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Energy economic expansion with production and consumption in BRICS countries

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ABSTRACT

Global energy demand for energy consumption is increasing day by day, and it seems complicated for most countries to meet energy demand with total energy production. In this regard, this study investigates the comparative impact of energy production and consumption on economic growth in the BRICS countries. This study conducts panel data modelling, more specifically, the fixed-effects model, random-effects, and panel FMOLS model, to find the impact of energy production and consumption on economic growth in the BRICS countries. This study finds that energy production and consumption significantly impact the economic development of the BRICS countries. More specifically, dry natural gas production and consumption, electricity generation and consumption, biofuel production, petroleum production, capital formation, and trade openness positively impact on economic growth, while coal production significantly and negatively impacts on economic growth. This research is of great significance to the economic integration of the BRICS economies.

1. Introduction

Energy production and consumption are one of the most burning research areas in present times. The production and consumption of energy are not only important research area but also crucial for environmental and economic concerns worldwide. While global primary energy consumption has increased over the past decade, primary energy production is expected to grow faster in the BRICS countries [1,2]. As consumption increases, the production also increases worldwide due to the excessive energy demand for different uses [3]. According to IEA, from 2016 to 2040, global energy demand will increase by 30%, equivalent to adding India and China to the current world demand.[1] Energy demand is projected to grow each year due to the overuse of energy for different purposes such as industry, travel, lighting, cooling, and buildings [4]. This increase is driven by the country's economic transformation plan and strong growth in GDP. The successful fulfilment of energy demand has also led to the realisation of sustainable development goals. By 2030, enabling universal access to adequate, modern, affordable, and economical energy services is one of the 17 SDGs objectives, more particularly SDG 7 refers to worldwide access to reliable, modern, and affordable energy access [5]. Accomplishing this goal also fosters and helps progress several other sustainable development goals. Thus, it has been widely accepted that meeting the universal energy demand and growing renewable energy may positively affect sustainable development goals [6–8].

Considering the economic perspective, researchers and scholars have focused on different models of both renewable and non-renewable energy resources [9]. Many existing literature experiments with the significance of energy production on economic growth. There is no dispute about the high importance of maximising the production of clean solar energy. Both the installation and operation of energy plants may have significant economic consequences in promoting energy production and creating employment. It also significantly impacts social, economic, and environmental issues [10]. Danish et al. [11] mention energy production as one of the critical forces of industrial expansion, economic growth, and overall economic development. Kazar et al. [12] also demonstrate that energy production has a significant positive impact on economic growth in the long run. Peach et al. [13] find that though there is a small energy production has a substantial effect on economic growth. Alola & Alola [14] designate energy as a positive driver of economic growth. In recent years, long-term policies have largely shifted to energy with the shift towards safer, more efficient, and cleaner energy sources. Energy consumption also significantly promotes economic growth. For example, Esen & Bayrak [15] find a significant impact of energy consumption on long-term economic growth. Silva et al. [16], Oguz et al. [17], Apergis & Payne [18], Inglesi-Lotz [19], and Kahia et al. [20] show

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[1] IEA (2020), World Energy Outlook 2020, IEA, Paris https://www.iea.org/reports/world-energy-outlook-2020.

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energy consumption has significant impacts on economic growth. In addition, not only renewable energy significantly influences economic growth, but also non-renewable energy consumption significantly influences economic growth [21,22]. Vidyarthi [23] also finds a significant long-term equilibrium relationship between energy consumption and economic development.

Considering the study background and previous literature, to the best of our knowledge, few studies have been focusing on comparing the comparative economic impact of energy production and consumption on economic aspects of the economy on a single platform. More specifically, the relative impact of energy production and consumption on economic aspects, especially in the BRICS countries. The BRICS countries include Brazil (B), Russia (R), India (I), China (I) and South Africa (S). This study identifies the lack of comparison of the economic impacts of energy production and consumption in the BRICS countries as a research gap. In addition, there are few studies on the impact of biofuel production and consumption, refined petroleum production and consumption, liquefied petroleum gases and ethane production and consumption on economic growth, and even few existing studies on the economic impact of these energy variables on the BRICS countries. This study considers the lack of those studies as a research gap. Aligning with the research gaps, this study specifies the research questions (RQs). *RQ1: How does energy production affect economic growth in the BRICS countries? RQ2 How does energy consumption affect economic growth in the BRICS countries? RQ3: How does the impact of energy production on economic growth differ from the impact of energy consumption on economic growth?*

Considering this lack of production and consumption relative impactful research as the study gap, aligning with the study gaps and research questions, this study specifies the research objective to investigate the impact of both energy production and consumption to economic growth. The purpose is extended to examine the relative effect of energy production and consumption on economic growth in the aspect of the BRICS economy. This study examines the effects of energy production and energy consumption in the same direction to explore the comparative effects of energy production and consumption economies. Worldwide, both energy production and consumption are seen as one of essential global economic drivers. Energy production and consumption have social, economic, and environmental impacts. Therefore, considering the importance of energy production and consumption for economic expansion, this study presents the comparative effect of energy production and consumption in the BRICS countries. Also, the relative impact of energy production and consumption may add significant value to the existing energy economics literature. With the study goal in mind, this study conducts experiments in two distinct phases. First, this study performs experiments on production models showing the impact of energy production on economic growth. This study then investigates consumption models showing energy consumption's effects on economic growth.

The BRICS countries are the most economically developed countries among emerging countries. Rapid economic growth in these countries makes them need more energy. Only one economic zone is studied here to present a specific comparative impact on energy production and consumption. The BRICS countries collectively produced 36% of their total energy output. According to EIA, China is the largest energy producer country in the world, Russia is the 3rd largest, India is the 6th largest, Brazil is the 10th largest, and South Africa is the 20th largest energy producer country. Brazil and Russia are both one of the top energy exporters. China and India are the world's biggest importers of natural gas, coal, and oil. China produces the cleanest energy in the world as well as China has rapidly switched to renewable energy as the 3rd greatest renewable energy investor, accounting for over half of the world's non-hydro renewables in 2020; yet, China is the top emitter, even with the highest solar and wind power capacity. China aims for carbon neutrality by 2060. China, Brazil, India, and Russia are the four leading clean energy investors in 2019, accounting for more than half of the world's investment. Also, South Africa, the wealthiest country in Africa, is a sustainable energy pioneer. According to UNEP, South Africa will be a potential market for renewable energy in the next decade due to its vast solar, biomass, wind, and other resources. For these reasons, BRICS countries are considered as a perfect research area for this study.

The contribution of the study is particular. This study is the first to simultaneously test the relative empirical effects on energy production and consumption in a single economic zone. Most studies focus only on the importance of fossil fuels or renewable energy. Also, in most cases, only dry gas and electricity production and consumption have been the focus. However, this study complements a single analysis after adding biofuel production and consumption, LPG and ethane production and consumption, and refined oil production and consumption as significant forces for economic growth. Among the findings, this study shows the comparative significance of energy production versus consumption and vice versa, which is the main contribution of this paper.

To accomplish the study with empirical justification, this study first analyses the fixed and random effect models and then chooses the best one from the Hausman test. Later, this study shows the additional measures and analysis to justify the outcome of the base models. Finally, this study finds a significant impact of energy production and consumption on economic growth.

This study follows structured research planning, such as an introduction in the first section and a literature review and methodology in the second and third sections. The fourth section presents the findings and analysis. And the fifth and sixth sections present the implications and conclusion of the study, respectively.

2. Literature review

Energy projects influence multiple aspects of global socioeconomic development, especially the relationship between natural resources and economic growth [24–26]. Natural resources affect the economy in different ways. Due to the increasingly positive impact of natural resources on the economy, energy usage and demand is increasing daily. Yang et al. [4] specify that energy demand is projected to grow each year due to the overuse of energy for different purposes such as industry, travel, lighting, cooling, and buildings. This increase is driven by the country's economic transformation program and strong GDP growth. The government has adopted and implemented various energy policies to meet this growing demand and address environmental problems [27]. Rashidi et al. [28] point out that the increasingly volatile demand for energy influences the national economic growth of developing countries. Liu, Saleem, et al. [9] evaluate the influences of globalisation, income, financial development, and governance on the volatility of natural resources in 14 MENA regions. They mention that natural resources are considered one of the most influential forces in global economic growth. Even the volatility associated with natural resources significantly influences the respective countries' sustainable economic development.

There is a heated debate about mining natural resources and their impact on economic growth in energy-producing countries. These arguments partly derive from the resource curse literature, suggesting that resource strength and economic growth are related inversely. Peach and Starbuck [13] investigate the connection between energy output and economic expansion and find that oil and gas mining positively impacts employment, population, and income. It implies that energy production significantly boosts economic development by creating job opportunities and increasing the per capita income of the respective countries.

Some other studies, such as [29,30,95,96] also justify the positive impact of dry natural gas on promoting economic expansion. Bilgili et al. [31] look into how shale gas affects the energy sector as well as how it affects macroeconomic factors like employment and economic growth. They find a one-way relationship between regional gas production and regional GDP available in some US states, including Colorado, West Virginia, and Ohio. Also, a two-way causal relationship exists between regional gas production and GDP in Texas, California, and Arkansas.

However, there is no link between regional GDP and regional gas production in Montana, Wyoming, and New Mexico. Shahbaz et al. [32] examine how natural gas consumption impacts economic growth and reveal that natural gas is one of the most important energy sources for industrial and economic development. Higher production of natural gas increases electricity generation as well as increases natural gas production and consumption significantly boosting economic expansion in Pakistan. Also, Sinaga et al. [33] very specifically emphasise and mention that dry natural gas is one of the most essential energy forces of Indonesian economic growth.

Electricity is one of the most important energy sources that always play significant roles in human life as well as economic integration. Yu et al. [34] examine how electricity production promos the country's industrial development and supports the respective countries' sustainable economic expansion. They reveal that electricity production simultaneously promotes both industrial and economic growth. Particularly electricity production from both renewable and non-renewable sources positively impacts economic integration [35,36]. Zeshan [37] demonstrates that the development of hydropower plants alsdirectly and indirectly benefits the economy. Mainly, hydropower development produces more clean power for the country and provides cost-effective electricity for industrial operations. Not only electricity generation but also the consumption of electricity for different purposes influence economic expansion. For example, a number of studies, such as [38–42], reveal that electricity consumption for daily activities, industrial operation, transportation, and other activities significantly boost economic growth.

Ravindranath et al. [43] demonstrate that the expected large-scale biofuel production has significant implications on economic growth through food production, biodiversity, and rural development. According to Bhattacharya et al. [44], renewable energy deployment and institutions are crucial in boosting economic growth. Ali et al. [45] also demonstrate that by adopting biogas technology in a country's rural area can considerably help promote economic growth in the respective countries. Global interest in biofuels is increasing, especially in India. India announced a biofuel policy to promote energy security, reclaim degraded land, and develop livelihood opportunities for remote communities [43]. Subramaniam and Masron [46] examine the impact of globalisation on biofuel on economic expansion. The findings demonstrate that economic globalisation has a favourable effect on the production of biofuels. They also contend that promoting globalisation's economic aspects will enhance the use of biofuels and lessen its adverse environmental impact. Another study, Al-Mulali et al. [47], investigate Brazil's biofuel consumption-based economic growth. It shows that increasing biofuel consumption increases the economic growth in Brazil.

Yuzbashkandi and Sadi [48] examine how petroleum production influences economic expansion. This study shows that petroleum production positively impacts on the economic growth of OPEC countries. More particularly, in all OPEC members except Venezuela and Ecuador, PP significantly influences GDP growth. This result indicates that adopting development policies in the petroleum production sector can benefit those countries. Venezuela and Ecuador showed no impact and must follow energy development policies in petroleum production. Due to a significant influence, this study considers petroleum production as one of the most important influencing factors for the economic growth of OPEC members. Not only petroleum production, but also petroleum consumption significantly impacts economic expansion. For example, Narayan et al. [49], explore how petroleum consumption impacts on economic expansion. They show that petroleum consumption adversely affects economic activity in lower- and middle-income Indian states.

Li et al. [50] investigate the connection between China's economic progress and coal development using data from 1997 to 2010. They show a significant positive association between China's coal production and economic growth. However, it has been suggested that the coal companies in China need to maintain a reasonable speed in coal production. Also, investment in technological innovation should be increased in coal production to reduce environmental damage. Barbier [51] looked into how natural resources affected economic development in developing nations. This study demonstrates that the plentiful supply of resources promotes economic expansion in developing countries.

Another study, such as [22], demonstrates that renewable energy can significantly contribute to strengthening energy security in each country, (3) an important role that can play renewable energy as a possible means of industrial diversification, employment and technology transfer, and improving the environment's quality. As a result of this growing interest, MENA's net oil exporters have increased and implemented several policies to promote the rapid deployment of renewable energy. And finally, (4) the low cost of the latest renewable energy technologies, such as wind and solar, can meet the growing energy demands of all pure oil exporters in the region.

Liu et al. [25] mention three energy trilemmas and refer to three common conflicting challenges, such as energy equity, security, and sustainability, that influence energy-based economic development and sustainable development. Similarly, Zahoor et al. [52] also mention three energy trilemmas, such as investment in fixed assets, energy use all, and sustainable energy transition, which simultaneously promote economic growth in the long run.

There are some other complications associated with the development of energy economics. To overcome these complications, especially the shortage of non-renewable energy resources in the future, many MENA crude oil exporters have the potential to produce energy from renewable resources, especially the sun and wind [22].

The growth in real GDP is the main measure of economic development. Energy economic variables are influential in increasing real GDP and promoting economic growth. However, there are still many additional economic growth indicators that are also required, such as increased levels of literacy, a decline in poverty, higher healthcare standards, and greater infrastructure [53].

After studying the literature, this study finds that most of the literature on energy economics area focuses on only one aspect, such as production or consumption. Therefore, to the best of our knowledge from the literature study, few studies focus on comparing the comparative economic impact of energy production and consumption on economic aspects of the economy on a single platform. Even there is no such study on the BRICS region. In addition, very few study focus on the impact of fuel ethanol production and consumption, liquefied petroleum gases and ethane production and consumption, and refined petroleum production and consumption. This lack motivates this study to specify the research questions and objectives.

3. Methodology

3.1. Variable measurement

The variables of this study have been specified after studying the literature. The dependent variable is the respective countries' GDP, which is measured as economic growth. FDI, Trade openness, and capital formation are the variables related to macro function and economic growth proxies. These three variables are used in both the production and consumption models. Other explanatory variables are dry natural gas production and consumption, electricity generation and production, biofuel production and consumption, hydrocarbon production and consumption, refined petroleum production and consumption, and coal production and consumption. Table 1 present the details of variable measurement.

3.2. Experimental strategies

Energy consumption and economic integration are burning research areas of this decade. Researchers studied energy economics research in different aspects, such as specific countries, special economic zone, geopolitical regions, continents, etc. Most of the studies used panel data

Table 1
Variable measurement.

Variables	Measurement
Dependent variable	
GDP	GDP measured in Billion 2015$
Economic proxies	
FDI	Foreign direct investment is measured in USD Billion
Capital formation	Gross capital formation measured in % of GDP, finally % converted to USD Billion
Trade openness	Trade openness measured in % of GDP, finally % converted to USD Billion
Energy production variables	
Dry natural gas production	Dry natural gas production measured in (bcf)
Electricity generation	Electricity generation, measured in billion kWh, calculated as the sum of electricity generation from nuclear, fossil fuels, renewables, and hydroelectric pumped storage. Renewables include the total of hydroelectricity & hon-hydroelectric renewables. Non-hydroelectric renewables include geothermal, solar, tide, wave, fuel cell, wind, biomass and waste.
Biofuel production	Biofuel production, measured in Mb/d, includes biomass-based diesel and fuel ethanol
Hydrocarbon production	Liquefied petroleum gases and ethane production, measured in Mb/d, includes the sum of liquefied petroleum gases and ethane (refinery), liquefied petroleum gases (non-refinery), and ethane (non-refinery).
Refined petroleum production	Refined Petroleum production, measured in Mb/d, includes motor gasoline, jet fuel, kerosene, distillate fuel oil, residual fuel oil, liquefied petroleum gases, and other petroleum liquids
Coal production	Coal production, measured in Mst, Anthracite (Mst), Metallurgical coal, Bituminous, Subbituminous, Lignite, Metallurgical coke
Energy consumption variables	
Dry natural gas consumption	Dry natural gas consumption measured in (bcf)
Electricity consumption	Electricity consumption, measured in billion kWh, calculated as the sum of electricity consumption of nuclear, fossil fuels, renewables, and hydroelectric pumped storage. Here, renewables include the total of hydroelectricity & hon-hydroelectric renewables. Non-hydroelectric renewables include geothermal, solar, tide, wave, fuel cell, wind, biomass and waste.
Biofuel consumption	Biofuel consumption, measured in Mb/d, includes biomass-based diesel and fuel ethanol
Hydrocarbon consumption	Liquefied petroleum gases and ethane consumption, measured in Mb/d, includes LPG & Ethane
Refined petroleum consumption	Refined Petroleum consumption, measured in Mb/d, include motor gasoline, jet fuel, kerosene, distillate fuel oil, residual fuel oil, liquefied petroleum gases, and other petroleum liquids
Coal consumption	Coal consumption, measured in Mst, Anthracite (Mst), Metallurgical coal, Bituminous, Subbituminous, Lignite, Metallurgical coke

Source: Authors' collection (Note: Mb/d refers millions of barrels per day, Mst refers millions of tons)

methods. This study also conducts panel data methods. This study follows the energy categories by the US EIA (www.eia.gov). They included dry natural gas, electricity, biofuel, hydrocarbon, petroleum, and coal as the element of energy. This study uses consumption and production data; electricity generation is considered production. Besides energy production and consumption, this study includes other variables directly related to economic growth. For example, foreign direct investment [54–57], gross capital [7,56,58,59], and trade openness [7,55,56]. The data range of this study is selected from 1992 to 2019. First, this study experiments with serial correlation for both the production and consumption model. To test serial correlation, this study conducts the *Wooldridge autocorrelation test* [60]. Here, the null hypothesis is assumed that there is no first-order autocorrelation, and the alternative hypothesis is assumed there is autocorrelation. In the production model, the F value is 6.106, and prob > F is 0.1321. This autocorrelation test is also conducted for the consumption model; the F value is 16.013, and prob > F is 0.100. Therefore, this study can't reject the null hypothesis for both the production and consumption model, indicating no autocorrelation. Also, this study tests the '*Breusch-Pagan/Cook-Weisberg test*' for heteroskedasticity. The null hypothesis is constant variance. This study finds there is no heteroskedasticity in both production and consumption model *[production model: $chi^2(9) = 17.61$, $Prob > chi^2 = 0.0400$, and consumption model: $chi2(9) = 30.21$, and $Prob > chi2 = 0.000$]*. Since there is an absence of serial autocorrelation and heteroskedasticity in both models, this study considers static panel data modelling to accomplish the objective of this study. This study uses the fixed effect model (FEM) and random effect model (REM). The baseline regression models are as follows.

The baseline regression for the energy production model is;

$$EcoGr_{it} = \beta_0 + \beta_1 FDI_{it} + \beta_2 CapFor_{it} + \beta_3 Trade_{it} + \beta_4 NgasProd_{it} + \beta_5 ElecGen_{it} + \beta_6 BiofuelProd_{it} + \beta_7 HydrocProd_{it} + \beta_8 PetroProd_{it} + \beta_9 CoalProd_{it} + \varepsilon_{it}$$

The baseline regression for the energy production model is;

$$EcoGr_{it} = \beta_0 + \beta_1 FDI_{it} + \beta_2 CapFor_{it} + \beta_3 Trade_{it} + \beta_4 NgasCons_{it} + \beta_5 ElecCons_{it} + \beta_6 BiofuelCons_{it} + \beta_7 HydrocCons_{it} + \beta_8 PetroCons_{it} + \beta_9 CoalCons_{it} + \varepsilon_{it}$$

Here, *EcoGr* refers to economic growth, *FDI* refers to foreign direct investment, *CapFor* refers to capital formation, *Trade* refers to trade openness, *NgasProd* dry natural gas production, *ElecGen* refers to electricity generation, *BiofuelProd* refers to biofuel production, *HydrocProd* refers to hydrocarbon production, *PetroProd* refers to petroleum production, and *CoalProd* refers to coal production. *NgasCons* dry natural gas consumption, *ElecCons* refers to electricity consumption, *BiofuelCons* refers to biofuel consumption, *HydrocCons* refers to hydrocarbon consumption, *PetroCons* refers to petroleum consumption, and *CoalCons* refers to coal consumption.

4. Findings and analysis

4.1. Descriptive statistics

The descriptive statistics of this study's variables are presented in Table 2. According to the Table 2, China has the highest number in all cases for energy production and consumption. Russia, India, Brazil, and South Africa are in the second, third, fourth, and fifth positions, respectively. In Table 2, there is no information regarding biofuel production and consumption. We couldn't find any significant biofuel production and consumption data for Russia and South Africa. This study examined 28 years of data for most variables, while petroleum and hydrocarbons have 23 years and 21 years of data, respectively.

4.2. Empirical findings

This study experiments with the energy production model to find the impact of energy production on the economic growth of BRICS countries.

The first section of empirical findings presents the output of energy production impact in Table 5. Following static panel data modelling concepts, FEM and REM have been experimented with the data in this study. Also, the FEM and REM are tested in two ways: energy variables without economic proxies and economic proxies. After the baseline regression analysis, this study experiments with the Hausman (1978) specification test to compare the FEM and REM estimation. Here, the null hypothesis is that the REM model is the appropriate model & the alternative hypothesis is that the FEM is appropriate. After estimating FEM and REM, the Hausman (1978) specification is conducted. The Hausman test shows a p-value of .000, which suggests rejecting the null

Table 2
Descriptive statistics

Variables	BRAZIL							
	Mean	Median	Max	Min	Std.D	Skew	Kurt	Obs
GDP	2391.88	2335.06	3124.05	1540.19	533.28	0.00	1.48	28
Capital	443.85	409.95	674.19	291.63	117.27	0.69	2.21	28
FDI	41.66	31.70	102.43	1.29	31.91	0.39	1.72	28
Trade	580.04	620.05	883.27	284.03	194.08	-0.25	1.80	28
Gas(P)	446.80	346.26	946.87	130.31	274.52	0.57	1.81	28
Gas(C)	706.48	670.10	1504.09	130.31	464.81	0.26	1.65	28
Electricity(P)	421.16	403.82	615.35	238.84	122.42	0.11	1.58	28
Electricity(C)	388.91	375.21	597.23	228.11	105.94	0.18	1.79	28
Biofuels(P)	352.07	291.57	640.82	184.00	142.17	0.46	1.85	28
Biofuels(C)	308.60	231.50	647.40	141.38	156.06	0.75	2.23	28
Hydrocarbon(P)	164.62	176.00	207.00	126.00	29.45	-0.09	1.35	21
Hydrocarbon(C)	207.10	212.00	239.00	169.00	19.84	-0.64	2.47	21
Petroleum(P)	2147.45	2091.93	2922.95	1491.00	417.11	0.07	2.02	23
Petroleum(C)	2464.75	2258.29	3279.27	1570.00	522.64	0.09	1.78	28
Coal(P)	22201	21453	29300	18185	2740	1.14	3.61	28
Coal(C)	57022	54418	73720	45515	8850	0.51	1.92	28
CHINA								
GDP	9721.43	7613.25	23129.50	2076.94	6620.10	0.61	2.04	28
Capital	4154.84	3054.07	10003.76	811.50	3027.13	0.54	1.83	28
FDI	126.23	114.10	290.93	11.16	91.45	0.44	1.73	28
Trade	4300.68	4724.33	8289.02	626.11	2739.58	-0.01	1.39	28
Gas(P)	2487.35	1914.74	6332.55	533.26	1836.44	0.61	2.04	28
Gas(C)	3260.85	1823.98	10826.67	516.77	3115.85	1.02	2.85	28
Electricity(P)	3083.44	2544.86	7136.23	716.04	2085.68	0.51	1.86	28
Electricity(C)	2901.64	2360.06	7130.20	666.14	2008.27	0.57	2.00	28
Biofuels(P)	49.47	54.81	95.00	5.00	23.86	-0.27	2.34	18
Biofuels(C)	53.46	54.64	102.12	5.00	27.89	-0.14	2.01	18
Hydrocarbon(P)	391.24	341.00	695.00	116.00	205.37	0.19	1.56	21
Hydrocarbon(C)	493.00	521.00	767.00	117.00	226.33	-0.33	1.64	21
Petroleum(P)	5905.71	5205.33	10851.87	2675.00	2662.65	0.45	1.87	23
Petroleum(C)	7632.48	7231.81	14409.69	2694.00	3730.40	0.34	1.80	28
Coal(P)	5741434	5750506	9294812	2543420	2539585	0.08	1.33	28
Coal(C)	5898531	5958142	9972386	2285639	2878574	0.09	1.33	28
INDIA								
GDP	4455.81	3879.00	9309.17	1703.28	2305.16	0.66	2.26	28
Capital	1475.42	1493.52	2816.34	431.48	804.79	0.13	1.50	28
FDI	19.32	13.65	50.61	0.28	17.66	0.34	1.49	28
Trade	1823.50	1704.28	3856.45	313.97	1238.57	0.21	1.45	28
Gas(P)	1008.27	1071.81	1848.39	476.75	335.51	0.58	3.06	28
Gas(C)	1336.48	1319.55	2277.46	476.75	627.55	0.13	1.45	28
Electricity(P)	813.40	701.55	1579.90	315.97	398.46	0.61	2.09	28
Electricity(C)	642.47	522.12	1301.22	255.69	338.77	0.70	2.11	28
Biofuels(P)	10.35	7.40	44.63	2.58	10.79	2.03	6.51	20
Biofuels(C)	9.83	5.03	44.55	2.24	10.89	2.08	6.60	20
Hydrocarbon(P)	214.95	230.00	309.00	113.00	67.98	-0.13	1.54	21
Hydrocarbon(C)	267.00	255.00	506.00	89.00	128.29	0.21	1.85	21
Petroleum(P)	2663.59	2550.82	4657.24	1128.00	1257.21	0.31	1.71	23
Petroleum(C)	2759.78	2565.17	5042.35	1274.00	1058.68	0.52	2.41	28
Coal(P)	990477	987713	1500183	562613	294621	0.11	1.64	28
Coal(C)	1134659	974890	2009126	516247	505140	0.42	1.67	28
RUSSIA								
GDP	2784.55	2845.67	3770.42	1734.12	714.65	-0.12	1.42	28
Capital	632.97	618.51	871.21	259.50	196.81	-0.30	1.75	28
FDI	22.15	12.09	74.78	0.69	22.86	0.86	2.51	28
Trade	1515.29	1586.30	2739.37	865.53	378.54	0.69	5.36	28
Gas(P)	21149.09	21463.04	23937.64	18900.59	1313.42	0.01	2.42	28
Gas(C)	14970.81	15225.36	17329.15	12298.45	1532.62	-0.29	1.78	28
Electricity(P)	923.01	938.85	1057.62	786.49	89.82	-0.15	1.56	28
Electricity(C)	807.87	816.32	965.16	675.26	88.03	-0.03	1.63	28
Hydrocarbon(P)	279.62	247.00	494.00	157.00	105.98	0.60	2.14	21
Hydrocarbon(C)	232.90	228.00	404.00	107.00	94.74	0.24	1.76	21
Petroleum(P)	4524.21	4421.55	6173.55	3376.00	780.64	0.42	2.10	23
Petroleum(C)	3008.38	2765.75	4424.00	2463.10	495.80	1.00	3.30	28
Coal(P)	694138	661626	999306	506227	142702	0.78	2.54	28
Coal(C)	533925	521830	718978	477468	50697	2.12	7.84	28
SOUTH AFRICA								
GDP	544.32	550.27	714.58	358.71	125.50	-0.04	1.48	28
Capital	102.92	106.06	145.44	55.06	30.49	-0.06	1.37	28
FDI	3.33	2.14	9.89	0.00	2.89	0.63	2.17	28

(*continued on next page*)

Table 2 (*continued*)

Variables	BRAZIL							
	Mean	Median	Max	Min	Std.D	Skew	Kurt	Obs
Trade	305.83	309.92	447.81	134.47	107.11	-0.14	1.53	28
Gas(P)	54.21	50.32	102.41	32.10	18.10	0.70	2.87	28
Gas(C)	116.48	132.96	179.15	44.50	49.28	-0.11	1.34	28
Electricity(P)	214.85	229.28	245.58	157.08	27.44	-0.69	2.07	28
Electricity(C)	192.93	204.83	220.42	143.58	23.16	-0.74	2.22	28
Biofuels(P)	3.22	3.22	6.41	0.03	4.51	0.00	1.00	2
Biofuels(C)	0.03	0.03	0.03	0.03	0.00	0.00	1.00	2
Hydrocarbon(P)	10.28	11.00	13.00	7.10	1.48	-0.46	2.63	21
Hydrocarbon(C)	10.79	11.00	18.00	5.50	2.86	1.24	4.96	21
Petroleum(P)	435.83	431.96	551.00	344.00	51.58	0.26	2.39	23
Petroleum(C)	536.80	505.01	701.00	401.60	96.30	0.12	1.51	28
Coal(P)	256979	269923	287195	188679	28683	-0.94	2.72	28
Coal(C)	185133	191137	208986	142963	19602	-0.72	2.32	28

Source: Author illustration

hypothesis; therefore, the FEM is appropriate for the energy production model. Finally, the FEM model is accepted here for the production model, and this study suggests FEM for further analysis and discussion of the impact of energy production on economic growth.

According to the FEM model of Table 3, among the energy production explanatory variables, the first one is dry natural gas production, which is positively significant to economic growth. This result indicates that a 1% increase in dry natural gas production increases GDP by 0.402% (without GDP proxy), but the coefficient is lower (0.247) after adjusting with economic proxies. Though the coefficient is lower, the result is significant at a 95% confidence interval greater than that without economic proxies. This result indicates that increasing dry natural gas production increases economic growth. This result supports the result of [31], which found that natural gas production has a unidirectional relationship with economic growth [13]. also found that gas production had a positive impact on income & employment that finally led to overall economic growth. The second variable of the energy production model is electricity generation, which has a significant positive impact on economic growth at $p < .01$. The coefficient is 2.922 after adjusting with other economic proxies. Electricity generation shows the highest impact among all the energy production variables, indicating that greater electricity generation boosts economic growth. The result of this study supports the output of previous literature that also found that increasing electricity generation significantly promoted both short and long-run economic growth [61–63]. Dincer [64] recommend electricity generation as a highly potential force of economic development. Another study [34] emphasises electricity production's significance as an important force of sustainable economic growth. The third variable of this model is biofuel production. Biofuel production shows different results in different models. Though biofuel production seems insignificant without adjusting with economic proxies, it shows a significant positive impact on GDP growth after adjusting with economic proxies ($p < .05$ level, the coefficient is 0.492). This result indicates that increasing biofuel production significantly increases economic growth. Also, biofuel significantly impacts economic globalisation, particularly in developing countries [46,65]. It also significantly impacts on sustainable development [43,66,67]. The bioethanol value chain's development also positively affects economic growth and employment [67]. The fourth variable, hydrocarbon is negatively significant without adjusting with other economic proxy models; however, in the economic proxies adjusted model, it shows an insignificant impact on economic growth. The fifth energy variable of this model is petroleum production, which is also positively significant at $p < .10$ level (coefficient is 0.126) on GDP. This finding indicates that increasing refined petroleum production moderately increases economic growth. The finding of refined petroleum production supports the results of other previous literature, such as Alshubiri et al. [68] & Yuzbashkandi and Sadi [48]. Besides the economic significance, refined petroleum production also significantly impacts financial development [68]. The final energy variable, coal production, shows a significant negative impact on GDP ($p < .01$ level, and the coefficient is −0.001 in both models). The coefficient value is deficient compared to other energy production variables. Still, the result is significant and refers to higher coal production hindering economic progress. However, the recommended consumption model shows no impact of coal consumption on economic growth (please see Table 4). But the other model (FEM model 2) shows the negative significance of the consumption model. Finally, this study recommends a negative impact of both coal production and consumption on economic growth. The output of this study finally indicates that countries are moving toward a decarbonised economy and reducing coal dependency. Li et al. [50] showed a significant positive correlation between coal development in economic growth in China. Although there was a significant positive correlation between coal development and economic growth in China, the government should control the speed of coal production, increase energy-efficient technologies, and increase environmental tax. Also, due to its extensive usage of coal, China is facing previously unheard-of environmental problems, including severe national smog, glasshouse gas emissions, and water depletion [69]. Countries have started moving toward coal-fired economic growth. For example, 2013 marked the end of China's coal-burning growth, with the country turning to post-coal growth, a stage of development in which China's economic growth, and improved living standards of its population. China would no longer depend on rising coal consumption,

Table 3
Impact of energy production on economic growth.

GDP (DV)	FEM		REM	
	1	2	1	2
Natural Gas	0.402*	0.247**	0.743***	0.415***
	(0.220)	(0.112)	(0.191)	(0.152)
Electricity	3.184***	2.922***	2.692***	1.762***
	(0.449)	(0.252)	(0.348)	(0.341)
Biofuel	−0.582	0.492**	−1.165***	−0.245
	(0.383)	(0.227)	(0.369)	(0.349)
Hydrocarbon	−2.161**	−0.938	−0.081	1.649**
	(0.910)	(0.585)	(0.871)	(0.707)
Petroleum	0.62***	0.126*	0.604***	0.386***
	(0.090)	(0.067)	(0.085)	(0.079)
Coal	−0.001***	−0.001***	−0.001***	−0.001***
	(0.000)	(0.000)	(0.000)	(0.000)
FDI		−1.591***		−1.096
		(0.592)		(1.009)
Capital formation		0.761***		0.711***
		(0.077)		(0.122)
Trade Openness		0.175***		−0.032
		(0.042)		(0.055)
R2	0.984	0.988	0.987	0.988

***$p < .01$, **$p < .05$, *$p < .1$, value in first parenthesis is standard error.
Source: Author's experiment

Table 4
Impact of energy consumption on economic growth.

GDP	FEM		REM	
	Model 1	Model 2	Model 1	Model 2
Natural Gas	0.750***	0.272**	1.146***	0.619***
	(0.159)	(0.115)	(0.220)	(0.041)
Electricity	3.218***	2.737***	1.576**	0.964**
	(0.682)	(0.432)	(0.449)	(0.098)
Biofuel	0.761	0.993**	−0.437	0.044
	(0.637)	(0.404)	(0.383)	(0.006)
Hydrocarbon	3.609***	0.195	3.404***	1.874
	(0.809)	(0.888)	(0.910)	(0.071)
Petroleum	−0.314*	0.063	0.027	0.235
	(0.185)	(0.129)	(0.090)	(0.086)
Coal	0.001	−0.001***	0.001	0.001
	(0.000)	(0.000)	(0.000)	(0.061)
FDI		−2.902**		−1.625
		(1.086)		(0.009)
Capital formation		0.762***		0.888***
		(0.101)		(0.038)
Trade Openness		0.278***		0.009
		(0.081)		(0.034)
R2	0.982	0.987	0.986	0.989

***p < .01, **p < .05, *p < .1, value in first parenthesis is standard error.
Source: Author's experiment

Table 5
Unit root test result.

Variables	Levin Lin-Chu		ADF	
	Stat.	p-value	Stat.	p-value
GDP	−1.444***	0.074	−1.326*	0.093
FDI	−6.224***	0.000	−6.400***	0.000
Capital	−3.181***	0.001	−3.947***	0.000
Trade	−6.494***	0.000	−6.308***	0.000
Natural Gas (P)	−1.707***	0.044	−3.030***	0.001
Natural Gas (C)	−1.943***	0.026	−2.811***	0.003
Electricity (G)	−4.475***	0.000	−3.638***	0.000
Electricity (C)	−1.952***	0.026	−2.526***	0.006
Biofuel (P)	0.127	0.551	−1.657**	0.050
Biofuel (C)	0.541	0.706	−1.788***	0.037
Hydrocarbon (P)	−3.649***	0.000	−4.029***	0.000
Hydrocarbon(C)	−4.713***	0.000	−4.978***	0.000
Petroleum (P)	−4.579***	0.000	−5.242***	0.000
Petroleum (C)	−6.236***	0.000	−4.889***	0.000
Coal (P)	−2.679***	0.004	−4.196***	0.000
Coal (C)	−3.144***	0.001	−5.267***	0.000

****p<.01, **p<.05, *] p<.1.*
Source: Author explanation *[Here, P and C refer to production and consumption, respectively.*

demotivating coal production. The possible explanations are that China's new development phase is characterised by a slowing economy, a fall in manufacturing, and a focus on clean air and energy, and focusing policy on clean energy and clean air is part of a long-term economic strategy [70].

Capital formation shows a highly significant positive impact on economic growth. Capital formation is significant at the p < .01 level (the coefficient is 0.761 in the energy production model and 0.762 in the energy consumption model). This output indicates that an economy's higher value of capital formation represents faster economic growth in its aggregate income. This finding also supports the results of Apergis & Payne [18], who show a 1% increase in the capital formation increases real GDP by 0.225%. Vidyarthi [23] also reveal that a 1% rise in the capital formation increases the GDP by 0.1956%. Also, another study by Kahia et al. [22] demonstrates a significant and positive impact of capital formation on economic growth.

Trade openness also positively impacts economic growth (significant at p < .01 level, and the coefficient is 0.175 in the energy production model and 0.278 in the energy consumption model). This output is meaningful in this aspect and indicates that a higher trade openness value increases economic growth with higher energy production and energy consumption. This finding supports the findings of Al-Mulali et al. [71], who also find a short-run bidirectional causality between economic growth and trade openness. There is some other significant literature that also supports the findings of this study. The literature investigates a positive relationship between trade openness and economic growth [72–74,94].

This study also analyses the impact of energy consumption on the economic growth of BRICS countries. The effect of energy consumption on economic growth is given in Table 4. According to the Hausman (1978) specification test, the p-value is 0.998, which suggests accepting the null hypothesis, and therefore the fixed effect model is rejected for the energy consumption model. The REM models are taken here and recommended for further analysis and discussion.

The first energy consumption variable is the dry natural gas consumption that is positively significant at the $p<.01$ level in REM model 2 (coefficient is 0.619). This study confirms that increasing the consumption of dry natural gas promotes economic growth. This study supports the result of Hasan & Raza (2022) show that natural gas consumption significantly causes economic growth in Bangladesh. Similarly, Sohail et al. [76] also confirm that dry natural gas consumption increases economic growth in Pakistan. Besides, Destek [77] reveal a bidirectional causality between dry natural gas consumption and economic development. Some other studies, such as [32,56,92,93,75,78–80], also confirm a significant impact of dry natural gas consumption on economic growth. The second energy consumption variable is electricity consumption, which is also positively significant in all models; more particularly, electricity consumption is significant at $p<.10$ in REM Model 2 (coefficient is 0.964). This study also confirms electricity consumption has a promoting economic impact. The output refers that the higher electricity consumption promotes industrial, financial, and economic growth. The result is also similar to some other previous literature. For example, Rahman [81] also found a long-run relationship between electricity consumption and economic growth and electricity consumption. Aydin [82] also confirms the permanent causality relation between renewable-non-renewable electricity consumption and economic development. Tang and Tan [83] find that there is both a short & long-run relationship between electricity consumption and economic growth. In addition, Shahbaz et al. [84] show a positive granger causality relationship between electricity consumption and economic development. Though energy can boost economic growth in the long and short run, there is a long-term effect of increasing energy consumption of environmental degradation. In this case, renewable electricity consumption significantly benefits the environment and the economy [85].

To focus the comparative significance discussion, energy production and consumption are highly significant economic, social, and environmental issues. This study finds that most of the production and consumption model variables significantly impact economic growth. Based on the findings from both production and consumption models, the comparative discussion is given in the following sections.

The production and consumption of natural gas and electricity are significant in both production and consumption models. This output shows that dry natural gas production and power generation contribute significantly to economic growth, and the economy uses both energy sources to develop itself. After considering the impact of natural gas, dry natural gas production has a moderate effect on economic growth, but natural gas consumption is highly significant in the consumption model. This comparative output indicates that dry natural gas consumption substantially influences economic development compared to dry natural gas production. In contrast, electricity generation has the highest impact on the production model compared to moderate significance in the consumption model. Though there are comparative differences of economic impact of these two variables, such as dry natural gas and electricity, both are highly important for the economic development of a country.

Without comparison to biofuel production, natural gas is the second most significant economic force that promotes the economy through promoting industrialisation. Biofuel is highly demandable due to its less adverse impact on the environment. In terms of production, biofuel production is the second most significant energy variable that promotes economic growth. Through both natural gas and biofuel production moderately impact economic growth, impact of biofuel production is relatively higher. To compare both production and consumption effects, electricity generation has a greater impact compared to electricity consumption, while dry natural gas consumption has a greater impact relatively to dry natural gas production.

Interestingly, without economic proxies, hydrocarbon production (Liquefied petroleum gases and ethane production) seems to have a negative impact on GDP. Still, liquefied petroleum gases and ethane consumption positively impact GDP. The refined petroleum products production seems increase countries economy, while refined petroleum products consumption seems insignificant in the consumption model. Considering coal energy, the investors, society, and government all put pressure on the coal mining sector to cut emissions. Coal mining accounts for 3%–6% of the world's GHG emissions. Also, the indirect emissions, including coal burning, make up a sizeable amount (28%) of world emissions. Thereby countries are focusing on the decarbonisation of the environment and economy. In this study, coal production hinders economic growth; however, consumption is insignificant.

4.3. Alternative measures (robustness)

4.3.1. Unit root test result

This study further examines the alternative measure of the impact of energy production and consumption on economic growth by conducting non-stationary panel modelling. First of all, this study checks the data stationarity. Several techniques are available to estimate the order of series integration in panel data. To show the robustness, two types of panel unit root tests were applied in this study. Here, this study assumed the null hypothesis as panel unit root (non-stationary variables), and no unit root (stationary variables) represented by the alternative hypothesis. First, we experiment with the Levin-Lin-Chu (LLC) model [86] which suggests a panel unit root test that is also considered an extension of the augmented Dickey-Fuller (ADF). LLC model with additional lags with the dependent variable. The model is mentioned in the following section:

$$\Delta y_{it} = \varnothing y_{i,t-1} + z_{it}^{'}\gamma_i + \sum_{j=1}^{p} \theta_{ij} \Delta y_{i,t-j} + u_{it}$$

Here, p defines the number of lags. After using sufficient lags of the dependable variable (Δy_{it}), u_{it} will be white noise; this test doesn't need the error term to be the same for all panels. Also, this study uses the augmented Dickey-Fuller (ADF) regression to show data stationarity's robustness. The concept of the ADF test has been taken from Ref. [87]. The model is mentioned in the following section

$$\Delta y_{it} = \alpha + \beta y_{t-1} + \delta t + \sum_{j=1}^{p} \zeta_j \Delta y_{t-j} + e_t$$

Here p is also used to define the number of lags. Here, we used the individual intercept in the test equation, and lag length is selected Akaike Info Criterion (AIC). The result of the unit root test is presented in Table 5 in the following section.

According to Table 5, almost all variables are stationary, indicating no unit root. Mainly, all variables are non-stationary when the level is 0 [I(0)]; however, the above result shows most of the variables are stationary at first difference [I(0)]. As there is no unit root, indicating stationary variables. To proceed with these circumstances, this study presents the cointegration test to show the cointegrated relationship. The Kao Residual Cointegration test is conducted here. In Table 6, model 1 consists of the energy production variables, including FDI, capital formation, and trade openness. Model 2 consists of energy consumption variables, including FDI, capital formation, and trade openness. According to Table 6, The null hypothesis is that "no cointegration' is rejected in both the energy production and consumption model according to the probability value. The rejection of the null hypothesis indicates that there is cointegration.

Table 6
Kao Residual cointegration test.

Model 1 - Energy production model		Model 2 - Energy production model	
t-Statistic	Prob.	t-Statistic	Prob.
−5.818	0.000	−5.902	0.000

Source: Author's explanation *[sample 1992 to 2019, included observation 140, Trend assumption (no deterministic trend), lag selection (automatic), Newey-West automatic bandwidth selection and Bartlett kernel]*

4.3.2. Panel Fully Modified Least Squares (FMOLS

Due to the presence of cointegration, this study also conducts a non-stationary panel data model. In this case, to justify the result of the static models (fixed effects and random effects model), this study further experiments with the *Seemingly Unrelated Regression (SUR)*, more particularly the *Panel Fully Modified Least Squares (FMOLS)* model. The SUR models are more appropriate in the case of N (5) < T (28).

Table 7 presents the outcome of FMOLS output. Here, the sample is adjusted from 1993 to 2012, and the automatic cross-section included 3, and Pooled estimation was conducted using the default Coefficient covariance computing method. The FMOLS model's outcome strongly justifies the energy production model (fixed effects) and energy consumption (random effects). Except for biofuel energy consumption, that is insignificant in energy consumption (random effects), however significant in the FMOLS energy consumption model.

4.3.3. Granger casualty

This study also experiments with both the direct and reverse casualty between the energy variables and GDP (key economic variables of this study for both models). Table 8 presents the result of the granger casualty test statistics. This study tests granger casualty for both the production and consumption models.

This study conducts *Pairwise Granger Causality Tests*, particularly the *Stacked test (common coefficient),* using samples from 1992 to 2019, and the number of lags is 2. The null hypothesis are '*Energy variable does not granger cause GDP*' and '*GDP does not granger cause energy variable*'.

Table 7
Panel fully modified least squares (FMOLS).

Variables	FMOLS (Energy production)	FMOLS (Energy consumption)
Natural Gas	0.218***	0.294***
	(0.077)	(0.107)
Electricity	2.943***	2.788***
	(0.209)	(0.384)
Biofuel	0.337**	0.790**
	(0.162)	(0.361)
Hydrocarbon	−0.362	1.000
	(0.422)	(0.823)
Petroleum	0.148***	0.056
	(0.048)	(0.132)
Coal	−0.001***	−0.000***
	(0.000)	(0.000)
FDI	−1.367***	−2.259**
	(0.405)	(0.984)
Capital formation	0.763***	0.715***
	(0.056)	(0.088)
Trade Openness	0.144***	0.239***
	(0.029)	(0.074)

***p < .01, **p < .05, *p < .1, value in first parenthesis is Standard error.
Source: Author's experiment

Table 8
Granger casualty test.

Null Hypothesis:	Obs	Production		Consumption	
		F-Statistic	Prob.	F-Statistic	Prob.
Natural gas (P/C) does not Granger Cause GDP	130	0.817	0.444	4.437***	0.014
GDP does not Granger Cause Natural gas (P/C)		3.429**	0.036	12.644***	0.000
Electricity (P/C) does not Granger Cause GDP	130	1.785	0.172	1.516	0.224
GDP does not Granger Cause Electricity (P/C)		2.823*	0.063	0.075	0.928
Biofuel (P/C) does not Granger Cause GDP	60	2.179	0.123	3.350**	0.042
GDP does not Granger Cause Biofuel (P/C)		0.001	1.000	0.040	0.961
Hydrocarbon (P/C) does not Granger Cause GDP	95	1.375	0.258	0.707	0.496
GDP does not Granger Cause Hydrocarbon (P/C)		0.962	0.386	0.396	0.674
Petroleum (P/C) does not Granger Cause GDP	105	1.293	0.279	1.948	0.147
GDP does not Granger Cause Petroleum (P/C)		4.752***	0.011	4.585***	0.012
Coal (P/C) does not Granger Cause GDP	130	8.968***	0.000	11.631***	0.000
GDP does not Granger Cause Coal (P/C)		1.874	0.158	0.923	0.400
FDI does not Granger Cause GDP	130	3.140**	0.047		
GDP does not Granger Cause FDI		7.929***	0.001		
CFOR does not Granger Cause GDP	130	1.398	0.251		
GDP does not Granger Cause CFOR		4.841***	0.009		
TO does not Granger Cause GDP	130	2.315	0.103		
GDP does not Granger Cause TO		4.845***	0.009		

Source: Author experiment (P/C refers to production/consumption, ****p<.01, **p<.05, *p<.10*)

According to Table 8 (Section A), among the six energy production variables, natural gas production does not granger cause GDP; however, natural gas consumption granger causes GDP. In the reverse casualty, GDP causes both natural gas production and consumption. The second variable, electricity generation and consumption, doesn't cause GDP; however, GDP causes only electricity production at $p < .10$. In the third energy variable, Biofuel consumption causes GDP; however, biofuel production doesn't cause GDP, and GDP doesn't cause both biofuel production and consumption. There is no causal relationship between hydrocarbon production and consumption with GDP at all. In the fifth variable, there is no causal relationship between petroleum production and consumption with GDP; however, there is a strong reverse causal relationship between GDP and petroleum production and consumption. In the sixth variable, coal production and consumption cause GDP; however, there is no reverse causal relationship between GDP and coal production and consumption. Among the proxies, only FDI cases GDP, while GDP causes all the proxies in the reverse casualty. The real GDP and capital formation have a causal relationship in the literature. There is also a bidirectional correlation between Eurasian countries' economic growth and energy consumption [18]. Interestingly, a lack of causality evidence between some energy variables with economic growth, and the lack of causality is assumed to be partly caused by the insufficient and unequal renewable energy sources development across the countries [88].

5. Implication of the study

In terms of practical policy implications, the BRICS nations must regulate energy production from non-renewable sources; thereby, it is highly recommended to emphasise renewable energy production. Also, considering the comparative significance of energy production and energy consumption, production should be highlighted first to make it available to consume in the second stage. When there is available production, the consumption will be more. In this context, however, this study emphasises promoting renewable energy consumption by producing renewable energy sources to reduce adverse environmental impacts while promoting economic growth. Furthermore, considering the global consequences, these countries are at the top of the list of energy-producing countries; therefore, policymakers in these countries should consider the global implications of non-renewable energy production and consumption for the benefit of humanity worldwide. This study also suggests some other specific policy implications. For example, since both the production and consumption of dry natural gas, as well as power generation and consumption, have a significant impact on economic growth, the policy means that respective policymakers should emphasise the highest importance of these two energy sources. These two types of energy significantly impact the development of industries that drive economic growth. Also, as coal mining increases global greenhouse gas emissions, a focus must be placed on decarbonising the environment and the economy. With coal energy in mind, investors, society and governments must all put pressure on the coal mining sector to reduce emissions. The study also means less reliance on the coal economy.

6. Conclusion

Energy economics is one of the areas of research that has been burning for the past decade. Based on this aspect, this paper focuses on energy economics. Here, research focuses on the concepts of energy production and consumption associated with economic growth. Based on this concept, the BRICS countries were selected as the research area for this study. Most data are collected from secondary sources. More specifically, the data come from the IEA, EIA and World Bank databases (1992–2019). This study conducts panel data modelling and finds that, in the production model, electricity generation, capital formation, and trade openness are highly and positively significant to economic growth. Dry natural gas production and biofuel production have a moderate positive impact on economic growth, while petroleum production slightly influences economic growth. These outputs indicate that greater value of electricity generation, dry natural gas production, biofuel production, petroleum production, higher capital formation, and higher tread openness increase economic growth. On the other hand, coal production is negatively significant with a very low coefficient value, indicating that coal production hinders economic growth. In the consumption model, only dry natural gas consumption highly influences economic growth, while electricity consumption has fewer effects on economic growth than natural gas in the BRICS region. Capital formation also has a highly significant impact on economic growth.

This study also has some limitations that will be overcome in the future if we get an opportunity to accomplish further research on this issue. It has been already mentioned in our methodology and unit root section that there is not much data available on biofuel consumption and production of biofuel for Russia and South Africa. Therefore, this is regarded as a limitation. Also, when the data was collected from the US EIA, there is data available covering from 1980 to 2019; however, Russia's energy data before 1992 is missing there. Therefore, this study selects data starting from 1992.

The study area consists of only five countries, and thereby, it is proposed that a study that will include the entire energy economy data, including some major segmentations, such as a comparison between the OECD and non-OECD, BRICS and G7, and so on. It is also possible to present a comparison of Europe, Asia, Africa, and South America.

Hopefully, those studies will cover more extended results and better comparisons. Also, this study considers very recent international issue, Russia-Ukraine war, for future research direction. As Russia is one of the biggest players in world energy economy or markets for oil, natural gas, as well as coal. There is significant market roiling out due to the Russian invasion of Ukraine [89]. Ultimately this war leads to soaring inflation and commodity prices around the world. And world energy market has already in volatile situation [90]. Though, other western countries already moved away from the dependency on Russian energies and made Russia isolated from the world economy, still there will be long term effects in energy market worldwide [91]. Thereby, this study also extends the future research on Russia- Ukraine was impact on world energy market.

Credit author statement

The author, Morshadul Hasan, has written and revised entire manuscript.

Declaration of competing interest

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

Data availability

Data will be made available on request.

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