

# DECARBONISING ECONOMIC GROWTH THROUGH INNOVATIONS IN RENEWABLE ENERGY

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**Abstract** *With the emerging consciousness of climate change and focus on climate-resilient growth across all developing nations, Brazil has proved to be a benchmark for the energy transition to an environmentally sustainable energy system. All the developing countries are heading towards decarbonised growth using alternative sources of energy. As a result, the paper explores the causal relationship between renewable energy consumption and economic growth in the case of Brazil, using the data for the last 12 years. The Granger causality test is performed to comprehend the relationship between the three crucial indicators of the newly emerging growth models. The paper examines the interdependence of renewable energy and economic growth using the Granger causality test to estimate two-way dependence in BRICS countries. The paper exhibits the evidence of one-sided long-run causality between the use of renewable energy and per capita GDP, concluding that the deployment of renewable energy Granger causes per capita GDP growth. The results of Granger causality and correlations further provide an adequate rationale for the state to invest in renewable energy technologies and innovations. In this backdrop, the paper attempts to analyse India's green growth compared to Brazil in the last 15 years.*

**Keywords** *Climate Change, Renewable Energy, Economic Growth, Human Capital, R&D, BRICS*

## INTRODUCTION

Climate change has taken centre stage among all global challenges that both developed and developing nations face today. Each developed and developing economies is determined to adopt newer, cleaner, and efficient ways of producing energy to mitigate the harmful and disastrous consequences. For the first time in 20 years, COP21 will aim to achieve a legally binding agreement, along with international climate agreements, to keep the average temperature below 20°C (UNFCCC, COP 21). India is going to play a critical role in meeting the targets. India aims to lower its emission intensity by 33% to 35% by 2030, below the 2005 levels (Times of India, 2 October 2016). In this context, most advanced countries have established a legal framework to encourage the shift from fossil-based energy to a non-conventional clean energy system. This attempt requires a well-planned conscious effort to accomplish global energy efficiency objectives and transition towards clean energy alternatives.

India is also committed to expanding the contribution of non-fossil-based capacity of electricity generation to 40% of the installed electric power capacity by 2030. The efforts are substantially towards decarbonisation, which reduces carbon-emitting conventional fuels and substitutes them

with renewable and zero-carbon sources of energy. India is struggling with its two-fold objectives of energy equity and sustainable energy growth. Under such circumstances, when the country is struck by many problems of unemployment, poverty, inequality, and lack of enough infrastructure that directly highlights an acute need for cheap sources of energy, it would be a real challenge for the nation to undergo energy transition in favour of alternate sources of energy. It is challenging for a developing nation and poor nations to adhere to the targets, as the conventional sources of energy are cheap and the alternative sources are expensive, as they involve technological innovations.

With emerging concerns of climate change, climate regime has formulated a very comprehensive or holistic energy regime. All the developed and developing countries are determined to undergo a transition in their energy system to attain climate-resilient growth, so that they are successfully able to trade-off between carbon emissions and economic growth. In this context, Brazil has been a remarkable example in achieving carbon-free growth, laying down benchmarks in energy innovation and transition pathway.

Brazil, a Latin American country, is the biggest in South America, and the fifth largest globally[1]. It is the most prominent country in terms of international trade in South America. Brazil's institutional regime, policy framework,

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and choices has made it possible to achieve successful carbon-intensive growth. About 45% of primary energy demand is met by renewable energy (IEA 2012), with ambitious targets of bio-power (19.3GW), small-scale hydropower (7.8GW), and wind power (15.6GW), by 2021 (Renewable Energy Policy Brief BRAZIL, June 2015).

In Brazil, renewable energy has a substantially higher proportion of total energy generated. The Brazilian government has played a leading role in promoting bio-fuels. It began substituting oil for ethanol in the 1970s. Between 1960 and 1990, the federal government worked in the arena of national and regional interest, while states limited their scope to generating, transmitting, and distributing electricity within their territories (Sybille, 2015).

This phenomenal success has been an outcome of considerable investment in research and development and innovation in renewable technology in Brazil. The country has provided a well-coordinated institutional structure, financing system, and political structure to foster the creation and make it commercially viable.

Maji (2015) investigates the impact of clean energy on economic growth to examine the cointegration among the two variables. A significant negative relationship, in the long run, is observed between clean energy and economic growth; however, a mixed negative and positive relationship was observed in the short run, though not significant.

Apergis and Danuletin (2014) confirmed the interdependence of consumption of renewable energy and economic growth by applying a long-run causality test. The paper concluded a positive causality from consumption of renewable energy to real GDP. Lutz et al. (2012) deployed economy–energy–environment model PANTA RHEI, and concluded that an increase in investment expands demand in the short-run and further minimises expenditure on energy in the long-run. However, at the regional level, renewable energy and efficiency create an additional value-added aspect and employment in the economy. The observed transition from conventional sources of energy (fossil fuels) to energy-saving techniques and renewable energy consumption supports the German economy, opening export opportunities for German industries.

Blazejczak et al. (2011) analyse the economic effects of using renewable energy in Germany by using the SEEM model, concluding that there is a positive impact on economic growth. Payne et al. (2010) concluded that the effects of nuclear and renewable energy are highly contradictory to each other. On the one hand, nuclear energy is found to have a significantly negative relationship with emissions, and the emissions and renewable energy are significantly positively related. The study mainly suggests that nuclear energy reduces emissions, while renewable energy has no significant impact on emission reduction.

By deploying the Granger causality test, a unidirectional causality was reported from consumption of nuclear energy to carbon dioxide emissions (Rufael, 2010). The work suggested a crucial role played by nuclear energy in mitigating carbon dioxide emissions. However, the results depicted that renewable energy could not make any significant impact.

Vlahinić-Dizdarević and Žiković (2010) applied a bivariate model using real GDP and selected energy variables, and reported a causality of real GDP growth to all the chosen energy variables. Apergis and Payne (2010) revealed a long-term relationship between real GDP, renewable energy consumption, real gross fixed capital formation, and labour force, using the cointegration and error correction model. Energy consumption and economic growth are cointegrated, and a unidirectional causal relation is obtained from economic growth to energy consumption in the short run (Hu et al., 2015). However, there prevails a unidirectional causality from energy consumption to economic growth. Gomez et al. (2018) analysed the causal link between aggregated and disaggregated use of energy and economic growth. The results depicted the existence of a long-run relationship between capital, labour, energy, and production. A non-linear causality also prevailed from energy consumption, transport sector, capital, and labour, to output. Thus, energy is fortified as a critical input for economic activity. Arango-Miranda et al. (2018) carried out energy analysis while implementing policies related to not only energy, but also the environment, in these countries, and concluded that the data of selected countries did not support Environmental Kuznets Curve.

Sengupta (2007) analysed the dual challenges of the environmental sustainability aspect of energy use and poverty eradication. The paper focuses on the instrumental role of energy efficiency and energy supply, fuel composition, and technology in determining the strength of the link between energy use and pollution intensity of energy. A unidirectional causality from carbon dioxide emissions necessitates renewable energy consumption (Ahmed & Shimada, 2019). The study recommends several policy initiatives to facilitate renewable energy investments. A unidirectional causality from economic growth to the production of renewable energy sources is evident both in the short run and long run (Armeanu et al., 2017).

Simsek and Simsek (2013) emphasised the significance of renewable energy and clean energy, when this era is marked by global climate change. Pilatowska et al. (2020) incorporated variables such as consumption of renewable energy, nuclear energy, carbon dioxide emission, and economic growth. The study indicates that both renewable and nuclear energy substantially reduce the emissions;

however, decoupling of economic growth from carbon dioxide emissions was not reported.

In this context, the paper considers Brazil as a benchmark in the renewable energy breakthrough and examines the role of renewable energy deployment in the economic growth in Brazil. Since BRICS includes all the fastest growing economies of the world, these nations are prone to emit more emissions. It is imperative to explore the role of renewable energy sources in these nations; therefore, the paper investigates the impact of renewable energy deployment on the economic growth of these nations. A comparison between India and Brazil is also presented to analyse the status of renewable energy deployment and its impact on economic growth.

The paper is organised into distinct sections. In addition to Section 1 that is introduction, Section 2 presents data and methodology adopted in achieving the objectives of the paper. Section 3 compiles all the results related to statistical models deployed and data analysed to achieve the objectives. The discussion related to the findings of the results are presented in Section 4. Finally, Section 5 summarises the study by concluding with the main findings, recommendations and policy suggestions.

## MATERIALS AND METHODS

To test the relationship between renewable energy and economic growth, per capita gross domestic product of Brazil has been taken as an economic growth indicator. This relationship is tested for the period 1960-2011. Data for the concerned variables are obtained from the World Bank website.

Augmented Dickey-Fuller is used to test the existence of unit roots, identifying the order of integration. If the indicators have unit roots, then it is expected that the trend of the variables towards long-run equilibrium, together with the unit roots, are conducted, taking into account intercept and time trend.

### Unit Root Test

In the time-series analysis, the variables are required to be stationary. In the case of non-stationary variables, such as the unit root, would imply that the mean and variance are dependent on time. To identify if there is any presence of unit root, the Dickey-Fuller test is used. Dickey and Fuller (1979) developed a methodology for testing the presence of random walk in a variable. Hamilton (1994, 528-529)

further depicted four distinct cases where the augmented Dickey-Fuller test is applicable.

### Cointegration

To test the hypothesis related to the relationship between the two variables having unit roots, integration of at least order one cointegration must be considered. In time-series data, it is imperative to find the non-stationary variable. However, the non-stationary series could be cointegrated. Cointegration is a technique used in cases where the variables are non-stationary and do not indicate any short-run relationships. The technique of cointegration peculiarly investigates the presence of long-run equilibrium.

### Granger Causality Test

Granger, in 1969, proposed the Granger causality test, the most popular way to investigate the causal relationships between the two variables. It is a statistical hypothesis for examining if one-time series is helpful in forecasting another.

## RESULTS

This section presents the correlation analysis of selected factors such as carbon emissions, national income, and renewable energy consumption, comparing both India and Brazil. The causal relationship between renewable energy consumption and GDP is tested using the Granger causality test for Brazil and BRICS.

### Results of Correlation Analysis

A simple correlation between the renewable energy consumption, per capita GDP, carbon dioxide emissions, and expenditure on R&D as percentage of GDP will indicate the underlying interlinks between these selected variables. The appropriate indicators are selected for the variables considered in the study. Details of the variables are as follows:

- A correlation analysis between the following variables is carried out for Brazil and India.
- GDP per capita growth (annual %): PCGDP
- Renewable energy consumption (% of total final energy consumption): REC
- CO<sub>2</sub> emissions (metric tons per capita): CO<sub>2</sub>
- Research and development expenditure (% of GDP): R&D

**Table 1: Results of Correlation between Per Capita GDP, Renewable Energy Consumption, and CO2 Emissions for India and Brazil for the Period 1990-2012**

		PCGDP	Brazil REC	CO2	PCGDP	India REC	CO2
	PCGDP	1					
Brazil	REC	-0.0750	1				
	CO2	0.400	-0.518	1			
	PCGDP	0.279	0.078	0.362	1		
India	REC	-0.421	0.1247	-0.900	-0.473	1	
	CO2	0.380	-0.132	0.901	0.435	-0.994	1

The correlation results indicate that renewable energy consumption and per capita GDP are negatively related in both Brazil and India, though not significant. Per capita GDP is positively associated with CO2 emissions, reconfirming that the growth is attained with the cost of emissions. It is seen that renewable energy consumption is significantly

negatively related to CO2 emissions, showing that more and more use of renewable energy has successfully reduced CO2 emissions. This result is more significant in the case of India, highlighted in yellow (-0.994). This exhibits a strong case for the government to invest in renewable energy sources.

**Table 2: Results of Correlation between Per Capita GDP, Renewable Energy Consumption, CO2 Emissions, and Research and Development for India and Brazil for the Period 2003-2011**

		PCGDP	Brazil REC	CO2 Emissions	R&D	PCGDP	India REC	CO2 Emissions	R&D
	PCGDP	1							
	REC	-0.15	1						
Brazil	CO2	0.485	-0.007	1					
	R&D	0.246	0.468	0.816	1				
	PCGDP	0.063	0.122	-0.152	-0.19	1			
	REC	-0.2	-0.435	-0.860	-0.91	0.009	1		
India	CO2	0.124	0.485	0.825	0.929	-0.123	-0.989	1	
	R&D	0.18	0.564	0.580	0.641	-0.233	-0.682	0.72	1

The simple correlation analysis in Table 2 indicates that the values in blue reflect the correlations for Brazil, and the ones in red reflect high correlation values for India. In the case of Brazil, per capita GDP is positively related to CO2 emissions, though not significantly correlated. Further, excessive use of renewable energy would be negatively associated with CO2 emissions. Expenditure on research and development (R&D) as a proportion of GDP is positively related to renewable energy consumption, indicating that in Brazil, research and development enhance the use of renewable energy. The correlation between CO2 emissions and research and development expenditure shows a significantly high positive correlation of around 0.816.

The carbon dioxide emissions and use of renewable energy are significantly negatively related, suggesting that between 2003 and 2011, as consumption of renewable energy increases, CO2 emissions decrease. The correlation is

highly significant, approximately -0.989. R&D expenditure as a proportion of GDP is significantly negatively related to renewable energy consumption, suggesting that research and development expenditure does not contribute positively to consumption of renewable energy. The correlation between research and development expenditure and CO2 emissions is positive.

To analyse causality on both sides, one needs to perform unit root and Granger causality test to assess any sense of causality between growth rates and renewable energy consumption. The following section explores the relationship between economic growth and the use of renewable energy for Brazil and BRICS separately.

After testing the unit roots for both the variables, we find that both per capita GDP and consumption of renewable energy as a percentage of final energy consumption becomes

stationary with a one-time lag. Therefore, the VAR model is set up.

## Results of Granger Causality Test

To test the causality between renewable energy consumption and economic growth, the Granger causality test is performed by deploying the statistical package STATA. By using the data of renewable energy consumption and per capita GDP from World Bank database, a vector autoregressive model is run for Brazil and BRICS. The results are presented below.

### Brazil

Wald Tests			
For Vector Autoregressive Model:			
Sample: 1990 2012			
Included observations: 21			
Dependent variable: DPCGDP_BRAZIL			
Excluded	Chi-sq	Df	Prob.
DREC_BRAZIL	4.858873	1	0.0275
All	4.858873	1	0.0275
Dependent variable: DREC_BRAZIL			
Excluded	Chi-sq	Df	Prob.
DPCGDP_BRAZIL	0.480831	1	0.4880
All	0.480831	1	0.4880

The consumption of renewable energy as a percentage of total energy consumption when considered with one time lag Granger causes PCGDP per capita gross domestic product with one time lag; on the other hand, PCGDP with one time lag does not Granger cause REC (renewable energy consumption) with one time lag in Brazil. The result is significant at 5% level.

### BRICS

Wald Tests for Vector Autoregressive Model			
Sample: 1990 2012			
Included observations: 21			
Dependent variable: DPCGDP_BRICS			
Excluded	Chi-sq	Df	Prob.
DREC_BRICS	4.026756	1	0.0448
All	4.026756	1	0.0448
Dependent variable: DREC_BRICS			
Excluded	Chi-sq	Df	Prob.
DPCGDP_BRICS	0.099117	1	0.7529
All	0.099117	1	0.7529

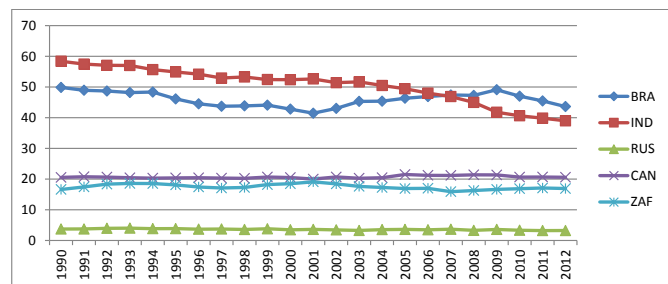
When consumption of renewable energy as a percentage of total energy consumption is taken as the lag of one time-period, then renewable energy consumption (REC) Granger causes PCGDP per capita gross domestic product taken as a lag in one time-period; however, PCGDP with one time-lag period does not Granger cause REC with one lag period in BRICS. The result is significant at a 5% level.

## DISCUSSION

Based on the results obtained, an analysis consisting of variables such as renewable energy consumption, national income, carbon dioxide emissions, and R&D expenditure is performed, to investigate the relationship between them. Besides, based on the analysis, a theoretical framework for growth model, integrating R&D expenditure is proposed.

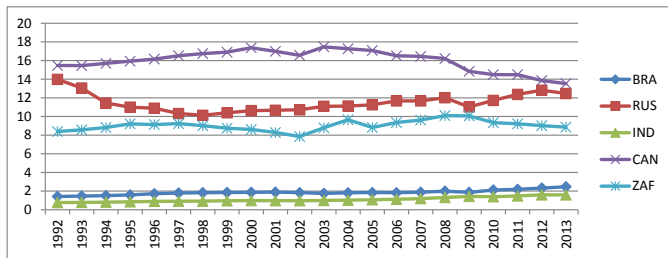
## Renewable Energy, Per Capita, Carbon Dioxide Emissions, and R&D Expenditure: A Comparison of BRICS

BRICS constitutes a group of countries like Brazil, Russia, India, China, and South Africa, which are among the fastest developing countries in the world. The growth is eventually accompanied by the cost of emissions that a country emits while growing. Therefore, observing data related to their change, CO<sub>2</sub> emissions, use of renewable energy, and expenditure on research and development would deliver a clear understanding of each country's performance regarding growth and emissions. The data for concerned variables is obtained for all BRICS countries from 1990 to 2013.



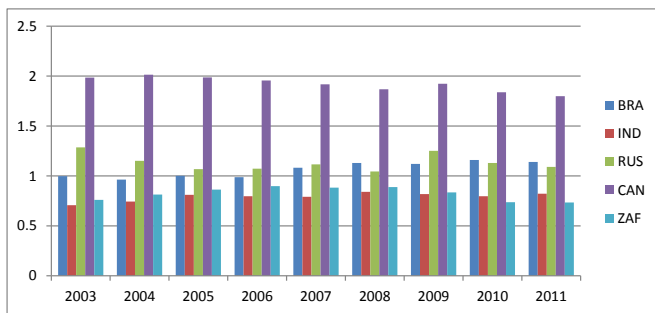
Source: World Bank Data.

Fig. 1: Consumption of Renewable Energy in BRICS



Source: World Bank Data.

**Fig. 2: Per Capita Carbon Dioxide Emissions in BRICS Countries**

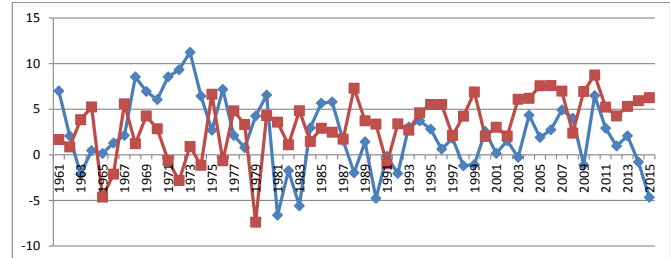


Source: World Bank Data.

**Fig. 3: Expenditure of Research and Development in BRICS Countries**

The above graphs indicate that CO2 emissions are highest in Canada and lowest in India. The emissions in Brazil are also low, but higher than in India. At the same time, the use of renewable energy as a percentage of total energy consumption is highest for Brazil and India, which perhaps is why these countries are emitting lower CO2. The data on research and development indicates that Canada spends the maximum amount on research and development as a proportion of its GDP. At the same time, India and South Africa have a lesser proportion of their GDP spent on research and development. This shows that the research and development expenditure may not be directed towards the innovation of renewable energy technologies.

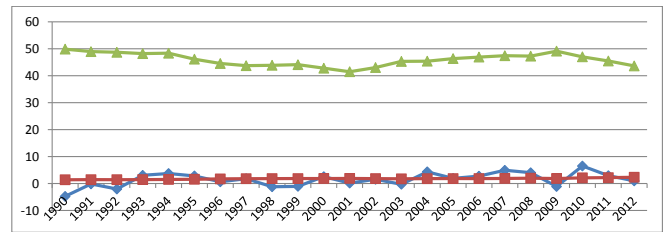
By studying the data from 1960-2016 for Brazil and India, data related to GDP per capita, research and development expenditure, consumption of renewable energy, and CO2 emissions per capita are observed and compared for these 2 countries.



Source: World Bank Data.

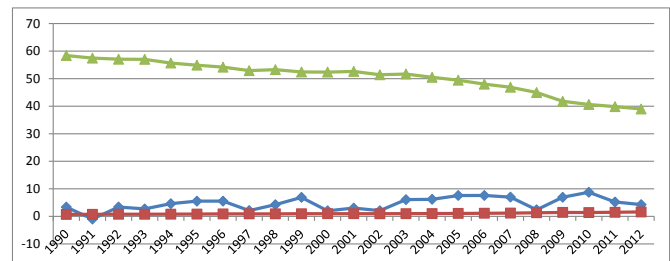
**Fig. 4: Trend in GDP Per Capita Growth in Brazil (Blue) and India (Red)**

The above trend confirms a highly fluctuating GDP per capita in both countries from 1961-2015. The GDP per capita growth becomes negative most of the time in both nations.



Source: World Bank database.

**Fig. 5: A Comparison of Trends in GDP, CO2 Emissions, and Renewable Energy Consumption in Brazil. (Blue): Per Capita GDP, (Red): Per Capita Carbon Dioxide Emissions, (Green): RE Consumption in Proportion**

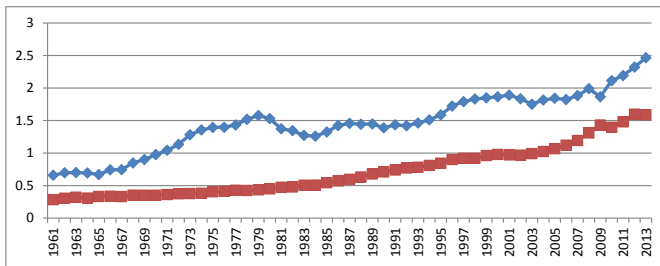


Source: World Bank database.

**Fig. 6: A Comparison of Trends in GDP, CO2 Emissions, and Renewable Energy Consumption in India. (Blue): Per Capita GDP Growth; (Red): Per Capita Carbon Dioxide Emissions; (Green): RE Consumption in Proportion**

The data of Brazil indicates a steady movement in renewable energy consumption and GDP per capita growth rates. CO<sub>2</sub> emissions per capita has been consistently rising.

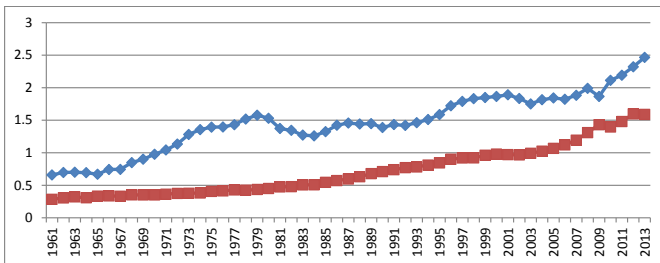
Similarly, the data between 1990 and 2012 reflects a steady decline in renewable energy consumption as a percentage of total final consumption. The GDP growth rates are fluctuating.



Source: World Bank database.

**Fig. 7: Trends in CO<sub>2</sub> Emissions in Brazil and India. (Blue): Per Capita Carbon Dioxide Emissions in Brazil; (Red): Per Capita Carbon Dioxide Emissions in India**

The trend in CO<sub>2</sub> emissions in Brazil and India depicts that in both countries the emissions have been rising consistently since 1961. The CO<sub>2</sub> emissions in Brazil are higher than the emissions in India.

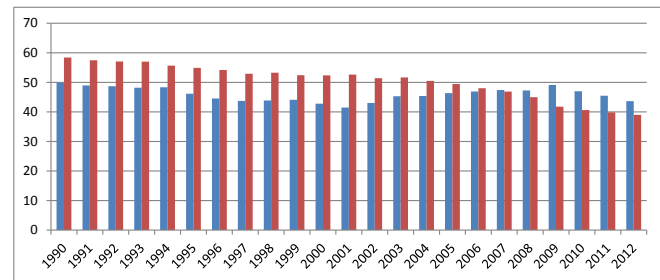


Source: World Bank database.

**Fig. 8: R&D Expenditure as a Percentage of GDP in Brazil (Red); Expenditure on R&D as a Percentage of GDP in India (Blue)**

The data indicates that Brazil spends a considerably more significant proportion of their GDP on research and development.

Fig. 9 depicts that the proportion of renewable energy used in the energy demand in India has been much higher than in Brazil till 2006. Still, the data indicates that from 2006 onwards, renewable energy consumption in Brazil has started rising.



Source: World Bank database.

**Fig. 9: Percentage of RE Consumption in Brazil (Red); Percentage of RE Consumption in India (Blue)**

## CONCLUSIONS

Energy plays one of the predominant roles in the process of development in all developing countries. All the growing countries require energy to meet the demands of their growth. In light of climate change, which is now a global issue, all the countries need to curtail their emissions and move towards energy transition from conventional energy fuels to more clean and renewable energy sources. As a result, it is crucial to comprehend whether renewable energy consumption would lead to economic growth. Simple correlation analysis of the concerned variables considerably highlights a strong significant negative correlation between renewable energy use and CO<sub>2</sub> emissions. The results of Granger causality conclude that in the case of both Brazil and BRICS, the proportion of renewable energy use as a percentage of total energy consumption, when considered with one time-period lag Granger causes PCGDP per capita gross domestic product with one time-period lag. The lagged values of renewable energy consumption directly indicate that the base established last year in renewable energy would contribute successfully to economic growth.

Data analysis of BRICS countries reveals that the proportion of GDP spent on research and development may not be renewable energy technologies. Since it is evident that more and more renewable energy consumption directly impacts CO<sub>2</sub> emissions, it makes a strong case for states to invest in research and development, specifically in clean energy technologies that would give an impetus to reduce CO<sub>2</sub> emissions.

The data demonstrate that renewable energy consumption has been persistently reducing after 1990, while Brazil's energy consumption is rising consistently. Brazil spends a substantial amount of its income on research and

development compared to India. Brazil is a growing country emitting more CO<sub>2</sub> emissions compared to India.

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