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# RETRACTED: Fossil Energy Demand and Economic Development in BRICS Countries

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RETRACTED

Energy is considered the oxygen of an economy fueling all economic activities. Energy utilization and its type have an intertemporal and size-based effect on economic development. Therefore, this study empirically analyzes the relationship of fossil energy consumption with economic development in the case of BRICS countries between 1990 and 2019. Fully modified ordinary least squares is used with the quadratic function of coal, oil, and gas consumption to assess the size-based effect across time. This study shows that coal and natural gas consumption follows the inverted U-shaped relationship with HDI, while coal consumption shows a negative relationship with HDI. Hence, coal and gas energy assists in development when its share is small, while over-consumption hampers development. The BRICS countries should optimize coal and gas consumption with respect to economic development. Reducing fossil energy should be substituted with alternative clean energy resources by using advanced technology such as the gasification process.

**Keywords: energy consumption, variable returns models, sustainability, BRICS countries, panel data**



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## INTRODUCTION

No one ignores the importance of energy consumption in this modern world because most economic activities depend upon energy consumption. Energy is considered the oxygen of an economy because, without energy, a country fails to run factories, houses, and all kinds of transportation in both developed and developing economies. All economic activities help produce goods and services, with an end goal of improvement in the living standard of humans (Kalim et al., 2021). So, energy consumption is an important indicator of economic development (Esen and Bayrak, 2017). By industrialization, production methods changed in the late 18th century, and it significantly increased the energy demand. Energy is the input that determines output production and is highly important for economic growth (Lee and Chang, 2008). Solow (1956) measured the economic growth by two basic inputs, labor and capital; later on, many economists added new inputs like human capital (Mankiw et al., 1992). There are numerous literature studies available in which economists added energy as an input along with labor and capital; previously, it was included in the land input (Kraft and Kraft 1978; Akarca and Long, 1980; Ramcharran, 1990; Tang and La, 1993; Asafu-Adjaye, 2000; Mehrara, 2007; Ahmad et al., 2016; Awodumi and Adewuyi, 2020; Kirikkaleli et al., 2021). Currently, fossil energy consumption is predominantly represented in overall energy consumption, especially in BRICS countries.

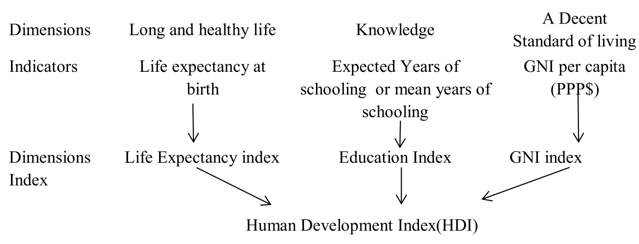


**FIGURE 1** | Flowchart of the Human Development Index. Source: UNDP.



The present study is a multidimensional investigation of the effect of coal, oil, and gas consumption on economic development in the BRICS countries. Here, the link is developed using the energy Kuznets curve to explore the variation in the effects because of the size of energy consumption. BRICS countries are the most developed countries among the emerging economies, namely, India, Russia, China, South Africa, and Brazil. These countries' economic growth is increasing rapidly, causing the energy demand to increase. Several studies in BRICS countries have examined how fossil fuel energy consumption is the key determined by economic growth (Chang et al., 2017; Sasana and Ghozali, 2017; Wang et al., 2022). However, according to the researcher's knowledge, there is a dearth of studies that examined the effect of coal, oil, and gas consumption on economic development and whether there is any room to optimize energy consumption.

Economic development is the border than economic growth. UNDP defined "Development as a multidimensional phenomenon to achieve a higher standard of living of all people in the society. Social development, economic development and environmental protection are closely interlinked and mutually strengthen sustainable growth. Sustainable economic growth is compulsory for the social and economic development of all the country." To measure economic development, in 1990, renowned Pakistani economist Dr. Mahbub ul Haq, Special Adviser of UNDP, provided a new idea of economic development with the Human Development Index (HDI). This index analyzes people and their capabilities that assess the economic development of the country. HDI not only includes economic growth, but it also includes basic knowledge and standard of living. HDI is the geometric mean of three dimensions, namely, education, health, and economic growth. **Figure 1** shows the flowchart of HDI.

Energy consumption affects the economic development of any country (Zahid et al., 2021). To fulfil the need for energy, usually, we get energy from two sources, renewable and non-renewable. Renewable energy sources are considered environmentally friendly, while on the other hand, non-renewable energy consists of fossil fuels that pollute the environment. But unfortunately, non-renewable fossil fuels are the big source of energy consumption in the BRICS (Ummalla and Goyari, 2020). In these countries, fossil fuel energy consumption increases economic growth, while renewable energy consumption has very little share in total energy consumption, so renewable energy consumption negatively impacts economic growth as it requires an initial investment in developing the infrastructure (Sasana and Ghozali, 2017; Zahid et al., 2021).

BRICS countries have a high proportion of coal, oil, and gas consumption because of high public demand. According to an ENERDATA report (2020), the BRICS countries' total coal consumption was reported to be 5,217 metric tons in 2019 compared to 1761 metric tons in 1990. Oil consumption was 1,138 metric tons in 2019 as compared to 641 metric tons in 1990, a growth of about 77.5%. Gas consumption was reported at 910 billion cubic meters in 2019 as compared to 506 billion cubic meters in 1990. Massive burning of fossil fuels has led to increased heat and greenhouse gases (EPA, 2021). These greenhouse gases badly impact the environment, having a very hazardous effect on the life of living things.

For the coal consumption of BRICS countries, China is the biggest coal consumer country that consumes 3,826 metric tons of coal, which is more than half of the total coal consumption of 5,217 metric tons. China is also the biggest country among the BRICS countries, which uses the highest oil consumption ratio. From the total oil consumption, 1,138 metric tons, China consumed 617 metric tons. This is more than half of the total oil consumption of BRICS. India comes in second, having used 224 metric tons of oil in 2019. In BRICS countries, China and India are considered the highest oil and coal consumers.

For the natural gas consumption in BRICS countries, Russia is the biggest natural gas-consuming country. It consumes 501 billion cubic meters, which is more than half of the total gas consumption of the remaining BRICS countries. In second place, China uses 304 billion cubic meters of natural gas.

According to the BRICS energy report (2020), fossil fuel energy consumption will remain dominant until the end of 2040. Details of the BRICS energy consumption are labeled in **Figure 2** for 2018 and 2040. The above discussion concluded that BRICS countries are the major consumer of oil, coal, and gas but are still enjoying high growth. Studies like the one by Zahid et al. (2021) pointed out that fossil energy may harm the future, but it can provide higher growth today because of its low cost in production and transmission in the short run compared to renewable energy.

**Figure 2** shows that in 2018 and 2040, coal will be the dominant portion of the energy consumption of BRICS. In 2018, coal's share was about half of the total energy consumption, which is 49%, while in 2040, it decreases slightly and reaches 36%. Another important source of energy consumption is oil consumption; in 2018, its consumption was 23%, while in 2040, it will be decreased slightly and reach 18%. While gas consumption had a lower share in BRICS energy consumption in 2018, 13%, in 2040, it will increase to 19%. These facts show that coal, gas, and oil are the major energy resources in the BRICS countries, while on the other hand, renewable energy sources have a minor share in total energy consumption.

BRICS countries cover about 43% of the population. These five countries have a special status all over the world. **Table 1** shows the coal, gas, and oil energy consumption in BRICS and remaining consumption worldwide in 2018 and 2040.

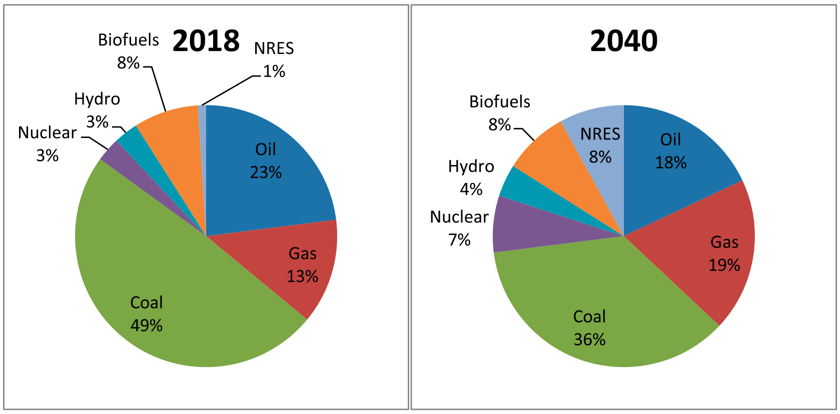


**FIGURE 2 |** Energy consumption in BRICS in 2018 and 2040. Source: BRICS Energy Report 2020.

**TABLE 1 |** BRICS and other countries' energy consumption in 2018 and 2040.

| Energy | Countries | 2018 (%) | 2040 (%) |
|---|---|---|---|
| Coal | BRICS | 68 | 72 |
| | Other countries | 32 | 28 |
| Gas | BRICS | 22 | 29 |
| | Other countries | 78 | 71 |
| Oil | BRICS | 27 | 21 |
| | Other countries | 73 | 79 |

Source: *BRICS, energy report (2020).*

**Table 1** shows that BRICS are the major coal consumption player globally. The coal consumption of BRICS countries was 68% coal in 2018 and will be 72% in 2040, while the remaining world coal consumption was 32% in 2018 and will be 28% in 2040. At the same time, oil consumption in BRICS was 27% in 2018, while it will decrease by only 6% in 2040. In BRICS, natural gas consumption has a lowered share in energy consumption; in 2018, it was 22%, while in 2040, it will increase the natural gas share by 7%.

All the earlier discussion concluded that oil, gas, and coal are energies majorly consumed by the BRICS countries. This high fossil fuel energy consumption causes carbon emissions in these countries. According to EIA (2020), consumption of one Btu (British thermal units) of different coals increases carbon emissions by an average of 216 pounds. One Btu of oil consumption increases carbon emission by 161.3 pounds. In the same way, one Btu of natural gas consumption increases carbon emission by 117 pounds. These facts show that coal and oil consumption causes a lot of carbon emissions, which may have a significant effect on environmental quality (Salem et al., 2021).

**Figure 3** shows the top 20 carbon emission countries in the world in 2019. China is the biggest carbon emission country with 28% of carbon emissions of total carbon emissions. The second biggest country is the United States, which consumes 15%, about less than half of China. India is the third largest carbon emission country and emits about 7% carbon. The fourth largest carbon emission country is the Russian Federation, and it emits 5% carbon. It is clear that three of the top four carbon emission countries are members of the BRICS countries. All BRICS countries are included in the top 20 countries.

If such high carbon emissions are documented because of fossil energy, a country may grow positively today, but it will badly affect the natural resource availability. So, sustainable development for a country may not be possible if the natural resources and environment are depleting. Zahid et al. (2021) pointed out that the country may face a tradeoff in shifting from fossil energy to renewable energy because of the cost of developing clean energy infrastructure. So, null hypothesis one is assumed, that is, coal, oil, and gas consumption does not affect economic development, while null hypothesis two is that coal, oil, and gas consumption's positive effect will not diminish with the increase in the proportion of this fossil energy consumption.

This study aimed to examine the incidence-based impact of different subtypes of fossil fuel (coal, oil, and gas) energy consumption on economic development for the case of BRICS countries. The idea is to explore if quadratic optimization of energy can increase development *via* the reduction of $CO_2$ emissions and assess the historical patterns using the decoupling method.

This study will be instrumental in the following domains:

1) Answering the question of why BRICS countries are still growing if they are high consumers of fossil energy and why developing countries like BRICS show a fast transition to clean energy.
2) Estimating the transition process by increasing the development potential from the existing fossil energy portfolio.
3) Checking if there is a need to revisit the current plan to greenify the development-targeted energy portfolio.

This study comprises the previous literature review in *Literature Review*, methodology and data in *Methods and Material*, and results and discussion in *Empirical results* and

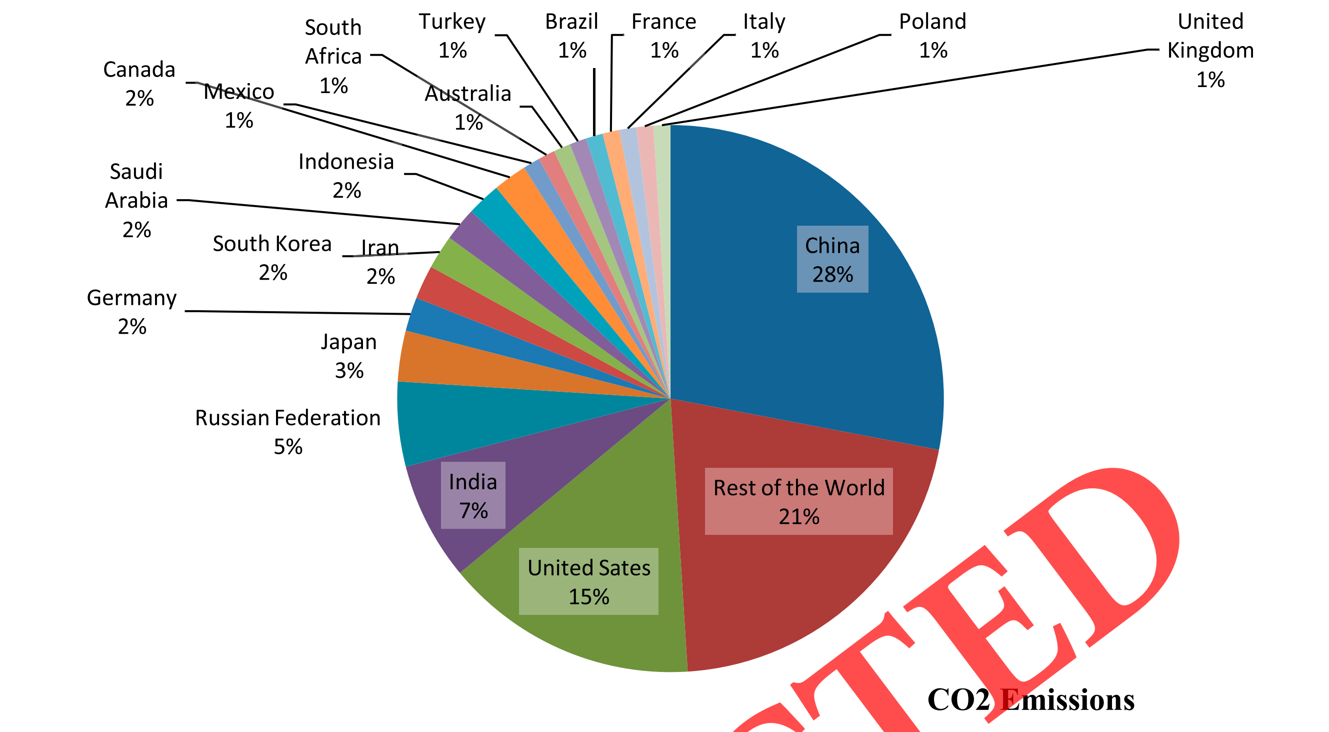


**FIGURE 3 |** Top 20 $CO_2$ emissions countries. Data: Earth systems science data, 2019.



*Discussions and Policy Recommendations*, and conclusion and policy recommendation are enlisted.

## LITERATURE REVIEW

The present literature studies the link between subtypes of fossil fuel energy consumption such as coal, oil, and gas consumption and economic development.

### Natural Gas Consumption and Development

Natural gas is a subtype of fossil fuel energy. There are few listed studies which show the positive relationship of NGC with economic growth. Hassan et al. (2017) demonstrated the impact of NGC on economic growth in Pakistan from 1977 to 2013. The Johansen maximum likelihood econometric approach concluded that NGC positively affected the economic growth of Pakistan in the long run. Shahbaz et al. (2013) also studied the impact of NGC on the economic growth of Pakistan. The ARDL model was applied and it was concluded that NGC, labor, capital, and export of goods and services positively affected Pakistan's economic growth. Das et al. (2013) examined the impact of NGC on the GDP of Bangladesh during 1980–2010 and showed positive causation between NGC and GDP. In Iran, Balsalobre-Lorente et al. (2019) investigated the positive associations between NGC and output growth during the 1990–2017 data set.

Few studies showed the inverse relationship between NGC and economic growth in the literature on the impact of NGC on economic growth. Fatai et al. (2004) compared energy conservation policies of the New Zealand economy with that of seven Asian economies and Australia. This study failed to examine the causal association between NGC and GDP in the case of New Zealand and Australia compared with other Asian economies by applying the ARDL approach. In Pakistan, Siddiqui (2004) conducted a study and found an inverse relationship between NGC and economic growth. Aqeel and Butt (2001) also evaluated that oil consumption leads to economic growth while NGC leads to an inverse relationship with economic growth. Isik (2010) explored the impact of NGC on GDP in the Turkish economy during 1977–2008. The ARDL bound test approach concluded that NGC negatively impacted the GDP in the long run while positively impacting it in the short run.

The impact of NGC on economic growth relationship panel countries was also carried out. Ucan et al. (2014) studied the 15 EU countries during 1990–2011. The heterogeneous cointegration test proposed that NGC had had a positive association with economic growth. Ozturk and Al-Mulali (2015) conducted the study in Gulf Cooperation Council countries; Destek (2016) conducted a study in 26 OECD countries. In both of these studies, they applied panel cointegration test, panel dynamic, and fully modified OLS approach and concluded that NGC positively affected the economic growth. Zhi-Guo et al. (2018) studied the Northeast Asia countries' (Korea, Japan, and China) NGC and economic growth during 1991–2015. In these counties, NGC affected economic growth positively. Balitskiy et al. (2016) separately proposed two models of the impact of NGC on economic growth and development in 26 EU countries during 1997–2011. The study concluded that NGC positively impacts economic growth while having an inverse relationship with economic development. Alam et al. (2016) investigated the NGS on GDP growth in the panel of 15 natural gas-consuming developing countries. The long run result suggested that among 15 countries, nine countries positively impacted NGC on GDP while only five countries have negatively impacted the NGC and GDP while trade variable positively impacted the GDP. Apergis and Payne (2010a) studied the panel of 67 countries during 1992–2005. The study showed that in the long run, NGC, gross fixed capital formation, and labor force leads to GDP.

## Oil Energy Consumption and Development

Oil energy consumption (OIL) impacts sustainable development. Few studies are discussed in this portion. Adekoya (2021) linked the oil consumption with economic growth with natural resources of 10 resource-rich countries and six resource-poor countries from 1990 to 2017. THE panel ARDL model found that in resource-rich countries, oil negatively responds in the long run, while in resource-poor countries, it failed to judge any positive or negative association with economic growth. Waleed et al. (2018) in Pakistan and Rahman et al. (2018) in Bangladesh attempted to examine the effect of oil on economic growth and found that oil directly affected economic growth. In China, Zou and Chau (2006) also found that oil caused economic growth in the long run from 1978 to 2000.

In the Latin American region, Behmiri and Manso (2014) divided the whole region into three panels: Caribbean countries, Central American countries, and South American countries. In the panel of Caribbean and South American countries, oil negatively impacted economic growth, while in case of the Central American panel, oil positively impacted economic growth.

## Coal Energy Consumption and Development

Coal energy consumption positively impacts economic development. Xu et al. (2018) studied the impact of coal energy consumption (COL) on sustainable development in China. Romer's growth drag theory applied by using the Johansen cointegration test concluded that coal enhanced China's economic development. In Turkey, Aktas (2018) found long-run cointegration between coal and GDP growth during 1970–2014. The Granger causality test supported the bidirectional causality between coal and GDP.

Few studies examined the way coal negatively impacted economic growth. One study was conducted in the 25 OECD countries. Apergis and Payne (2010a) showed that coal consumption negatively affected economic growth in the short run and long run. In the same way, Irwandi (2018) carried out their findings in Indonesia and found no causal relationship between coal and economic growth. In BRICS countries, Chang et al. (2017) suggested that CEC and economic growth were not sensitive to each other. Meanwhile, in the case of individual countries, coal caused economic growth in China and negatively impacted economic growth in South Africa. In the case of India, there existed a bidirectional relationship.

Nguyen-Van (2010) proposed the energy consumption Kuznets curve with income per capita for the group of panel data. The study concluded that energy consumption also increased with the increase in income.

By increasing coal consumption, air and water pollution has affected residential societies badly. Burning oil produces $NO_2$ (nitrogen dioxides), $SO_2$ (sulfur dioxides), and various heavy metals, which ultimately affect human health (Hendryx et al., 2020; Finkelman et al., 2021; Guo et al., 2021).

## Fossil Energy Consumption and Development

Few studies examined the relationship of all subtypes of fossil fuel energy consumption and economic growth. Ahmed and Shimada (2019) studied the impact of renewable energy consumption and fossil fuel energy consumption on economic suitability in all world countries. The study found that due to the increase in the amount of renewable energy consumption, economic growth increased in South Asian and most of the African countries; on the other hand, non-renewable energy consumption enhanced economic growth in Caribbean countries.

In G-7 countries, Destek and Okumus (2017) investigated the impact of oil, coal, and natural gas consumption on economic growth during 1970–2013. It concluded that oil consumption caused economic growth in the United States, the United Kingdom, Japan, and Italy.

Siddique et al. (2016) used the subtypes of fossil fuel energy consumption, and studied the impact of gas, oil, and coal and electricity energy consumption on economic growth during 1982–2015 in Pakistan. It concluded that all subtypes significantly impact economic growth. Faridi and Murtaza (2013) analyzed that oil, gas, and electricity consumptions are the key factors to enhance GDP growth and agriculture sector output of Pakistan during 1972–2011. The ARDL model approach suggested that coal, gas, and electricity are important determinates of GDP growth.

Steinberger and Roberts (2009) investigated the simulation-based association between energy use and HDI and found that energy use had positively affected the HDI. Asghar et al. (2020) investigated the impact of coal, oil, and gas consumption on the human development index in Pakistan. The study concluded that due to coal, oil, and gas consumption, air pollution, TB cases, measles, and the mortality rate have increased, which affected the HDI. In the SAARC region, Zahid et al. (2021) proposed the topic of the impact of quadratic energy consumption on the human development index from 1990 to 2017. The GLS method concluded that energy consumption shows the inverted U-shaped association with HDI.

For sustainable development, health indicators also played a significant role. Oil, gas, and coal consumption adversely affects the health indicators. Due to the increase in fossil fuels, carbon emissions increase, which causes different kinds of diseases such as tuberculosis, which increase the mortality rate (Hanif, 2018).

## Sectorial Consumption of Coal, Oil, and Gas

Coal, oil, and gas are not substituted for each other. These energy sources are used in different projects. Coal is considered the major portion of energy consumption worldwide. A bulk portion of coal is consumed for power production, industry, and domestic use. According to IEA (2019), about 38% of electricity is produced through coal. Many private industries have developed their own power plants to generate electricity by using coal (Ghafoor and Weiss, 1999). Paper industries burn coal to produce heat, and steel industries use coal coke in furnaces. It also uses coal coke to smelt ore iron into pure iron and then make steel (Carpenter, 2012). Coal is also used in cement industries because cement is made from a mixture of silica, carbonate, alumina, and iron oxide, which requires a high temperature that is achieved by burning coal (Osborne and Gupta, 2013). On the other hand, coal has a minor share in transportation and residential purposes as coal-based steam engines are not used in railways.

Oil consumption is used in transportation and in electricity generation at the residential level. According to IEA (2018a), about 49.3 percent of oil is consumed for road and air transportation. All kinds of vehicles run by oil consumption.

Gas is an important fossil fuel because it has special importance worldwide as it produces low carbon emissions. According to IEA (2018b), about 37% gas is consumed in industries. Most industries consume gas for heating purposes in power systems and combined heat and as raw material to produce hydrogen, chemicals, and fertilizers (Solarte-Toro et al., 2018). The residential sector also consumed a lot of gas to heat the buildings and water, dry clothes, and cook food. Worldwide, it consumed about 30% in the residential sector (IEA, 2018c).

## Exports of Goods and Services on Development

While discussing the impact of exports of goods and services on economic development, it can be observed that the export of goods and services plays a significant role in economic development. More than 200 years ago, all economists and philosophers agreed that free trade begets better living standards by improving health, education, and income. Exports directly affect the income and indirectly affect non-income factors. Numerous previous literatures show that exports positively affected economic development (Feder, 1983; Fosu, 1990; Anwer and Sampath, 2000; Davies and Quinlivan, 2006). In the case of BRICS countries, Rani and Kumar (2018) empirically evaluated that a one percent increase in export will increase 0.44 percent of GDP per capita in the long run.

## Labor Force Participation and Development

In the classical Solow model, labor is an important component of economic growth. BRICS countries' population is about 43% of the total population. Due to this massive total population, there is a big share of labor force participation. Numerous previous literatures showed the positive relationship of labor force participation to economic growth (Paudel and Perera, 2009; Lahoti and Swaminathan, 2013; Amir et al., 2015).

Several studies have been mentioned in the literature review that had tried to connect fossil fuel use with development *via* growth or $CO_2$ emissions channel. But very few studies have explored the nonlinear effect of fossil energy components in the panel data on development to assess the intertemporal and size-based effect. This study has estimated the quadratic fit for fossil energy components against HDI, which provides the incidence/size-based effect of energy consumption for each country. It helps in planning country-specific strategies to increase HDI by optimizing the portfolio of fossil energy demand.

# METHODS AND MATERIAL

## Sample of the Study

The sample of this study is selected from the BRICS countries, namely, India, China, South Africa, Brazil, and Russia. Thirty years of data sets during 1992–2018 were collected from various sources (**Table 2**). The main purpose of selecting the BRICS countries is that they have high energy consumption due to their fast economic growth and development (Camioto et al., 2016). BRICS countries' coal, oil, and gas consumption is playing a significant role in industrialization and sustainable economic development (BRICS energy report, 2020).

## Data and Variables

To estimate **Eq. 1**, **Table 2** demonstrates the description of the variables. The data of five BRICS countries are collected from 1992 to 2018. The human development index (HDI) has been used as the dependent variable in this study, including three variables: per capita income, life expectancy, and literacy rate (HDR, 2020).

This study focuses on the impact of the subtypes of three forms of non-renewable energy consumption, namely, oil consumption (OIL), natural gas consumption (NGC), and coal consumption (COL), on economic development. Due to the enhancement of energy resources, export of goods and services (EXPO) and labor force (LFTOT) also impact economic development. **Table 2** presents all variables used in this study. All variables except HDI are transformed into the natural logarithm to facilitate elasticity base comparison.

## Econometric Model

This study will start with assessing the empirical movement of data using the decoupling method proposed by Tapio (2005). This method constitutes an index DI, a ratio of % change in HDI to a % change in fossil energy consumption. According to the literature, the decoupling will be favorable for the country if DI < 0, and it is best when, along with DI < 0, the independent variable (fossil energy)'s % change is negative (Dahmani et al., 2021).

To build the theoretical econometrics model, Environmental Kuznets Curve (EKC) suggested that economic growth (GDP) initially degrades the environment, but after maturity, it improves the environment quality and shows the U-shaped relationship. Sometimes EKC suggested that GDP initially increased the environmental quality, but after maturity, it degrades the environmental quality and shows the inverted U-shaped

**TABLE 2 |** Description of the variables.

| Symbol | Indicator | Units | Sources |
|---|---|---|---|
| HDI | Human Development Index | 0 to 1 | United Nation Development Program |
| OIL | Oil consumption | (% of total) | Energy Information Administration |
| NGC | Natural gas consumption | (% of total) | Energy Information Administration |
| COL | Coal consumption | (% of total) | Energy Information Administration |
| EXPO | Export of goods and services | % of GDP | World Development Indicators |
| LFTOT | Labor force | Total | World Development Indicators |

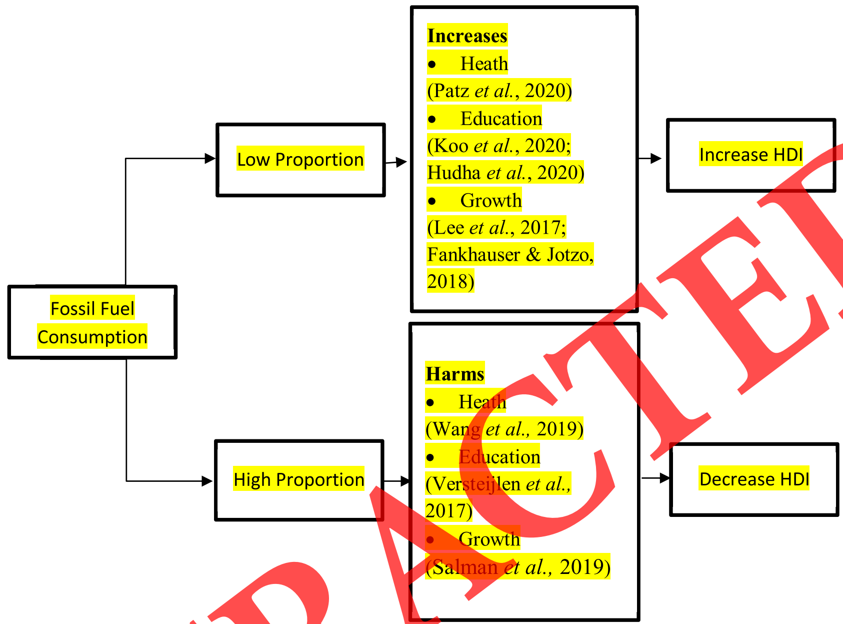


**FIGURE 4 |** Theoretical model.



hypothesis (Apergis and Ozturk, 2015; Sarkodie and Strezov, 2019; Dogan and Inglesi-Lotz, 2020; Sarkodie and Ozturk, 2020; Ahmad et al., 2021; Chu, 2021; Murshed et al., 2021).

Inspired by this model, we built the energy human development index Kuznets curve in this study. This means that, initially, an increase in fossil fuel energy consumption produces lower carbon emissions and footprint. In this stage, utilization of fossil energy is actually increasing the productivity of other inputs, leading to improvement in income, health, and education (Haines and Dora, 2012; Koo et al., 2014; Lee et al., 2017; Fankhauser and Jotzo, 2018; Hudha et al., 2020; Patz et al., 2020). Later on, the use of fossil fuel energy consumption will increase carbon emissions and footprint. Due to high carbon emissions, it will deteriorate environmental quality, health, and productivity; thus, economic development deteriorates (Versteijlen et al., 2017; Salman et al., 2019; Wang et al., 2019).

**Figure 4** presents the theoretical model of this study. To assess energy utilization, this study has used the square terms of the subtypes of fossil fuels. A similar methodology was adopted by Hanif et al. (2019a, b) and Arshed et al. (2018, 2019). The estimation model is as follows:

$$\begin{aligned} HDI = \beta_0 + \beta_1 (LNCOL)_{it} + \beta_2 (LNCOL)^2_{it} + \beta_3 (LNOIL)_{it} \\ + \beta_4 (LNOIL)^2_{it} + \beta_5 (LNNGC)_{it} + \beta_6 (LNNGC)^2_{it} \\ + \beta_7 (LNNEXP)_{it} + \beta_8 (LNLFTOT)_{it} + (\varepsilon)_{it}, \end{aligned} \quad (1)$$

where HDI, Human Development Index; LNCOL, Natural Logarithm of Coal Consumption percentage of total energy consumption; $LNCOL^2$, Square of LNCOL; LNOIL, Natural Logarithm of Oil Consumption percentage of total energy consumption; $LNOIL^2$, Square of LNOIL; LNNGC, Natural Logarithm Natural Gas Consumption percentage of total energy consumption; $LNNGC^2$, Square of LNNGC; LNEXP, Natural Logarithm of Export of goods and services; LNLFTOT, Natural Logarithm of total labor.

The key advantage of applying the square form is that it indicates a deviation from the constant return to the scale assumption, under which the variable explains the marginal effect (Hayes, 2017). Furthermore, the square form helps determine the cut-off value of the variable from where the

**TABLE 3 |** Descriptive statistics.

| | Mean | Median | Standard deviation | Skewness | Kurtosis | Jarque Bera | Probability |
|---|---|---|---|---|---|---|---|
| HDI | 0.635 | 0.642 | 0.078 | −0.701 | 3.114 | 12.38 | 0.002 |
| LNCOL | 2.842 | 2.861 | 1.136 | 0.001 | 1.308 | 17.88 | 0.000 |
| LNOIL | 3.456 | 3.486 | 0.429 | −0.095 | 1.341 | 17.41 | 0.000 |
| LNNGC | 2.071 | 1.976 | 1.075 | 0.617 | 2.343 | 12.22 | 0.002 |
| LNEXPO | 2.988 | 3.064 | 0.454 | −0.457 | 2.484 | 6.898 | 0.032 |
| LFTOT | 18.66 | 18.29 | 1.345 | −0.088 | 1.741 | 10.09 | 0.006 |

*Note. Author's own calculations.*

effects change direction (Arshed et al., 2018, 2019). The following equation is used to determine the cut-off value of natural gas, oil, and coal consumption with respect to HDI.

Here, the cut-off value of LNCOL is as follows:

$$\frac{\partial HDI}{\partial LNCOL} = \beta_1 + 2\beta_2 LNCOL = 0, \quad LNCOL^* = -\frac{\beta_1}{2\beta_2}. \tag{2}$$

The cut-off value of LNOIL is as follows:

$$\frac{\partial HDI}{\partial LNOIL} = \beta_3 + 2\beta_4 LNOIL = 0, \quad LNOIL^* = -\frac{\beta_3}{2\beta_4}. \tag{3}$$

The cut-off value of LNNGC is as follows:

$$\frac{\partial HDI}{\partial LNNGC} = \beta_5 + 2\beta_6 LNNGC = 0, \quad LNNGC^* = -\frac{\beta_5}{2\beta_6}. \tag{4}$$

**Eqs 2–4** demonstrated the minimum value of the U-shaped function or the maximum value of the inverted U-shaped function of the quadratic functions (Chiang and Wainwright, 2005).

## Estimation Technique

Since the data vary across cross sections and time periods are more than 20 for each time period (Arshed et al., 2018), this study has opted for the dynamic panel data model. Under this premise, the variables are tested for LLC and IPS panel unit root tests, and further KAO panel cointegration is applied if any one of the variables is non-stationary. This study has used the fully modified least squares (FMOLS) model (Iqbal et al., 2021).

# EMPIRICAL RESULTS

**Table 3** provides the descriptive statistics of dependent variable HDI and all concerned independent variables such as COL, OIL, NGC, EXPO, and LFTOT. The mean value is higher than the standard deviation for all the variables, confirming that they are under dispersed. This denotes that for the selected sample, the data are scattered homogenously around a common mean. Jarque Bera normality tests are significant at the 5% level. Kurtosis values show outliers, which makes an inference from the ordinary least square model redundant (Zahid et al., 2021). This study uses the central limit theorem to assume that the variables are asymptotically normal.

**Figure 5** visualizes the correlation between energy consumption indices, export of goods and services, labor force participation, and human development index. It is observed that LNLFTOT is most correlated with LNCOL compared to other energy consumption indicators.

**Figures 6–8** show that the increase in the subtype of fossil energy consumption has a nonlinear association with the human development index (HDI). The nonlinear association depicts that the proportion of each energy consumption does play a role in determining how fossil energy consumption affects human development. Further ignoring the quadratic effects in estimation may lead to missing specification bias.

**Table 4** provides the DI index values which compare the HDI change with each fossil energy type. Here, the bolded numbers are the cases where DI is negative, while the starred items are the cases where the % change in fossil energy is also negative. The case where bold and star coincide shows the ideal decoupling case. The results showed that in recent years, there is ideal decoupling for all countries except for the case of gas consumption in China.

**Table 5** provides the results of LLC and IPS panel unit root tests. Here, we can see that variables like HDI, LNCOL, LNCOL, LNOIL, and LNNGC are non-stationary at level, while LNEXPO and LFTOT are stationary at level. This confirms that the data are intertemporal and static panel data models may provide spurious results. Furthermore, the KAO panel cointegration test statistic is -3.35 with a probability of 0.00, which confirms that the selected variables are cointegrated in the long run.

**Table 6** labels the detailed results of FMOLS estimates. It used 130 observations of five BRICS countries across time. The R square suggests that the selected variables are explaining 86% variation in the HDI.

The level coefficient of coal consumption is positive and significant while the square of coal consumption is negative and significant, which proposed the inverted U-shaped relationship between LNCOL and HDI. In case of economic development, at lower coal consumption level, 1 percent increase in coal consumption will increase economic development by 0.21 percent (similar finding by Xu et al., 2018; Aktas, 2018). This positive effect is not constant; this effect diminishes with the size of coal energy, such that 1 percent increase in the coal

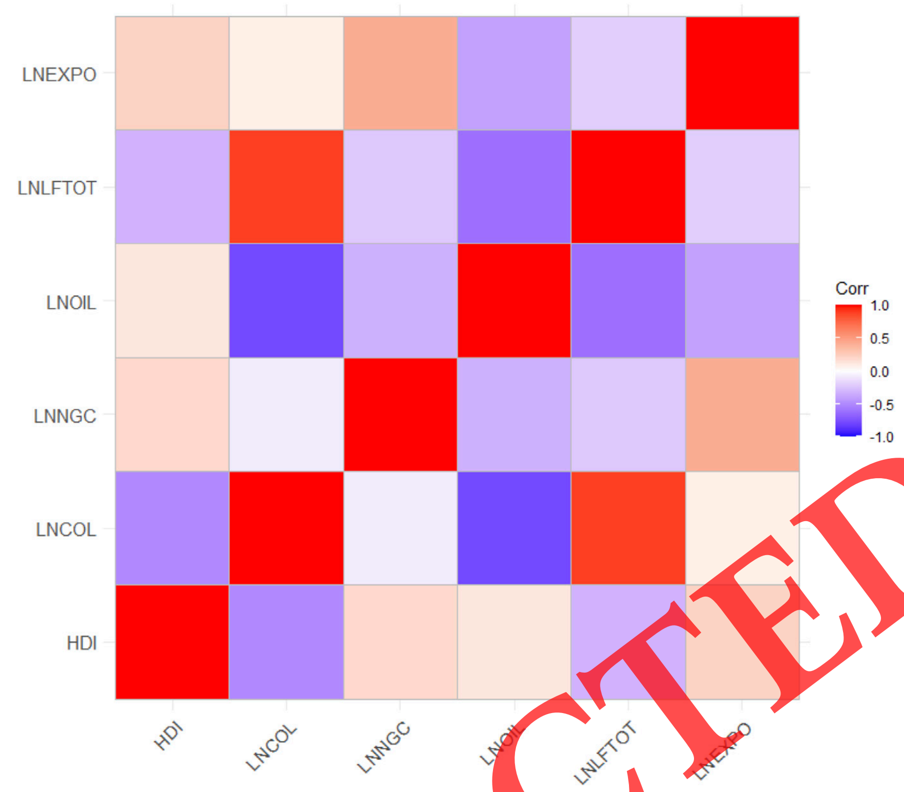


**FIGURE 5 |** Correlation matrix.



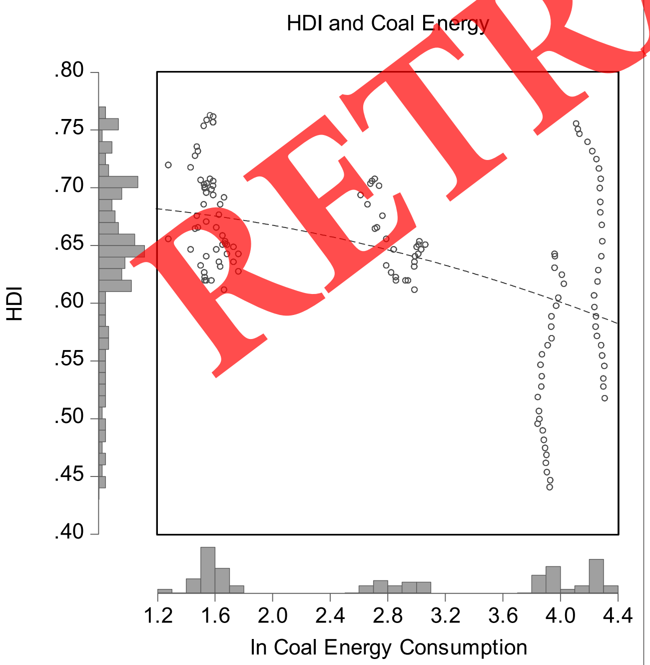


**FIGURE 6 |** Nonlinear associations between HDI and COAL.

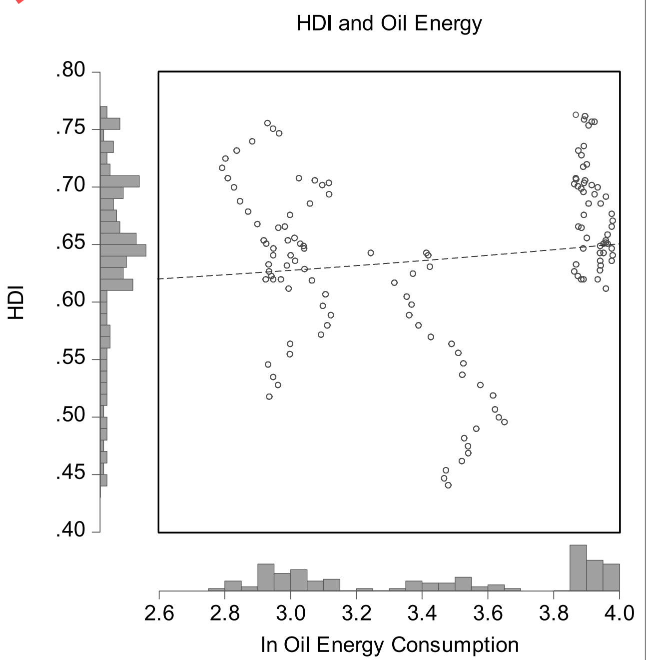


**FIGURE 7 |** Nonlinear associations between HDI and OIL.

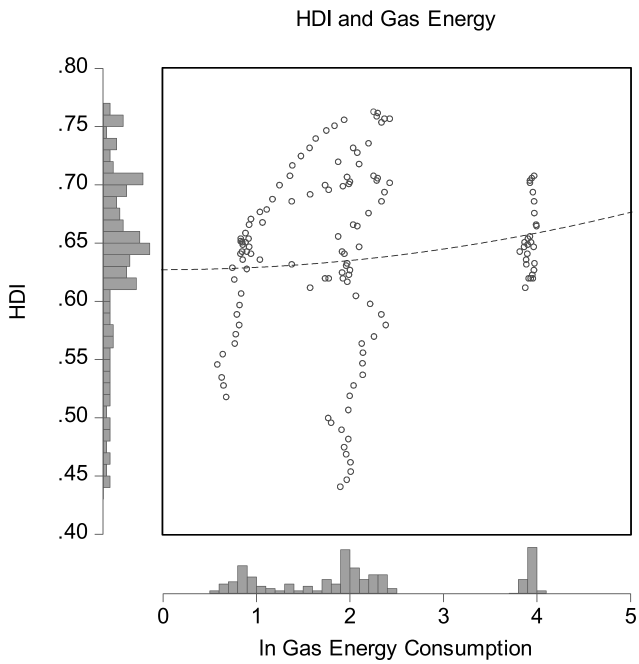


**FIGURE 8 |** Nonlinear associations between HDI and NGC.

**TABLE 5 |** Panel unit root tests.

| | At level | | At first difference | |
|---|---|---|---|---|
| | **LLC** | **IPS** | **LLC** | **IPS** |
| HDI | *–0.73 (0.23)* | *1.73 (0.96)* | *–4.61 (0.00)* | *–4.70 (0.00)* |
| LNCOL | *–0.166 (0.43)* | *0.01 (0.47)* | *–7.94 (0.00)* | *–8.23 (0.00)* |
| LNOIL | *–0.39 (0.35)* | *–0.53 (0.30)* | *–5.86 (0.00)* | *–6.02 (0.00)* |
| LNNGC | *1.68 (0.95)* | *1.66 (0.95)* | *–6.67 (0.00)* | *–6.84 (0.00)* |
| LNEXPO | *–2.07 (0.02)* | *–1.97 (0.02)* | — | — |
| LFTOT | *–10.71 (0.00)* | *–7.03 (0.00)* | — | — |

*The italic values are the probabilities of each of the statistics.*

**TABLE 6 |** Detailed results of the FGLS regression algorithm.

**Dependent variable: HDI**

| HDI | Coefficient | Standard error | t-stat | P > z |
|---|---|---|---|---|
| LNCOL | 0.65 | 0.02 | 41.02 | 0.00 |
| $LNCOL^2$ | –0.14 | 0.00 | –45.17 | 0.00 |
| LNOIL | –0.32 | 0.06 | –5.39 | 0.00 |
| $LNOIL^2$ | 0.00 | 0.01 | 0.10 | 0.92 |
| LNNGC | 0.12 | 0.00 | 21.28 | 0.00 |
| $LNNGC^2$ | –0.06 | 0.00 | –30.13 | 0.00 |
| LNLFTOT | 0.49 | 0.01 | 61.20 | 0.00 |
| LNEXPO | –0.02 | 0.00 | –8.95 | 0.00 |

Number of obs = 130; R-sq = 0.86

**TABLE 4 |** Decoupling analysis of BRICS countries.

| Year | China | | | India | | | South Africa | | | Russia | | | Brazil | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | DI - COAL | DI - Gas | DI - Oil | DI - COAL | DI - Gas | DI - Oil | DI - COAL | DI - Gas | DI- Oil | DI - COAL | DI - Gas | DI - Oil | DI - COAL | DI - Gas | DI - Oil |
| 1993 | **–1.11*** | **–0.34*** | 0.38 | 1.52 | 0.08 | **–0.49*** | **–0.18*** | **–0.14*** | 12.76 | **–0.50*** | 0.07 | **–0.03*** | **–0.24*** | **–0.18*** | 17.02 |
| 1994 | **–179.28*** | **–0.34*** | **–0.49*** | **–0.30*** | 0.17 | 1.35 | **–0.04*** | **–0.33*** | 0.20 | 0.14 | 0.06 | **–0.02*** | **–0.16*** | **–1.16*** | 0.69 |
| 1995 | 1.52 | **–0.24*** | **–0.71*** | **–1.01*** | **–2.91*** | 0.17 | **–0.24*** | **–0.19*** | 0.41 | 0.57 | **–0.10*** | 0.05 | **–0.72*** | **–0.57*** | 1.24 |
| 1996 | **–0.54*** | 0.15 | 0.14 | 1.26 | **–0.15*** | 0.35 | 0.16* | **–0.06** | **–0.58** | **–0.07** | 0.08* | **–0.08** | **–0.37*** | 0.13 | 1.35 |
| 1997 | **–1.47*** | 0.07 | 5.94 | **–0.63*** | **–0.28*** | **–4.66*** | 0.09* | **–0.10** | –0.30 | 0.13* | 0.73* | **–0.33** | **–0.16*** | 0.18 | 0.53 |
| 1998 | **–0.27*** | 0.74 | 0.09 | **–0.75*** | 0.15 | **–0.62*** | 0.09* | **–0.34** | **–2.61** | 0.15* | **–0.17** | 0.15* | **–0.07*** | 0.28 | 2.17 |
| 1999 | **–0.87*** | 0.22 | 0.42 | **–0.99*** | **–0.11*** | 0.22 | **–0.06** | **–0.05** | 2.27 | 0.99* | 0.38* | **–0.38** | 0.07 | 0.06 | **–2.72*** |
| 2000 | 3.52 | **–0.36*** | 0.83 | **–0.17*** | **–0.05*** | 0.07 | **–0.48** | **–0.01** | 0.12* | 1.96* | **–1.06** | 0.16* | 1.09 | 0.03 | **–0.26*** |
| 2001 | **–0.77*** | 0.28 | **–0.33*** | 0.33 | **–0.13*** | **–0.23*** | **–0.76** | **–0.10** | **–1.25*** | **–7.73** | 1.50* | **–3.76** | 0.23 | 0.03 | 0.37 |
| 2002 | **–4.51*** | 0.59 | 1.26 | **–1.75*** | 0.03 | **–0.60*** | **–0.06*** | 0.05 | **–0.32** | **–0.17*** | 0.23 | **–0.34*** | **–0.06*** | 0.05 | **–0.32*** |
| 2003 | 0.49 | **–0.17*** | **–0.29*** | **–1.82*** | 0.80 | **–2.03*** | 0.00 | 0.00 | 0.00* | 0.00* | 0.00 | 0.00* | **–0.34** | **–0.10** | 0.09* |
| 2004 | 2.15 | –0.45* | **–0.45*** | 0.38 | 0.23 | **–0.23*** | 0.00 | 0.00 | 0.00* | 0.00* | 0.00 | 0.00* | 0.08 | 0.02 | **–0.44*** |
| 2005 | 0.54 | 0.14 | **–0.13*** | 2.03 | 0.09 | **–0.16*** | **–0.06*** | 0.05 | **–0.29*** | **–1.18*** | **–0.39*** | 0.17 | **–0.04*** | 0.03 | **–0.19*** |
| 2006 | 2.07 | 0.15 | **–0.45*** | **–1.00*** | **–3.13*** | 2.98 | **–1.55*** | 0.32 | **–0.38*** | **–0.13*** | 0.25 | **–0.52*** | **–0.78*** | 0.16 | **–0.19*** |
| 2007 | **–3.87*** | 0.09 | **–0.74*** | 0.78 | 2.09 | **–0.59*** | **–0.23*** | **–0.18*** | 1.20 | **–0.18*** | 0.79 | **–5.15*** | **–0.15*** | **–0.12*** | 0.80 |
| 2008 | **–1.02*** | 0.24 | **–0.39*** | 0.21 | **–0.68*** | **–0.38*** | **–0.20*** | 0.11 | 0.64 | 0.28 | **–1.48*** | 0.94 | **–0.16*** | 0.08 | 0.50 |
| 2009 | 39.52 | 0.15 | **–0.36*** | 0.22 | 0.05 | **–0.10*** | **–0.06*** | **–0.04*** | 0.82 | **–0.18*** | **–0.24*** | 0.14 | **–0.01*** | **–0.01*** | 0.18 |
| 2010 | **–3.19*** | 0.16 | **–0.66*** | **–2.88*** | 0.08 | **–0.27*** | 0.05 | 0.04 | **–0.56*** | **–0.11*** | 0.13 | **–0.19*** | 0.04 | 0.04 | **–0.50*** |
| 2011 | 1.45 | 0.07 | **–0.42*** | 4.64 | **–0.19*** | **–0.32*** | 0.05 | **–0.02*** | **–0.10*** | 0.07 | **–0.19*** | 0.05 | 0.21 | **–0.09*** | **–0.40*** |
| 2012 | **–0.75*** | 0.36 | **–0.53*** | 0.28 | **–0.08*** | 1.26 | **–1.34*** | 0.06 | 0.58 | 0.26 | **–0.55*** | 0.63 | **–0.54*** | 0.02 | 0.23 |
| 2013 | **–0.50*** | 0.09 | 0.82 | 0.44 | **–0.05*** | **–0.48*** | 0.21 | 0.07 | 0.69 | **–0.10*** | **–4.57*** | 0.17 | 0.37 | 0.13 | 1.25 |
| 2014 | **–0.23*** | 0.08 | 0.21 | 0.31 | **–0.13*** | **–0.32*** | 0.12 | 0.25 | 0.44 | **–0.17*** | **–0.63*** | 0.14 | 0.05 | 0.09 | 0.17 |
| 2015 | **–0.25*** | 0.12 | 0.17 | **–0.61*** | **–0.14*** | 0.14 | **–5.73*** | 0.14 | **–0.92*** | 0.06 | **–0.26*** | **–0.40*** | 0.00* | 0.00 | 0.00* |
| 2016 | **–0.12*** | 0.06 | 0.09 | **–0.12*** | 0.14 | 0.12 | **–0.05*** | **–0.01*** | **–0.09*** | **–0.03*** | **–25.75*** | 0.10 | **–0.05*** | **–0.01*** | **–0.09*** |
| 2017 | **–0.38*** | 0.05 | **–0.22*** | 2.91 | **–0.56*** | **–1.84*** | 0.04 | 0.20 | 0.89 | 0.19 | 0.10 | **–0.05*** | 0.07 | 0.30 | 1.34 |
| 2018 | **–0.38*** | 0.05 | **–0.28*** | **–0.65*** | **–0.08*** | **–0.38*** | **–0.10*** | **–0.05*** | **–0.07*** | 0.11 | 0.09 | **–0.04*** | **–0.05*** | **–0.02*** | **–0.04*** |

*Bolded values are DI < 0 and * are %Δ Fossil energy <0.*

**TABLE 7** | Turning point.

| | LNCOL | LNOIL | LNNGC |
|---|---|---|---|
| Level coefficients | 0.65 | −0.32 | 0.12 |
| Squared coefficients | −0.14 | 0.00 | −0.06 |
| Cut off | 2.32 | — | 1.00 |
| Antilog of cut off | 10.17 | — | 2.72 |

consumption decreases economic development by 0.07 percent (similar findings by Finkelman et al., 2021; Guo et al., 2021; Hendryx et al., 2020; Irwandi, 2018; Chang et al., 2017; Apergis and Payne, 2010b). So, this study rejected the proposition of constant returns to scale used by past studies.

The level form coefficient of oil consumption (OIL) is negative and statistically significant, while the squared form coefficient is positive but statistically insignificant. This relationship is negatively linear between LNOIL and HDI. A 1 percent increase in oil consumption will lead to a 0.32 percent decrease in HDI (similar results by Adekoya, 2021; Camioto et al., 2016; Behmiri and Manso, 2014). Here, this study accepts the hypothesis of constant negative returns to scale between LNOIL and HDI.

The level form coefficient of natural gas consumption (LNNGC) is positive and statistically significant, while the squared form coefficient is negative and statistically significant. This demonstrates the inverted U-shaped relationship between them. Hence, natural gas consumption, initially at a lower share of the consumption phase, plays a positive role in the economic development of BRICS countries (similar finding by Balsalobre-Lorente et al., 2019; Zhi-Guo et al., 2018; Hassan et al., 2017; Ozturk and Al-Mulali, 2015; Shahbaz et al., 2013; Das et al., 2013). Beyond a certain limit of consumption share, further increase in natural gas consumption may obstruct economic development (similar findings by Isik, 2010; Fatai et al., 2004; Siddiqui, 2004; Aqeel and Butt, 2001). So the hypothesis of constant returns to scale is rejected by this study.

For the case of control variables, export of goods and services (LNEXPO) significantly affects the economic development in BRICS countries. A 1 percent increase in exports will lead to a decrease in the human development index by 0.02 percent. This can be reasoned by the fact that the major source of production of export commodities is fossil fuels. Labor force participation also influences human development index in BRICS countries. A 1 percent increase in the LFTOT increases human development by 0.49 percent. These results are similar to the outcome of other studies (Paudel and Perera, 2009; Lahoti and Swaminathan, 2013; Amir et al., 2015). Referring to **Table 7**, the thresholds are estimated. According to this, beyond 10.17% of coal energy consumption and 2.72% of gas energy consumption with respect to total energy consumption, country will experience development depreciating effect of fossil energy. Hence, countries should limit coal energy consumption to 2.32% and gas to 2.72%.

This study has visualized the quadratic effects using the method from the study by Dawson (2014), whereby the size of the quadratic variable is on the $x$ axis and its marginal effect is on the $y$ axis. **Figures 9–11** show the estimated effects of fossil energy; it is evident here that coal energy and gas energy are depicting an inverted U shape, while oil energy is showing a negative effect.

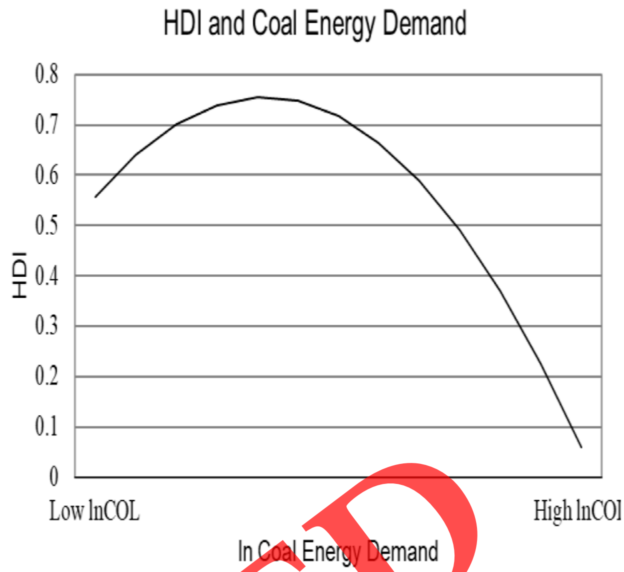


**FIGURE 9** | Traced effect of coal consumption (LNCOL).

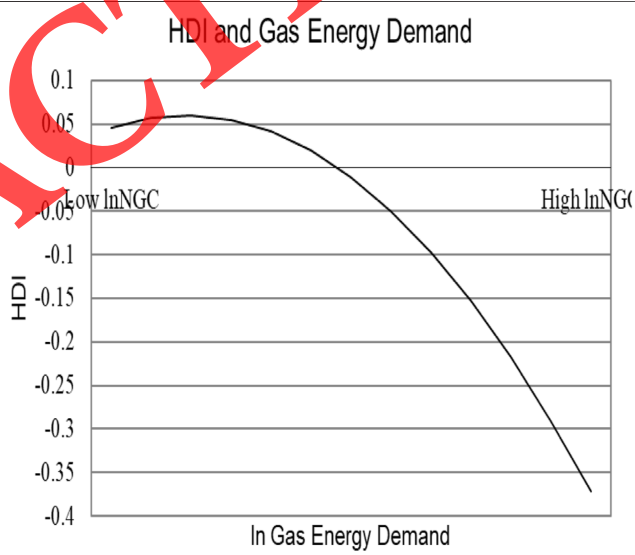


**FIGURE 10** | Traced effect of oil consumption (LNOIL).

## DISCUSSIONS AND POLICY RECOMMENDATIONS

The inverted U-shaped curve of coal and gas consumption suggests that an initial increase in coal and gas consumption

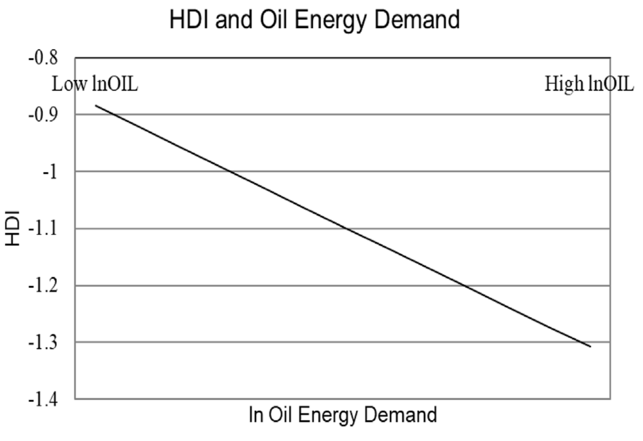


**FIGURE 11** | Traced effect of natural gas consumption (LNNGC).

enhances economic development. At the same time, after a certain limit, further increase in coal and gas consumption negatively impacts the economic development in BRICS countries. On the other hand, oil consumption and the HDI curve are negative. It means each unit of additional coal consumption will cause a decrease in economic development. So, we can say that coal and gas consumption has diminishing marginal returns when studying against development. It can easily be concluded that subtypes of fossil fuels such as coal, oil, and gas consumption negatively impact the economic development in BRICS countries. This study contradicts previous studies conducted in the BRICS countries that determined that fossil fuel consumption is an engine of economic growth (Chang et al., 2017; Sasana and Ghozali, 2017). Fossil fuel may increase economic growth while it is inversely related to economic development. The massive consumption of fossil fuels increases greenhouse gas emissions, directly affecting the global environment and natural resources. Environmental degradation creates global warming and many diseases in humans. According to the United Nations sustainable development goals, no country can develop with the consumption of high fossil fuels. At the same time, the BRICS energy (2020) report projected that the BRICS countries would continue to consume fossil fuels till 2040 at almost the same speed. Coal and oil consumption causes a lot of carbon emissions. Unfortunately, two of the BRICS member countries, China and India, are the biggest users of coal and oil worldwide. Both of these countries consume about more than half of the world coal consumption. It is a very alarming situation for all over the world. It will severely affect climate change and cause global warming. A big challenge of the United Nations Environment Programme (UNEP) is to save this planet from more pollution.

## Policy Implications

In the policy recommendation portions, the BRICS countries should follow the policies to reduce fossil fuel energy consumption.

1. Member countries of BRICS, especially China and India, pay special attention to clean energy consumption instead of coal, oil, and gas consumption. The governments of these countries should efficiently use technology to improve clean energy resources such as wind energy and solar energy.
2. BRICS countries should construct more and more hydroelectric energy sources to fulfil the energy requirements.
3. BRICS countries can use coal by using advanced technology gasification. In this method, coal is buried underground, and only steam and oxygen are used for the energy process.
4. BRICS countries should give subsidies to private investors to promote clean energy.
5. The UN environmental agencies should play their role to decrease fossil fuel consumption. Under the Kyoto Protocol agreement (1997), BRICS countries should buy more and more carbon credits for the other countries due to the negative externalities impact of fossil fuel consumption.
6. In BRICS, exports of goods and services play an important role once the nation shifts toward renewable energy.



## DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/Supplementary Material; further inquiries can be directed to the corresponding authors.

## AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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