumption in all four models.

Model 1 and 3 shows that trade openness had a non-significant positive impact on energy consumption whilst a significant positive relationship running from trade openness towards energy consumption was observed in model 2 and 4. These results are supported by literature (Ismail *et al.* 2017; Rasiah *et al.* 2018). In support of

findings produced by Ergun *et al.* (2019) and Lefevre and Mainguy (2020), energy consumption was driven up by economic growth across all the four models.

In contrast with available literature, model 1 and 2 shows a non-significant negative influence of FDI on energy consumption. However, model 3 and 4 shows that FDI had a significant positive effect on energy consumption, in line with earlier empirical researchers such as Ergun *et al.* (2019). Consistent with Yessengali and Murat (2018) and Reddy *et al.* (2001), this study reveals that a significant positive relationship running from infrastructural development towards energy consumption exists across all the four models.

6. Concluding Remarks

This study investigated the determinants of energy consumption in BRICS countries using panel data analysis methods (fixed effects, FMOLS, pooled OLS, random effects) with panel data ranging from 1996 to 2018. Under fixed effects, financial development was found to have had a significant positive influence on energy consumption in model 1 and a significant negative effect on energy consumption in model 3. Human capital development, financial development, the interaction between financial and human capital development and economic growth were all found to have had a significant positive influence on energy consumption across all the four models. FDI had a significant positive effect on energy consumption in model 1 and 2 whilst infrastructural development had a significant positive influence on energy consumption in model 1, 3 and 4.

Under pooled OLS methodology, financial development, human capital development, interaction variable, trade openness and economic growth were found to have had a significant positive impact on energy consumption across all models. FDI's significant positive influence on energy consumption was observed in model 4 only whilst infrastructural development had a significant positive effect on energy consumption in model 1 and 4. Under random effects, financial development influenced energy consumption in a significant positive manner in model 2 and 3. Both human capital development and the interaction term separately had a significant positive impact on energy consumption across all the four models whilst trade openness and infrastructural development's influence on energy consumption was positive and significant in model 1 and 3. Yet economic growth and FDI were found to have had a significant positive influence on energy consumption in model 1 and 4.

Under FMOLS, four variables which had a significant positive effect on energy consumption across all the four models include human capital development, the interaction term, economic growth, and infrastructural development. Whilst trade openness had a significant positive impact on energy consumption in model 2 and 4, FDI's impact on energy consumption was observed to be positive and significant under model 3 and 4. BRICS countries are therefore urged to design and implement

policies aimed at enhancing human capital development, the complementarity between financial and human capital development, economic growth and infrastructural development in order to increase renewable and fossil fuel energy usage (energy usage that preserves the ecosystem and promotes sustainable growth).

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