Three Essays in Energy Economics: A Study on BRICS Countries

A thesis submitted to the University of Hyderabad
in partial fulfillment of the requirement for the award of

DOCTOR OF PHILOSOPHY
IN
ECONOMICS

By

UMMALLA MALLESH
Registration No: 14SEPH16

Thesis Supervisor
Prof. Phanindra Goyari

School of Economics
University of Hyderabad
Hyderabad-500046 (INDIA)
December 2020

Dedicated to My Beloved Parents

School of Economics
University of Hyderabad
Hyderabad-500046, India

DECLARATION

I, Ummalla Mallesh, hereby declare that this thesis entitled "**Three Essays in Energy Economics: A Study on BRICS Countries**" submitted by me under the guidance and supervision of Prof. Phanindra Goyari, School of Economics, University of Hyderabad, is a *bonafide* research work, which is also free from plagiarism. I also declare that it has not been submitted previously in part or full to this University or any other University or Institution for the award of any degree or diploma. I hereby agree that my thesis can be deposited in Shodganga/INFLIBNET.

A report on plagiarism statistics from the University Librarian is enclosed.

Name: Ummalla Mallesh

U. Mallesh

Signature of the scholar

Registration No.14SEPH16

Date: 29 December 2020

Place: University of Hyderabad

School of Economics
University of Hyderabad, Hyderabad-500046 (India)

CERTIFICATE

This is to certify that the thesis entitled "Essays in Energy Economics: A Study on BRICS Countries" submitted by Ummalla Mallesh bearing registration number 14SEPH16 in partial fulfillment of the requirements for award of Doctor of Philosophy in the School of Economics is a bonafide work carried out by him under my supervision and guidance. This thesis is free from plagiarism and has not been submitted previously in part or in full to this or any other University or Institution for award of any degree or diploma. The candidate has satisfied the UGC Regulations of publications and conference presentations before the submission of this thesis. Details are given below:

A. Publications

1. Mallesh, Ummalla, Asharani Samal and Phanindra Goyari (2019): "Nexus among the Hydropower Energy Consumption, Economic Growth and CO_2 Emissions: Evidence from BRICS Countries" in: *Environmental Science and Pollution Research,* Vol. 28, Issue 34, pp. 35010-3502, Print ISSN: 0944-1344 and e-ISSN: 1614-7499, Scopus and UGC CARE listed journal, Source: https://link.springer.com/content/pdf/10.1007/s11356-019-06638-1.pdf

2. Mallesh, Ummalla and Phanindra Goyari (2020): "The Impact of Clean Energy Consumption on Economic Growth and CO_2 Emissions in BRICS Countries: Does the Environmental Kuznets Curve Exist?" in: *Journal of Public Affairs,* First Online: 25 March, pp. 1-12, ISSN: 1479-1854, ABDC Ranked B, Scopus and UGC CARE listed journal, Source: https://onlinelibrary.wiley.com/doi/full/10.1002/pa.2126.

B. Presentations in conferences:

1. Presented a paper: "The impact of Clean Energy Consumption on Economic Growth and CO_2 Emissions in a Panel of BRICS Countries" in: 56thAnnual Conference of The Indian Econometric Society (TIES), at Madurai Kamaraj University, Madurai, 8-10 January 2020.

2. Presented a paper: "Does Institutional Quality Matter for Renewable Energy use and CO_2 Emissions in BRICS Countries?" in: 13th Doctoral Thesis Conference at ICFAI Business School (IBS), Hyderabad, 8-9 October 2020.

Further, the student has passed the following courses towards fulfillment of coursework requirement for Ph.D./was exempted from doing coursework (recommended by Doctoral Committee) on the basis of the following courses passed during his MPhil program and the MPhil degree was awarded:

Course Code	Course Title	Credits	Pass/Fail
ECON611	Research Methodology in Economics	6	Pass
ECON612	Econometrics: Theory & Applications	6	Pass
ECON613	Study Area Paper	6	Pass

Signature of PhD Supervisor

29.12.2020

Prof. Phanindra Goyari

DR. PHANINDRA GOYARI
Professor
School of Economics
University of Hyderabad
Hyderabad-500046, India

Dean

ACKNOWLEDGEMENTS

My PhD journey started with passion and emotion. I have enjoyed this journey in every stage, both ups and downs, and tried to make the best out of it. Here, I would like to express my deepest appreciation to many people for their moral support throughout this journey.

First and foremost, I would like thank GOD for giving me such a wonderful supervising teacher for my PhD thesis work. There are no words to express my profound gratitude to my GURU Prof. Phanindra Goyari for his patience, motivation and enthusiasm. Prof. Goyari has supported me throughout my research with his knowledge and motivation. He offered not only academic guidance but also knowledge in other aspects of life.

My special thanks to my Doctoral Committee members, Dr. G. Sridevi and Dr. Prajna Paramita Mishra, for their support, valuable inputs and suggestions. I express my sincere thanks to all other faculty members at the School of Economics, University of Hyderabad for their support and fruitful discussion on research. My special thanks to Prof. S. Raja Sethu Durai, Dr, Motilal Bicchal, Dr. K. Ramachandra Rao, and Dr. Krishna Reddy Chittedi for their positive research culture, motivation, and interaction on various issues.

Research in Economics is something special. Every work should give some solutions for the problems in the society. In this regard, my special thanks to my co-authors, Dr. Sudharshan Reddy Paramati, Assistant Professor of Economics, University of Dundee, UK and Prof. Nicholas Apergis, Department of Banking and Financial Management, University of Piraeus, Greece, who found the research attitude in me.

I would like to thank my near and dear friends Kumarasamy Alle, Raju Mushika, Narasimha Rao, Asha and Rajesh who always stand behind me in each and every situation of my life. I am also greatly indebted to my seniors, Hanumanthu Naik, Dr. Seenaiah Kale, Dr. Mallaiah Jalle, Dr. Satyanarayanna Murthy, Vikram Didde, Dr. M. Ramesh, Dr. A. Sri Hari Nayudu, Kalpna Negi, Dr. Kirtti Ranjan Paltasingh, Dr. Asis Kumar Senapati, Dr. Babu Rao Gona, Dr. Priyabrata Sahoo, Dr. Priyadarshi Joshi, Dr. Ranjan Mohanty, Dr. Sarbesh Pradhan, Dr. Suresh Patra, Dr. Arif Billah Dar, Dr. Niyati Bhanja, Dr. Venkatappa Naik, Dr. Chapalati, and Dr. Balaji Belekere.

I have come across many good friends during the period of my research work. I am thankful to Chakradhar Jadhav, Dayakar Peddi, Sidheswar Panda, Balaji Vejju, Ramesh Kuruva, Sankar Upasarathi,, Dr. Anandarao Suvvari, Kaladhar Thopununi, Naveen, Bhaskar, Raju Guntukula, Jagannath Behera, Lingaraj Mallick, Susant Kumar Sethy, Dr. Dinabhandu Sethy, Bebina and Aurosmita Sahoo. I greatly value their friendship and deeply appreciate their support. I would also like to thank my lovely juniors, Kali Kumar Behera, Dilip Kumar Muduli, Bruhid Rabha, Jotirmayee Sahoo, Manamani Sahoo, Priyanka Sahoo, Laxmipriya Debata, Salman Haider and Ansari Ansari for their love, affection and support during this study period. Discussions on research with other department seniors always kept me with positive vibes on research. I am very grateful to Dr. Sandeep Kumar Marka, Dr. Ravi, G. Pundarikam, and Battini Nagaraju in this regard.

Finally, no words to express my feelings towards my beloved parents, Mr. Ummalla Ilaiah and Mrs. Ummalla Sammakka, who are my true inspirations. Despite financial conditions, they supported my entire career to achieve my academic goals. Thank you Bapu and Amma for keeping faith on me. My deepest thanks to my sister and brother-in-law, Mrs. Vasantha Kampe and Mr. Ravi Kampe, who believed in me and realised my passion on academics. Thanks to my two adorable nieces, Miss Sushma and Miss Soumya, who always remind my age and goals. Thank you All for your unconditional love, affection and support in my life.

Ummalla Mallesh

CONTENTS

LIST OF TABLES

List of Abbreviations

AIC	Aukaike Information Criteria
AMG	Augmented Mean Group
ARDL	Autoregressive distributed lag
BRIC	Brazil, Russia, India, China
BRICS	Brazil, Russia, India, China, South Africa
CAP	Capital
CD	Cross-sectional Dependence
CEC	Clean Energy Consumption
CIPS	Cross-sectional Augmented IPS
CO_2	Carbon dioxide
EIA	Energy Information Administration
EKC	Environmental Kuznets curve
FDI	Foreign Direct Investment
FMOLS	Fully Modified Ordinary Least Square
GDP	Gross Domestic Product
GF	Government Effectiveness
GHG	Greenhous Gas
HYD	Hydropower Energy Consumption
INDC	Intended Nationally Determined Contribution
IPS	Im-Pesaran-Shin
IQI	Institutional Quality Index
IRENA	International Renewable Energy Agency
LAB	Labour force
LLC	Levin-Lin-Chu
MITS	Mexico, Indonesia, South Korea, and Turkey
Mt	Million Tonnes
MTOE	Million Tonnes Oil Equivalent
NREC	Non-renewable Energy Consumption
ODA	Official Development Assistance
PCA	Principal Component Analysis
PI	GDP Per Capita

POP	Population
PQR	Panel Quantile Regression
PS	Political Stability and Absence of Violence/Terrorism
R&D	Research and Development
RD&D	Research, Development and Demonstration
REC	Renewable Energy Consumption
RL	Rule of Law
RQ	Regulatory Quality
SBC	Schwartz Information Criteria
VA	Voice and Accountability
WDI	World Development Indicators

Three Essays in Energy Economics: A Study on BRICS Countries

Abstract

This PhD thesis consists of three essays in the domain of empirical energy economics. Each essay has a unique research problem, data period, and econometric methodology. Based on the empirical results of each essay, some of the policy implications have been proposed for these selected emerging market economies.

The first essay (discussed in Chapter 2) has examined the impact of clean energy consumption on economic growth and CO_2 emissions within a framework of environmental Kuznets curve (EKC) hypothesis for the period 1992-2014. The results have indicated that clean energy consumption and energy consumption have a significant positive impact on economic growth, while CO_2 emissions have a negative impact on it. Results also have showed that energy consumption and economic growth increase CO_2 emissions while clean energy consumption significantly reduces it. Further, the study has found that the EKC hypothesis is valid in the BRICS countries. However, the study has not found a causal relationship between clean energy consumption and economic growth. In the second essay (discussed in Chapter 3), the study has attempted to explore the effects of hydropower energy consumption on economic growth and CO_2 emissions during the period 1990-2016. The results of panel autoregressive distributed lag have confirmed that hydropower energy consumption has a positive association with economic growth in the long-run and short-run, and a negative association with CO_2 emissions in the long-run. Further, the panel quantile regression results have showed that the effects of independent variables on economic growth and CO_2 emissions are heterogeneous across the quantiles. The third essay (discussed in Chapter-4) has demonstrated the impact of intuitional quality on renewable energy consumption and CO_2 emissions in a panel of BRICS countries, spanning the period 1996Q4-2016Q4. The AMG estimator results have revealed that institutional quality has a significant positive impact on renewable energy consumption. Non-renewable energy consumption has a positive association with CO_2 emissions, while institutional quality and renewable energy consumption significantly reduce CO_2 emissions. Finally, the study has found no causal nexus between the main variables. Overall, given these findings, this thesis offers substantial value to the empirical literature and also provides important policy implications.

Keywords: Clean energy consumption, hydropower energy, institutional quality, CO_2 emissions, environmental Kuznets curve, BRICS countries

JEL Classifications: C33, Q42, Q43, Q53, Q56

Chapter 1

Introduction

1.1. Introduction

Energy is an essential element for human need. It has also a determining role in the development of the economy. Due to rapid industrialization, urbanization, and high economic growth targets, demand for energy has been significantly increasing during the last few decades. The world energy system is dominated by fossil fuels (84%), of which oil accounts for 33%, followed by coal (28%) and natural gas (23%). These are responsible for 36%, 43%, and 20% of global carbon dioxide (CO_2) emissions, respectively. Further, according to the International Energy Outlook (2016), the average growth of the world's gross domestic product (GDP) will be maintained at 3.3% annually from 2012 to 2040, where developed and developing countries will account for 2.0% and 4.2 % per annum, respectively. Similarly, the global demand for energy will grow by 48% during 2012-2040. Energy use in developing countries was higher than the developed countries in 2010, and developing countries are projected to consume two-third of world total energy by 2040. For the same period, the global CO_2 emissions will grow from 35.6 to 43.2 billion metric tonnes, and the developing countries account for 51% higher energy-related CO_2 emissions than the 2012 level where developed countries will be 8%. This shows that the developing countries are anticipated to produce more CO_2 emissions than the developed economies.

Therefore, there is a growing international concern about the impact of conventional energy use on global warming and climate change which is primarily caused by carbon dioxide (CO_2) emissions. Thus, international organizations are compelling the nations to reduce their level of CO_2 emissions by consuming clean energy sources, which can build a path to zero-carbon economies in the future. The clean energy will increase as countries strive to achieve an affordable, secure, and sustainable energy system for the future generation. The 7th point of UN Agenda 2030 also clearly indicated that "*Affordable and Clean Energy ensure reliable, sustainable, modern, and affordable access to energy for all*".

The BRICS (Brazil, Russia, India, China and South Africa) countries have witnessed speedy economic growth during the last few decades, and there is a massive demand for energy. For example, both in China and India, energy consumption significantly increased over a period of time. In 1990, both countries accounted for about 10 percent of total world energy consumption, and it increased to 24% in 2010. According to the International Energy Outlook (2013), China and India combined energy consumption will grow at 34% of total world energy consumption in 2030. The BRICS countries have ample opportunities for efficiency improvements and more renewable deployment. Renewable energy help develop transition from fossil fuel energy sources to a future of reliable and affordable carbon-free energy system. In order to meet this energy demand and make sure of energy supply, BRICS countries' policymakers should formulate better policies to encourage the use of clean energy and create an appropriate platform for the investors to invest more in clean energy projects, which, in turn, will help in moving towards a low-carbon economy and sustainable economic growth. According to Bloomberg New Energy Finance (BNEF, 2015), China and India occupied the first and seventh-largest clean energy investors in the world, respectively. Further, few BRICS summits have come out with some energy negotiations. For example, Fourth BRICS summit 2012 farmed the new area of cooperation among the group countries. Since fossil fuel dominates the energy system, we should increase clean and renewable in total energy mix to combat climate change. Sixth BRICS summit established a public-private partnership mechanism to increase green investment. Seventh Summit identified that clean and renewable should be affordable to all, and enhance green financing for the low-carbon economy and sustainable development. The BRICS Energy Research Cooperation platform (ERCP) is established to promote sustainable energy development, strengthen the energy security of the BRICS countries, and BRICS should give a stronger voice on energy-related issues in the global scenario.

1.2. Overview of issues, motivation and research question

1.2.1. Research problem and gap for the first essay (Research question in chapter 2)

The issues of greenhouse gas emissions and climate change have become an emerging topic among policymakers, environmental scientists, and government officials. This tended to evoke the importance of clean energy consumption in the world. To ensure sustainable economic growth and minimize CO_2 emission, many countries are accelerating clean energy sources rather than heavily reliance on conventional energy sources to only reach the goal of maximizing optimal economic outcome. The BRICS countries have enormous clean energy sources. Since these emerging market economies have a place at top CO_2 emitters, and in order to achieve emerging market economies growth targets, a huge amount of clearer energy will be required. The use of clean resources has many advantages than non-renewable energy. Clean energy contributes to low CO_2 emission with less cost of production. However, the production of electricity based renewable energy techniques and non-energy techniques more expansive than clean energy sources like hydropower, nuclear, geothermal, and solar power and among others. To remove obstacles to clean energy infrastructure, the government should follow the right national policy framework with clear goals and incentives for clean energy investment. They are investing in promoting research, development, and deployment of clean energy technologies. Therefore, the main goals of the first essay are to empirically answer the following questions: First, does clean energy consumption has a positive impact on economic growth and a negative impact on CO_2 emissions? Second, does the EKC (Environmental Kuznets Curve) exist in BRICS countries?

Empirically, the significance of accelerating clean energy sector has attracted attention in the literature. A few studies, four research papers only till now as our knowledge and information, have investigated the nexus between clean energy consumption and economic growth. For example, Aslan and Cam (2013) in Isreal, Maji (2015) in Nigeria, Pao et al. (2014) in MITS countries (namely, Mexico, Indonesia, South Korea, and Turkey), and Hamit-Haggar (2016) in 11 sub-Saharan African countries. However, only one study has probed the nexus among clean energy use, economic growth, and CO_2 emissions in G7 countries (Cai et al., 2018). More specifically, as per our knowledge and information, no study has examined the nexus among clean energy consumption, economic growth, and CO_2 emissions in the BRICS countries. Hence, this study attempts to fulfil this research gap.

1.2.2. Research problem and gap for the second essay (Research question in chapter 3)

Many countries depend on hydropower energy to meet their energy demand and reduce environmental degradation. Hydropower energy plays a significant role in the world with more than 160 countries producing hydropower energy and contributing nearly 16.6% of the global total electricity supply (Bilgili et al., 2018). Hydropower energy is presently the largest single contributor to renewable energy with a global installed capacity of 1292 GW in 2018. The top ten global capacity of countries are China, Brazil, Canada, United States, Russian Federation, India, Norway, Turkey, Japan, and France, and these countries together accounted for more than two-thirds of global capacity at the end of 2018 (IHA, 2019). The increase in hydropower is just not because of increase in demand for energy but also for its own features, i.e., clean and reliable, and lowest-cost energy source based on maturity technology. It is considered as one of the best promising sources of environmentally friendly energy. Sternberg (2010) stated that "*hydropower turns into an instrument of reciprocal, complementary benefits, providing essential electricity, and supporting a host electro-mechanical industries"*. Most recently, Eddie Rich, CEO of the International Hydropower Association also said that "*hydropower is the major renewable energy source as well as driving more use of other renewable sources such as solar and wind. It will play a major role in the transition to renewable energy, as no country has successfully transitioned to renewable energy without a significant hydropower component*". In hydropower- rich countries, namely, China, India, Russia, and Brazil, hydropower power construction helps in the promotion of industrialization (Sternberg, 2010). The BRICS countries accounted for 37% of the world's total energy demand and accountable for 41.4% of global CO_2 emissions in 2015 (BRICS Energy Indicators, 2015). The share of hydropower energy consumption in total energy mix is approximately 29.5% in Brazil, 6.0% in Russia, 0.2% in South Africa, 8.3% in China, and 4.0% in India. In terms of global hydropower share, it is 9.24% from Brazil, 4.453% from Russia, 0.02% from South Africa, 28% from China, and 3.33% from India (BP Statistical Review of World Energy, 2019). In this context, the main aim of the present study in second essay is to answer the following questions: First, whether hydropower energy consumption positively affects economic growth?. Second, does hydropower energy use reduce CO_2 emissions?

Few studies have examined the nexus among hydropower energy use, economic growth, and CO_2 emissions in the previous research. For example, Bildirici (2014) in 15 countries, Lau et al. (2016) in Malaysia, Bildirici and Gokmenoglu (2017) in G7 countries, Solarin et al. (2017a) in India and China, and Ummalla and Samal (2018) in China. More specifically, this is the first study to explore the nexus among the hydropower energy use, economic growth, and CO_2 emissions in the case of BRICS countries. Given the scarce literature on the BRICS regarding this issue, the second essay aims to fill this research gap by employing more recent longer data set, a more robust model, and appropriate panel modelling techniques.

1.2.3. Research problem and gap for the third essay (Research question in chapter 4)

For the establishment of a zero-carbon economy with the development of clean and renewable energy, countries should have a good institutional quality which is more important in energy security and environmental protection as well as the sustainable development of economy. Recently, institutional quality has become an emerging issue for the debate among policy makers and environmental scientists, as it may a have positive or negative impact on environmental degradation. The weak quality of institutions may weaken environmental regulations by ineffective governance and regulation, biasedness, and corruption, while strong institutional quality can enhance the quality of environment by good governance and absence of corruption, etc. Further, the BRICS countries represent 24.2 % of renewable energy and 71.0% of fossil fuels in their total energy generation. Among the BRICS countries, Brazil accounts for 74%, followed by China (24.0%), Russia (16.0%), India (16.0%), and South Africa (2.0%). As suggested by international organizations, many countries framed renewable energy targets to reduce their level of greenhouse gas emissions. According to the Renewable Energy Policy Network for the 21 Century (REN21, 2016), 173 nations have adopted renewable energy targets and estimated that 146 countries had renewable energy support policies in place. This provides a considerable motivation to the present study to explore the impact of institutional quality on renewable energy use and CO_2 emissions. The present study in the third essay proceeds to argue that better institutions are necessary for the protection of environmental quality and sustainable use of energy sources. Therefore, this study can give answers to the following questions empirically, does institutional quality promote the use of renewable energy, and reduce CO_2 emissions?

Despite the significance of institutional quality, relatively less number of studies has examined the impact of institutional quality on renewable energy use in the empirical domain. Some examples include Bhattacharya et al. (2017) in 85 developed and developing countries, Wu and Broadstock (2015) in 22 emerging market economies, and Saidi et al. (2020) in MENA countries. However, few studies have explored the effect of institutional quality on CO_2 emissions. For instance, Lau et al. (2014) in Malaysia, Danish et al (2019a) in BRICS, and Hassan et al (2020) in Pakistan. Moreover, to our knowledge and information, no study has been conducted on the effects of institutional quality on renewable energy consumption and CO_2 emissions in BRICS. So, this third essay attempts to fill this gap.

1.3. Institutional background

In this section, we provide the some unique features of individual sample countries, particularly on a major source of energy in these economies, the level of CO_2 emissions, investments in clean and renewable energy sector and future targets for renewable energy, etc. These countries are highly investing on and deploying new technologies in renewable energy. Therefore, if we identify a pivotal source of finance in renewable energy in these sample countries, governments can frame appropriate policies for attracting domestic and foreign capital, and a reduction in CO_2 emissions.

1.3.1. Brazil

Brazil is rich in oil and natural gas reserves. However, hydropower is the main source of Brazil's electricity generation which accounts for about 70% of total generation in the country. However, Brazil is the 7th largest CO_2 emitter and 8th largest total energy consumer in the world. Therefore, to reduce the level of CO_2 emissions, it is shifting focus from the use of conventional energy sources to renewable energy. According to the National Energy Balance Report (BEN, 2012), 88.8% of electricity is supplied from renewable energy sources. Investment in renewable energy has significantly increased from $0.8 billion in 2004 to $6.2 billion in 2017. Brazil's target for renewable energy use is 45% by 2030.

1.3.2. Russia

Russia is rich in both fossil fuels and renewable, with hydropower and bio-energy as important sources of total energy mix. In 2010, hydropower and bio-energy accounted for 70% and 30% of total renewable energy where its renewable energy share was 3.6% in total energy consumption. The deployment of more renewable energy led in reduction of domestic consumption of oil and gas, which turn, led to potential exporter of these two energy sources. Their energy is mainly driven by energy exports only. Oil and natural gas accounted for 36% of total revenue in 2016. In 2016, Russia consumed 26.74 Btu of total energy. Out of it, natural gas, oil, and coal are accounted for 52%, 22%, and 13%, respectively. According to International Renewable Energy Agency (IRENA, 2017), Russia will increase renewable energy share from 4.9% to 11.3% of total energy consumption in 2030.

1.3.3. India

Coal is the main source of energy consumption, which accounts for 59% of total fossil-fuel primary energy consumption and 55% of total primary energy consumption. India's CO_2 emissions increased to 4.4% in 2013 and became the fourth largest CO_2 emitter in the world. Energy consumption will reach 19000 million tons of oil equivalent (Mtoe) by 2040. It has abundant renewable energy sources and among those, wind power is the largest source of renewable energy. The government has taken many renewable energy policies and regulations to attract investment in renewable energy projects. Therefore, investment in renewable energy has increased from $2.7 billion in 2004 to $13.5 billion in 2017. An estimated US$3.4 billion invested in wind power and US$3.0 billion in solar power in 2014. India's target for renewable energy is 40% by 2030.

1.3.4. China

Coal and natural gas are the main energy sources in China. China's 78.5% of greenhouse gas emission came from energy consumption in 2012. However, now China is the world's best developer of clean energy technologies and occupying larger positions in not only production of clean and renewable energy but also in innovation and deployment of new methods in energy sector. The Twelfth Five-Year Plan (FYP) (2011-2015) for renewable energy consumption stated that renewable generation is the major source of power. Renewable energy accounted for 22.4 % of the total energy generation in 2014. China is also rich with enormous renewable energy sources, such as hydro, solar and wind. Hydropower is the largest source of renewable energy in China, which accounts for 18% of total electricity. China invested $15.6 billion in hydropower in 2014. China was the one country occupied first place in energy consumption, CO_2 emissions, and investment in renewable energy in 2014 (Song et al., 2015). Investment in renewable energy has significantly increased from $3.0 billion in 2004 to $147.2 billion in 2017. China's target for renewable energy is 30% by 2030.

1.3.5. South Africa

South Africa is largely dependent on fossil fuel sources; among those, about 72% of the country's total primary energy consumption came from coal in 2013 (EIA, 2015). Due to the high coal consumption, South Africa is becoming one of the leading CO_2 emitters in African countries and the 13th largest emitter in the world. Recognizing the importance of renewable energy role in reducing greenhouse gas emissions and also in order to diversify and flexibility of energy supply, South Africa has targeted to have 42% of total electricity generation with renewable energy by 2030. In 2014, it invested $5.5 billion in renewable energy. Approximately 29% and 71% of the total investment went on wind and solar energy, respectively.

1.4. Objectives of the study

In the light of the importance of renewable and clean energy use, and institutional quality, the present thesis effectively empirically evaluates those issues of the BRICS countries. Given the above-mentioned gaps in the literature also help us to frame appropriate objectives. The specific objectives of the present study are:

1. to examine the impact of clean energy consumption on economic growth and CO_2 emissions in BRICS countries in the context of the environmental Kuznets curve,
2. to examine the nexus among the hydropower energy consumption, economic growth, and CO_2 emissions in BRICS countries, and
3. to evaluate whether the institutional quality matters on renewable energy consumption and CO_2 emissions.

1.5. Data and methodology

1.5.1. Data and sources

This thesis has used different data periods and estimation techniques for each main chapter based on the availability of data and its properties[1]. The balanced panel data set of five emerging market economies has been used in this study. All the data sets for each empirical chapter are obtained from the different data sources like World Development Indicators, BP Statistical Review of World Energy, US Energy Information Administration (EIA), and Worldwide Governance Indicators.

1.5.2. Methodology

In the literature, previous studies have used different methodologies in the energy economics. This study has used different panel econometric models to examine study objectives. It is briefly explained here.

Chapter 2 aims to examine the impact of clean energy consumption on economic growth and CO_2 emissions, and also to verify the validation of the EKC hypothesis. To achieve the objectives of the first empirical study (Chapter 2), two-panel unit roots tests, LLC and IPS, are used on the selected variables to check the stationary properties. To examine the long-run equilibrium association among the variables, the study has employed the Johanson Fisher

[1]Justification for selecting the sample period and econometric techniques are well explained in each empirical chapter.

panel cointegration test. Further, panel FMOLS estimates have been applied to examine the long-run elasticities of clean energy consumption and CO_2 emissions, and also the existence of the EKC hypothesis. Finally, Dumistrescu-Hurlin (2012) panel causality test is used to examine the short-run causal relationship among the study variables.

Chapter 3 aims to investigate the effects of hydropower energy consumption on economic growth and CO_2 emissions in BRICS countries. This study has applied several panel econometric techniques to achieve this study objective. Since data on panel series may have a problem of cross-sectional dependence in the series. Therefore, first this study has employed Pesaran's (2004) cross-sectional dependence (CD) to verify the given series is a cross-sectional dependant or not. After finding of cross-sectional dependency in data series, it has employed Pesaran's (2007) two-panel unit root test, CADF and CIPS, to examine the order of integration of the variables in the presence of cross-sectional dependency and heterogeneity. Based on the order of integration, panel ARDL model is applied, which is propounded by Pesaran et al. (1999), to know the short-run and long-run nexus among hydropower energy use, economic growth and CO_2 emissions,. Finally, panel quantile regression has been applied to know the effect of independent variables on economic growth and CO_2 emissions.

The final empirical study (Chapter 4) aims to examine the impact of institutional quality on renewable energy use and CO_2 emissions. To achieve this objective of thesis, this study has used Pesaran's (2004, 2007) CD test for cross-sectional dependency and CIPS panel unit test for stationary properties, respectively. To explore the long-run equilibrium relationship among the variables, Westerlund (2007) panel cointegration test has been applied. This study also has investigated the long-run impact of independent variables on renewable energy consumption and CO_2 emissions by utilizing the Augmented Mean Group (AMG) estimator (Eberhardt and Bond, 2009; Eberhardt and Teal, 2010). Finally, a bivariate heterogeneous panel non-causality test based on the approach developed by Dumitrescu and Hurlin (2012) has been applied to examine the short-run causality between the variables.

1.6. Organization of the thesis

The present thesis has been organized into five chapters. Chapter 2 to 4 constitute the core of the thesis where main study objectives have been examined.

The Chapter 1 provides an introduction, overview of issues, motivation and research question, institutional background, objectives of the thesis, data and methodology, and organization of the thesis.

Chapter 2 provides the first empirical study, i.e., the impact of clean energy consumption on economic growth and CO_2 emissions. More precisely, it deals with the effects of clean energy use on economic growth and CO_2 emissions and it has verified the existence of the EKC hypothesis. This chapter has explained the issue and theoretical hypothesis in the introduction, relevant review of literature, data and estimation techniques, empirical findings and discussion, and finally, conclusion and policy implications. The empirical findings of this chapter help us to understand to what extent clean energy use has a positive impact on economic growth and a negative effect on CO_2 emissions, and validation of the EKC hypothesis.

Chapter 3 provides the second empirical study, on the nexus among hydropower energy consumption, economic growth, and CO_2 emissions. More specifically, it has examined the impact of hydropower energy consumption on economic growth and CO_2 emissions in the BRICS countries. This chapter has given a brief introduction and reason for framing this objective, review of literature, data and methodology, empirical results and analysis, and finally, conclusion and policy implication. The findings of this chapter will be more useful for policy makers and government officials to know the significant impact of hydropower energy consumption in promoting economic growth and mitigation CO_2 emissions.

Chapter 4 has discussed the third and final empirical study, on the question of whether the institutional quality matters for renewable energy consumption and CO_2 emissions in BRICS countries. It has given a review of literature, data and methodology, empirical findings and discussion, and finally conclusion and policy implications. This chapter helps us to understand to what extent institutional quality promotes renewable energy use and reduces CO_2 emissions.

Finally, Chapter 5 provides an overall summary of the entire thesis with major findings, policy implications, and limitations of the study. Few directions for the future research are also provided.

Chapter 2

Clean Energy Consumption, Economic Growth, and CO_2 Emissions

2.1. Introduction[1]

Energy consumption is a towering functioning factor of economic growth along with capital and labor for any nation as they are inputs in the production of goods and services. Each stage of economic activities, from production to consumption, the county largely relies on energy. Therefore, energy is the main driving force of economic growth and industrialization. However, high energy consumption increases higher CO_2 emissions. According to the World Bank (2019), the world gross domestic product (GDP) has increased significantly, approximately two times, from $39,170.1 billion (constant 2010 US$) in 1992 to $73,690.3 billion in 2014, with an average annual growth rate of 2.9%. At the same time, global energy consumption has increased from 8,223.6 million tonnes oil equivalent (Mtoe) in 1992 to 12,939.7 Mtoe in 2014, with an average yearly growth rate of 2.0%. The massive combustion for energy, especially conventional energy sources, led to environmental issues. Therefore, global CO_2 emission has increased from 21,354.0 million tons (Mt) in 1992 to 32,844.8 Mt in 2014 (BP Statistical Review of World Energy, 2018). In search of alternatives to carbon-intensive fossil fuel, clean energy use has the considerable most effective source of energy in the world.

Therefore, international organizations, economists, environmental scientists, and policymakers are alarming the developed and developing countries to shift their energy consumption patterns from non-clean to clean energy sources. In order to reduce CO_2 emissions and control global warming, the demand for clean energy has been increasing in the world. The clean energy consumption has many benefits over non-clean energy sources. First, it is non-carbohydrate energy that does not emit CO_2 emissions when generated. Second, clean energy can be widely used in both domestic (solar energy) and industrial sector. Third, development of clean energy projects in rural areas also fills the gap between rural-urban energy in terms of accessible, reliable, and affordable. Fourth, generation of clean energy will reduce the dependence of imported non-clean energies, i.e., oil, gas, and coal, etc.

[1]Main content of this chapter has been published by the scholar as Mallesh Ummalla and Phanindra Goyari (2020): "The impact of clean energy consumption on economic growth and CO_2 emissions in BRICS countries: Does the environmental Kuznets curve exist? In: *Journal of Public Affairs*, ISSN: 1479-1854, 2020:e2126, pp. 1-12, First online published on 25 March 2020 (Available at https://onlinelibrary.wiley.com/doi/full/10.1002/pa.2126).

It will stabilize the macroeconomic performance of the economy. Finally, installation of clean energy projects will create job opportunities directly or directly in the economy.

The BRICS countries have accounted for 20.3% of the world GDP, 36.7% of global energy consumption, and contributed 41.9% of global CO_2 emissions in 2014. The fact is that the significant development of clean energy needed; otherwise, these countries will be struck into the insecure, inefficient, and carbon-intensive energy system. To overcome this, the BRICS countries have been heavily investing in clean energy projects. Pao et al. (2014) also suggested the development of clean energy is a feasible solution for addressing energy security and climate change issues. In 2014, Brazil's clean energy consumption accounted for 10.8% of total energy use, Russia's was 8.1%, India's was 2.6%, China's was 5.1%, and South Africa's was 2.6% (World Bank, 2019). Further, in the 2015 Paris Climate Change Conference, these five emerging market economies have signed on Intended Nationally Determined Contribution (INDC) to reduce greenhouse gas (GHG) emissions by 2030[2].

The significance of accelerating the clean energy sector has attracted attention in the literature. Our study may suggest that four types of hypotheses in clean energy consumption and economic growth nexus. They are: first, *the growth hypothesis* asserts that there is a unidirectional causality running from clean energy consumption to economic growth. Under the growth hypothesis, energy plays a significant positive or negative role in the economic growth process. In this case, expansionary energy policies will have a positive impact on economic growth, while any energy conservation policies will have a negative influence on economic growth. Second, *the conservation hypothesis* suggests that unidirectional causality running from economic growth to clean energy consumption. In this situation, any reduction in clean energy consumption will not have a negative impact on economic growth. Third, *the feedback hypothesis* shows that bidirectional causality between clean energy consumption and economic growth. This relationship postulates that a reduction in clean energy consumption retards economic growth and vice versa. Under this hypothesis, we can observe that the interdependent and complementary nexus between clean energy consumption and economic growth. Lastly, *the neutrality hypothesis* documents that no causal nexus between clean energy consumption and economic growth, therefore reduction in one variable will not influence on another one.

[2]Brazil's was 37% in 2025 and 43% in 2030 below 2005 levels, Russia's was 25%-30% from 1990 levels, India's was 33%-35% from 2005 levels, China's was 60%-65% from 2005 levels, South Africa's was 398-614 metric tons of carbon dioxide equivalent during 2025-2030 (Carbon Brief, 2015).

The increase in clean energy consumption can mitigate CO_2 emissions. This may help to establish the EKC (environmental Kuznets curve) hypothesis between CO_2 emissions and economic growth in the BRICS economies. The EKC hypothesis postulates that economic growth stimulates CO_2 emissions initially and then decreases after economic growth reaches a certain level where a negative relationship exists between these two variables. More specifically, any country's economy starts the development of industrialization to achieve higher economic growth goals. This industrialization needs massive natural resources, especially energy, and the enormous combustion of energy sources leads to higher CO_2 emissions. As the country's economic growth continues, in the experience of post-industrialization, governments, policymakers, and people start to increase the awareness of environmental quality, energy efficiency, and uses of clean energy sources, resulting in a reduction of CO_2 emissions. Therefore, inverted-U shaped relationship can be established between CO_2 emissions and economic growth. Hence, the main objectives of present study are to answer the following questions: First, does clean energy consumption has a positive impact on economic growth and a negative impact on CO_2 emissions? Second, does the EKC exist in BRICS countries?

The significance of accelerating clean energy sector has attracted attention in the literature. A few studies, four research papers only, have explored the nexus between clean energy consumption and economic growth. For example, Aslan and Cam (2013) in Isreal, Maji (2015) in Nigeria, Pao et al. (2014) in MITS countries (namely, Mexico, Indonesia, South Korea, and Turkey), and Hamit-Haggar (2016) in 11 sub-Saharan African countries. However, only one study has probed the nexus among clean energy consumption, economic growth, and CO_2 emissions in G7 countries (Cai et al., 2018). More specifically, no study was examined the nexus among clean energy consumption, economic growth, and CO_2 emissions in the BRICS countries. Hence, the novelty of this study is to fulfil this research gap.

The study in this chapter contributes significant lines to the existing literature. First, to the best of our knowledge, no previous study has empirically examined the impact of clean energy consumption on economic growth and CO_2 emissions in the BRICS countries. Only a single study has disentangled the nexus among clean energy consumption, economic growth, and CO_2 emissions in G7 countries (Cai et al., 2018). Second, Cai et al. (2018) have conducted on time series data set for their analysis. Nevertheless, we utilize panel data to get a more accurate estimation of model parameters and more temporal and dynamics of the relationship, which cannot be addressed by a single time series data (Hsiao, 2007). Third, they fail to explore the nexus between CO_2 emissions and economic growth. Therefore, we address the EKC hypothesis in our analysis. Fourth, it applies several panel econometric techniques to answer the research questions empirically.

The main outcomes of present study indicate that clean energy consumption, energy consumption, and capital increase economic growth, while CO_2 emissions reduces it. The findings also show that economic growth and energy consumption have a positive impact on CO_2 emissions, but clean energy consumption significantly reduces CO_2 emissions. Further, our results established an inverted U-shaped nexus between CO_2 emissions and economic growth. In other words, the EKC hypothesis is valid. Finally, we could not develop a causal nexus between clean energy consumption and economic growth in a panel of BRICS countries.

We proceed with the rest of chapter as follows. Section 2.2 is devoted to the literature review. Section 2.3 describes the data and estimation techniques used for this analysis. Section 2.4 delivers empirical findings and discussion. Finally, Section 2.5 concludes the study with policy implications.

2. 2. Literature Review

2.2.1. Renewable energy consumption, economic growth and CO_2 emissions nexus

Numerous studies have examined the relationship among renewable energy consumption, economic growth, and CO_2 emissions across the globe. For example, Saidi and Mbarek (2016) investigated the nexus among renewable energy consumption, economic growth, and CO_2 emissions in nine developed countries during 1990-2013. They found that renewable energy consumption increases economic growth and decreases CO_2 emissions. Their Granger causality results showed that unidirectional between renewable energy consumption and economic growth in the short-run, and bidirectional causality between renewable energy consumption and economic growth and unidirectional causality from economic growth to CO_2 emissions in the long-run. Bhattacharya et al. (2017) examine the impact of renewable energy consumption on economic growth and CO_2 emissions in 85 developed and developing countries, spanning the period 1991-2012. They found that renewable energy consumption has a positive impact on economic growth and a negative impact on CO_2 emissions. Paramati et al. (2017b) found that renewable energy consumption has a positive impact on economic growth and a negative influence on CO_2 emissions in full panel of G20 countries as well as developed and developing nations of its member countries during 1991-2010. Similar results were documented by Paramati et al. (2017c) in a panel of Next-11 countries. Sharif et al. (2019) also revealed that renewable energy consumption has significantly reduced CO_2 emissions while non-renewable energy consumption (NREC) has increased it in a panel of 74 countries, spanning the period 1990-2015. Further, the nexus among these three variables have been widely scrutinized in the empirical domain in the context of BRICS countries also. For example, Salim and Rafiq (2012) examined the determinants of renewable energy consumption in six emerging market economies, including Brazil, China, and India. They reported that renewable energy consumption is mainly determined by economic growth and CO_2 emissions as a panel and in Brazil, China, India, and Indonesia, while mostly by economic growth in the Philippines and Turkey. Their causality test results showed that bidirectional causality between renewable energy consumption and economic growth, renewable energy consumption and CO_2 emissions, and unidirectional causality from economic growth to CO_2 emissions in both Brazil and China. In the case of India, one-way causality is from economic growth and CO_2 emissions to renewable energy consumption, and bidirectional causality between CO_2 emissions and renewable energy consumption. Rafiq et al. (2014) probed the dynamic relationship among renewable energy consumption, economic growth, and CO_2 emissions in China and India during 1972-2011. They found that unidirectional causality from renewable energy consumption to economic growth, and CO_2 emissions to economic growth and renewable energy consumption in the short-run, while feedback causality among renewable energy consumption, economic growth, and CO_2 emissions in the long-run in India. In China, they found that unidirectional causality from economic growth to renewable energy consumption, and CO_2 emissions to renewable energy consumption in the short-run, while economic growth causes renewable energy consumption, and feedback causality between CO_2 emissions and renewable energy consumption in the long-run. Dong et al. (2018) assessed the relationship among the renewable energy consumption, natural gas consumption, CO_2 emissions, and economic growth in China during 1993-2016. They found that renewable energy consumption and natural gas consumption mitigate CO_2 emissions. Further, one-way causality from renewable energy consumption to CO_2 emissions in the short-run, and feedback causality among renewable energy consumption, natural gas consumption, and CO_2 emissions in the long-run. But, there was no causal connection between renewable energy consumption and economic growth. Recently, Kutan et al. (2018) found that renewable energy consumption and non-renewable energy consumption have a positive impact on economic growth, and renewable energy consumption reduced CO_2 emissions while non-renewable energy consumption increased it in four emerging market economies during 1990-2012. Finally, they reported that one-way causal association from non-renewable energy consumption to CO_2 emissions. Most recently, Ummalla and Samal (2019) investigated the impact of natural gas consumption and renewable energy consumption on CO_2 emissions and economic growth in China and India from 1965 to 2016. They found that one-way causality from renewable energy consumption to economic growth in India and no causality established between the above-mentioned variables in China in the short-run. Finally, in the long-run, they found that two-way causation among the variables in both countries. Danish et al. (2019b) analyzed the impact of natural resources, renewable energy consumption, and economic growth on CO_2 emissions in BRICS nations over the period from 1990 to 2015. They established that natural resources and renewable energy consumption reduced CO_2 emissions in Russia and South Africa, and Brazil, China, India, and Russia, respectively. However, economic growth has significantly increased CO_2 emissions in all BRICS countries. Further, as a panel, renewable energy consumption and natural resources did not have any impact on CO_2 emissions, but economic growth has increased CO_2 emissions. Finally, they reported that bidirectional causal connection between natural resources and economic growth, renewable energy consumption and CO_2 emissions, and unidirectional causal association from CO_2 emissions to economic growth in these emerging market economies.

2.2.2. Clean energy consumption, economic growth and CO_2 emissions nexus

There is a growing international consensus that clean energy will play a substantial part in the world's energy transformation to reduce CO_2emissions and meet the demand for energy. Therefore, some studies have empirically probed nexus among these variables in the literature. Aslan and Cam (2013) inspected the relationship between clean energy consumption and economic growth in Isreal, spanning the period 1985-2009. They found that one-way causality running from clean energy consumption to economic growth. Maji (2015) investigated the impact of clean energy consumption on economic growth in Nigeria during 1971-2011. The author found that clean energy consumption has a negative impact on economic growth. Pao et al. (2014) examined nexus among clean energy consumption, non-clean energy consumption and economic growth in the MITS countries. They found that growth hypothesis in the long-run and feedback hypothesis between clean energy consumption and economic growth in the short-run. Hamit-Haggar (2016) found that one-way causality running from clean energy consumption to economic growth in 11 sub-Saharan African countries, spanning the period 1971-2007.

Recently, a few studies have examined the relationship among clean energy consumption, economic growth, and CO_2emissions in the world. Paramati et al. (2016) demonstrated that clean energy consumption has a significant positive influence on economic growth and negative on CO_2emissions in 20 emerging market economies during 1991-2012. However, they did not prove causal nexus between clean energy consumption and economic growth, but CO_2emissions causes clean energy consumption. Paramati et al. (2017a) documented that clean energy consumption brings about a positive influence on economic growth and negative impact on CO_2emissions across the panels of EU, G20 and OECD economies, spanning the period 1993-2012. Further, they found that clean energy consumption causes economic growth in OECD countries, economic growth causes clean energy consumption in EU countries, and two-way causality between clean energy consumption and economic growth in G20 countries. Most recently, Cai et al. (2018) probed the nexus among clean energy consumption, economic growth, and CO_2 emissions in G7 countries. They found that unidirectional causality is running, from clean energy consumption to economic growth in Canada, Germany and, the US, from clean energy consumption to CO_2emissions in the US, and bidirectional causality between clean energy consumption and CO_2 emissions in Germany.

2.2.3. EKC analyses for the BRICS nations

Last few decades, ample studies have verified the validity of the EKC in developed and developing countries. For example, Apergis et al. (2018) examine the validation of the EKC hypothesis in 19 developed countries during 1962-2010 by incorporating the export concertation index. Their empirical results found that the existence of the EKC hypothesis. Fang at al. (2019) also verify the EKC hypothesis in 82 developing countries by incorporating energy consumption, natural resources consumption, and trade openness. Their results supported the EKC hypothesis. However, few studies have tested on the BRICS nations as a panel and country-specific wise. For instance, Pao and Tsai (2011a) studied the nexus between CO_2 emissions, economic growth, and energy consumption in Brazil during 1980-2007. They found that an inverted U-shaped relationship between economic growth and CO_2 emissions, i.e., validation of the EKC hypothesis. Pao et al. (2011) also investigated nexus among CO_2 emissions, economic growth, and energy consumption in Russia, spanning the period 1990-2007. They unveiled that there is no evidence of the EKC hypothesis in their analysis. Jayanthakumaran et al. (2012) investigated nexus among CO_2 emissions, economic growth, and energy consumption in China and India during 1971-2007. Their empirical results supported the existence of the EKC hypothesis in both countries. Tiwari et al. (2013) examined economic growth and CO_2emissions nexus in India during 1966-2011 by including coal consumption and trade openness. They found that the EKC hypothesis is valid for India in the short-run and long-run. Further, they reported that bidirectional causality between economic growth and CO_2 emissions, and coal consumption and CO_2 emissions. Kohler (2013) also found the same results in South Africa, spanning the period 1960-2009. Govindaraju and Tang (2013) explored the nexus among the CO_2 emissions, economic growth, and coal consumption in China and India during 1965-2009. The results did not support the existence of the EKC hypothesis in both countries. Further, they found that unidirectional causality from economic growth to CO_2emissions in China in the short-run and long-run, while only short-run causality detected in the case of India. Boutabba (2014) investigated the EKC hypothesis in the case of India during 1971-2008 by incorporating the role of energy consumption, financial development (FD), and trade openness. The author found that evidence of the EKC hypothesis. Solarin et al. (2017a) tested the validity of the EKC hypothesis and its nexus with hydropower energy consumption and urbanization in China and India during 1965-2013. Their results supported that the EKC hypothesis in both countries. Further, they revealed that economic growth and urbanization significantly increase CO_2 emissions, while hydropower energy consumption reduces CO_2emissions in both countries. Gozgor and Can (2017) also tested the EKC hypothesis in China by incorporating trade and export quality index. Their results supported the EKC hypothesis. Ummalla and Samal (2018) probed the nexus among the CO_2 emissions, hydropower energy consumption, and economic growth in China covering the period 1965-2016. They did not find the EKC hypothesis for China. Finally, they reported that bidirectional causality among the variables. However, Dong et al. (2018) supported the EKC hypothesis in China. Usman et al. (2019) analyzed the EKC hypothesis in India during 1971-2014 by including energy consumption and democracy as well. Their empirical results confirmed the existence of the

EKC hypothesis in India. Further, they documented that energy consumption significantly increases CO_2 emissions, whereas democracy reduces it.

Tamazian et al. (2009) explored the impact of economic growth, financial development, and energy consumption on CO_2emissions in BRIC nations, namely Brazil, Russia, India, and China, during 1992-2004. The empirical results supported the EKC hypothesis, and the high stages of economic growth and financial development reduce CO_2emissions. Pao and Tsai (2010) examined the relationship among CO_2 emissions, economic growth, and coal consumption in BRIC countries. Their panel estimation result supported the EKC hypotheses in BRIC countries. However, in their country-wise analysis, the EKC hypothesis was found in India and China only. Another study by Pao and Tsai (2011b) analyzed the impact of economic growth, financial development, energy consumption on CO_2emissions in BRIC countries. Their empirical results supported the EKC hypothesis, and EC and FD have a positive impact on CO_2 emissions. Chang et al. (2015) tested the scope for low carbon emission in G7 and BRICS countries during 2000-2010. The author tested the EKC hypothesis by incorporating energy intensity, carbon intensity, and carbonization value in their estimations. They found that U-shaped EKC rather than an inverted U-shaped EKC in their study period. However, Chakravarty and Mandal (2016) supported the EKC hypothesis in BRICS countries, spanning the period 1997-2011. Dong et al. (2017) investigated the nexus among CO_2 emissions, economic growth, natural gas consumption, and renewable energy consumption in BRICS countries during 1985-2016. They found that panel and country-specific results were supported the EKC hypothesis. Abdouli et al. (2018) analyzed the EKC hypothesis in BRICS countries, including Turkey, which was the part of the study during 1990-2014. They found that the existence of the EKC hypothesis in a panel and country-specific (except Russia). Further, they reported that energy consumption increases CO_2 emissions, and financial development increases CO_2emissions in a panel, China and Russia while it reduces CO_2emissions in Turkey. Danish et al. (2019b) analyzed the impact of natural resources, renewable energy consumption, and economic growth on CO_2emissions in BRICS countries between the years from 1990 to 2015. Their empirical results supported the EKC hypotheses in a panel and country-specific (except India). They suggested that natural resources combat CO_2emissions in Russia, while it increases CO_2emissions in South Africa. Finally, they found that bidirectional causality link between natural resources and CO_2 emissions.

To sum up, the above review of literature clearly shows that the bulk of studies has discussed the link among renewable energy consumption, economic growth, and CO_2 emissions. However, there was little research has done on the nexus among clean energy consumption, economic growth, and CO_2 emissions. Most importantly, clean energy use has neglected in the EKC hypothesis framework. Therefore, to the best of our knowledge, this is the first study that examines the relationship among the clean energy consumption, economic growth, and CO_2 emissions within the EKC hypothesis framework in a panel of BRICS countries during 1992-2014.

2.3. Data and Estimation Techniques

2. 3.1. Data

The current study is selected balanced panel of BRICS countries, namely Brazil, Russia, India, China, and South Africa, spanning the period from 1992 to 2014. The study has collected data on clean energy consumption (CEC) as a % of total energy use, energy consumption (EC) in million tonnes oil equivalent (Mtoe), CO_2emissions (CO_2) in millions metric tons, GDP in constant 2010 US$, gross fixed capital formation (constant 2010 US$) is proxy for capital (CAP), total labor force (LAB) in million, and finally, total population (POP) is measured in million. The CEC, EC, $CO_{2,}$ and GDP are in per capita terms. The data on CEC, GDP, CAP, LAB and POP are drawn from the Word Development Indicators, 2018. Similarly, data on EC and CO_2 are collected from the BP Statistical Review of World Energy, 2018. All variables are converted into natural logarithm form.

2. 3.2. Estimation Techniques

The main aim of study is to probe the effect of clean energy consumption on economic growth and CO_2 emissions and also verity the EKC in these emerging market economies. So, we frame the following equations for the empirical investigation:

$$lnGDP_{it} = \alpha_1 + \beta_1 lnCAP_{it} + \beta_2 lnLAB_{it} + \beta_3 lnCO_{2it} + \beta_4 lnCEC_{it} + \beta_5 lnEC_{it} + e_{1it}$$

(2.1)

$$lnCO_{2it} = \alpha_2 + \beta_6 lnGDP_{it} + \beta_7 lnGDP_{it}^2 + \beta_8 lnCEC_{it} + \beta_9 lnEC_{it} + \beta_{10} lnPOP_{it} + \mu_{2it}$$

(2.2)

Where $GDP_{it}, CAP_{it}, LAB_{it}, CO_{2it}, CEC_{it}, EC_{it}, GDP_{it}^2, POP_{it}$ denote per capita GDP, capital, labor, per capita CO_2 emissions, per capita clean energy consumption, per capita energy consumption, square term per capita GDP and population, respectively. The α_1 andα_2 are the intercepts, βs are the slope coefficients, i refers to county, and t is the time. Finally, e_{1it} and μ_{2it} are error terms. To verify the EKC hypothesis, we expect per capita GDP is positively link with per capita CO_2 emissions, i.e., $\beta_6 > 0$ while square term per capita GDP is negatively link with per capita CO_2 emissions, i.e., $\beta_7 < 0$.

2.3.2.1. Unit root tests

The first step of any econometric exercise is to explore whether a given series is stationary or not. For this purpose, our study applies two-panel unit root techniques developed by Levin et al. (2002, hereafter LLC) and Im et al. (2003, hereafter IPS).

For the LLC panel unit root test, consider the following panel ADF process:

$$\Delta y_{i,t} = \rho_i y_{i,t-1} + \sum_{j=1}^{\rho_i} \rho_{i,j}\, \Delta y_{i,t-j} + \varepsilon_{i,t} \tag{2.3}$$

The LLC (2002) assumes that the persistence parameters $\rho_i$are common across cross-sections, i.e., $\rho_i = \rho$ for all i. Δ shows the first differences, Δy and $\Delta y_{i,t-j}$ have the individual regressions with $\Delta y_{i,t-j}$ and residuals. $j$stands for an optimal lag chosen by AIC and SIC. The null hypothesis of a unit root tested over the alternative hypothesis of no unit root, i.e., $H_0: \rho_i = 0$ for all i and $H_1: \rho_i < 0$ for all i.

The IPS (2003) test is also similar to Equation (2.3), nevertheless, unlike LLC test, it assumes ρ_i to be heterogeneous across cross-sections. The null and alternative hypothesis are $H_0: \rho_i = 0$ for all i and $H_1: \rho_i < 0$ at least one or some of the i, respectively. If the considerable variables are stationary at the first order of integration, i.e. I (1), then it suggest that all the selected variables are non-stationary at their levels and become stationary at the first order difference.

2.3.2.2. Panel cointegration test

In the next step, we explore the long-run equilibrium relationship among the selected variables. For this purpose, we employ the Fisher-Johanson panel cointegration test proposed by Maddala and Wu (1999). Johanson (1988) proposed two different approaches, namely, trace statistics and maximum eigen value statistics. These two statistics help to determine the existence of cointegrating vectors on the non-stationary data series. The trace statistics and maximum eigen value statistics are as follows:

$$\lambda_{trace}(r) = -T \sum_{i=r+1}^{n} \ln(1 - \hat{\lambda}_i)$$

$$\lambda_{max}(r, r+1) = -T \ln (1 - \hat{\lambda}_i)$$

Where$\hat{\lambda}_i$, T and r indicate the estimated eigenvalue, number of observations, and number of cointegrating vectors, respectively. The trace statistics test the null hypothesis of at most $r$cointegrating vector against the alternative hypotheses of full rank $r = n$ cointegrating vector. The null and alternative hypothesis of maximum eigen value statistics check r cointegrating vector against the alternative hypotheses of $r + 1$ of cointegrating vectors. Fisher-Johanson panel cointegration test is a panel version of the individual Johanson cointegration test. This method is based on the aggregates of p-values of individual Johanson maximum eigen values and trace statistics (Maddala and Wu, 1999). If p_i is the p-value from an individual cointegration test for cross-section i, under the null hypothesis of the test statistic for a panel is as follows:

$$-2\sum_{i=1}^{n} \log \quad (p_i) \sim \chi^2_{2n} \tag{2.4}$$

In other words, the null hypothesis (H_0) of no cointegration relationship for cross-section i is tested against the alternative hypothesis(H_1) of cointegration for cross-section i.

2.3.2.3. Panel long-run estimates

After confirming the cointegration relationship among the variables, fully modified ordinary least squares (FMOLS) is applied to estimate the long-run coefficients. The FMOLS approach has proposed by Pedroni (2001a, 2000b, and 2004). The main advantages of the

FMOLS are that it accounts for both endogeneity and serial correlation problem. He proposed the following equation:

$$W_{i,t} = \alpha_i + \beta_i X_{i,t} + \varepsilon_{i,t} \tag{2.5}$$

Where $W_{i,t}$ and $X_{i,t}$ are cointegrated with slopeβ_i, it may or may not be homogenous across i. In the other way, he developed Equation (2.5) as follows:

$$W_{i,t} = \alpha_i + \beta_i X_{i,t} + \sum_{k=-k_i}^{k_i} \gamma_{i,k}\, \Delta X_{i,t-k} + \varepsilon_{i,t} \tag{2.6}$$

Further, he also considered: $\xi_{i,t} = (\hat{\varepsilon}_{i,t}, \Delta X_{i,t})$ and

$\Omega_{i,t} = \lim T \rightarrow \infty E[\left(\frac{1}{T}\right)\left(\sum_{t=1}^{T} \xi_{i,t}\right)\left(\sum_{t=1}^{T} \xi_{i,t}\right)']$ is the long-run covariance for this vector process which can be decomposed into $\Omega_i = \Omega_i^0 + \Gamma_i + \Gamma_i'$ where Ω_i^0 is the contemporaneous covariance and Γ_i is a weighted sum of covariance.

Thus, the FMOLS model can be written as follows:

$$\hat{\beta}^{*}_{FMOLS} = \frac{1}{N}\sum_{i=1}^{N}\left[\left(\sum_{t=1}^{T}(X_{i,t} - \overline{X}_i)^2\right)^{-1}\left(\sum_{t=1}^{T}(X_{i,t} - \overline{X}_i)W_{i,t}^{*} - T\hat{\gamma}_i\right)\right] \tag{2.7}$$

Where $W_{i,t}^{*} = W_{i,t} - \overline{W}_i - (\hat{\Omega}_{2,1,i}/\hat{\Omega}_{2,2,i})\Delta X_{i,t}$ and

$\hat{\gamma}_i = \hat{\Gamma}_{2,1,i} + \hat{\Omega}_{2,1,i}^0 - (\hat{\Omega}_{2,1,i}/\hat{\Omega}_{2,2,i})(\hat{\Gamma}_{2,2,i} + \hat{\Omega}_{2,2,i}^0)$

2.3.2.4. Panel Granger causality test

Finally, this study explores the short-run bivariate Granger causality among these variables by employing a panel Granger causality test. For this purpose, we use the methodology suggested by Dumistrescu-Hurlin (2012). To apply this test, we require stationary data; hence, we conducted it on the first difference data series of the selected variables. The unique nature of this test is that it takes into account heterogeneity across the nations. This test is based on the average standard of Wald statistics of Granger-non causality tests for individual time series. The causal relationship between Y and X follows the linear model:

$$\Delta y_{i,t} = \alpha_i + \sum_{j=1}^{j} \lambda_i^j \Delta y_{i,t-j} + \sum_{j=1}^{j} \beta_i^j \Delta x_{i,t-j} + \varepsilon_{i,t} \tag{2.8}$$

$$\Delta x_{i,t} = \alpha_i + \sum_{j=1}^{j} \lambda_i^j \Delta x_{i,t-j} + \sum_{j=1}^{j} \beta_i^j \Delta y_{i,t-j} + \varepsilon_{i,t} \tag{2.9}$$

Where Δ, α_1, λ^j and β_i^j indicate first difference, constant term, lag parameter, coefficient, respectively. Dumistrescu-Hurlin (2012) states that "*a homogeneous specification of the relation between the variables x and y does not allow interpreting the causality relations if any individual from the sample has an economic behaviour different from that of the others*". Under this circumstance, the null hypothesis of $x_{i,t}$does not homogeneous Granger cause $y_{i,t}$ can be tested as $H_0{:}\,\beta_i = 0, (i = 1, \dots N)$ against the alternative hypothesis of $x_{i,t}$does not heterogeneous Granger cause $y_{i,t} H_0{:}\,\beta_i = 0, (i = 1, \dots N_1)$; $H_1{:}\,\beta_i \neq 0, (i = N_1 + 1,\ N_1 + 2, \dots N)$ (for some cross-sections). In other words, the null hypothesis says no homogenous Granger causality for all the cross sections against alternative hypothesis supports at least one causal relationship in some cross sections. Under the alternative hypothesis, two sub-groups of cross-sections are specified. A causality runs from x to y be observed for the first subgroup, but not merely on the same model. No causal nexus between x and y is observed from the second subgroup. The acceptance or rejection of the null hypothesis is based on the average standard of Wald statistics for each country, and it expresses as:

$$W_{N,T}^{Hnc} = \frac{1}{N} \sum_{i-1}^{N} W_{i,T} \tag{2.10}$$

Where $W_{i,T}$ indicates individual Wald statistics for the each ith cross-section.

2.4. Empirical findings and discussion

2.4.1. Preliminary analysis

Table 1 provides the annual average growth rate of the selected variables. The highest growth rate of clean energy consumption is attained by China (7.20%), followed by Russia (2.13%) and India (0.20%). South Africa and Brazil are experienced the lowest clean energy consumption during this period. Similarly, China is the highest energy consumer with an annual growth rate of 7.75%, followed by India (3.55%) and Brazil (2.40%). South Africa and Russia are the lowest energy consumers with an annual growth of 0.18% and -0.54%, respectively. Moreover, CO_2 growth rates are highest in China (5.31%) and India (3.60%), while Russia is the lowest (-1.13%). In the case of economic growth, higher growth is achieved by China (9.17%) and India (4.72%) and lower by South Africa (1.49%). In addition, China is also registered the highest growth rate in capital and population, while the lowest is Russia in both variables. Finally, the higher and lower growth rate of labor is occupied by Brazil (2.11%) and Russia (-0.02%), respectively. Overall, Table 2.1 shows that the annual average growth rates of all consider variables (except labor) are the highest in the case of China. However, the annual average growth rate of energy consumption is higher than the clean energy consumption in the BRICS countries during the study period. Therefore, we can argue that still, clean energy consumption needs to grow for mitigating CO_2emissions without compromising economic growth in these emerging market economies.

Table 2.1: Annul average growth rate, 1992-2014 (per cent).

Variable	Brazil	Russia	India	China	South Africa	Average
CEC	-1.82	2.13	0.20	7.20	-0.88	1.36
EC	2.40	-0.54	3.55	5.75	0.18	2.26
CO_2	2.74	-1.13	3.60	5.31	0.22	2.14
GDP	1.96	2.10	4.72	9.17	1.49	3.88
GDP^2	4.00	4.64	9.69	19.22	3.04	8.11
CAP	4.31	1.72	8.73	16.62	5.39	7.35
LAB	2.11	-0.02	1.69	0.82	1.97	1.31
POP	1.27	-0.15	1.63	5.31	1.49	1.91

Note: The growth rates were calculated using original data.

2.4.2. Results of panel unit root tests

We initiate our empirical analysis with panel unit root tests to verify integration properties of the variables using LLC and IPS. These tests help us in the case of selecting suitable empirical techniques. For the all tests, null hypothesis of a unit root is tested over alternative hypothesis of no unit root. These unit root tests results are depicted in Table 2.2. The results show that all the variables per capita GDP, square term of per capita GDP, capital, labor, per capita energy consumption, per capita clean energy consumption, and per capita CO_2 emissions are non-stationary at the level but it becomes stationary in its first difference.

Table 2.2: Panel unit root test results

	Level				Fist Difference			
	LLC test		IPS test		LLC test		IPS test	
Variable	Statistic	Prob.	Statistic	Prob.	Statistic	Prob.	Statistic	Prob.
CEC	0.006	0.502	1.556	0.940	-5.194***	0.000	-5.260***	0.000
EC	0.732	0.768	1.775	0.962	-2.453***	0.007	-2.865***	0.002
CO_2	1.239	0.892	1.934	0.973	-1.905**	0.028	-2.342***	0.009
GDP	0.397	0.654	3.315	0.999	-3.236***	0.000	-3.334***	0.000
GDP^2	1.061	0.855	3.771	0.999	-3.011***	0.001	-3.017***	0.001
CAP	-1.058	0.145	1.496	0.932	-2.010**	0.022	-3.154***	0.000
LAB	-1.386	0.082	-1.377	0.084	-2.211**	0.013	-2.196**	0.014
POP	-1.428	0.076	1.185	0.882	-3.185***	0.000	-1.288*	0.098

Notes: *, **, and *** indicate the rejection of null hypothesis of unit root at the 10%, 5%, and 1% significant levels, respectively.

2.4.3. Results of panel cointegration test

After confirming the all variables are stationary at the first difference, we investigate the long-run link among the variables of Equation (2.1) and (2.2) using the Fisher-Johanson panel cointegration test. The results of panel cointegration test are reported in Table 2.3. These results confirm that the null hypothesis of no cointegration is rejected for the trace test and max-eigen test in both Equations (2.1) and (2.2). It demonstrates that there an existence of a long-run equilibrium relationship among the selected variables in both equations in these emerging market economies.

Table 2.3: Johanson Fisher panel cointegration test results

	$GDP = f\ (CAP, LAB, CO_2, CEC, EC)$				$C0_2 = f(GDP, GDP^2, CEC, EC, POP)$			
Hypothesized No. of CE(s)	trace test	Prob.	Mag-eigen test	Prob.	trace test	Prob.	Mag-eigen test	Prob.
None	226.2***	0.000	128.0***	0.000	251.6***	0.000	127.9***	0.000
At most 1	137.4***	0.000	71.56***	0.000	167.6***	0.000	87.89***	0.000
At most 2	85.37***	0.000	47.74***	0.000	112.9***	0.000	62.43***	0.000
At most 3	46.41***	0.000	26.82***	0.002	65.62***	0.000	42.59***	0.000
At most 4	29.81***	0.000	25.37***	0.004	35.01***	0.000	33.24***	0.000
At most 5	18.03**	0.054	18.03**	0.054	15.68	0.109	15.68	0.109

Notes: ** and *** indicate the rejection of null hypothesis of no cointegration at the 10% and 1% significant levels, respectively.

2.4.4. Panel estimates of long-run economic growth and CO_2 emissions elasticities

The panel cointegration test does not show the nature of cause and effect nexus among economic growth, capital, labor, CO_2 emissions, clean energy consumption, and energy consumption. Therefore, this study applies the panel FMOLS technique to examine the impact of selected independent variables on economic growth and clean energy consumption in the BRICS countries. The results of FMOLS long-run estimates are displayed in Table 2.4.

The outcomes confirm that a 1% increase in clean energy consumption, energy consumption, and capital raise 0.209%, 1.278% and 0.447% of economic growth, respectively, while a 1% increase in CO_2emissions reduces economic growth by 1.080% in the BRICS countries. More specifically, clean energy consumption, energy consumption, and labor are positively affecting economic growth, while CO_2emission is negatively affecting it. These results suggest that increasing clean energy consumption raises economic growth and significantly reduces CO_2 emissions. Therefore, governments and policymakers should encourage clean energy consumption in the total energy mix in these emerging market economies. This outcome is in line with Paramati et al. (2016) and Paramati et al. (2017a), who point out that clean energy consumption has a significant positive impact on economic growth and negative influence on CO_2emissions in their studies. Similarly, this finding is also consistence with Hamit-Haggar (2016) who find that a 1% increase in clean energy consumption raises economic growth by 0.093% in sub-Saharan African countries during 1971-2017, but this finding contrasts with Maji (2015) who find that a 1% increase in clean energy consumption reduces economic growth by 0.713% in Nigeria during 1971-2011.

The long-run estimates of CO_2emissions reveal that a 1% rise in energy consumption increases CO_2emissions by 1.077%, while clean energy consumption reduces CO_2emissions by 0.118%. It indicates that energy consumption has a significant positive impact on CO_2 emissions, while clean energy consumption has a negative impact on CO_2 emissions. These findings are in line with our expectations that clean energy sources can be consider as the most effective substitute for other non-clean energy sources. In other words, an increase in clean energy consumption combats CO_2emissions in BRICS countries. These empirical results are corroborated with Paramati et al. (2016) and Paramati et al. (2017a) who conclude that energy consumption is significantly increases CO_2emissions while clean energy consumption substantially reduces CO_2emissions in their studies. The other variable population also helps to reduce CO_2 emissions. However, coefficients of GDP and square term of GDP are positive and negative, respectively. It indicates the existence of the EKC hypothesis in a panel of these emerging market economies. This implies that per capita CO_2emissions go up in the early stage but eventually declines when per capita GDP rises over the period. Similar finding was found by Dong et al. (2017), Abdouli et al. (2018), and Danish et al. (2019b) in the case of BRICS countries.

Table 2.4: Panel results of FMOLS estimator

Variable	Coefficient	t-Statistic	Prob.
	$GDP = f\ (CAP, LAB, CO_2, CEC, EC)$		
CAP	0.447***	15.874	0.000
LBR	-0.048	-0.444	0.657
CO_2	-1.080***	-3.762	0.000
CEC	0.209***	3.472	0.000
EC	1.278***	3.998	0.000
	$C0_2 = f(GDP, GDP^2, CEC, EC, POP)$		
GDP	0.346***	2.661	0.009
GDP^2	-0.023***	-3.323	0.001
CEC	-0.118***	-4.420	0.000
EC	1.077***	32.874	0.000
POP	-0.117*	-1.676	0.096

Notes: * and *** indicate the significance level at the 10% and 1%, respectively.

2.4.5. Time-series analysis of long-run economic growth and CO_2 emissions elasticities

We previously explored panel data analysis of long-run economic growth and CO_2emissions elasticities in the above section. Here we aim to examine the time-series analysis of long-run economic growth and CO_2emissions elasticities for each of the individual countries across a panel. This analysis is more important to understand the impact of clean energy consumption on economic growth and CO_2emissions and to verify the existence of the EKC hypothesis in individual countries. The country-specific results of FMOLS estimator are reported in Table 2.5 when economic growth is a dependent variable. Table 2.5 shows that clean energy consumption has a significant positive impact on economic growth in both Russia (0.736%) and India (0.130%) countries. In contrast, clean energy consumption is negatively associated with economic growth in Brazil (-0.344%) and China (-0.163%). This indicates that a 1% increase in clean energy consumption will increase economic growth by 0.736% in Russia and 0.130% in India, while it will decrease economic growth by 0.344% in Brazil and 0.163% in China. In the remaining country, i.e., South Africa, clean energy consumption does not have either a positive or negative impact on economic growth. Similarly, CO_2emission has a negative impact on economic growth in Brazil (-0.441%) and China (-2.610%), while a positive impact in India (0.523%). However, energy consumption has a significant positive association with economic growth in China (2.966%) only. Finally, capital has a significant positive impact on economic growth in these individual emerging market economies.

Table 2.5: Country-specific results of FMOLS estimator (Dependent variable: GDP)

Country	Variable	CAP	LBR	CO_2	CEC	EC	Adj.R^2
Brazil	Coefficient	0.447***	0.194***	-0.441***	-0.344***	0.299	0.989
	t-Statistic	15.874	2.989	-3.277	-3.957	1.310	
	Prob.	0.000	0.008	0.004	0.001	0.208	
Russia	Coefficient	0.462***	-0.652	-0.417	0.736***	0.502	0.992
	t-Statistic	8.359	-1.510	-0.628	5.124	0.610	
	Prob.	0.000	0.150	0.5384	0.000	0.550	
India	Coefficient	0.054**	0.739***	0.523**	0.130***	0.298	0.997
	t-Statistic	2.093	11.343	2.387	4.545	1.185	
	Prob.	0.052	0.000	0.029	0.000	0.253	
China	Coefficient	0.422***	0.837	-2.610***	-0.163**	2.966***	0.998
	t-Statistic	4.783	1.343	-4.299	-2.025	4.295	
	Prob.	0.000	0.198	0.000	0.059	0.000	
South Africa	Coefficient	0.276***	0.070	0.842	-0.038	-1.104	0.987
	t-Statistic	5.716	0.555	1.299	-0.765	-1.601	
	Prob.	0.000	0.586	0.212	0.455	0.128	

Notes: ** and *** indicate the significance level at the 10% and 5%, respectively.

The country-specific results of FMOLS estimator are reported in Table 2.6 when CO_2 emission is dependent variable. The results show that clean energy consumption has a significant negative impact on CO_2 emissions in individual BRICS countries. More specifically, a 1% increase in clean energy consumption reduces CO_2 emissions by 0.504%, 0.207%, 0.099%, 0.054%, and 0.048% in Brazil, Russia, India, China, and South Africa, respectively. In addition, energy consumption has a positive and significant influence on CO_2 emissions in all individual countries. Specifically, a 1% increase in energy consumption increases CO_2 emissions by 1.353%, 1.002%, 0.945%, 1.089%, and 1.082% in Brazil, Russia, India, China, and South Africa, respectively. These results imply that all individual countries of BRICS should focus more on clean energy use rather than non-clean energy to significantly reduce CO_2 emissions. Finally, we did not find the validation of the EKC hypothesis in all five BRICS countries (except China). This finding falls in a similar line with the results of Pao et al. (2011), Ummalla and Samal (2018), and Govindaraju and Tang (2013) who failed to establish the EKC hypothesis in Russia, China, and China and India, respectively. This finding, however, opposes with Pao and Tsai (2011a), Jayanthakumaran et al. (2012), Tiwari et al. (2013) and Boutabba (2014), Kohler (2013) in China, China and India, India, South Africa, respectively; who found that an evidence of the EKC hypothesis in their studies.

Based on the above results we can infer that that all five countries where clean energy consumption has a positive impact on economic growth and negative impact on CO_2 emissions, we suggest that these individual countries should focus more on clean energy use rather than non-clean energy to achieve sustainable economic growth by significantly reducing CO_2 emissions. In China, energy consumption has a positive impact on economic growth but clean energy consumption has a negative influence on it. However, clean energy consumption significantly reducing CO_2 while energy consumption increasing it. It because of China heavily depends on coal consumption which leads to CO_2 emissions. Therefore, China's policymakers should promote efficient use of clean energy and also investment in clean energy technologies. Further, the non-existence of the EKC hypothesis countries should have sound economic and energy policies.

Table 2.6: Country-specific results of FMOLS estimator (Dependent variable: CO_2)

Country	Variable	GDP	GDP^2	CEC	EC	POP	$Adj.R^2$
Brazil	Coefficient	3.197	-0.209	-0.504***	1.353***	-0.247	0.979
	t-Statistic	0.269	-0.326	-4.438	7.538	-0.927	
	Prob.	0.790	0.748	0.000	0.000	0.367	
Russia	Coefficient	1.677	-0.096	-0.207***	1.002***	-0.211	0.986
	t-Statistic	1.481	-1.603	-3.561	8.788	-0.382	
	Prob.	0.157	0.128	0.002	0.000	0.707	
India	Coefficient	-2.650***	0.187***	-0.099***	0.945***	0.305**	0.999
	t-Statistic	-9.241	9.745	-8.957	26.334	2.899	
	Prob.	0.000	0.000	0.000	0.000	0.010	
China	Coefficient	1.099**	-0.068***	-0.054***	1.089***	-1.217***	0.999
	t-Statistic	6.894	-8.173	-5.492	82.150	-3.989	
	Prob.	0.000	0.000	0.000	0.000	0.001	
South Africa	Coefficient	-0.603	0.045	-0.048***	1.082***	-0.200**	0.990
	t-Statistic	-0.226	0.304	-3.810	28.053	-2.849	
	Prob.	0.823	0.764	0.001	0.000	0.011	

Notes: ** and *** indicate the significance level at the 10% and 5%, respectively.

2.4.6. Panel causality test results

The presence of long-run cointegration relationship among the variables suggests that there must be one way Granger causality at least. For this purpose, we test the direction of causality among the selected variables by using Dumistrescu- Hurlin (2012) panel causality test. The empirical results of the short-run panel causality test are documented in Table 2.7. The findings show that energy consumption Granger causes economic growth and bidirectional causality between energy consumption and CO_2 emissions, while CO_2 emissions Granger causes economic growth. However, we found no causal relationship between clean energy consumption and economic growth and also among economic growth, capital, labor, and clean energy consumption in Equation 2.1. Similarly, from Equation 2.2, we find that unidirectional causality from energy consumption to economic growth and bidirectional causality between energy consumption and CO_2 emissions, while one-way causality from CO_2 emissions to economic growth.

Table 2.7: Dumitrescu - Hurlin panel causality test results

Equation 2.1:						
Dependent Variable	Independent Variable					
	GDP	CAP	LBR	CEC	EC	CO_2
GDP	-	0.798	1.045	1.080	2.966**	3.111**
		(0.676)	(0.919)	(0.954)	(0.018)	(0.011)
CAP	1.362	-	0.910	1.308	1.452	1.122
	(0.762)		(0.783)	(0.814)	(0.676)	(0.997)
LBR	0.803	0.968		1.140	1.599	0.955
	(0.681)	(0.841)		(0.984)	(0.544)	(0.828)
CEC	0.882	1.687	0.278	-	0.127	0.043
	(0.756)	(0.472)	(0.280)		(0.203)	(0.167)
EC	1.437	0.749	0.893	0.592	-	2.462**
	(0.690)	(0.632)	(0.767)	(0.496)		(0.088)
CO_2	1.213	1.621	1.419	0.411	3.461***	-
	(0.910)	(0.526)	(0.707)	(0.362)	(0.002)	
Equation 2.2:						
	CO_2	GDP	GDP^2	CEC	EC	POP
CO_2	-	1.213	1.292	0.411	3.461***	1.231
		(0.910)	(0.830)	(0.362)	(0.002)	(0.891)
GDP	3.111**	-	0.563	1.080	2.966**	0.903
	(0.011)		(0.473)	(0.954)	(0.018)	(0.778)
GDP^2	3.191***	0.750	-	1.099	3.116**	1.337
	(0.008)	(0.633)		(0.974)	(0.011)	(0.786)
CEC	0.043	0.882	0.753	-	0.127	1.841
	(0.167)	(0.756)	(0.635)		(0.203)	(0.36)
EC	2.462**	1.437	1.575	0.592	-	0.666
	(0.088)	(0.690)	(0.565)	(0.496)		(0.558)
POP	1.570	2.755**	2.838**	1.390	1.474	-
	(0.570)	(0.035)	(0.028)	(0.734)	(0.656)	
Direction of causality						
EC → GDP, GDP ↔ CO_2, EC ↔ CO_2, EC → GDP^2, CO_2 → GDP^2, GDP → POP, GDP^2 →POP						

Notes: ** and *** indicate the significance level at the 10% and 5%, respectively.

Further, there is unidirectional causality from economic growth to population. However, we found no causal relationship between clean energy consumption and economic growth. Finally, these results suggest that energy consumption influences economic growth, and bidirectional casualty between energy consumption and CO_2 emissions, but no evidence of causality between clean energy consumption and economic growth. This can be portrayed as energy consumption plays a significant role in economic growth and this energy consumption stimulates CO_2 emissions in the BRICS countries. However, given the concern on climate change and greenhouse gas emissions, these emerging market economies should encourage clean energy uses by providing tax incentives in clean energy projects without compromising economic growth. This result is in line with Paramati et al. (2016) who found no causality between clean energy consumption and economic growth in 20 emerging market economies. This is inconsistent with Pao et al. (2014) and Hamit-Haggar (2016) who documented unidirectional causality between these two variables in MITS and 11 sub-Saharan African countries, respectively.

2.5. Conclusion and policy implications

This Chapter has examined the impact of clean energy consumption on economic growth and CO_2 emissions by incorporating capital, labor, energy consumption, and population, and tested the EKC hypothesis in the BRICS countries over the period 1992-2014. We estimated two separate specification models where in the first model, economic growth is a dependent variable, and in the second model, CO_2 is a dependent variable. For empirical analysis, this study used LLC and IPS unit tests to check the stationary properties of the selected variables. The Johanson-Fisher panel cointegration is applied to examine the long-run equilibrium relationship among the variables. The long-run elasticities of economic growth and CO_2 emissions were estimated by employing panel FMOLS. Finally, Dumistrescu-Hurlin (2012) panel causality test is used to examine the short-run causal relationship among the variables.

The results of the panel cointegration test confirmed the long-run equilibrium association among the variables in both Equations (2.1) and (2.2). The long-run elasticities of economic growth and CO_2 emissions show that energy consumption, clean energy consumption, capital have a significant positive impact on economic growth, while CO_2 emission has a negative impact on it in a panel of BRICS countries. The findings also show that economic growth and energy consumption increase CO_2 emission, but clean energy consumption reduces CO_2 emissions. Further, our results established the existence of the EKC hypothesis in a panel of these emerging market economies. Finally, energy consumption causes economic growth, but no reverse causality between them. However, we found no causal relationship between clean energy consumption and economic growth in the BRICS nations. This result is in line with Paramati et al. (2016) in 20 emerging market economies. This is inconsistent with Pao et al. (2014) and Hamit-Haggar (2016) in MITS and 11 sub-Saharan African countries, respectively. Based on the above results, we can observe that rapid economic growth and energy consumption yield higher CO_2 emissions, which postulates that these two variables are mainly triggering CO_2 emissions in BRICS countries. However, energy consumption increases CO_2 emissions where clean energy consumption reduces it, which indicates that clean energy consumption is the potential determinants of mitigating CO_2 emissions. Here, it is importance to note that rapid economic growth and energy consumption are important to any emerging economies to achieve convergence with advanced countries. But clean energy consumption is a vital factor not only to mitigate CO_2 emissions and path to sustainable economic growth but also to create a healthy environment. Therefore, our findings of the present paper suggest that policymakers of the BRICS countries should cut down CO_2 emissions by consuming clean energy rather than non-clean energy to achieve sustainable economic growth.

From the above empirical analysis, we can draw important policy implications. First, energy consumption and clean energy consumption have a positive impact on economic growth. However, energy consumption increases CO_2 emissions, while clean energy consumption significantly reduces it. Therefore, the BRICS governments and policymakers should support the development of clean energy so that it not only meet the demand for energy but also combat CO_2 emissions. Second, to accelerate and development of clean energy these emerging market economies should share their knowledge and expertise, strengthen the rules and regulations, and collaborating research, development and demonstration (RD&D) activities. Third, the BRICS countries should attract more domestic and foreign investment in clean energy projects. Ummalla et al. (2019) also suggested that financing hydropower energy projects will give a solution to environmental issues. Fourth, they should improve the technological innovation in three economic activities (namely, agriculture, industry and services) to reduce CO_2 emissions.

The main limitations of the present study are that it is conducted on BRICS countries only and more extended period data on clean energy consumption are not available. Despite these limitations, our research has provided valuable policy implications regard to the nexus among clean energy consumption, economic growth and CO_2 emissions in the context of BRICS countries. However, considering clean energy as an alternative to fossil fuels, a study can be conducted on these variables in developed and developing countries. Finally, the present study has considered clean energy consumption at the aggregate level for the impact on CO_2 emissions and economic growth, and has verified the existence of the EKC hypothesis. Therefore, a future study can be considered clean energy consumption at the disaggregated level (i.e., nuclear, hydro, wind, and solar) for both developed and developing countries.

Chapter 3

Hydropower Energy Consumption, Economic Growth, and CO_2 Emissions

3.1. Introduction[1]

In recent years, there is a growing concern among the environmental scientists and policymakers on energy transformation from conventional sources to non-conventional energy sources. Because, climate change and greenhouse gas emissions (GHS) are indisputable facts, which are mainly causing by human activities and combustion of fossil fuels. Therefore, most of the countries in the world have gradually reduced reliance on fossil fuels and sought for renewable and clean energy sources which mitigate CO_2 emissions. Most recently, in the Republic of South Korea, the United Nations Intergovernmental Panel on Climate Change (IPCC) report highlights that limit the increase in the global average temperature to 1.5 C. In order to restrict it, coal-fired electricity must end by 2050. According to IPCC (2011), it is predicted that about 80% of the global total primary energy supplied by renewable sources in 2050. Hydropower is one of the main fasters-growing sources from renewable energy. It provides 40% and 75% of share in total renewable energy generation in both the developed and developing countries during 2012-2040 (IEO, 2016). It clearly indicates the development of hydropower energy in developing countries, especially in BRICS nations. Therefore, hydropower energy consumption can give a solution to climate change and GHG emissions.

Over the past, the BRICS countries have been the fastest-growing emerging economies in the world. In 2015, the BRICS countries accounted for 30.8% and 42% of global GDP and world population, respectively. Concurrently, this group consumed 37% of the total world energy, while they are responsible for 41.4% of global CO_2 emissions. Furthermore, these countries have heavily relied on fossil-fuel energy sources; hence, 71% of their total energy generation come from fossil-fuels only (BRICS Energy Indicators, 2015). However, these economies are shifting their energy use from fossil-fuel to renewable sources to mitigate greenhouse gas

[1]Main content of this chapter has been published by the scholar as Mallesh Ummalla, Asharani Samal and Phanindra Goyari (2019): “Nexus among the hydropower energy consumption, CO_2 emissions and economic growth: Evidence from BRICS countries”, In: *Environmental Science and Pollution Research*, ISSN: 0944-1344, 28(34), 35010-3502 (Link at https://link.springer.com/content/pdf/10.1007/s11356-019-06638-1.pdf).

emissions. Further, investment in renewable energy sources is significantly growing in the BRICS countries[2]. Therefore, a massive amount of installed capacity has been increasing. Atop six countries together accounted for 63% of total global hydropower installed capacity in 2015[3]. Among the six countries, four countries are from the BRICS countries. More precisely, this group of counties accounts for 45% of the world's total hydropower generation. Therefore, we argue that increasing the share of hydropower energy not only combats CO_2 emissions but also meets the demand for energy. Then, the main aim of our study is to answer the following question: First, whether hydropower energy consumption positively affects economic growth? Second, does hydropower energy use reduce CO_2 emissions?

Given the above background, it is important to empirically investigate the nexus among the hydropower energy use, economic growth, and CO_2 emissions in the BRICS countries because empirical results invoke essential policy implications for energy economists and policymakers. However, in the literature, less studies which have probed the nexus among hydropower energy use, economic growth, and CO_2 emissions. For example, Bildirici (2014) in 15 countries, Lau et al. (2016) in Malaysia, Bildirici and Gokmenoglu (2017) in G7 countries, Solarin et al. (2017a) in India and China, and Ummalla and Samal (2018) in China. More specifically, this is the first study to explore the nexus among the hydropower energy use, economic growth, and CO_2 emissions in the case of BRICS countries. Given the scarce literature on the BRICS regarding this issue, the present study aims to fill this research gap by employing more recent longer data set, a more robust model, and appropriate panel modelling techniques.

The contribution of this study is five-fold. First, to the best of knowledge, this is the first piece of study that empirically explores the nexus among the hydropower energy consumption, economic growth, andCO_2 emissions in the BRICS countries. Second, most of the previous studies have used time series data for empirical investigation among these three variables. However, we use panel data to explore nexus among the variables which provide the more accurate estimation of model parameters with more degrees of freedom and less

[2] During the Six BRICS summit, held in Brazil in July 2014, the delegates from the BRICS countries highlighted that financial and energy security were the main agenda. Accordingly, the member countries are signed on the establishment of 'BRICS development bank' and 'BRICS energy association'. The main aim of the bank is to mobilize financial recourses for infrastructure and sustainable energy development, and the energy association will work on the creation of 'fuel reserve bank' and 'energy policy institute' for the member countries.

[3]Those countries are China (27.9%), Brazil (8.6%), United States (7.5%), Canada (7.4%) and Russia (4.5%), and India (4.4%).

multicollinearity, and more temporal and dynamics of relationship which cannot be addressed by a single time series data (Hsiao, 2007). Third, due to financial integration and globalization, macroeconomic variables are strongly cross-sectional dependent (Banerjee et al., 2004; Paramati et al. 2016). Furthermore, the traditional panel data estimators such as random and fixed effects are inconsistent and give invalid inference in the presence of cross-sectional dependence. To overcome this problem, we apply cross-sectional dependence (CD) test developed by Pesaran (2004). Fourth, conventional unit root tests provide inappropriate results due to low power when they used on a series which is cross-sectional dependent. Therefore, this study has applied Pesaran's (2007) cross-sectional augmented ADF (CADF) panel unit root test and cross-sectional IPS (CIPS) panel unit root test which assume cross-section dependence. Fifth, this study utilizes the panel ARDL model to examine the short-run and long-run relationship among the variables. Finally, it employs the panel quantile regression to investigate the impact of independent variables on economic growth and CO_2 emissions at their different quantile levels.

The main findings of our study demonstrate that hydropower energy consumption, CO_2 emissions, and population have a positive impact on economic growth. However, hydropower energy consumption and population have a negative impact on CO_2 emissions, while economic growth is positively contributes to CO_2 emissions in the long-run. In the short-run, hydropower energy consumption has a positive association with economic growth, while hydropower energy consumption and population have a negative association with CO_2 emissions, and economic growth has a positive impact on it at the insignificant level. Furthermore, our panel quantile regression results indicate that the effects of independent variables on economic growth and CO_2 emissions are heterogeneous across the quantiles.

The rest of the chapter is structured as follows. Section 3.2 includes a review of the literature. Section 3.3 explains the nature of data, their measurement and the empirical methodology. Section 3.4 presents empirical findings and its analysis. Section 3.5 offers the conclusion and its policy implications.

3.2. Review of Literature

There are abundant studies which have investigated the linkages among energy use, economic growth and, CO_2 emissions across the globe. Alam and Paramati (2015) examined the nexus among oil consumption, economic growth and, CO_2 emissions in 18 major oil-consuming developing counties, spanning the period 1980-2012. They found that bidirectional causality among the selected variables in the short-run and long-run. Alam et al. (2017) investigated the relationship among natural gas consumption, trade openness, and economic growth in 15 top natural gas-consuming developing countries during 1990-2012. They reported that natural gas consumption and trade openness have a positive impact on economic growth. Further, they found that bidirectional causality among these three variables. Alam et al. (2018) probed the nexus between access to electricity and labor productivity in 56 developing countries covering the period 1991-2013. They reported that access to electricity and economic growth has a positive impact on labor productivity. Finally, they found that bidirectional causality among access to electricity, labor productivity and economic growth in their analysis. Similarly, many studies have conducted on the relationship among renewable energy use, economic growth, and CO_2 emissions. However, the findings of the studies are diverse across countries using different econometric methods and datasets for both the time-series and panel studies. For example, Sadorsky (2009) investigated the nexus between renewable energy consumption and real income in 18 emerging market economies during 1994-2003. The results indicated that real income has a positive association with renewable energy use. Similarly, Lin and Moubarak (2014) reported that an increase in economic growth promotes renewable energy use in China, spanning the period 1977–2011. The results also established that bidirectional causal relationship between renewable energy use and economic growth, whereas Apergis and Payne (2010a) demonstrated that renewable energy use has a positive and significant impact on economic growth in 20 OECD countries during 1985–2005. Further, they reported that there is exists a bidirectional causal relationship between renewable energy consumption and economic growth. Another other study is by Apergis and Payne (2010b, 2011) who also established similar conclusion in the case of 13 Eurasia countries and 6 Central American countries, respectively. Further, Salim et al. (2014) argued that an increase in renewable energy consumption boosts economic growth in 29 OECD countries during 1980–2011. Their results concluded that unidirectional causal linkages exist from economic growth to renewable energy consumption. Shahbaz et al. (2015) revealed that renewable energy consumption promotes economic growth in Pakistan over the period1972Q1–2011Q4.The Granger causality test revealed that bidirectional causal relationship between these variables. Bhattacharya et al.(2016) examined the relationship between renewable energy consumption and economic growth from the top 38countries over the period 1991-2012. The long-run estimates revealed that renewable energy use has a positive association with economic growth. Inglesi-Lotz (2016) argued that renewable energy consumption plays a positive and significant role in promoting economic growth in 34 OECD economies during 1990-2010.Gozgor (2016) confirmed the presence of convergence in renewable energy consumption in the case of China and India while divergence in the case of Brazil during 1971-2014. Koçak and Şarkgüneşi (2017) examined the nexus between renewable energy consumption and economic growth in 9 Black Sea and Balkan countries during 1990-2012. The authors reported that renewable energy consumption induces economic growth. Further, the study also confirmed that two-way causal relationship between these variables. Ito (2017) investigated the nexus among CO_2 emissions, renewable and non-renewable energy consumption, and economic growth in 42 developed economies during 2002–2011.The results showed that renewable energy consumption increases economic growth and reduces CO_2emissions in the long-run.Paramati et al. (2017b) documented that an increase in the use of renewable energy is positively associated with economic growth and negatively with CO_2 emissions in the G20 nations during 1991-2012.

By contrast, Marques and Fuinhas (2012) argued that renewable energy consumption has a negative impact on economic growth in 24 European countries, spanning the period 1990–2007.Ocal and Aslan (2013) also found that renewable energy use retards economic growth in Turkey during 1990-2000.Further, they also found that unidirectional causal linkages from economic growth to renewable energy consumption. Dogan (2015) documented that non-renewable energy consumption increases economic growth while renewable energy consumption reduces economic growth in Turkey, although insignificant in the long-run during 1990-2012.Further, the author also established that one-way causal linkage running from renewable energy consumption to economic growth, while two-way causal linkages is established between non-renewable energy consumption and economic growth in the long run. Bhattacharya et al. (2017) documented that renewable energy consumption promotes economic growth in 85 developed and developing economies during the period 1991-2012. However, Menegaki (2011) could not find any causal linkage between renewable energy consumption and growth in 27 European countries during1997–2007. Again, Ben Aissa et al. (2014) examined the nexus between output, renewable energy consumption, and economic growth in 11 African countries during1980-2008. The authors also reported that no causal nexus is detected between renewable energy consumption and economic growth. Kutan et al. (2018) revealed that no causality is found between renewable energy use and economic growth in 4 major emerging market economies, namely, Brazil, India, China, and South

Africa during 1990-2012. Similarly, Paramati et al. (2018a) also revealed similar results in 17 countries from the G20 nations, spanning the period 1980-2012. Recently, Gozgor (2018) and Gozgor et al. (2018) reported that renewable energy use has a positive association with economic growth in the USA and 27 OECD countries, respectively. Most recently, Ummalla and Samal (2019) documented that unidirectional Granger causality from renewable energy use to economic growth in India, while no causality found in China in the short-run. Further, in the long-run, they found that bidirectional causality between these two variables in both China and India, spanning the period 1965-2016.

3.2.1. Hydropower energy consumption and economic growth

Many studies have devoted to examining the nexus between renewable energy consumption and economic growth in the literature. However, a minuscule amount of studies have conducted on the nexus between hydropower energy consumption and economic growth in the world. For example, Abakah (1993) probed the linkages between three disaggregate sources of energy, i.e., charcoal, petroleum, and hydroelectricity consumption, with economic growth in Ghana during 1976-1990. The empirical results displayed that hydroelectricity and petroleum consumption have a positive association with economic growth in short-run and long-run, while charcoal consumption has a negative association with economic growth. Okafor (2012) examined the linkages among the selected disaggregate energy, i.e., coal, hydro and oil consumption and economic growth in Nigeria and South Africa, spanning the period 1970-2010. The results of the Granger causality test indicated that coal consumption and economic growth are Granger causes each other in South Africa, while coal consumption Granger causes economic growth in Nigeria. However, hydropower energy use and economic growth Granger causes each other in Nigeria and South Africa.Ziramba (2013) proved the nexus between hydroelectricity consumption and economic growth in three African countries, namely, Egypt, South Africa, and Algeria over the period 1980-2009. Their findings indicated that hydroelectricity consumption promotes economic growth in both Egypt and South Africa. The author also found that hydroelectricity consumption and economic growth are Granger causes to each other in Algeria, while economic growth Granger causes hydroelectricity consumption in South Africa. However, no causal linkage is detected between hydroelectricity consumption and economic growth in Egypt. Ohler and Fetters (2014) reported that hydroelectricity consumption positively contributes to economic growth in 20 OECD countries during 1990-2008. Further, Granger causality test results documented that hydroelectricity consumption and economic growth Granger causes to each other in both the short-run and long-run. Solarin and Ozturk (2015) investigated the causal linkages between hydroelectricity consumption and economic growth in Seven Latin American countries during 1970-2012. The long-run estimates of without structural break revealed that hydroelectricity consumption has positively associated with economic growth in Brazil, Peru, and Venezuela, while negatively in Colombia and Ecuador. However, hydroelectricity consumption promotes economic growth for all the countries except Venezuela with two structural breaks analysis. Their causality test results without break revealed that hydroelectricity consumption Granger causes economic growth for all the six countries except Chile in the long-run. Their findings from two structural break confirmed that hydroelectricity consumption and economic growth are Granger causes each other in Argentina and Venezuela, whereas hydroelectricity consumption Granger causes economic growth in Brazil, Chile, Colombia, Ecuador, and Peru, respectively. Apergis et al. (2016) reported that economic growth promotes hydroelectricity consumption in the top 10 hydroelectricity consuming countries. The Granger causality test results indicated that economic growth Granger causes hydroelectricity consumption in the pre-1988 period, whereas hydroelectricity consumption and economic growth are Granger causes each other in the post-1988 period in both the short-run and long-run. They suggested that bidirectional linkage not only established between hydroelectricity consumption and economic growth but also created a more significant impact on economic growth via the increasing role of hydro energy source for the break year 2000 and 2009. Bildirici (2016) examined the nexus between hydropower energy consumption and economic growth in OECD and non-OECD high-income countries, spanning the period1980-2011. The empirical results confirmed that hydropower energy consumption reduces economic growth in Brazil, Canada, Finland, Mexico, and the USA, while an increases economic growth in Turkey. The results of Granger causality test revealed that hydropower energy consumption Granger causes economic growth in OECD countries with high income. Further, in the short-run, the study also found that economic growth Granger causes hydropower energy consumption in Brazil, the U.S, Finland, Mexico, and Turkey. Finally, the author detected that hydroelectricity consumption and economic growth are Granger causes each other in the long-run.

3.2.2. Hydropower energy consumption, economic growth and CO_2 emissions

In the literature, there is evolving regarding the nexus between hydropower energy consumption and economic growth. However, investigating the impact of hydropower energy use on CO_2 emissions is very scarce, although hydropower use can improve the environmental quality. In recent years, a minuscule amount of available literature probed the relationship among the hydropower energy consumption, economic growth, and CO_2 emissions in the developed and developing countries. For instance, Bildirici (2014) explored the linkages among the hydropower energy consumption, environmental pollution, and economic growth in 15 countries. The results from Toda-Yamamoto causality test revealed that unidirectional causality running from hydropower energy consumption to economic growth in Austria, from economic growth to hydropower energy consumption in Germany and an absence of any causality between hydropower energy consumption and economic growth in the United Kingdom. However, bidirectional causality is established between hydropower energy consumption and economic growth in the rest of the countries**.** Furthermore, the author also found no causality between hydropower energy consumption and CO_2 emissions in Belgium, Iceland, and the United Kingdom, while a unidirectional causality exists from CO_2 emissions to hydropower energy consumption in the rest of the countries. Further, Lau et al. (2016) explored the nexus among the hydroelectricity consumption, economic growth, and CO_2 emissions in Malaysia, spanning the period 1965-2010. The short-run results revealed that unidirectional causal linkage exists from hydroelectricity consumption to CO_2 emissions. However, in the long-run, unidirectional causality runs from economic growth and hydroelectricity consumption to CO_2 emissions. Bildirici and Gokmenoglu (2017) investigated the relationship among hydropower energy consumption, economic growth, and CO_2 emissions in G7 during 1961-2013. Their empirical results revealed that unidirectional causality running from hydropower energy consumption to economic growth in overall and bidirectional causality between hydropower energy consumption to economic growth in few of G7 countries. The authors also detected CO_2 emissions Granger causes hydropower energy consumption in the first, second and third regime, while hydropower energy consumption Granger causes CO_2emissions in some of the G7 countries. Recently, Solarin et al. (2017a) examined the linkages among the hydroelectricity consumption, urbanization, economic growth and, CO_2 emissions in India and China during 1965-2013. Their long-run results revealed that economic growth and urbanization have a positive association with CO_2 emissions, while hydroelectricity consumption has a negative association with it in both India and China. The findings from the Granger causality test showed that there exists a unidirectional causality running from hydroelectricity consumption to CO_2 emissions, from economic growth to hydroelectricity consumption, and from hydroelectricity consumption to CO_2 emissions in the short-run. However, a bidirectional causality is established between hydroelectricity consumption and CO_2 emissions, hydroelectricity consumption and economic growth in both India and China in the long run. Furthermore, the authors also found the presence of environmental Kuznets curve (EKC) in both countries. Recently, Ummalla and Samal (2018) documented that hydropower energy consumption increases economic growth and reduces CO_2 emissions in the long-run. Their empirical results confirmed that unidirectional causality running from hydropower energy consumption to economic growth in the short-run, while bidirectional causality among the hydropower energy consumption, economic growth, CO_2 emissions in the long-run. However, they did not find the existence of EKC in China during 1965-2016.

Based on the above literature, it confirmed that empirical results differ regardless of the country selection, the data period, the frequency of observations, and the econometric techniques of probing the nexus among variables. However, there are hardly any studies which have investigated the linkages among hydropower energy consumption, economic growth, and CO_2 emissions in a time series framework. To the best of our knowledge, this is the first study which explores the nexus among hydropower energy consumption, economic growth, and CO_2 emissions in a panel of BRICS countries, spanning the period 1990-2016.

3.3. Data and Methodology

3.3.1. Data

The present study used annual data for the BRICS countries (namely Brazil, Russia, India, China, and South Africa) during 1990-2016.The selected variables of the present study include per capita hydropower energy consumption (HYD) in million tonnes oil equivalent (Mtoe), per capita GDP (constant 2010 US$), per capita carbon dioxide emissions (CO_2) in million metric tons. The data on HYD and CO_2 are obtained from the BP Statistical Review of World Energy, 2017, whereas population and GDP data are retrieved from the World Development Indicators (WDI) online database. All the selected variables are transferred into natural logarithms.

3.3.2. Methodology

The main objective of the study is to investigate the short-run and long-run nexus among the hydroelectricity, economic growth and CO_2 emissions in the BRICS countries. To fulfil the objective, our study employs the panel ARDL bounds testing approach. Further, panel quantile regression was applied to probe the effects of independent variables on economic growth and CO_2 emissions at their different quantile levels. The simple framework of the model can be written as follows:

$$lnGDP_{it} = \alpha_1 + \beta_1 lnHYD_{it} + \beta_2 lnCO_{2it} + \beta_3 lnPOP_{it} + e_{1it} \tag{3.1}$$

$$lnCO_{2it} = \alpha_2 + \beta_4 lnHYD_{it} + \beta_5 lnGDP_{it} + \beta_6 lnPOP_{it} + e_{2it} \tag{3.2}$$

Where GDP_{it}, HYD_{it}, CO_{2it},and POP_{it}denoteper capita GDP, per capita hydropower energy consumption, per capita CO_2 emissions, and population, respectively. The subscript $i(i = 1 \ldots. N)$ and $t(t = 1 \ldots. T)$ represent country and time period, respectively. Finally, e_{1it} and e_{2it} are the two residual terms which are assumed to be normally distributed.

3.3.2.1. Cross-sectional dependence

We first aim to identify whether the given series is cross-sectional dependent or independent. The fact is that heterogeneity may exist across the countries for the considerable variables. Therefore, the prerequisite panel econometric tests are required before commencing analysis[4]. Henceforth, this study employs Pesaran's (2004) cross-sectional dependence (CD) test which takes into account both issues. The null hypothesis of cross-sectional independence is tested against the alternative hypothesis of cross-sectional dependence. If we reject the null hypotheses, it suggests that there is a presence of cross-sectional dependence among all of the variables.

3.3.2.2. Panel unit root tests

With the existence of cross-sectional dependence, we did not apply the first generation unit root tests such as IPS and LLC because it does not address the issue of cross-sectional dependence. Therefore, we employ the Pesaran (2007) CADF and CIPS panel unit root tests in our analysis. It is worth noting to mention that both of these panel unit root tests produce more reliable and accurate results in the presence of both cross-sectional dependence and

[4]Several authors (e.g., Alam et al., 2015; Alam et al., 2017; Paramati et al., 2016; Paramati et al., 2017a) argue the cross-sectional dependence and heterogeneity in their analysis.

heterogeneity across the sample countries[5]. These unit root tests were used to verify the order of integration among the variables. The null hypothesis of a unit root is tested against the alternative hypothesis of no unit root.

3.3.2.3. Panel ARDL model

In this chapter, we apply the panel ARDL model with a country fixed effect and the period fixed effect propounded by Pesaran et al. (1999) to investigate the short-run and long-run relationship among the hydropower energy consumption, economic growth, CO_2 emissions, and population in the BRICS countries. This method also helps to estimate the consistent and efficient estimators by eliminating the problem of endogeneity. The specified model can be written as follows:

$$\begin{aligned}\Delta lnGDP_{it} = {} & \delta_0 + \sum_{i=1}^{q} \delta_{1i} \Delta lnGDP_{i,t-1} + \sum_{i=1}^{q} \delta_{2i} \Delta lnHYD_{i,t-1} + \sum_{i=1}^{q} \delta_{3i} \Delta lnCO_{2i,t-1} \\ & + \sum_{i=1}^{q} \delta_{4i} \Delta lnPOP_{i,t-1} + \delta_5 lnGDP_{i,t-1} + \delta_6 lnHYD_{i,t-1} + \delta_7 lnCO_{2i,t-1} \\ & + \delta_8 \, lnPOP_{i,t-1} + e_{1it} \qquad (3.3)\end{aligned}$$

$$\begin{aligned}\Delta lnCO_{2it} = {} & \beta_0 + \sum_{i=1}^{q} \beta_{1i} \Delta lnCO_{2i,t-1} + \sum_{i=1}^{q} \beta_{2i} \Delta lnHYD_{i,t-1} + \sum_{i=1}^{q} \beta_{3i} \Delta lnGDP_{i,t-1} \\ & + \sum_{i=1}^{q} \beta_{4i} \Delta lnPOP_{it-1} + \beta_5 lnCO_{2i,t-1} + \beta_6 lnHYD_{i,t-1} + \beta_7 lnGDP_{i,t-1} \\ & + \beta_8 lnPOP_{i,t-1} + e_{2it} \qquad (3.4)\end{aligned}$$

Where q is the lag order. e_{1it} and e_{2it} are the error terms which are assumed to be an identically and independently distributed. Equations (3.3) and (3.4) can be transformed into error correction model (ECM) to Equations (3.5) and (3.6) as follows:

[5]The previous studies (e.g., Dogan et al., 2017; Mallick et al., 2016; Paramati et al., 2017a) used the CADF and CIPS cross-sectional unit root tests in their empirical analysis.

$$\Delta lnGDP_{it} = \delta_0 + \sum_{i=1}^{q} \delta_{1i}\Delta lnGDP_{i,t-1} + \sum_{i=1}^{q} \delta_{2i}\Delta lnHYD_{i,t-1} + \sum_{i=1}^{q} \delta_{3i}\Delta lnCO_{2i,t-1} + \sum_{i=1}^{q} \delta_{4i}\Delta lnPOP_{i,t-1} + \xi(lnGDP_{i,t-1} + \pi_1 lnHYD_{i,t-1} + \pi_2 lnCO_{2i,t-1} + \pi_3 lnPOP_{i,t-1}) + e_{1it} \quad (3.5)$$

$$\Delta lnCO_{2it} = \beta_0 + \sum_{i=1}^{q} \beta_{1i}\Delta lnCO_{2i,t-1} + \sum_{i=1}^{q} \beta_{2i}\Delta lnHYD_{i,t-1} + \sum_{i=1}^{q} \beta_{3i}\Delta lnGDP_{i,t-1} + \sum_{i=1}^{q} \beta_{4i}\Delta lnPOP_{it-1} + \xi(lnCO_{2i,t-1} + \theta_1 lnHYD_{i,t-1} + \theta_2 lnGDP_{i,t-1} + \theta_3 lnPOP_{i,t-1}) + e_{2it} \quad (3.6)$$

Where ξ is the speed of adjustment parameter. π_1, π_2 and π_3 are the long-run coefficients of per capita hydropower energy consumption, per capita CO_2 emissions, and population, respectively in Equation (3.5), while θ_1, θ_2, and θ_3 are the long-run coefficients of per capita hydropower energy consumption, per capita GDP, and population, respectively in Equation(3.6). γ_{1i}, γ_{2i}, γ_{3i} and γ_{4i} and α_{1i}, α_{2i}, α_{3i} and α_{4i} are denote the short-run coefficients in Equations (3.7) and (3.8). Therefore, the panel ARDL (*p, q, k* and *g*) models are written as:

$$\Delta lnGDP_{it} = \gamma_0 + \sum_{i=1}^{p} \Delta\gamma_{1i}\Delta lnGDP_{i,t-1} + \sum_{i=1}^{q} \Delta\gamma_{2i}\Delta lnHYD_{i,t-1} + \sum_{i=1}^{k} \Delta\gamma_{3i}\Delta lnCO_{2i,t-1} + \sum_{i=1}^{g} \Delta\gamma_{4i}\Delta lnPOP_{i,t-1} + \xi(lnGDP_{i,t-1} + \pi_1 lnHYD_{i,t-1} + \pi_2 lnCO_{2i,t-1} + \pi_3 lnPOP_{i,t-1}) + e_{1it} \quad (3.7)$$

$$\Delta lnCO_{2it} = \alpha_0 + \sum_{I=1}^{p} \Delta\alpha_{1i}\Delta lnCO_{2i,t-1} + \sum_{i=1}^{q} \Delta\alpha_{2i}\Delta lnHYD_{i,t-1} + \sum_{i=1}^{k} \Delta\alpha_{3i}\Delta lnGDP_{i,t-1}$$
$$+ \sum_{i=1}^{g} \Delta\alpha_{4i}\Delta lnPOP_{it-1} + \xi(lnCO_{2i,t-1} + \theta_1 lnHYD_{i,t-1} + \theta_2 lnGDP_{i,t-1}$$
$$+ \theta_3 lnPOP_{i,t-1}) + e_{2it} \quad (3.8)$$

3.3.2.4. Panel quantile regression

We have applied the fixed effect panel quantile regression model to explore the impact of hydropower energy use on economic growth and CO_2 emissions in the BRICS countries throughout the conditional distribution. The advantages of the panel quantile regression model are: a) it is an extension of classical ordinary least square (OLS) method of conditional mean which enables to estimate with different point of conditional probability distribution of dependent variables. b) This method also takes into account the heterogeneous structure of the different levels of growth and CO_2 emissions as the OLS does not consider it. c) It minimizes the problem of outlier observations and issues related to heavy distributions. d) It is a more efficient method than the ordinary least square (OLS) estimators if the error terms are not normally distributed. e) It enables us to assess the conditional heterogeneous covariance effects of CO_2emissions and economic growth. f) It also helps to investigate the impact of the hydropower energy consumption on economic growth and CO_2 emissions at different level of the conditional distribution of the dependent variables. In quantile regression, the conditional distribution of dependent variable is divided into different quantiles, where the 50^{th} quantile represent the median (Hübler,2017). Therefore, we can represent the τ^{th} quantile as the conditional distributions of dependent variables (per capita economic growth andCO_2emissions), given the set of independent variablesX_{it}, the equation can be specified as:

$$Q_\tau\left(\frac{lnGDP_{it}}{X_{it}}\right) = \alpha_\tau + \beta_\tau X_{it} + \alpha_\tau \mu_{it} \quad (3.9)$$

$$Q_\tau\left(\frac{lnCO_{2,it}}{X_{it}}\right) = \alpha_\tau + \beta_\tau X_{it} + \alpha_\tau \mu_{it} \quad (3.10)$$

Where, in Equations (3.9) and (3.10), $lnGDP_{it}$ and $lnCO_{2,it}$ are the natural logarithms of per capita economic growth and CO_2 emissions of country i in time period t, and X_{it} denotes vector of three independent variables, namely, per capita hydropower energy consumption, CO_2 emissions, and population, respectively and vice versa for Equation (3.10). u_{it}represents unobservable factors. The coefficients in Equations (3.9) and (3.10) are estimated minimizing the absolute value of residuals by using the following objective functions:

$$Q_\tau(\beta_\tau) = \min_\beta \sum_{i=1}^{n} [|lnGDP_{it} - \beta_\tau X_{it}|]$$

$$= \min_\beta \left[\sum_{i:lnGDP_{it} \geq \beta X_i}^{n} \tau |lnGDP_{it} - \beta_\tau X_{it}| + \sum_{i:lnGDP_{it} < X_{it}}^{n} (1-\tau) \, |lnGDP_{it} \right.$$

$$\left. - \beta_\tau X_{it}| \right] \qquad (3.11)$$

The same procedure follows when the CO_2emissionis a dependent variable. Koenker(2004) estimated the vector of individual effects using shrinkage methodology which does not capture the unobserved factors with fixed effects regression model and later on, Canay (2011) found that Koenker's methodology is computationally intensive; therefore, he introduced two-step procedure of fixed effect panel quantile regression model. In the first stage, the conditional mean of u_{it} is estimated and the estimated coefficients are to be calculated to obtain individual fixed effects. In the second stage, estimated individual fixed effects would be deducted from the original dependent variable and finally, standard estimation of quantile regression is used. Our empirical analysis is carried out using the above methodology of Canay (2011). Further, some of the previous studies have applied quantile regression to panel data in their analysis(Apergis et al. 2018; Gozgor et al. 2018; Zhu et al. 2018).

3.4. Empirical results and analysis

3.4.1. Preliminary Results

The annual average growth rate (in percent) of selected variables for individual countries are presented in Table 3.1.The highest growth rate of output is experienced in China (9.634) followed by India (6.593), while the lowest growth rate is experienced by Russia(0.690).Similarly, the annual growth rate of CO_2 emissions is higher in the case of India (5.332) and China (5.331) and lowest and negative in Russia (-1.552). Among the

BRICS countries, the growth rate of hydropower energy consumption is highest in South Africa (32.032) and China (9.217) followed by India (3.127) and lowest in Russia (0.719). Further, South Africa and India have positive and highest average growth rate of the population, whereas the growth rate of Russia (-0.085) is negative during the sample period 1990-2016.In general, it is observed from Table1 that the highest average growth rate of output and CO_2 emissions are occupied by China and India. However, hydropower energy consumption and the population are highest in the case of South Africa. Further, the annual average growth rate of all the considered variables is lowest and negative in Russia.

Table 3.1: Annual average growth rate, 1990-2016 (Percent)

Variable	Brazil	Russia	India	China	South Africa
GDP	2.296	0.690	6.593	9.634	2.377
HYD	2.468	0.719	3.127	9.217	32.032
POP	1.295	-0.085	1.645	0.777	1.648
CO_2	3.104	-1.552	5.332	5.331	1.434

Note: The growth rate were calculated using original data.

The mean statistics of individual countries of the BRICS are reported in Table 3.2.The highest per capita output belongs to China (28.732) and Brazil (28.167) followed by Russia(27.835), India (27.638), and South Africa (26.428). It suggests that there is a consistent development of per capita output across the sample countries. The per capita hydropower energy consumption is higher in China (4.368) and Brazil (4.252) than Russia(3.648) and India (3.031), whereas hydropower energy consumption is lowest and negative in South Africa (-1.351). The average per capita CO_2 emissions in China (8.485) and Russia (7.382) are higher than in South Africa (5.921) and Brazil (5.775). The population is highest in China (20.965) and India (20.814) in comparison to Russia (18.795) and South Africa (17.648) during the sample study period.

Table 3.2: Mean statistics for individual countries, 1990–2016.

Country	GDP	HYD	POP	CO_2
Brazil	28.167	4.252	19.008	5.775
Russia	27.835	3.648	18.795	7.382
India	27.638	3.031	20.814	7.039
China	28.732	4.368	20.965	8.485
South Africa	26.428	-1.351	17.648	5.921

Note: HYD: per capita hydropower energy consumption in million tonnes oil equivalent; GDP: per capita real GDP in constant 2010 US$; CO_2: per capita carbon dioxide emissions in million tonnes oil equivalent; POP: total population.

The summary statistics of panel dataset are shown in Table 3.3. The results show that the average economic output across the sample countries is 27.76%. It implies that selected countries have a significant economic outcome during the study period. The average population is about 19.44%, while CO_2 emissions are 6.92%. Finally, hydropower energy consumption accounts for 2.78%. It suggests hydropower energy use remains relatively low, but it is significantly growing in a panel of the BRICS countries.

Table 3.3: Panel summary statistics

Variable	Mean	Std. Dev.	Minimum	Maximum
GDP	27.760	0.885	26.098	29.882
HYD	2.789	2.177	-3.410	5.572
POP	19.446	1.275	17.420	21.044
CO_2	6.921	1.051	5.284	9.129

3.4.2. Results of cross-sectional dependence test

Before applying any econometric techniques which deal with panel data analysis, one should always check whether there is a presence of cross-sectional dependence or independence among the variables. The results of conventional unit root tests are spurious and misleading if the variables are found to be cross-sectional dependence because it is based on the assumption of cross-sectional independence. Hence, we employed the cross-sectional dependence (CD) test propounded by Pesaran (2004) in order to investigate the presence of cross-sectional dependence and heterogeneity problem associated in our study. The CD tests results are shown in Table 3.4. The results reveal that the null hypothesis of cross-sectional independence is significantly rejected against the alternative hypothesis of cross-sectional dependence at the 1% level of significance. It suggests that there is a presence of cross-sectional dependence among all of the variables.

Table 3.4: Cross-sectional dependence test results

Variable	GDP	HYD	POP	CO_2
Pesaran CD test	14.73***	6.68***	3.89***	5.46***
P-Value	0.000	0.000	0.000	0.000

Notes: *** indicates the rejection of null hypothesis of cross-sectional independence (CD test) at the 1% significance level.

3.4.3. Results of panel unit root tests

Since conventional unit root tests are not appropriate in the presence of cross-sectional dependence across the sample, we have utilized Pesaran's (2007) CADF and CIPS cross-sectional augmented panel unit root tests which account for cross-sectional dependence. The CADF and CIPS tests results are reported in Table 3.5. The results indicate that the data series is stationary at the level for population and CO_2 emissions variables which follows I(0), while other variables, namely, economic growth and hydropower energy consumption, are stationary at the first difference which follows I(1). However, all of these variables reject the null hypothesis of non-stationary at the first difference. Based on these findings, we conclude that the consider variables have different order of integration, i.e., I (0) and I (1). Therefore, we have applied the panel ARDL model to analyse the short-run and long-run relationship among hydropower energy consumption, economic growth, population, and CO_2 emissions in the BRICS countries.

Table 3.5: Panel unit root test results

Variable	CADF		CIPS	
	Ztbar	P-value	Ztbar	P-value
GDP	-0.968	0.166	3.126	0.999
HYD	0.779	0.782	-0.619	0.267
POP	-5.982***	0.000	-6.905***	0.000
CO_2	-1.396*	0.081	0.813	0.791
ΔGDP	-1.998**	0.023	-2.939***	0.001
ΔHYD	-7.111***	0.000	-6.518***	0.000
ΔPOP	-1.821**	0.034	0.729	0.767
ΔCO_2	-3.745***	0.000	-4.230***	0.000

Notes: Δ is the first difference term. *, ** and *** indicate the rejection of null hypothesis of unit root at the 10%, 5% and 1% significance levels, respectively.

3.4.4. Results of panel ARDL model

To examine the short-run and long-run relationship among the variables, we have employed the panel ARDL model. This test can provide more robust and reliable results even in the presence of different orders of integration in the model. The results of long-run and short-run estimates based on panel ARDL model are reported in Table 3.6. When economic growth is a dependent variable, the results of long-run estimates show that hydropower energy consumption, CO_2emissions, and population are positively associated with economic growth. It implies that a1% increase in hydropower energy consumption, CO_2emissions and population increases economic growth by 0.038%, 0.349%, and 0.834%, respectively. Our results are consistent with Ziramba (2013) in Egypt and South Africa, and Solarin and Ozturk

(2015) in seven Latin American countries. The ECM coefficient is negative (-0.629) but not significant. Moreover, in the short-run, the results also revealed that hydropower energy consumption promotes economic growth. More technically, a 1% increase in hydropower energy consumption increases economic growth by 0.098% and 0.048% in the lagged periods.

When CO_2 emission is a dependent variable, economic growth increases CO_2 emissions while hydropower energy consumption and population mitigateCO_2 emissions. It indicates that a 1% rise in economic growth increases CO_2 emissions by 0.282%, while a 1% increase in hydropower energy consumption and population decrease CO_2 emissions by-0.227% and -1.375, respectively. This suggests that high economic growth plays a very significant role in promoting CO_2 emissions which may be due to rapid industrialization and urbanization in recent periods, while hydropower energy consumption helps to mitigate CO_2 emissions in the BRICS countries. Our results are similar with Solarin et al. (2017a)in India and China, and contradict to Ummalla and Samal (2018) in China. The ECM coefficient is negative (-0.452) and statistically significant at the 1% level. In the short-run, we have observed that hydropower energy consumption and population have a negative impact on CO_2 emissions, while economic growth has a positive impact on it at the insignificant level.

Table 3. 6: Panel ARDL estimation results

GDP = f (HYD, CO_2, POP)			CO_2= f(HYD, GDP, POP)		
Variable	Coefficient	Prob.	Variable	Coefficient	Prob.
Long-Run Equation			Long-Run Equation		
HYD	0.038**	0.021	HYD	-0.227*	0.076
CO_2	0.349***	0.000	GDP	0.282**	0.020
POP	0.834***	0.000	POP	-1.375**	0.037
Short-Run Equation			Short-Run Equation		
COINTEQ01	-0.629	0.409	COINTEQ01	-0.452***	0.000
D(GDP(-1))	0.261	0.549	D(CO_2(-1))	-0.129	0.522
D(GDP(-2))	-0.012	0.953	D(CO_2(-2))	-0.101	0.625
D(GDP(-3))	0.300**	0.014	D(CO_2(-3))	-0.172	0.327
D(HYD)	0.040	0.585	D(HYD)	-0.063	0.405
D(HYD(-1))	0.083	0.333	D(HYD(-1))	-0.031	0.739
D(HYD(-2))	0.098**	0.011	D(HYD(-2))	-0.004	0.938
D(HYD(-3))	0.048*	0.084	D(HYD(-3))	-0.010	0.742
D(CO_2)	0.031	0.949	D(GDP)	0.381	0.225
D(CO_2(-1))	-0.025	0.944	D(GDP(-1))	0.034	0.856
D(CO_2(-2))	0.152	0.260	D(GDP(-2))	0.213	0.139
D(CO_2(-3))	0.030	0.854	D(GDP(-3))	0.158	0.422
D(POP)	-175.520	0.244	D(POP)	-181.966	0.154
D(POP(-1))	306.328	0.252	D(POP(-1))	379.017	0.152
D(POP(-2))	-228.693	0.233	D(POP(-2))	-233.877	0.312

D(POP(-3))	38.855	0.230	D(POP(-3))	-7.741	0.937
Constant	5.630	0.429	Constant	12.605***	0.000

Notes: *, ** and *** indicate significance levels at the 10%, 5% and 1%, respectively.

In sum, regarding the panel ARDL test results on all the considerable variables, we can highlights that hydropower energy consumption, CO_2 emissions and population are considered as the significant drivers in order to achieve higher economic growth in the BRICS countries. The economic growth and population rise CO_2 emissions, while hydropower energy use reduces it. Therefore, governments and policymakers should take appropriate policy initiatives, namely, shifting tax incentives, invest fund on hydropower energy projects through foreign direct investment and foreign institutional investment in order to promote hydropower energy use rather than non-renewable energy sources. The increase investment in hydropower energy projects increases the energy generation capacity and meets the demand for hydropower energy consumptions to mitigate CO_2 emissions without compromising in achieving higher economic growth in the BRICS countries.

3.4.5. Results of panel quantile regression (PQR) estimates

The results of panel quantile regression estimates (PQR) are reported in the upper panel of Table 3.7 when economic growth is considered as a dependent variable. The results of 10th, 20th, 30th, 40th, 50th, 60th,70th, 80th, 90th, and 95th percentiles are represented in conditional growth distributions. The impact of hydropower energy consumption on economic growth is heterogeneous across quantiles. The marginal impact of hydropower energy consumption on economic growth is higher at the higher quantile levels. The hydropower energy consumption significantly promotes economic growth at the 1% level of significance across the quantiles (except the 10thquantile level). It demonstrates that a1% rise in hydropower energy consumption promotes economic growth by 0.214%-0.319%. More technically, whether in low-income countries or high-income countries, based on these findings we urge that hydropower energy consumption is a primary source of energy for enhancing economic growth in the BRICS countries over the period.

Next, regarding the CO_2 emissions variable, we can see that there is a presence of the heterogeneous impact ofCO_2 emissions on economic growth across the quantile in the conditional distribution of economic growth. The impact of CO_2 emissions on economic growth is positive and insignificant at the first three quantile levels, namely, 10th, 20th and 30th, while the coefficients are positive and significant at the higher quantile levels (60th-95thquantiles) which indicates that the influence of CO_2 emissions on economic growth is positive. It implies that a1% increase in CO_2 emissions promotes economic growth by 0.336%-0.473% in high-income countries. The marginal impact of CO_2emissions on economic growth is higher at the higher quantiles of income. From these results, we can see that the high-income countries are more reliant on fossil fuels, in turn to high CO_2 emissions which have a severe impact on climate change, to achieve their high growth targets. However, we can suggest that high-income countries should mitigate CO_2emissions by consuming renewable energy sources without compromising economic growth. In other words, high-income countries should invest more funds on the development of energy infrastructure, setting of new less-energy intensive industries, and spending on research and development (R&D) which can combat CO_2 emissions and also boost economic growth. Regarding population variable, the impact of population on economic growth is different across quantiles. The coefficients of population are negative and insignificant in most of the quantiles. However, it is negative and significant in higher quantiles, namely, 90th and 95thquantiles. These findings imply that an increase in the population reduces the economic growth. It suggests that the population retards economic growth in the BRICS countries.

The results of panel quantile regression estimates (PQR) are represented in the lower panel of Table 3.7 when CO_2 emissions are considered as a dependent variable. We also observe that the influence of hydropower energy consumption on CO_2 emissions is heterogeneous in the conditional distribution of CO_2emissions. The impact of hydropower energy consumption on CO_2 emissions is negative and significant at the 5% level at the lower quantile levels (i.e., 10th, 20th, 30th and 40thquartiles).These empirical findings demonstrate that hydropower energy consumption plays a significant role in mitigating CO_2 emissions in lower CO_2 emissions countries. However, coefficients became insignificant in 50th and 60th quantiles. Further, the coefficients of hydropower energy consumption are positive and significant on CO_2 emissions in higher quantiles (i.e., 80th, 90th and 95thquantiles). It suggests that hydropower energy consumption promotes CO_2 emissions in higher CO_2 emissions countries. In other words, these countries are heavily consuming non-renewable energy rather than renewable energy for their economic activities. Therefore, the use of hydropower energy does not help to mitigate CO_2 emissions in high-CO_2 emissions countries. Further, coefficients of economic growth are positive and significant at the 1% levels on CO_2 emissions across the quantiles. These results suggest that whether in low-CO_2 emissions or high-CO_2 emissions countries, economic growth has significantly increases emissions. Moreover, the findings also revealed that coefficients of the population are significant and positive at the 1% level across the quantiles. From these results, we can report that the population has significantly enhanced emissions in the BRICS countries.

3.5. Conclusion and policy implications

In the recent period, there is a concern on global warming and climate change among the policymakers and environmental scientists, which are mainly caused by combustion of conventional energy sources for achieving the high economic growth target, rapid industrialization, and rising population. Therefore, many international organizations and individual countries in the world have taken it as the early warning system and started promoting renewable energy sources in order to mitigate CO_2 emissions in a side and meet the demand for energy on another side. Given the above background, in this chapter, we aim to explore the effects of hydropower energy consumption on economic growth and CO_2 emissions in the BRICS countries, spanning the period 1990-2016.For this purpose, we have applied several panel econometrics methodological approaches.

The empirical findings based on the panel ARDL model manifest that in the long-run hydropower energy consumption, CO_2 emissions, and population promote economic growth. However, hydropower energy consumption and population reduces CO_2 emissions, while economic growth is positively contributes to CO_2 emissions. These results are similar to the findings of Solarin et al. (2017a) in China and India. However, it contrasts with findings of Ummalla and Samal (2018) in China. In the short-run, hydropower energy consumption has a positive association with economic growth, while hydropower energy consumption and population have a negative association with CO_2 emissions, and economic growth has a positive impact on it at the insignificant level. These outcomes are similar with Solarin et al. (2017a) in China and India.

Furthermore, our panel quantile regression results indicate that the effects of independent variables on economic growth and CO_2 emissions are heterogeneous across the quantiles. When economic growth is a dependent variable, the marginal impact of hydropower energy consumption on economic growth is positive and significant at the 1% level at all the quantile levels (except the 10^{th}quantile). It implies that hydropower energy consumption has a substantial positive impact on economic growth in low-and high-income countries. Next, CO_2 emissions have a positive and significant impact on economic growth at the low- and high quantile levels (i.e., 40^{th}-95^{th} quantile). Finally, an increase in the population reduces the economic growth at higher quantiles (namely, 90^{th} and 95^{th} quantiles)in BRICS countries.

When CO_2 emissions is a dependent variable, hydropower energy consumption plays a significant role in mitigating CO_2 emissions in lower CO_2 emissions countries (i.e., 10^{th}, 20^{th}, 30^{th} and 40^{th}quantiles).However, hydropower energy consumption promotes CO_2 emissions at the higher quantile levels (i.e., 80^{th}, 90^{th} and 95^{th}quantiles) in higher CO_2 emissions countries. Further, coefficients of economic growth are positive and significant on CO_2 emissions across the quantiles. Besides, the findings also revealed that higher population enhances the CO_2 emissions across quantiles in the BRICS countries. the economic growth and it shows that hydropower energy is driving force of economic growth. Similarly, use of the hydropower energy negatively affects CO_2 emissions which postulates that hydropower energy is the potential determinants of mitigating CO_2 emissions. Therefore, the benefits of this type of energy consumption help to cut down CO_2 emissions in line with the goal of sustainable economic growth. Hence, our findings of this chapter imply that policymakers of the BRICS countries should reduce CO_2 emissions by using hydropower energy without reliance on fossil fuels in order meet their energy demands and sustainable economic growth.

Based on the above findings, we highlight the following important policy implications. 1) The hydropower energy consumption is considered as an essential driver to achieve rapid economic growth, and it also helps in mitigating CO_2 emissions in the BRICS countries. Therefore, governments and policymakers should frame appropriate policies in favour of the deployment of hydropower energy projects. 2) Any conservation hydropower energy policies will have a negative impact on economic growth. Therefore, expansionary of hydropower energy policies are useful for the BRICS countries. 3) Since expansionary hydropower energy policies are beneficial to the countries, it should consider a feasible policy and also substituting it for fossil fuel to mitigate CO_2 emissions (Solarin and Ozturk, 2015). 4) Policymakers should also promote hydropower energy generation and consumption by introducing appropriate incentives, i.e., tax rebates and subsidies (Apergis et al, 2016). 5) Financing in hydropower energy projects through the stock market developments, foreign direct investment (FDI) and official development assistance (ODA) will promote the hydropower energy generation which is a solution for addressing global warming and climate change. 6) Governments of the BRICS countries should encourage public-private partnership investments in hydropower energy projects. 7) These economies should also introduce investment subsidies and tax incentives to attract investors in energy projects to ensure energy security and stability. 8) As suggested by the Paris summit, developed countries should do financial support to developing countries, and BRICS development bank also increases more funds and allocate among the BRICS countries for adaption of innovations and technologies in hydropower energy generation and mitigate of CO_2 emissions. Finally, since hydropower energy use has a positive impact on economic growth and negative impact on CO_2emissions, the BRICS countries should follow the expansionary hydropower policies for better sustainable economies in the world.

The present study is conducted on the BRICS countries. However, in the light of awakening global awareness towards mitigating CO_2 emissions and sustainable economic growth, future studies should be conducted on developed and developing counties to capture the larger impact of hydropower energy consumption. Furthermore, researchers can examine the impact of hydropower energy consumption on economic growth and CO_2 emissions in these countries by incorporating other variables like institutional quality, R&D, and financial development in the model.

Table 3.7: Panel quantile regression (PQR) results

Variable	10^{th}	20^{th}	30^{th}	40^{th}	50^{th}	60^{th}	70^{th}	80^{th}	90^{th}	95^{th}
					GDP= f (HYD, CO_2, POP)					
Constant	25.773***	27.818***	26.921***	26.694***	25.985***	26.641***	27.200***	27.821***	28.618***	28.236***
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
HYD	0.214	0.342***	0.337***	0.344***	0.327***	0.322***	0.339***	0.348***	0.336***	0.319***
	0.225	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.0000	0.000
CO_2	0.336	0.037	0.101	0.170**	0.180**	0.302***	0.366***	0.425***	0.468***	0.473***
	0.436	0.564	0.102	0.015	0.016	0.006	0.001	0.000	0.000	0.000
POP	-0.075	-0.081	-0.050	-0.059	-0.019	-0.088	-0.137	-0.186	-0.236**	-0.214**
	0.325	0.108	0.311	0.313	0.069	0.471	0.356	0.167	0.035	0.047
Pseudo R-squared	0.599	0.606	0.603	0.591	0.578	0.573	0.590	0.627	0.702	0.737
Adjusted R-squared	0.590	0.597	0.594	0.582	0.966	0.563	0.580	0.618	0.695	0.731
					CO_2 = f (HYD, GDP, POP)					
Constant	-31.298***	-29.334***	-28.878***	-28.029***	-22.446***	-20.837***	-16.658***	-13.063***	-11.514***	-11.871***
	0.000	0.000	0.000	0.002	0.000	0.000	0.000	0.0000	0.000	0.000
HYD	-0.402***	-0.416***	-0.407***	-0.396***	-0.085	-0.053	0.012	0.079**	0.114***	0.099***
	0.0000	0.000	0.000	0.000	0.219	0.420	0.802	0.034	0.000	0.000
GDP	0.922***	0.864***	0.854***	0.846***	0.975***	0.870***	0.695***	0.556***	0.540***	0.567***
	0.000	0.000	0.002	0.006	0.000	0.000	0.000	0.000	0.000	0.000
POP	0.671***	0.659***	0.650***	0.619***	0.140**	0.209**	0.242**	0.251***	0.192***	0.177***
	0.000	0.000	0.000	0.000	0.053	0.017	0.012	0.005	0.009	0.004
Pseudo R-squared	0.462	0.455	0.442	0.422	0.450	0.469	0.516	0.584	0.657	0.672
Adjusted R-squared	0.449	0.443	0.429	0.409	0.437	0.456	0.505	0.575	0.649	0.665

Notes: ** and *** imply the significance levels at the 5% and 1%, respectively.

Chapter 4

Institutional Quality, Renewable Energy Consumption, and CO_2 Emissions

4.1. Introduction

The institutions may play a significant role in the deployment of renewable energy technologies to compact on CO_2 emissions in a country. The institutional quality may have a positive or negative impact on the quality of environment. The weak quality of institutions may be weakened environmental regulations by poor governance, poor judiciary system, and no protection of property rights. On the other hand, strong quality of institutions can enhance the quality of environment by good governance, quality of judiciary systems, protection of property rights, absence of corruption, and trade policies. Hence, the stability and predictability of policy frameworks are required in order to attract investment, production capacity targets, and develop new technologies in the renewable energy sector to mitigate CO_2 emissions. Therefore, many economists, environmental scientists, and policymakers are giving more attention to exploring the nexus between institution quality and environmental degradation. For instance, Papyrakis and Gerlah (2007) argued that institutional quality is the main factor in determining the environmental policies[1]. Further, Ibrahim and Law (2014) also stated that institutional quality would give the solution to the environmental problems. Bhattacharya et al. (2017) documented that institutional quality has a significantly positive impact on renewable energy deployment and a negative impact on CO_2 emissions.

It is undeniable that institutions also play a vital role in the adoption of renewable energy technologies. Many governments are designed a concrete and ambitious plan to reduce greenhouse gas emissions by increasing renewable energy targets. According to the Renewable Energy Policy Network for the 21 Century (REN21, 2016), 173nations have adopted renewable energy targets and estimated that 146 countries had renewable energy support policies in place. The significant role of institutional quality is that it can attract domestic and foreign capital in renewable energy projects. Therefore, both international organizations and national governments have recognized the importance and impact of institutional quality on the environment and have now started conceiving and financing for deployment of renewable energy technologies. Hence, in recent years, investments in renewable energy have significantly increased in the world. Therefore, this study can give

[1]They have treated corruption as the institutional quality.

answers to the following questions empirically, does institutional quality promote the use of renewable energy, and reduce CO_2 emissions?

In the last two decades, the BRICS countries have been the fastest-growing emerging economies in the world. These countries have significantly contributed to global CO_2 emissions due to the high consumption of conventional energy sources. In 2011, the top five CO_2 emitter countries (China, U.S, Russia, India, and Japan) accounted for 55% of global CO_2 emissions. By 2030, the top five CO_2 emitter countries are being accounts at 59% (China, U.S, India, Russia, and Japan). In the above, three out of five high CO_2 emitters are from the BRICS countries. Therefore, these nations had adopted targets for the deployment of renewable energy by 2030[2]. These targets are both in terms of total installed capacity and contribution of renewable energy in total electricity generation. In 2014, renewable energy expanded significantly in terms of capacity installed and power generation in the world. However, the top five countries regarding the deployment of renewable energy capacity are China, the United States, Germany, Spain, and India. Hence, investigating the impact of institutional quality on renewable energy consumption and CO_2 emissions in emerging market economies is important in the world, and results would play a significant role for energy economists and policymakers.

Given the significance of institutional quality, a few studies have examined the impact of institutional quality on renewable energy use in the empirical domain. For example, Bhattacharya et al. (2017)in 85 developed and developing countries, Wu and Broadstock (2015) in 22 emerging market economies, and Saidi et al. (2020) in MENA countries. However, few studies have explored the effect of institutional quality on CO_2 emissions. For instance, Lau et al. (2014) in Malaysia, Danish et al (2019a) in BRICS, and Hassan et al (2020) in Pakistan. More precisely, there has no study conducted on the effects of institutional quality on renewable energy consumption and CO_2 emissions in BRICS. Therefore, this present study aims to fill the research gap in the literature.

The novel contributions of this study are as follows. First, to the best of our knowledge, none of the earlier research has empirically explored the impact of institutional quality on renewable energy consumption and CO_2 emissions in the BRICS countries. Only a single study has probed the effect of institutional quality on CO_2 emissions in the BRICS countries

[2] Brazil (45%), Russia (14%), India (40%), China (30%) and South Africa (45%)

(Danish et al., 2019a). Second, Danish et al. (2019a) neglected the role of renewable energy use in his study which helps to mitigate CO_2 emissions in the economy. Therefore, we address this issue in our analysis. Third, we incorporate population, per capita income, and non-renewable energy consumption as important variables in renewable energy and CO_2 emissions models. Fourth, it applies several panel econometric techniques that account for cross-sectional dependency.

The main findings of the study show that institutional quality increases renewable energy consumption, while CO_2 emissions reduce it. The results also reveal that non-renewable energy consumption increases CO_2 emissions, while institutional quality and renewable energy consumption significantly reduce CO_2 emissions. Finally, we did not confirm any causal relationship between institutional quality, renewable energy consumption, and CO_2 emissions in the BRICS countries.

The remaining of the chapter is structured as follows: Section 4.2 provides review of literature and shows the research gap in the literature which the present study tries to fill up it. Section 4.3 explains the data and methodological framework. Section 4.4 provides empirical findings and discussion. Finally, section 4.5 concludes the study with policy implications.

4.2. Review of Literature

4.2.1. Institutional quality and renewable energy consumption

In the literature, a few studies have examined the role of institutional quality in the promotion of renewable energy uses. For example. Apergis and Eleftheriou (2015) documented that institutional policies are crucial for public-private cooperation on renewable energies and energy-saving technologies in the emerging market economies. Therefore, effective institutional policies are driving forces for the adoption of renewable energy technologies and attain economic growth in the long-run. Wu and Broadstock (2015) examined the impact of economic, financial, and institutional development on renewable energy consumption in 22 emerging market economies, spanning the period 1990-2010. Using system GMM method, authors found that financial development and institutional quality have a positive effect on renewable energy consumption. Finally, they suggest that governments should coordinate between financial development and institutional quality in promoting renewable energy projects. Bhattacharya et al. (2017) reported that institutions and deployment of renewable energy have a positive impact on economic growth in 85 developed and developing countries, spanning the period 1991-2012. Further, they suggest that institutions are the main driving forces to promote the use of renewable energy across economic activities to ensure sustainable economic development. Saidi et al. (2020) examined the role of institutional quality in renewable energy consumption and economic growth nexus in MENA countries during 1986-2015. They found that unidirectional causality running from each institutional quality measure to renewable energy consumption. Additionally, they conclude that the proper institutional framework can attract investment in renewable energy projects and also accelerate economic growth.

4.2.2. Institutional quality and CO_2 emissions

In recent years, attention has been driven to institutional and policy variables to measure its impact on environmental degradation. Tamazian and Rao (2010) found that financial development and trade openness have increased CO_2 emissions in the short-run when institutional quality is low, whereas financial development and trade openness have reduced CO_2 emissions in the log-run when institutional quality is strong in 24 transitional countries during 1993-2004. They suggested that transitional countries do not have adequate incentives to invest in the energy sector to control environmental degradation because of the weak institutional structure. Therefore, economic and financial reforms are necessary to strengthen the institutional structure, which, in turn, to provide adequate incentives for controlling CO_2 emissions. Ibrahim and Law (2016) examined the relationship among the institutional quality, CO_2 emissions, and trade openness in a panel of 40 Sub-Sahara African countries, spanning the period 2000-2010. They found that trade openness has increased CO_2 emissions when institutional quality is low, whereas trade openness has reduced CO_2 emissions in high institutional quality countries. Similarly, Solarin et al. (2017b) found FDI, economic growth, financial development, and trade openness have a positive impact on CO_2 emissions, while institutional quality[3] has a negative impact on CO_2 emissions in Ghana during 1980-2012.

Some studies have directly examined the impact of intuitional quality on CO_2 emissions in the literature. Gani (2012) examined the relationship between five measurements of institutional quality (i.e., political stability, government effectiveness, regulatory quality, rule of law, and control of corruption) and CO_2 emissions in 99 developing countries. The empirical results confirmed that political stability, rule of law, and control of corruption have significantly reduced CO_2 emissions. Zhang et al. (2016) probed the effect of institutional quality (corruption) on CO_2 emissions in 19 APEC countries during 1992-2012. They

[3]They have estimated institutional quality by calculating the averages of two components-Political rights and Civil liberties.

documented that institutional quality has both a direct and indirect effect on CO_2 emissions. Further, they suggest that more corruption always triggers more CO_2 emissions. Halkos and Tzeremes (2013) analyzed the impact of institutional quality on CO_2 emissions in G20 nations during 1996-2010. They reported that different institutional quality measures have different impact levels on CO_2 emissions. Lau et al. (2014) examined the role of institutional quality (i.e., law and order) on CO_2 emissions and economic growth in Malaysia during 1984-2008. They found that institutional quality plays a significant role in reducing CO_2 emissions in the course of economic growth. Abid (2016) investigated the impact of economic, financial, and institutional development on CO_2 emissions in 25 Sub-Saharan African countries during 1996-2010. They found that political stability, government effectiveness, democracy, and control of corruption impact CO_2 emissions positively, while rule of law and regulatory quality impact CO_2 emissions negatively. Abid (2017) investigate the effect of economic, financial, and institutional development on CO_2 emissions in 58 MENA and 41 EU countries, spanning the period 1990-2011. They reported that institutional quality is very important for enhancing economic growth and reducing CO_2 emissions. Bhattacharya et al. (2017) reported intuitional quality has significantly reduced CO_2 emissions in 85 developed and developing countries, spanning the period 1991-2012. Zakaria and Bibi (2019) investigated the impact of financial development and institutional quality on CO_2 emissions in South Asian countries during 1984-2015. They found that both variables have a significant negative impact on CO_2 emissions. Salman et al. (2019) examined the impact of institutional quality on economic growth and CO_2 emissions in a panel of three East Asian countries, namely, Indonesia, South Korea, and Thailand, during 1990-2016. They found that a significant positive relationship between institutional quality and CO_2 emissions by indicating efficient institutions are important to increase economic growth and reduce CO_2 emissions. Further, they reported that unidirectional causality running from institutional quality to economic growth and CO_2 emissions. Finally, they suggest that strengthen the role and effectiveness of institutions in order to mitigate CO_2 emissions in the course of economic development. Ali (2019) also examined the nexus between institutional quality (corruption, rule of law, and bureaucratic quality) and CO_2 emissions in 47 developing countries during 2004-2010. They found that institutional quality has a significant negative impact on CO_2 emissions. Danish et al. (2019a) probed the impact of institutional quality on CO_2 emissions in a panel of BRICS counties during 1996-2017. They concluded that institutional quality has a significant negative impact on CO_2 emissions. Further, they suggest that institutional quality helps to the existence of the EKC hypothesis in the study period. Most recently, Hassan et al. (2020) examined the nexus between institutional quality and CO_2 emissions in Pakistan during 1984-2016. By using the ARDL model, they found that institutional quality has significantly increased CO_2 emissions in both the short-run and long-run. Finally, their results showed that bidirectional quality between institutional quality and CO_2 emissions. They suggested that institutional quality should strengthen to combat CO_2 emissions.

Overall, the review suggests that there are few studies that have examine nexus between institutional quality and renewable energy consumption, and institutional quality and CO_2 emissions by using different institutional quality indicators, which is presented in Table 4.1. However, there is no specific study that examined the impact of institutional quality on renewable energy consumption and CO_2 emissions in the BRICS countries by constructing institutional quality index. This therefore motivates us to empirically examine the nexus among the variables in these emerging market economies.

4.3. Data and Methodology

4.3.1. Nature of the data and measurement

The present study uses the annual data for BRICS countries (namely, Brazil, Russia, India, China, and South Africa), spanning the period 1996Q4-2016Q4[4]. The selection of the sample period is purely based on the availability of data. To meet our study objective, we collected data on renewable energy consumption and non-renewable energy consumption from the US US Energy Information Administration (EIA), while population and per capita income from World Development Indicators, World Bank, 2019. CO_2 emissions are taken from the BP Statistical Review of World Energy, 2019. Finally, institutional quality indicators are obtained from Worldwide Governance Indicators, World Bank, 2019.

Renewable energy consumption (REC) is measured in quadrillion Btu, non-renewable energy consumption (NREC) is the sum of total coal, natural gas, and petroleum consumption in quadrillion Btu, GDP per capita (PI) is measured in constant 2010 US$; population (POP) is measured in million; CO_2 emissions (CO_2) measured in million tons; finally institutional quality index (IQI) constructed based on six indicators that measure the quality of institutions, such as: (i) control of correction (CC), captures perceptions of the extent to

[4]By using the linear interpolation method, we have converted the annual data into the quarterly time series data. Because the high-frequency data increases the power of a statistical test and provide robust results (Zhou, 2001). The quarterly interpolation method has been widely used in the empirical analysis (Tang & Chua, 2012; Shahbaz et al. 2014; Paramati et al. 2018b)

which public power is exercised for private gain, including both petty and grand forms of corruption, as well as "capture" of the state by elites and private interests, (ii) government effectiveness (GE), captures perceptions of the quality of public services, the quality of the civil service and the degree of its independence from political pressures, the quality of policy formulation and implementation, and the credibility of the government's commitment to such policies, (iii) political stability and absence of violence/terrorism (PS), measures perceptions of the likelihood of political instability and/or politically-motivated violence, including terrorism, (iv) rule of law (RL), captures perceptions of the extent to which agents have confidence in and abide by the rules of society, and in particular the quality of contract enforcement, property rights, the police, and the courts, as well as the likelihood of crime and violence, (v) regulatory quality (RQ), reflects perceptions of the ability of the government to formulate and implement sound policies and regulations that permit and promote private sector development, and finally (vi) voice and accountability (VA), captures perceptions of the extent to which a country's citizens are able to participate in selecting their government, as well as freedom of expression, freedom of association, and a free media[5]. After the construction of institutional quality index, all the variables are transformed into natural logarithms.

4.3.2. Methodology

In this regard, the aim of this study is to investigate the effect of institutional quality on renewable energy use and CO_2 emissions in BRICS countries. To achieve this objective of this study, we use of following equations.

$$REC_{it} = f\left(CO_{2,it,} POP_{it}, PI_{it},\ IQI_{it},\ NREC_{it},\ V_i\right) \tag{4.1}$$

$$CO_{2,it} = f(POP_{it}, PI_{it},\ IQI_{it},\ NREC_{it},\ REC_{it},\ V_i) \tag{4.2}$$

Where REC, CO_2, POP, PI, IQI, and NREC represent renewable energy consumption, CO_2 emissions, population, per capita income, institutional quality index, non-renewable energy consumption, respectively, while V_i indicates individual fixed country effects. Similarly, countries are indicated by the subscript i $(\mathrm{i} = 1, \dots, \mathrm{N})$ and t represents the time period$(\mathrm{t} = 1, \dots, \mathrm{T})$.

[5]The missing values in the institutional quality indicators are filled by the linear interpolation method. The previous studies (e.g., Danish et al. 2018 and Danish et al. 2019a) have used this method in their studies.

4.3.2.1. Cross-sectional dependence test

In the case of panel data analysis, it is essential to investigate the cross-sectional dependency issue because one shock in one country may spill-over to the other counters due to globalization and financial integration in the world. Therefore, Pesaran (2004) CD test is expressed as:

$$CD = \sqrt{\frac{2T}{N(N-1)}}\left(\sum_{i-1}^{N-1} \sum_{j=i+1}^{N} \rho_{ij}\right) \tag{4.3}$$

Where N is the sample size, T is the time period, ρ_{ij} is the estimated cross-sectional correlation of errors of countries i and j. The null hypothesis of cross-sectional independence is tested against the alternative hypothesis of cross-sectional dependence.

4.3.2.2. Panel unit root test

In the presence of cross-sectional dependence in selected variables, first-generation panel unit root tests will provide ineffective results. Therefore, the second-generation unit root test is recommended to check the stationary properties because it accounts for cross-sectional dependence. Pesaran (2007) used a cross-sectional augmented version of IPS test to find unit roots.

$$\Delta x_{it} = \alpha_{it} + \beta_i x_{it-1} + \rho_i T + \sum_{j=1}^{n} \theta_{ij}\, \Delta x_{i,t-j} + \varepsilon_{it} \tag{4.4}$$

Where Δ is first difference operator,x_{it} is the selected variable, α is an individual intercept, T is the time trend, and ε_{it} is the error term. The null hypothesis of a unit root is tested against the alternative hypothesis of no unit root.

4.3.2.3. Panel cointegration technique

Next, we employ the panel cointegration test to examine the long-run association among the selected variables during the study period. Under the presence of cross-sectional dependence, we use Westerlund (2007) cointegration test. This test is divided into two group statistics (Gt, Ga) and two panel statistics (Pt, Pa). The Westerlund test considers the error correction model as:

$$\Delta Y_{it} = \delta_i' d_t + \alpha_i Y_{i,t-1} + \lambda_i' X_{i,t-1} + \sum_{j=1}^{pi} \alpha_{i,j} \Delta \mathrm{Y}_{i,t-1} + \sum_{j=-qi}^{pi} \gamma_{ij} \Delta \mathrm{X}_{i,t-1} + \varepsilon_{it} \tag{4.5}$$

Where i is the cross-sections, t is the time trend, d_t is the deterministic components and α_i measures the speed of adjustment after an unexpected shocks. The null hypothesis of no-cointegration is for at least once cross-section for group statistics (Gt, Ga) and all cross-sections for panel statistics (Pt, Pa).

4.3.2.4. Long-run elasticities

We examine the long-run elasticities of renewable energy and CO_2 emissions by using the Augmented Mean Group (AMG) Estimator developed by Eberhardt and Bond (2009) and Eberhardt and Teal (2010). This method is suitable for heterogeneous across panel members and gives consistent and efficient elasticities in the presence of cross-sectional dependence. The AMG estimator includes a common dynamic process which indicates unobservable common factors in the given model. The AMG estimation contains two stages.

AMG-Stage 1

$$\Delta y_{it} = \alpha_i + \beta_i \Delta x_{it} + \gamma_i f_t + \sum_{t=2}^{T} \delta_i \Delta D_t + \varepsilon_{it} \tag{4.6}$$

AMG-Stage 2

$$\hat{\beta}_{AMG} = N^{-1} \sum_{i=1}^{N} \hat{\beta}_i \tag{4.7}$$

Where Δ is first difference operator, x_{it} and y_{it} are the observables, β_i is the country-related coefficients, f_t shows the unobservable common factor, δ_i is the coefficient of the time dummies called as the common dynamic process, $\hat{\beta}_{AMG}$ shows the mean group estimator for AMG, α_i is the intercept, and ε_{it} shows the error term.

4.3.2.5. Panel Granger causality test

In the next step, we examine the short-run bivariate Granger causality among the selected variables. This method has been recently propounded by Dumistrescu and Hurlin (2012). The significance of this method is that it accounts for cross-sectional dependence and heterogeneity. This test is based on the average standard of Wald statistics of Granger-non causality tests for individual time series. The causal relationship between Y and X follows the linear model:

$$\Delta y_{i,t} = \alpha_i + \sum_{j=1}^{j} \lambda_i^j \Delta y_{i,t-j} + \sum_{j=1}^{j} \beta_i^j \Delta x_{i,t-j} + \varepsilon_{i,t} \tag{4.8}$$

$$\Delta x_{i,t} = \alpha_i + \sum_{j=1}^{j} \lambda_i^j \Delta x_{i,t-j} + \sum_{j=1}^{j} \beta_i^j \Delta y_{i,t-j} + \varepsilon_{i,t} \tag{4.9}$$

Where Δ, α_1, λ^j and β_i^j indicate first difference, constant term, lag parameter, coefficient, respectively. The null hypothesis of no Granger casualty tested against the alternative of hypothesis of Granger causality for some cross-sections.

4.3.3. Construction of institutional quality index

Many researchers have used different institutional quality indicators. These few indicators may not be captured the whole institutional quality performance. To overcome this problem, the present study has taken six variables. We believed that data on multi-institutional quality variables or indicators gives the precise meaning of institutional quality. Table 4.2 reports the pair-wise correlation among the institutional quality indicators. This table shows the evidence of control of corruption has a high positive correlation with each variable. Government effectiveness has the highest correlation with rule of law and regulatory quality. Similarly, high correlation between political stability and regulatory quality, and rule of law and voice and accountability. This reveals that there is an existence of multicollinearity among these institutional equality indicators. Therefore, in order to overcome the problem of multicollinearity, we use principal component analysis to construct institutional equality index.

Table 4.2: Correlation matrix

	CC	GF	PS	RL	RQ	VA
COR	1.000					
GF	0.797	1.000				
PS	0.693	0.517	1.000			
RL	0.784	0.712	0.343	1.000		
RQ	0.789	0.729	0.745	0.511	1.000	
VA	0.603	0.360	0.230	0.732	0.507	1.000

Notes: CC: Control of corruption; GE: Government effectiveness; PS: Political stability and absence of violence/terrorism; RG: Regulatory quality; RL: Rule of law; VA: Voice and accountability.

Therefore, to overcome the multi-collinearity problem among the institutional quality variables, we constructed institutional quality index (hereafter IQI) based on the principal component analysis (PCA). PCA is a statistical technique that linearly transfers the original set of variables into smaller set of uncorrelated variables that gives the most information from the original variables (Jolliffe, 2002). This method can be applied by using original values of the X_js, by their deviations from the means $x_j = X_j - \bar{X}_j$ or by the standardized variables $Z_j = {x_j}/{s_{xj}}, x_j = X_j - \bar{X}_j$. In our study, we proceed with the second method as it is assumed to more general and can be applied on different units of the variables. Finally, the following equation is used to construct the institutional quality index:

$$IQI = \sum_{i=1}^{6} w_{ij} \frac{X_{ij}}{Sd(X_i)} \tag{4.10}$$

Where IQI is the institutional quality index,w_{ij} is the factor loads for the IQI indicator, SD is the standard deviation of the IQI indicator, $i = 1 - 6$ represents the indicator of the IQI,$j = 1 - 5$ represents the country,X_{ij} is the value of IQI indicator i for country$j$.

Table 4.3: Principle component analysis

Number	Value	Difference	Proportion	Cumulative Proportion
1	4.067	3.075	0.677	0.677
2	0.991	0.475	0.165	0.843
3	0.516	0.248	0.086	0.929
4	0.267	0.168	0.044	0.973
5	0.099	0.041	0.016	0.990
6	0.057	---	0.009	1.000

We used variance-explained criteria (OECD, 2008) for selecting the number of principal components. According to variance-explained criteria, we select the components where it accounts for 90% of the variation[6]. We selected the first three components because the first three components are accounted for more than 90% of the variation (See Table 4.3). Therefore, more precisely, to construct institutional quality index, weights of three principal components are used as for the formula given below:

$$PC1 = (0.480)\,CC + (0.419)\,GE + (0.356)\,PS + (0.406)\,RL + (0.431)\,RQ + (0.339)VA$$

[6] The variance criteria and Equation 4.10 have been widely used for selection of components and construction of a composite index by using principal component analysis in several studies (Mirshojaeian Hosseini and Kaneko, 2011& 2012; Pradhan et al. 2013; Menyah and Wolde-Rufael, 2014; Pradhan et al. 2019).

$$PC2 = (-0.025)\ CC + (-0.109)\ GE + (-0.573)\ PS + (0.471)\ RL + (-0.298)\ RQ + (0.588)\ VA$$

$$PC3 = (-0.086)\ CC + (-0.666)\ GE + (0.346) PS + (-0.249)\ RL + (0.265)\ RQ + (0.544)\ VA$$

Then, we add the values derived from the above three principal components in each year to construct institutional quality index for a panel of BRICS countries.

Table 4.4: Variables and its factor loadings in each principle component

Variable	PC 1	PC 2	PC 3	PC 4	PC 5	PC 6
CC	0.480	-0.025	-0.086	0.188	-0.843	-0.120
GE	0.419	-0.109	-0.666	-0.295	0.172	0.501
PS	0.356	-0.573	0.346	0.534	0.267	0.259
RL	0.406	0.471	-0.249	0.419	0.402	-0.460
RQ	0.431	-0.298	0.265	-0.619	0.159	-0.494
VA	0.339	0.588	0.544	-0.176	0.014	0.458

4.4. Empirical findings and discussion

4.4.1. Results of cross-sectional dependence (CD) test

Before commencing any econometric tests on panel data series, we better to verify whether a cross-sectional dependency exists or not. Further, conventional unit root tests can give invalid results in the presence of cross-sectional dependence. Therefore, in our study, we apply the Pesaran (2004) cross-sectional dependence (CD) test to examine the existence of the cross-sectional dependence among the variables. The results of CD test are reported in Table 4.5. It shows that the null hypothesis of cross-sectional independence is rejected at the 1% level of significance. Based on this result, we can observe that there is strong evidence of cross-sectional dependence in all selected variables.

Table 4.5: Cross-sectional dependence (CD) test results

Variables	CD-test	Prob
REC	7.468***	0.000
CO_2	22.510***	0.000
IQI	5.856***	0.000
PI	27.453***	0.000
NREC	26.722***	0.000
POP	7.593***	0.000

Notes: *** indicates the rejection of null hypothesis of cross-sectional independence (CD test) at the 1% significance level.

4.4.2. Results of panel unit root test

Next step, we employ the Pesaran (2007) cross-sectional augmented IPS (CIPS) test that accounts for cross-sectional dependence in the series. The CIPS results are documented in Table 4.6. These results reveal that the null hypothesis of unit root cannot be rejected for all the variables expect intuitional quality index and population. However, at the first difference, the null hypothesis of a unit root can be rejected at the 5% level of significance. The CIPS results suggest that all variables are non-stationary except intuitional quality index and population variables at levels, and all variables are became stationary at their first differences. Therefore, our results suggest that selected variables are followed the mixed order of integration, i.e., I (0) and I (1). However, instead of Pedroni and Fisher-Johanson cointegration tests, better to apply second-generation cointegration test like Westerlund (2007) panel cointegration test in the presence of cross-sectional dependence.

Table 4.6: Panel unit root test (CIPS) results

Variable	Level		First Difference	
	Zt-bar	Prob	Zt-bar	Prob
REC	6.978	1.000	-4.843***	0.000
CO_2	1.785	0.962	-3.502***	0.000
IQI	-3.813***	0.000	-5.296***	0.000
PI	2.700	0.996	-1.932**	0.026
NREC	1.394	0.918	-4.054***	0.000
POP	-11.728***	0.000	-3.182***	0.000

Notes: ** and *** indicate the rejection of null hypothesis of unit root at the 5% and 1% significance levels, respectively.

4.4.3. Results of panel cointegration test

We employ the Westerlund (2007) panel cointegration test on equations (4.1) and (4.2) to explore the long-run relationship among the variables. The results of this test are reported in Table 4.7. The findings of this study show that two statistics out of four are statistically significant at the 5% level. Based on these results, we can reject the null hypothesis of no-cointegration in equations (4.1) and (4.2). It implies that there is a long-run equilibrium association among the variables in our study.

Table 4.7: Westerlund (2007) cointegration test result

Test	Value	Z-value	P-value
	$REC = f\ (CO_2, POP, PI, IQI, NREC)$		
Gt	-3.157	-2.107	0.018**
Ga	-9.574	0.626	0.734
Pt	-6.071	-1.525	0.064*
Pa	-8.501	-0.132	0.448
	$CO_2 = f\ (POP, PI, IQI, NREC, REC)$		
Gt	-3.027	-1.822	0.034**
Ga	-6.245	1.595	0.945
Pt	-6.969	-2.260	0.012**
Pa	-5.508	0.710	0.761

Notes: * and ** indicates the rejection of no-cointegration null hypothesis at the 10% and 5% significance levels, respectively.

4.4.4. Results of long-run elasticities

This study applies the AMG estimations to examine the impact of selected independent variables on renewable energy consumption and CO_2 emissions in the BRICS countries. The findings of AMG long-run estimations are documented in Table 4.8.

The long-run estimates of renewable energy consumption reveal that a 1% increase in institutional quality raises 0.534% of renewable energy consumption, while a 1% increase in CO_2 emissions reduces renewable energy consumption by 0.393% in the BRICS countries. More specifically, CO_2 emissions have a negative impact on renewable energy consumption, while institutional quality has a positive effect on it. This result implies that increasing institutional quality significantly increases renewable energy consumption in a panel of BRICS countries. Therefore, governments and policymakers should strengthen the institutional quality to encourage the use of renewable energy in these emerging market economies. These findings are similar with Wu and Broadstock (2015) who found that intuitional quality (political stability) has a positive impact on renewable energy use in 22 emerging market economies.

The long-run estimates of CO_2emissions reveal that a 1% rise in non-renewable energy consumption increases CO_2emissions by 0.859 %, while institutional quality and renewable energy consumption reduce CO_2emissions by 0.120 and 0.050, respectively. These results clearly indicate that non-renewable energy has a significantly increases $CO_{2,}$ emissions, while institutional quality and renewable energy consumption mitigate CO_2 emissions in a panel of BRICS countries. These results suggest that these emerging market economies should strengthen institutional quality and promote renewable energy uses for a cleaner environment. Our findings are similar with Bhattacharya et al. (2017) who found that non-renewable energy use increases CO_2 emissions, and institutional quality and renewable energy reduce it in 85 developed and developing countries. More precisely, this outcome is in line with Danish et al. (2019a), Zakaria and Bibi (2019), and Hassan et al. (2020) who reported that institutional quality has a significant negative impact on CO_2 emissions in their studies. However, this finding is not similar with Hassan et al. (2020) who found that institutional quality significantly increases CO_2 emissions in Pakistan.

Table 4.8: Augmented Mean Group Estimations

Variable	Coefficient	Prob
	$REC = f\ (CO_2, POP, PI, IQI, NREC)$	
CO_2	-0.393**	0.058
POP	-0.777	0.738
PI	0.684	0.421
IQI	0.534***	0.001
NREC	0.525	0.133
	$CO_2 = f\ (POP, PI, IQI, NREC, REC)$	
POP	0.712	0.294
PI	0.132	0.436
IQI	-0.120**	0.027
NREC	0.859***	0.000
REC	-0.050	0.137

Notes: ** and *** indicate the significance levels at the 5% and 1%, respectively.

4.4.5. Time-series analysis of long-run renewable energy use and CO_2 emissions elasticities

In the above section, we already explored panel data analysis of long-run renewable energy consumption and CO_2emissions elasticities in a panel of BRICS countries. However, here we examine the long-run impact of independent variables on renewable energy consumption and CO_2emissions for each of the five individual BRICS countries. The country-specific results of the AMG estimator are reported in Table 4.9when renewable energy consumption is a dependent variable. These findings show that institutional quality has a significant positive impact on renewable energy consumption in four countries, i.e., Russia (0.544), India (0.734), China (0.596), South Africa (0.857) but it has a negative impact on renewable energy consumption in Brazil (-0.059). More specifically, a 1% increase in institutional quality will increases renewable energy use by 0.544% in Russia, 0.734% in India, 0.596% in China, and 0.857% in South Africa, while it reduces renewable energy use by 0.059% in Brazil. Likewise, economic growth has a positive impact on renewable energy use in Brazil (0.557), Russia (2.016), India (1.728), and China (1.688), while a negative impact in South Africa (-2.568).

Table 4.9: Country-wise AMG estimation results (Dependent variable: REC)

Country	Variable	CO_2	POP	PI	IQI	NREC
Brazil	Coefficient	-1.116***	3.745***	0.557***	-0.059***	1.141***
	Prob.	0.000	0.000	0.000	0.000	0.000
Russia	Coefficient	0.158	-8.068	2.016**	0.544**	-0.325
	Prob.	0.891	0.157	0.012	0.022	0.668
India	Coefficient	-0.209	-2.345***	1.728***	0.734**	0.170
	Prob.	0.481	0.005	0.000	0.069	0.652
China	Coefficient	-0.435	-1.938	1.688***	0.596***	0.096
	Prob.	0.106	0.360	0.000	0.000	0.789
South Africa	Coefficient	-0.364	4.722***	-2.568***	0.857**	1.542**
	Prob.	0.242	0.000	0.001	0.059	0.022

Notes: ** and *** indicate the significance levels at the 5% and 1%, respectively.

The country-specific outcomes of the AMG estimator are reported in Table 4.10 when CO_2emission is a dependent variable. It is found that institutional quality has a negative impact on CO_2 emission in Brazil (-0.016), Russia (-0.052), India (-0.308), and China (-0.179). More technically, a 1% increase in institutional quality reduces CO_2 emissions by 0.016% in Brazil, 0.052% in Russia, 0.308 in India, and 0.179% in China. However, we did not find any relationship between these two variables in South Africa. Similarly, renewable energy use significantly reduces CO_2 emissions by 0.164 in Brazil and 0.087 in India, but it increases CO_2 emissions by 0.026 in Russia. In the remaining countries, i.e., China and South Africa, renewable energy consumption does not have either a positive or negative impact on CO_2 emissions. The non-renewable energy consumption has a significant positive association with CO_2 emissions in all five individual BRICS countries. Finally, economic growth has a positive relation with CO_2 emissions in India. Finally, population reduces CO_2 emissions in India, while increases in China and South Africa.

The above results suggest that in all five countries (except Brazil) institutional quality has a positive impact on renewable energy consumption. It implies that these countries have a strong institutional quality that gives full access to information and political support from all the ways to frame and promoting uses of renewable energy. Brazil might have poor institutional quality, and it might not be supporting energy policy implications. Similarly, in all five BRICS countries (except South Africa), institutional quality significantly reduces CO_2 emissions. Therefore, the BRICS countries should strengthen their institutional quality in terms of government effeteness, no corruption, political stability, voice and accountability, quality of judiciary systems, and protection of property rights which help in framing and implementation of efficient energy and environmental policies. Further, non-renewable energy consumption increases CO_2 emissions in all individual countries, while renewable energy use significantly reduces it in Brazil and India. Therefore, the BRICS countries should design proper renewable energy policies to culminate CO_2 emissions by strengthening their institutional quality.

Table 4.10: Country-wise AMG estimation results (Dependent variable: CO_2)

Country	Variable	POP	PI	IQI	NREC	REC
Brazil	Coefficient	0.015	-0.015	-0.016***	1.039***	-0.164***
	Prob.	0.919	0.806	0.004	0.000	0.000
Russia	Coefficient	0.511	-0.017	-0.052**	0.594***	0.026***
	Prob.	0.253	0.667	0.018	0.000	0.005
India	Coefficient	-0.949***	0.808***	-0.308**	0.659***	-0.087**
	Prob.	0.000	0.000	0.029	0.000	0.042
China	Coefficient	3.145***	-0.116	-0.179***	0.990***	-0.006
	Prob.	0.000	0.102	0.000	0.000	0.833
South Africa	Coefficient	0.840***	0.004	-0.045	1.015**	-0.021
	Prob.	0.000	0.982	0.762	0.000	0.559

Notes: ** and *** indicate the significance levels at the 5% and 1%, respectively.

4.4.6. Panel causality test results

Since our results confirmed a long-run equilibrium association among the variables, we expect that there must be the existence of one-way directional causality. In this context, we apply the Dumistrescu- Hurlin (2012) panel causality test to explore the direction of causality among variables[7]. The results of Granger causality are presented in Table 4.11. The results show that renewable energy consumption Granger causes economic growth and bidirectional causality between renewable energy consumption and CO_2 emissions. This result is not line with Kutan et al. (2018) who found unidirectional causality from renewable energy consumption to CO_2 emissions in BICS countries. It implies that the rapidly rising demand for renewable energy not only achieve economic growth targets but also mitigate BRICS

[7] To apply this test, we require stationary data. But our variables have mixed order of integration, i.e. I (0) and I (1). Therefore, for the purpose of constituency in measurement of variables, we converted all selected variables into first difference before conducting panel Granger causality test. This procedure has been done by few studies (e.g., Adams et al. 2018; Hafeez et al.2018; Koçak and Şarkgüneşi, 2017;Paramati and Nguyen, 2019).

CO_2emissions in the future. Further, results reveal that bidirectional causality between institutional quality and population, and unidirectional causality running from non-renewable energy consumption to population and institutional quality. However, we did not establish any causal relationship between institutional quality, renewable energy consumption, and CO_2 emissions. These results are contrast with Saidi et al. (2020) and Hassan et al. (2020) who found that unidirectional causality from institutional quality to renewable energy consumption and bidirectional causality between institutional quality and CO_2 emissions in MENA countries and Pakistan, respectively. Overall, our short-run panel Granger causality test suggests that there is bidirectional causality between renewable energy use and CO_2 emissions. Still, it is the driving force of economic growth in the BRICS countries.

Table 4.11: Dumitrescu - Hurlin panel causality test results

Dependent Variable	Independent Variable					
	REC	CO_2	POP	PI	IQI	NREC
REC	-	1.925**	3.208	2.969	7.694	2.746
		(0.035)	(0.205)	(0.155)	(0.100)	(0.117)
CO_2	1.170***	-	3.798	3.463	6.703	11.827
	(0.009)		(0.376)	(0.271)	(0.317)	(2.E-0)
POP	1.835**	4.208	-	6.430	18.355***	1.879**
	(0.003)	(0.536)		(0.410)	(0.000)	(0.033)
PI	2.153**	3.790	7.605	-	5.180	3.365
	(0.051)	(0.374)	(0.113)		(0.990)	(0.244)
IQI	3.444	3.761	2.192**	2.942	-	1.545**
	(0.265)	(0.364)	(0.054)	(0.150)		(0.019)
NREC	7.356	3.118	3.523	5.675	2.677	-
	(0.154)	(0.185)	(0.288)	(0.739)	(0.107)	
Directional of causality: REC ↔ CO_2 , REC → PI, NREC → IQI, POP, IQI →POP						

Notes: ** and *** indicate the significance levels at the 5% and 1%, respectively.

4.5. Conclusion and policy implications

This Chapter has examined the impact of institutional quality on renewable energy consumption and CO_2 emissions in BRICS countries during the period 1996Q4-2016Q4. The study has used CD test for cross-sectional dependency, CIPS panel unit test for check the stationarity of the variables, the Westerlund (2007) panel cointegration test to explore the long-run relationship among the variables, and finally AMG estimations to examine the long-run impact of selected independent variables on renewable energy consumption and CO_2 emissions in the BRICS countries.

The main findings of the present study are as follows. First, the results of CD test have confirmed the strong cross-sectional dependence in all the selected variables due to globalization and financial integration in the world. Second, panel cointegration test has confirmed the long-run equilibrium association among the variables in both Equations (4.1) and (4.2). Third, panel AMG estimations have shown the institutional quality has a significant positive impact on renewable energy consumption, whileCO_2 emissions have a negative impact on it. Further, this study has indicated that non-renewable energy increases CO_2 emissions, while institutional quality and renewable energy consumption mitigate CO_2 emissions in a panel of BRICS countries. Fourth, panel Granger causality test has provided no causal relationship among the institutional quality, renewable energy consumption, and CO_2 emissions.

The empirical findings of this study have highlighted the following important policy implications: First, the institutional quality increases the use of renewable energy and reduces CO_2 emissions in BRICS countries. Therefore, these countries should strengthen the institutions to promote the use of renewable energy. Further, the development of strong quality institutions can help to reduce CO_2 emissions and improve the quality of environment. Second, the governments should increase the public awareness on the environmental issues, hence people will demand a clean environment that might increase institutional performance to promote renewable energy use. Third, having strong institutions in these BRICS countries can improve the quality of environment by good governance, quality of judiciary systems, protection of property rights, and absence of corruption. Fourth, better institutions, especially government effectiveness, control of corruption and political stability, can attract more foreign and domestic investment in renewable energy projects which eventually mitigates CO_2 emissions.

The present study has conducted on BRICS countries only. However, future studies can be examined on the impact of institutional quality on renewable energy consumption and CO_2 emissions in developed and developing countries. It helps to researchers to understand the larger impact of institutional quality. Furthermore, a future paper can also look into the role of institutional quality in renewable energy use and CO_2 emissions in democracy and non-democracy countries in the world.

Table 4.1: Institutional quality variables considered by previous studies

Study	Indicators	Source
Part A: In nexus with renewable energy consumption		
Apergis and Eleftheriou (2015)	Size of government, Legal system and property rights, Freedom to trade internationally, Regulation level.	Economic Freedom
Wu and Broadstock (2015)	Political stability and absence of violence, Voice and accountability, Regulatory quality	Global Insight
Bhattacharya et al. (2017)	Economic Freedom Index	Freedom House
Saidi et al (2019)	Corruption, Bureaucracy quality, Democracy accountability, Law and order, Ethnic tensions	ICRG
Part B: In nexus with CO_2 emissions		
Tamazian and Rao (2010)	Democracy, Rule of law	Freedom House
Ibrahim and Law (2016)	Safety and rule of Law, Participation and human Right, Sustainable economic opportunity, Human development	IIAG
Solarin et al. (2017b)	Political rights, Civil liberties	Freedom House
Gani (2012)	Control of corruption, Government effectiveness, Political stability, Regulatory quality, Rule of law.	World Bank
Zhang et al (2012)	Corruption, Democracy	ICRG
Halkos and Tzeremes (2013)	Control of corruption, Government effectiveness, Political stability and absence of violence, Regulatory quality, Rule of law, Voice and accountability	World Bank
Lau et al. (2014)	Law and order	ICRG
Abid (2016)	Control of corruption, Government effectiveness, Political stability and absence of violence, Regulatory quality, Rule of law, Democracy	World Bank, Freedom House
Abid (2017)	Control of corruption, Government effectiveness, Political stability and absence of violence, Regulatory quality, Rule of law.	World Bank
Bhattacharya et al. (2017)	Economic Freedom Index	Freedom House
Zakaria and Bibi (2019)	Corruption	ICRG
Salman et al (2019)	Law and order	ICRG
Ali (2019)	Corruption, Bureaucracy quality, Rule of law	ICRG
Danish et al (2019a)	Control of corruption, Government effectiveness, Political stability and absence of violence, Regulatory quality, Rule of law, Voice and accountability	World Bank
Hassan et al (2020)	12 Political risk indicators	ICRG

Source: Author's own compilations

Chapter 5

Summary, Findings and Conclusion

5.1. Summary

Energy plays a significant role in any economy. To continue economic growth, any country should depend on energy consumption along with capital and labor. However, it leads to a puzzle between increasing energy consumption for higher economic growth and a negative impact of conventional energy sources on environmental quality. The high degree of energy consumption in the economy emits various types of greenhouse gases, which have a severe impact on climate change. Therefore, it could cause for energy conservation policies and promotion of renewable energy use. Renewable energy plays a vital role in giving a solution for environmental damage and sustainable economic development. It can meet the demand for energy in the worldwide. It is widely believed that the use of renewable energy sources, i.e., zero-carbon energy, not only improve the economic performance but also ensuring energy security. Therefore, given the significant importance of renewable energy use, both developed and developing economies have shifted their focus on reducing greenhouse gas emissions by minimizing the use of fossil fuel, replacing with renewable energy sources in the economic activities. Hence, the utilization of renewable energy sources in the industrial sector has improved as it has been used for power generation and reduction in CO_2 emissions. Further, the international organizations are also completing developed and developing countries to reduce CO_2 emissions.

The BRICS countries are not free from the problem of CO_2 emissions. These countries are the world's superpower in economic growth, the largest energy consumers, and CO_2emitters. To become world's superpower, these countries are heavily depended on conventional energy consumption, which results in generating CO_2 emissions. To overcome a negative impact of CO_2 emissions, these countries are witnessing energy transformation from conventional to non-conventional energy sources. Further, with the establishment of a zero-carbon economy with the development of clean and renewable energy, countries should have a good institutional quality that is more important in energy security and environmental protection and the sustainable development of economy. In the light of the importance of renewable and clean energy use, and institutional quality, this study has empirically examined the three objectives. The main three objectives of the thesis are:

1. to examine the impact of clean energy consumption on economic growth and CO_2 emissions in BRICS countries in the context of the environmental Kuznets curve,
2. to examine the nexus among the hydropower energy consumption, economic growth, and CO_2 emissions in BRICS countries, and
3. to evaluate whether the institutional quality matters on renewable energy consumption and CO_2 emissions.

The entire thesis is organized into five chapters. Chapter 2 to 4 are the core chapters where the main objectives are empirically examined. Chapter 1 provides an introduction, overview of issues, motivation and research questions, institutional background, objectives of the thesis, data and methodology, and organization of the thesis. Chapter 2 explores the first empirical study, on the impact of clean energy consumption on economic growth and CO_2 emissions. More precisely, it deals with the effects of clean energy use on economic growth and CO_2 emissions and verifies the existence of the EKC hypothesis. For the empirical analysis, it utilized the Johanson Fisher panel cointegration test, panel FMOLS estimates, and Dumistrescu-Hurlin (2012) panel causality test. Chapter 3 provides the second empirical study, on nexus among hydropower energy consumption, economic growth, and CO_2 emissions. More specifically, the impact of hydropower energy consumption on economic growth and CO_2 emissions in the BRICS countries. For that we utilized panel ARDL model propounded by Pesaran et al. (1999) and panel quantile regression. Chapter 4 discussed the third and final empirical study, the impact of institutional quality on renewable energy use and CO_2 emissions. For that, this study used Westerlund (2007) panel cointegration test, Augmented Mean Group (AMG) estimator (Eberhardt and Bond, 2009; Eberhardt and Teal, 2010), and Dumitrescu and Hurlin (2012)panel causality test.

5.2. Major findings

The empirical results of Chapter 2 declared that, in the long-run, energy consumption, clean energy consumption, capital have a significant positive impact on economic growth, while CO_2 emissions have a negative impact on economic growth. Economic growth and energy consumption increase CO_2 emissions, but clean energy use significantly reduces CO_2 emissions. Further, results established the existence of the EKC hypothesis. Finally, the study found no causal nexus between clean energy consumption and economic growth in the BRICS countries.

Chapter-3 findings illustrate that hydropower energy consumption, CO_2 emissions and, population have a positive impact on economic growth. However, hydropower energy consumption and population have a negative impact on CO_2 emissions, while economic growth is positively contributing to CO_2 emissions in the long-run. In the short-run, hydropower energy consumption has a positive association with economic growth, while hydropower energy consumption and population have a negative association with CO_2 emissions, and economic growth has a positive impact on it at the insignificant level. Furthermore, panel quantile regression results indicate that the effects of independent variables on economic growth and CO_2 emissions are heterogeneous across the quantiles.

Finally, the main findings of Chapter-4 show that institutional quality increases renewable energy consumption, while CO_2 emissions reduce it. The results also reveal that non-renewable energy consumption increases CO_2 emissions, while institutional quality and renewable energy consumption significantly reduce CO_2 emissions. Finally, the study did not establish any causal relationship between institutional quality, renewable energy consumption, and CO_2 emissions in the BRISC countries.

5.3. Policy implications

The study has drawn important policy implications based on these three empirical studies. In the case of Chapter 2, the BRICS governments and policy makers should support the development of clean energy so that it not only meets the demand for energy but also combats CO_2. Second, to accelerate and development of clean energy, these emerging market economies should share their knowledge and expertise, strengthen the rules and regulations, and collaborating research, development and demonstration (RD&D) activities. Third, the BRICS countries should attract more domestic and foreign investment in clean energy projects. These investments give a boost to the development, deployment, and integration of clean energy technologies, which bring two benefits of stimulating economic growth and accelerating clean energy transitions. Fourth, they should improve technological innovation in three economic activities (namely, agriculture, industry, and services) to reduce CO_2 emissions.

In the case of Chapter 3, hydropower energy consumption is considered as an essential driver to achieve rapid economic growth, and it also helps in mitigating CO_2 emissions in the BRICS countries. (i) Therefore, governments and policymakers should frame appropriate policies in favour of the deployment of hydropower energy projects. (ii) Any conservation hydropower energy policies will have a negative impact on economic growth. Therefore expansionary of hydropower energy policies are useful for the BRICS countries. (iii) Since expansionary hydropower energy policies are beneficial to the countries, it should be considered as a feasible policy and also substituting it for fossil fuel to mitigate CO_2 emissions. (iv) Policy makers should also promote hydropower energy generation and consumption by introducing appropriate incentives, i.e., tax rebates and subsidies. Due to these incentives, producers and users can significantly promote the development of hydropower energy. (v) Financing in hydropower energy projects through the stock market developments, foreign direct investment and, official development assistance will promote the hydropower energy generation, which is a solution for addressing global warming and climate change. (vi) Governments of the BRICS countries should encourage public-private partnership investments in hydropower energy projects. (vii) These economies should also introduce investment subsidies and tax incentives to attract investors in energy projects to ensure energy security and stability. (viii) Establish long-run confidence indications to create foster confidence among the investors. (ix) These countries should promote R & D and share their knowledge of increasing hydropower energy generation. (x) As suggested by the Paris summit, developed countries should do financial support to developing countries, and BRICS development bank also increases more funds and allocate among the BRICS countries for adaption of innovations and technologies in hydropower energy generation and mitigate CO_2 emissions. Finally, since hydropower energy use promotes economic growth and mitigate CO_2emissions, the BRICS countries should follow the expansionary hydropower policies for better sustainable economies in the world.

Finally, empirical findings of Chapter 4 highlight the following important policy implications: First, the institutional quality increases the use of renewable energy and reduces CO_2 emissions in BRICS countries. Therefore, these countries should strengthen the institutions to promote the use of renewable energy. Further, the development of strong quality institutions can help to reduce CO_2 emissions and improve the quality of environment. Second, the governments should increase public awareness on environmental issues; hence people will demand a clean environment that might increase institutional performance to promote renewable energy use. Third, having strong institutions in these BRICS countries can improve the quality of environment by good governance, quality of judiciary systems, protection of property rights, and absence of corruption. Fourth, better institutions, especially government effectiveness, control of corruption, and political stability, can attract more foreign and domestic investment in renewable energy projects, which eventually mitigates CO_2 emissions.

5.4. Limitations of the study

The main limitations of Chapter-2 to 4 are that we have conducted on only one region of the world, i.e., BRICS countries. The reason for selecting a group of BRICS is that it is a group of emerging countries with rapid energy consumption and CO_2 emissions in the world, and the empirical results are very useful to policymakers and governmental officials. Consistent and comparable data on some variables are not available. For instance, longer period data on clean energy consumption and institutional quality indicators are not available. Further, this thesis has not included other variables that can influence the variables in the models.

5.5 Directions for future research

In spite of the above limitations, this thesis makes a significant contribution in the energy economic literature. In the case of hydropower energy consumption, future studies should be conducted on developed and developing counties to capture the larger impact of hydropower energy consumption, including other variables like institutional quality, research and development (R&D), and financial development in the model. In the case of clean energy use, a future study can be considered clean energy consumption at the disaggregated level (i.e., nuclear, hydro, wind, and solar) for both developed and developing countries. Finally, future studies can be conducted on the effect of institutional quality on renewable energy consumption and CO_2 emissions in developed and developing countries. Furthermore, future research may be conducted on the role of institutional quality in renewable energy use and CO_2 emissions in democracy and non-democracy countries in the world.

References

Abakah, E. M (1993). A review of economic growth and energy consumption in a developing country: Ghana. *OPEC Energy Review*, 17(1): 47-61.

Abdouli, M., Kamoun, O., & Hamdi, B. (2018). The impact of economic growth, population density, and FDI inflows on CO_2 emissions in BRICTS countries: Does the Kuznets curve exist? *Empirical Economics*, 54(4): 1717-1742.

Abid, M. (2016). Impact of economic, financial, and institutional factors on CO_2 emissions: Evidence from Sub-Saharan Africa economies. *Utilities Policy*, 41: 85-94.

Abid, M. (2017). Does economic, financial and institutional developments matter for environmental quality? A comparative analysis of EU and MEA countries. *Journal of Environmental Management*, 188: 183-194.

Adams, S., Klobodu, E. K. M., & Apio, A. (2018). Renewable and non-renewable energy, regime type and economic growth. *Renewable Energy*, 125: 755-767.

Alam, M. S., & Paramati, S. R. (2015). Do oil consumption and economic growth intensify environmental degradation? Evidence from developing economies. *Applied Economics*, 47(48): 5186-5203.

Alam, M. S., Miah, M. D., Hammoudeh, S., & Tiwari, A. K. (2018). The nexus between access to electricity and labour productivity in developing countries. *Energy Policy*, 122: 715-726.

Alam, M. S., Paramati, S. R., Shahbaz, M., & Bhattacharya, M. (2017). Natural gas, trade and sustainable growth: empirical evidence from the top gas consumers of the developing world. *Applied Economics*, 49(7): 635-649.

Alam, M.S., Paramati, S.R., Shahbaz, M., & Bhattacharya, M. (2015). Dynamics of natural gas consumption, output and trade: Empirical evidence from the emerging economies. Discussion paper 21/15, Department of Economics, Monash University.

Ali, H. S., Zeqiraj, V., Lin, W. L., Law, S. H., Yusop, Z., Bare, U. A. A., & Chin, L. (2019). Does quality institutions promote environmental quality? *Environmental Science and Pollution Research*, 26(11): 10446-10456.

Apergis, N., & Eleftheriou, S. (2015). Renewable energy consumption, political and institutional factors: Evidence from a group of European, Asian and Latin American countries. *The Singapore Economic Review*, 60(01): 1-19.

Apergis, N., & Payne, J. E. (2010a). Renewable energy consumption and economic growth: Evidence from a panel of OECD countries. *Energy Policy*, 38(1): 656-660.

Apergis, N., & Payne, J. E. (2010b). Renewable energy consumption and growth in Eurasia. *Energy Economics,* 32(6): 1392-1397.

Apergis, N., & Payne, J. E. (2011). The renewable energy consumption–growth nexus in Central America. *Applied Energy,* 88(1): 343-347.

Apergis, N., Can, M., Gozgor, G., & Lau, C. K. M. (2018). Effects of export concentration on CO_2 emissions in developed countries: An empirical analysis. *Environmental Science and Pollution Research*, 25(14): 14106-14116.

Apergis, N., Chang, T., Gupta, R., & Ziramba, E. (2016). Hydroelectricity consumption and economic growth nexus: Evidence from a panel of ten largest hydroelectricity consumers. *Renewable and Sustainable Energy Reviews,* 62: 318-325.

Aslan, A., & Çam, S. (2013). Alternative and nuclear energy consumption–economic growth nexus for Israel: Evidence based on bootstrap-corrected causality tests. *Progress in Nuclear Energy*, 62: 50-53.

Banerjee, A., Marcellino, M., Osbat, C. (2004). Some cautions on the use of panel methods for integrated series of macroeconomic data. *Econometrics Journal,* 7(2): 322-340.

Ben Aïssa, M. S., Ben Jebli, M., & Ben Youssef, S. (2014). Output, renewable energy consumption and trade in Africa. *Energy Policy,* 66: 11-18.

Bhattacharya, M., Awaworyi Churchill, S., & Paramati, S. R. (2017). The dynamic impact of renewable energy and institutions on economic output and CO_2 emissions across regions. *Renewable Energy*, 111: 157-167.

Bhattacharya, M., Paramati, S. R., Ozturk, I., & Bhattacharya, S. (2016). The effect of renewable energy consumption on economic growth: Evidence from top 38 countries. *Applied Energy*, 162: 733-741.

Bildirici, M. (2016). The relationship between hydropower energy consumption and economic growth. *Procedia Economics and Finance,* 38: 264-270.

Bildirici, M. E. (2014). Hydropower energy consumption, environmental pollution, and economic growth. *The Journal of Energy and Development,* 40(1/2): 189-208.

Bildirici, M. E., & Gökmenoğlu, S. M. (2017). Environmental pollution, hydropower energy consumption and economic growth: Evidence from G7 countries. *Renewable and Sustainable Energy Reviews,* 75: 68-85.

Bilgili, M., Bilirgen, H., Ozbek, A., Ekinci, F., & Demirdelen, T. (2018). The role of hydropower installations for sustainable energy development in Turkey and the world. *Renewable Energy,* 126: 755-764.

Bloomberg New Energy Finance, 2015. Global trends in renewable energy investment, Report, Frankfurt School-UNEP Centre.

Boutabba, M. A. (2014). The impact of financial development, income, energy and trade on carbon emissions: Evidence from the Indian economy. *Economic Modelling*, 40: 33-41.

BP Statistical Review of World Energy (2017). BP statistical review of world energy. London.

BP Statistical Review of World Energy (2018). BP statistical review of world energy. London.

BP Statistical Review of World Energy (2019). BP statistical review of world energy. London.

BRICS Energy Indicators (2015), BRICS Energy Indicators, Ministry of Mines and Energy, Namibia. Retrived from http://www.mme.gov.br/documents/10584/3580500/06+-+BRIC+Energy+Indicators+%28year+-+2015%29+%28PDF%29/470882ae-364b-4d37-8463-8f1220016315?version=1.2.

Cai, Y., Sam, C. Y., & Chang, T. (2018). Nexus between clean energy consumption, economic growth and CO_2 emissions. *Journal of Cleaner Production*, 182: 1001-1011.

Canay, I. A. (2011). A simple approach to quantile regression for panel data. *The Econometrics Journal*, 14(3): 368-386.

Carbon Brief, 2015. Paris 2015: tracking country climate pledges. Available at: https://www.carbonbrief.org/paris-2015-tracking-country-climate-pledges

Chakravarty D, & Mandal, S-K. (2016) Estimating the relationship between economic growth and environmental quality for the BRICS economies-a dynamic panel data approach. *Journal of Developing Areas*, 50(5): 119–130.

Chang, M.-C. (2015). Room for improvement in low carbon economies of G7 and BRICS countries based on the analysis of energy efficiency and environmental Kuznets curves. *Journal of Cleaner Production*, 99: 140-151.

Danish, Baloch, M. A., & Wang, B. (2019a). Analyzing the role of governance in CO_2 emissions mitigation: The BRICS experience. *Structural Change and Economic Dynamics*, 51: 119-125

Danish, Baloch, M. A., Mahmood, N., & Zhang, J. W. (2019b). Effect of natural resources, renewable energy and economic development on CO_2 emissions in BRICS countries. *Science of The Total Environment*, 678: 632-638.

Danish, Wang, B., & Wang, Z. (2018). Imported technology and CO_2 emission in China: Collecting evidence through bound testing and VECM approach. *Renewable and Sustainable Energy Reviews*, 82: 4204-4214.

Dogan, E. (2015). The relationship between economic growth and electricity consumption from renewable and non-renewable sources: A study of Turkey. *Renewable and Sustainable Energy Reviews,* 52: 534-546.

Dogan, E., Seker, F., & Bulbul, S. (2017). Investigating the impacts of energy consumption, real GDP, tourism and trade on CO_2 emissions by accounting for cross-sectional dependence: A panel study of OECD countries. *Current Issues in Tourism,* 20(16): 1701-1719.

Dong, K., Sun, R., & Hochman, G. (2017). Do natural gas and renewable energy consumption lead to less CO_2 emission? Empirical evidence from a panel of BRICS countries. *Energy*, 141: 1466-1478.

Dong, K., Sun, R., Jiang, H., & Zeng, X. (2018). CO_2 emissions, economic growth, and the environmental Kuznets curve in China: What roles can nuclear energy and renewable energy play? *Journal of Cleaner Production*, 196: 51-63.

Dumitrescu, E.-I., & Hurlin, C. (2012). Testing for Granger non-causality in heterogeneous panels. *Economic Modelling*, 29(4): 1450-1460.

Eberhardt, M., & Bond, S. (2009). Cross-section dependence in nonstationary panel models: A novel estimator. MPRA paper 17692. University Library of Munich. Germany.

Eberhardt, M., & Teal, F. (2010). Productivity analysis in global manufacturing production. Economics Series, Working Papers: 515. University of Oxford Department of Economics.

EIA, 2015. Annual Energy Outlook 2015 with Projections to 2040. U.S. Energy Information Administration, United States.

Fang, J., Gozgor, G., Lu, Z., & Wu, W. (2019). Effects of the export product quality on carbon dioxide emissions: evidence from developing economies. *Environmental Science and Pollution Research*, 26(12): 12181-12193.

Gani, A. (2012). The relationship between good governance and carbon dioxide emission: Evidence from developing economies. *Journal of Economic Development,* 37(1): 77-93.

Govindaraju, C, V. G. R., & Tang, C. F. (2013). The dynamic links between CO_2 emissions, economic growth and coal consumption in China and India. *Applied Energy*, 104: 310-318.

Gozgor, G. (2016). Are shocks to renewable energy consumption permanent or transitory? An empirical investigation for Brazil, China, and India. *Renewable and Sustainable Energy Reviews*, 66: 913-919.

Gozgor, G. (2018). A new approach to the renewable energy-growth nexus: evidence from the USA. *Environmental Science and Pollution Research*, 25(17): 16590-16600.

Gozgor, G., & Can, M. (2017). Does export product quality matter for CO_2 emissions? Evidence from China. *Environmental Science and Pollution Research*, 24(3): 2866-2875.

Gozgor, G., Lau, C. K. M., & Lu, Z. (2018). Energy consumption and economic growth: New evidence from the OECD countries. *Energy*, 153: 27-34.

Hafeez, M., Chunhui, Y., Strohmaier, D., Ahmed, M., & Jie, L. (2018). Does finance affect environmental degradation: evidence from One Belt and One Road Initiative region? *Environmental Science and Pollution Research*, 25(10): 9579-9592.

Halkos, G. E., & Tzeremes, N. G. (2013). Carbon dioxide emissions and governance: A nonparametric analysis for the G-20. *Energy Economics*, 40: 110-118.

Hamit-Haggar, M. (2016). Clean energy-growth nexus in sub-Saharan Africa: Evidence from cross-sectionally dependent heterogeneous panel with structural breaks. *Renewable and Sustainable Energy Reviews*, 57: 1237-1244.

Hassan, S. T., Danish, Khan, S. U.-D., Xia, E., & Fatima, H. (2020). Role of institutions in correcting environmental pollution: An empirical investigation. *Sustainable Cities and Society*, 53: 1-7.

Hsiao, C. (2007). Panel data analysis—advantages and challenges. TEST, 16(1): 1-22.

Hübler, M. (2017). The inequality-emissions nexus in the context of trade and development: A quantile regression approach. *Ecological Economics*, 134: 174-185.

Ibrahim, M. H., & Law, S. H. (2016). Institutional quality and CO_2 emission–trade relations: Evidence from Sub-Saharan Africa. *South African Journal of Economics*, 84(2): 323-340.

IEO, 2016. International Energy Outlook, U.S. International Energy Administration. Washington, DC.

IHA, 2019. International Hydropower Association, Hydropower Status Report, Sutton., United Kingdom.

Im, K. S., Pesaran, M. H., & Shin, Y. (2003). Testing for unit roots in heterogeneous panels. *Journal of Econometrics*, 115(1): 53-74.

Inglesi-Lotz, R. (2016). The impact of renewable energy consumption to economic growth: A panel data application. *Energy Economics*, 53: 58-63.

International Energy Outlook (2013), IEO, U.S. International Energy Administration. Washington, DC.

International Energy Outlook (2016), IEO, U.S. International Energy Administration. Washington, DC.

IPCC, 2011. IPCC Special Report Renewable Energy Sources. Abu Dhabi, United Arab Emirates.

IRENA, 2015. International Renewable Energy Agency. Renewable 2015 global status report.

Ito, K. (2017). CO_2 emissions, renewable and non-renewable energy consumption, and economic growth: Evidence from panel data for developing countries. *International Economics*, 151: 1-6.

Jayanthakumaran, K., Verma, R., & Liu, Y. (2012). CO_2 emissions, energy consumption, trade and income: A comparative analysis of China and India. *Energy Policy*, 42: 450-460.

Johansen, S. (1988). Statistical analysis of cointegration vectors. *Journal of Economic Dynamics and Control*, 12(2): 231-254.

Jolliffe, I.T., 2002. *Principal Component Analysis*. Springer, New York.

Koçak, E., & Şarkgüneşi, A. (2017). The renewable energy and economic growth nexus in Black Sea and Balkan countries. *Energy Policy*, 100: 51-57.

Koenker, R. (2004). Quantile regression for longitudinal data. *Journal of Multivariate Analysis*, 91(1): 74-89.

Kohler, M. (2013). CO_2 emissions, energy consumption, income and foreign trade: A South African perspective. *Energy Policy*, 63: 1042-1050.

Kutan, A. M., Paramati, S. R., Ummalla, M., & Zakari, A. (2018). Financing renewable energy projects in major emerging market economies: Evidence in the perspective of sustainable economic development. *Emerging Markets Finance and Trade*, 54(8): 1761-1777.

Lau, E., Tan, C.-C., & Tang, C.-F. (2016). Dynamic linkages among hydroelectricity consumption, economic growth, and carbon dioxide emission in Malaysia. *Energy Sources, Part B: Economics, Planning, and Policy*, 11(11): 1042-1049.

Lau, L.-S., Choong, C.-K., & Eng, Y.-K. (2014). Carbon dioxide emission, institutional quality, and economic growth: Empirical evidence in Malaysia. *Renewable Energy*, 68: 276-281.

Levin, A., Lin, C.-F., & James Chu, C.-S. (2002). Unit root tests in panel data: asymptotic and finite-sample properties. *Journal of Econometrics,* 108(1): 1-24.

Lin, B., & Moubarak, M. (2014). Renewable energy consumption – Economic growth nexus for China. *Renewable and Sustainable Energy Reviews,* 40: 111-117.

Maddala, G. S., & Wu, S. (1999). A comparative study of unit root tests with panel data and a new simple test. *Oxford Bulletin of Economics and Statistics*, 61(S1): 631-652.

Maji, I. K. (2015). Does clean energy contribute to economic growth? Evidence from Nigeria. *Energy Reports*, 1(0): 145-150.

Mallick, L., Ummalla, M., & Jaganath, B. (2016). Does tourism affect economic growth in Indian states? Evidence from panel ARDL model. *Theoretical and Applied Economics*, 23(1): 183-194.

Marques, A. C., & Fuinhas, J. A. (2012). Is renewable energy effective in promoting growth? *Energy Policy*, 46: 434-442.

Menegaki, A. N. (2011). Growth and renewable energy in Europe: A random effect model with evidence for neutrality hypothesis. *Energy Economics*, 33(2): 257-263.

Menyah, K., Nazlioglu, S., & Wolde-Rufael, Y. (2014). Financial development, trade openness and economic growth in African countries: New insights from a panel causality approach. *Economic Modelling*, 37: 386-394.

Mirshojaeian Hosseini, H., & Kaneko, S. (2011). Dynamic sustainability assessment of countries at the macro level: A principal component analysis. *Ecological Indicators*, 11(3): 811-823.

Mirshojaeian Hosseini, H., & Kaneko, S. (2012). Causality between pillars of sustainable development: Global stylized facts or regional phenomena? *Ecological Indicators*, 14(1): 197-201.

Ocal, O., & Aslan, A. (2013). Renewable energy consumption–economic growth nexus in Turkey. *Renewable and Sustainable Energy Reviews,* 28: 494-499.

OECD (2008), Handbook on constructing composite indicators: Methodology and user guide. OECD Publishing, Paris.

Ohler, A., & Fetters, I. (2014). The causal relationship between renewable electricity generation and GDP growth: A study of energy sources. *Energy Economics*, 43: 125-139.

Okafor, Harrison O. (2012). Testing the relationship between energy consumption and economic growth: Evidence from Nigeria and South Africa. *Journal of Economics and Sustainable Development*, 3(11): 111-124.

Pao, H.-T., & Tsai, C.-M. (2010). CO_2 emissions, energy consumption and economic growth in BRIC countries. *Energy Policy,* 38(12): 7850-7860.

Pao, H.-T., & Tsai, C.-M. (2011a). Modeling and forecasting the CO_2 emissions, energy consumption, and economic growth in Brazil. *Energy*, 36(5): 2450-2458.

Pao, H.-T., & Tsai, C.-M. (2011b). Multivariate Granger causality between CO_2 emissions, energy consumption, FDI (foreign direct investment) and GDP (gross domestic product): Evidence from a panel of BRIC (Brazil, Russian Federation, India, and China) countries. *Energy*, 36(1): 685-693.

Pao, H.-T., Li, Y.-Y., & Hsin-Chia, F. (2014). Clean energy, non-clean energy, and economic growth in the MIST countries. *Energy Policy*, 67: 932-942.

Pao, H.-T., Yu, H.-C., & Yang, Y.-H. (2011). Modeling the CO_2 emissions, energy use, and economic growth in Russia. *Energy,* 36(8): 5094-5100.

Papyrakis, E., & Gerlagh, R. (2007). Resource abundance and economic growth in the United States. *European Economic Review*, 51(4): 1011-1039.

Paramati, S. R., & Nguyen, T. P. T. (2019). Does financial market growth improve income distribution? A comparison of developed and emerging market economies of the global sample. *International Journal of Finance & Economics,* 24(1): 629-646.

Paramati, S. R., Apergis, N., & Ummalla, M. (2017a). Financing clean energy projects through domestic and foreign capital: The role of political cooperation among the EU, the G20 and OECD countries. *Energy Economics*, 61: 62-71.

Paramati, S. R., Apergis, N., & Ummalla, M. (2018a). Dynamics of renewable energy consumption and economic activities across the agriculture, industry, and service sectors: evidence in the perspective of sustainable development. *Environmental Science and Pollution Research,* 25(2): 1375-1387.

Paramati, S. R., Bhattacharya, M., Ozturk, I., & Zakari, A. (2018b). Determinants of energy demand in African frontier market economies: An empirical investigation. *Energy*, 148: 123-133.

Paramati, S. R., Mo, D., & Gupta, R. (2017b). The effects of stock market growth and renewable energy use on CO_2 emissions: Evidence from G20 countries. *Energy Economics,* 66: 360-371.

Paramati, S. R., Sinha, A., & Dogan, E. (2017c). The significance of renewable energy use for economic output and environmental protection: evidence from the Next 11 developing economies. *Environmental Science and Pollution Research*, 24(15): 13546-13560.

Paramati, S. R., Ummalla, M., & Apergis, N. (2016). The effect of foreign direct investment and stock market growth on clean energy use across a panel of emerging market economies. *Energy Economics,* 56: 29-41.

Pedroni, P. (2001a). Fully modified OLS for heterogeneous cointegrated panels. In T. B. F. Badi H. Baltagi, R. Carter Hill (Ed.), Nonstationary Panels, Panel Cointegration, and Dynamic Panels (Vol. 15, pp. 93-130): Emerald Group Publishing.

Pedroni, P. (2001b). Purchasing power parity tests in cointegrated panels. *The Review of Economics and Statistics*, 83(4): 727–731.

Pedroni, P. (2004). Panel cointegration: Asymptotic and finite sample properties of pooled time series tests with an application to the PPP hypothesis. *Econometric Theory*, 20(3): 597-625.

Pesaran, M. H. (2004). General diagnostic tests for cross section dependence in panels. Working paper. University of Cambridge.

Pesaran, M. H. (2007). A simple panel unit root test in the presence of cross-section dependence. *Journal of Applied Econometrics,* 22(2): 265-312.

Pesaran, M. H., Shin, Y., & Smith, R. P. (1999). Pooled mean group estimation of dynamic heterogeneous panels. *Journal of the American Statistical Association,* 94(446): 621-634.

Pradhan, R. P., Arvin, M. B., & Hall, J. H. (2019). The nexus between economic growth, stock market depth, trade openness, and foreign direct investment: The case of Asian countries. *The Singapore Economic Review*, 64(03): 461-493.

Pradhan, R. P., Mukhopadhyay, B., Gunashekar, A., Samadhan, B., & Pandey, S. (2013). Financial development, social development, and economic growth: the causal nexus in Asia. *Decision*, 40(1): 69-83.

Rafiq, S., Bloch, H., & Salim, R. (2014). Determinants of renewable energy adoption in China and India: a comparative analysis. *Applied Economics*, 46(22): 2700-2710.

Renewable Energy Policy Network for the 21 Century (REN21), 2016. Renewables 2016 Global Status Report, REN21, Paris.

Sadorsky, P. (2009). Renewable energy consumption and income in emerging economies. *Energy Policy,* 37(10): 4021-4028.

Saidi, H., El Montasser, G., & Ajmi, A. N. (2020). The role of institutions in the renewable energy-growth nexus in the MENA region: A panel cointegration approach. *Environmental Modeling & Assessment, 25*(2): 259-276.

Saidi, K., & Ben Mbarek, M. (2016). Nuclear energy, renewable energy, CO_2 emissions, and economic growth for nine developed countries: Evidence from panel Granger causality tests. *Progress in Nuclear Energy,* 88: 364-374.

Salim, R. A., & Rafiq, S. (2012). Why do some emerging economies proactively accelerate the adoption of renewable energy?.*Energy Economics*, 34(4): 1051-1057.

Salim, R. A., Hassan, K., & Shafiei, S. (2014). Renewable and non-renewable energy consumption and economic activities: Further evidence from OECD countries. *Energy Economics,* 44: 350-360.

Salman, M., Long, X., Dauda, L., & Mensah, C. N. (2019). The impact of institutional quality on economic growth and carbon emissions: Evidence from Indonesia, South Korea and Thailand. *Journal of Cleaner Production*, 241: 118331.

Shahbaz, M., Arouri, M., & Teulon, F. (2014). Short- and long-run relationships between natural gas consumption and economic growth: Evidence from Pakistan. *Economic Modelling*, 41: 219-226.

Shahbaz, M., Loganathan, N., Zeshan, M., & Zaman, K. (2015). Does renewable energy consumption add in economic growth? An application of auto-regressive distributed lag model in Pakistan. *Renewable and Sustainable Energy Reviews,* 44: 576-585.

Sharif, A., Raza, S. A., Ozturk, I., & Afshan, S. (2019). The dynamic relationship of renewable and non-renewable energy consumption with carbon emission: A global study with the application of heterogeneous panel estimations. *Renewable Energy*, 133: 685-691.

Solarin, S. A., & Ozturk, I. (2015). On the causal dynamics between hydroelectricity consumption and economic growth in Latin America countries. *Renewable and Sustainable Energy Reviews,* 52: 1857-1868.

Solarin, S. A., Al-Mulali, U., & Ozturk, I. (2017a). Validating the environmental Kuznets curve hypothesis in India and China: The role of hydroelectricity consumption. *Renewable and Sustainable Energy Reviews,* 80: 1578-1587.

Solarin, S. A., Al-Mulali, U., Musah, I., & Ozturk, I. (2017b). Investigating the pollution haven hypothesis in Ghana: An empirical investigation. *Energy*, 124: 706-719.

Song, R., W. Dong, J. Zhu, X. Zhao, and Y. Wang. 2015. Assessing implementation of China's climate policies in the 12th 5-Year Period. Working Paper. Washington, DC: World Resources Institute.

Sternberg (2010). Hydropower's future, the environment, and global electricity systems. *Renewable and Sustainable Energy Reviews*, 14(2): 713-723.

Tamazian, A., & Bhaskara Rao, B. (2010). Do economic, financial and institutional developments matter for environmental degradation? Evidence from transitional economies. *Energy Economics*, 32(1): 137-145.

Tamazian, A., Chousa, J. P., & Vadlamannati, K. C. (2009). Does higher economic and financial development lead to environmental degradation: Evidence from BRIC countries. *Energy Policy*, 37(1): 246-253.

Tang, C. F., & Chua, S. Y. (2012). The savings-growth nexus for the Malaysian economy: A view through rolling sub-samples. *Applied Economics,* 44(32): 4173-4185.

Tiwari, A. K., Shahbaz, M., & Adnan Hye, Q. M. (2013). The environmental Kuznets curve and the role of coal consumption in India: Cointegration and causality analysis in an open economy. *Renewable and Sustainable Energy Reviews*, 18: 519-527.

Ummalla, M., & Samal, A. (2018). The impact of hydropower energy consumption on economic growth and CO_2 emissions in China. *Environmental Science and Pollution Research*, 25(35): 35725-35737.

Ummalla, M., & Samal, A. (2019). The impact of natural gas and renewable energy consumption on CO_2 emissions and economic growth in two major emerging market economies. *Environmental Science and Pollution Research*, 26(20): 20893-20907.

Ummalla, M., Samal, A., & Goyari, P. (2019). Nexus among the hydropower energy consumption, economic growth, and CO_2 emissions: Evidence from BRICS countries. *Environmental Science and Pollution Research,* 26(34): 35010-35022.

Usman, O., Iorember, P. T., & Olanipekun, I. O. (2019). Revisiting the environmental Kuznets curve (EKC) hypothesis in India: The effects of energy consumption and democracy. *Environmental Science and Pollution Research,* 26(13): 13390-13400.

Westerlund, J. (2007). Testing for error correction in panel data. *Oxford Bulletin of Economics and Statistics,* 69(6): 709-748.

World Bank (2019), World development indicators, World Bank. Available at: https://databank.worldbank.org/reports.aspx?source=world-development-indicators.

World Development Indicators, (2018). WDI, World Bank. Available at: https://databank.worldbank.org/reports.aspx?source=world-development-indicators.

Wu, L., & Broadstock, D. C. (2015). Does economic, financial and institutional development matter for renewable energy consumption? Evidence from emerging economies. *International Journal of Economic Policy in Emerging Economies*, 8(1): 20-39.

Zakaria, M., & Bibi, S. (2019). Financial development and environment in South Asia: The role of institutional quality. *Environmental Science and Pollution Research*, 26(8): 7926-7937.

Zhang, Y.-J., Jin, Y.-L., Chevallier, J., & Shen, B. (2016). The effect of corruption on carbon dioxide emissions in APEC countries: A panel quantile regression analysis. *Technological Forecasting and Social Change*, 112: 220-227.

Zhou, S. (2001). The power of cointegration tests versus data frequency and time spans. *Southern Economic Journal*, 67(4): 906-921.

Zhu, H., Xia, H., Guo, Y., & Peng, C. (2018). The heterogeneous effects of urbanization and income inequality on CO_2 emissions in BRICS economies: Evidence from panel quantile regression. *Environmental Science and Pollution Research*, 25(17): 17176-17193.

Ziramba, E. (2013). Hydroelectricity consumption and economic growth nexus: Time series experience of three African countries, *European Scientific Journal*, 9(1): 85-96.

Environmental Science and Pollution Research
https://doi.org/10.1007/s11356-019-06638-1

Annexure-1

RESEARCH ARTICLE

Check for updates

Nexus among the hydropower energy consumption, economic growth, and CO_2 emissions: evidence from BRICS countries

Mallesh Ummalla[1] · Asharani Samal[1] · Phanindra Goyari[1]

Received: 11 June 2019 / Accepted: 26 September 2019

Abstract
The present paper investigates the effects of hydropower energy consumption on economic growth and CO_2 emissions in the BRICS countries, spanning the period 1990–2016. To achieve this aim of the study, we employ the panel autoregressive distributed lag (ARDL) model and panel quantile regression (PQR) estimations. The results confirm that hydropower energy consumption has a positive association with economic growth in the long run and short run, and negative association with CO_2 emissions in the long run. Further, our panel quantile regression showed that the effects of independent variables on economic growth and CO_2 emissions are heterogeneous across the quantiles. Specifically, the effect of hydropower energy use significantly promotes economic growth across all quantiles (expect 10th quantile), while hydropower energy use has a negative and positive impact on CO_2 emissions in the lower and higher quantiles, respectively. Given these findings, our study offers substantial value to empirical literature and also provides important policy implications.

Keywords Hydropower energy · Economic growth · CO_2 emissions · BRICS countries

JEL Classification Q42 · Q43 · Q53 · C33

Introduction

In recent years, there is a growing concern among the environmental scientists and policymakers on energy transformation from conventional sources to non-conventional energy sources. Because, climate change and greenhouse gas (GHG) emissions are indisputable facts, which are mainly caused by human activities and combustion of fossil fuels. Therefore, most of the countries in the world have gradually reduced reliance on fossil fuels and sought for renewable and clean energy sources which mitigate CO_2 emissions. Most recently, in the Republic of South Korea, the United Nations Intergovernmental Panel on Climate Change (IPCC) report highlights that limit the increase in the global average temperature to 1.5 °C. In order to restrict it, coal-fired electricity must end by 2050. According to IPCC (2011), it is predicted that about 80% of the global total primary energy supplied by renewable sources in 2050. Hydropower is one of the main faster-growing source forms of renewable energy. It provides 40% and 75% of share in total renewable energy generation in both the developed and developing countries during 2012–2040 (IEO 2016). It clearly indicates the development of hydropower energy in developing countries, especially in BRICS nations. Therefore, hydropower energy consumption can give a solution to climate change and GHG emission.

Over the past, the BRICS countries have been the fastest-growing emerging economies in the world. In 2015, the BRICS countries accounted for 30.8% and 42% of global GDP and world population, respectively. Simultaneously, this group consumed 37% of the total world energy, while they are responsible for 41.4% of global CO_2 emissions. Furthermore, these countries have heavily relied on fossil fuel energy sources; hence, 71% of their total energy generation come from fossil fuels only (BRICS Energy Indicators 2015).

Responsible editor: Muhammad Shahbaz

✉ Mallesh Ummalla
mallesh.ummalla@gmail.com

Asharani Samal
ashasamal01@gmail.com

Phanindra Goyari
phanin12@gmail.com

[1] School of Economics, University of Hyderabad, Hyderabad 500046, India

However, these economies are shifting their energy use from fossil fuel to renewable sources to mitigate greenhouse gas emissions. Further, investment in renewable energy sources is significantly growing in the BRICS countries[1]. Therefore, a massive amount of installed capacity has been increasing. Top six countries together accounted for 63% of total global hydropower installed capacity in 2015[2]. Among the six countries, four countries are from the BRICS countries. More precisely, this group of countries accounts for 45% of the world's total hydropower generation. Therefore, we argue that increasing the share of hydropower energy not only combats CO_2 emissions but also meets the demand for energy. Then, the main aim of our study is to answer the following question: First, Is economic growth positively affected by hydropower energy consumption? Second, Do CO_2 emissions decrease by the use of hydropower energy?

Given the above background, it is important to empirically investigate the nexus among the hydropower energy use, economic growth, and CO_2 emissions in the BRICS countries because empirical results invoke essential policy implications for energy economists and policymakers. However, in the literature, there are not many studies which have probed the nexus among hydropower energy use, economic growth, and CO_2 emissions, for example, Bildirici (2014) in 15 countries, Lau et al. (2016) in Malaysia, Bildirici and Gökmenoğlu (2017) in G7 countries, Solarin et al. (2017) in India and China, and Ummalla and Samal (2018) in China. More specifically, this is the first study to explore the nexus among the hydropower energy use, economic growth, and CO_2 emissions in the case of BRICS countries. Given the scarce literature on the BRICS regarding this issue, the present study aims to fill this research gap by employing more recent longer dataset, a more robust model, and appropriate panel modelling techniques.

The contribution of this study is fivefold. First, to the best of our knowledge, this is the first piece of study that empirically explores the nexus among the hydropower energy consumption, economic growth, and CO_2 emissions in the BRICS countries. Second, most of the previous studies have used time series data for empirical investigation among these three variables. However, we use panel data to explore nexus among the variables which provide the more accurate estimation of model parameters with more degrees of freedom and less multicollinearity, and more temporal and dynamics of relationship which cannot be addressed by a single time series data (Hsiao 2007). Third, due to financial integration and globalization, macroeconomic variables are strongly cross-sectional dependent (Banerjee et al. 2004; Paramati et al. 2016). Furthermore, the traditional panel data estimators such as random and fixed effects are inconsistent and give invalid inference in the presence of cross-sectional dependence. To overcome this problem, we apply cross-sectional dependence (CD) test developed by Pesaran (2004). Fourth, conventional unit root tests provide inappropriate results due to low power when they are used on a series which is cross-sectional dependent. Therefore, this study applies Pesaran's (2007) cross-sectional augmented ADF (CADF) panel unit root test and cross-sectional IPS (CIPS) panel unit root test which assume cross-section dependence. Fifth, this study utilizes the panel autoregressive distributed lag (ARDL) model to examine the short-run and long-run relationships among the variables. Finally, it employs the panel quantile regression to investigate the impact of independent variables on economic growth and CO_2 emissions at their different quantile levels.

The main findings of our study illustrate that hydropower energy consumption, CO_2 emissions, and population have a positive impact on economic growth. However, hydropower energy consumption and population have a negative impact on CO_2 emissions, while economic growth positively contributes to CO_2 emissions in the long run. In the short run, hydropower energy consumption has a positive association with economic growth, while hydropower energy consumption and population have a negative association with CO_2 emissions, and economic growth has a positive impact on it at the insignificant level. Furthermore, our panel quantile regression results indicate that the effects of independent variables on economic growth and CO_2 emissions are heterogeneous across the quantiles.

The rest of the paper is structured as follows. The "Review of the Literature" section includes a review of the literature. The "Data and methodology" section explains the nature of data, their measurement, and the empirical methodology. The "Empirical results and analysis" section presents empirical findings and its analysis. The "Conclusion and policy implications" section offers the conclusion and its policy implications.

Review of the literature

There are numerous studies which have investigated the linkages among energy use, economic growth, and CO_2 emissions across the globe. Alam and Paramati (2015) examined the nexus among oil consumption, economic growth, and CO_2 emissions in 18 major oil-consuming developing countries, spanning the period 1980–2012. They found bidirectional causality among the selected variables in the short run and

[1] During the Six BRICS Summit, held in Brazil in July 2014, the delegates from the BRICS countries highlighted that financial and energy security were the main agenda. Accordingly, the member countries are signed on the establishment of "BRICS development bank" and "BRICS energy association." The main aim of the bank is to mobilize financial recourses for infrastructure and sustainable energy development, and the energy association will work on the creation of "fuel reserve bank" and "energy policy institute" for the member countries.

[2] Those countries are China (27.9%), Brazil (8.6%), USA (7.5%), Canada (7.4%), Russia (4.5%), and India (4.4%).

long run. Alam et al. (2017) investigated the relationship among natural gas consumption, trade openness, and economic growth in 15 top natural gas–consuming developing countries during 1990–2012. They reported that natural gas consumption and trade openness have a positive impact on economic growth. Further, they found bidirectional causality among these three variables. Alam et al. (2018) probed the nexus between access to electricity and labor productivity in 56 developing countries covering the period 1991–2013. They reported that access to electricity and economic growth have a positive impact on labor productivity. Finally, they found bidirectional causality among access to electricity, labor productivity, and economic growth in their analysis. Similarly, many studies have conducted on the relationship among renewable energy use, economic growth, and CO_2 emissions. However, the findings of the studies are diverse across countries using different econometric methods and datasets for both the time-series and panel studies. For example, Sadorsky (2009) investigated the nexus between renewable energy consumption and real income in 18 emerging market economies during 1994–2003. The results indicated that real income has a positive association with renewable energy use. Similarly, Lin and Moubarak (2014) reported that an increase in economic growth promotes renewable energy use in China, spanning the period 1977–2011. The results also established bidirectional causal relationship between renewable energy use and economic growth, whereas Apergis and Payne (2010a) demonstrated that renewable energy use has a positive and significant impact on economic growth in 20 OECD countries during 1985–2005. Further, they reported that there exists a bidirectional causal relationship between renewable energy consumption and economic growth. Other studies by Apergis and Payne (2010b, 2011) also established similar conclusions in the case of 13 Eurasian countries and 6 Central American countries, respectively. Further, Salim et al. (2014) argued that an increase in renewable energy consumption boosts economic growth in 29 OECD countries during 1980–2011. Their results concluded that unidirectional causal linkages exist from economic growth to renewable energy consumption. Shahbaz et al. (2015) revealed that renewable energy consumption promotes economic growth in Pakistan over the period 1972Q1–2011Q4. The Granger causality test revealed bidirectional causal relationship between these variables. Bhattacharya et al. (2016) examined the relationship between renewable energy consumption and economic growth from the top 38 countries over the period 1991–2012. The long-run estimates revealed that renewable energy use has a positive association with economic growth. Inglesi-Lotz (2016) argued that renewable energy consumption plays a positive and significant role in promoting economic growth in 34 OECD economies during 1990–2010. Gozgor (2016) confirmed the presence of convergence in renewable energy consumption in the case of China and India while divergence in the case of Brazil during 1971–2014. Koçak and Şarkgüneşi (2017) examined the nexus between renewable energy consumption and economic growth in 9 Black Sea and Balkan countries during 1990–2012. The authors reported that renewable energy consumption induces economic growth. Further, the study also confirmed the two-way causal relationship between these variables. Ito (2017) investigated the nexus among CO_2 emissions, renewable and non-renewable energy consumption, and economic growth in 42 developed economies during 2002–2011. The results showed that renewable energy consumption increases economic growth and reduces CO_2 emissions in the long run. Paramati et al. (2017b) revealed that an increase in the use of renewable energy is positively associated with economic growth and negatively with CO_2 emissions in the G20 nations during 1991–2012.

By contrast, Marques and Fuinhas (2012) argued that renewable energy consumption has a negative impact on economic growth in 24 European countries, spanning the period 1990–2007. Ocal and Aslan (2013) also found that renewable energy use retards economic growth in Turkey during 1990–2000. Further, they also found unidirectional causal linkages from economic growth to renewable energy consumption. Dogan (2015) documented that non-renewable energy consumption increases economic growth while renewable energy consumption reduces economic growth in Turkey, although insignificant in the long run during 1990–2012. Further, the author also established one-way causal linkage running from renewable energy consumption to economic growth, while two-way causal linkages are established between non-renewable energy consumption and economic growth in the long run. Bhattacharya et al. (2017) documented that renewable energy consumption promotes economic growth in 85 developed and developing economies during the period 1991–2012. However, Menegaki (2011) could not find any causal linkage between renewable energy consumption and growth in 27 European countries during 1997–2007. Again, Ben Aïssa et al. (2014) examined the nexus between output, renewable energy consumption, and economic growth in 11 African countries during 1980–2008. The authors also reported that no causal nexus is detected between renewable energy consumption and economic growth. Kutan et al. (2018) revealed that no causality is found between renewable energy use and economic growth in 4 major emerging market economies, namely, Brazil, India, China, and South Africa during 1990–2012. Similarly, Paramati et al. (2018) also revealed similar results in 17 countries from the G20 nations, spanning the period 1980–2012. Recently, Gozgor (2018) and Gozgor et al. (2018) reported that renewable energy use has a positive association with economic growth in the USA and 27 OECD countries, respectively. Most recently, Ummalla and Samal (2019) documented unidirectional Granger causality from renewable energy use to economic growth in India, while no causality found in China in the short run. Further, in the long run, they found bidirectional causality between these two variables in both China and India, spanning the period 1965–2016.

Hydropower energy consumption and economic growth

Many studies have devoted to examining the nexus between renewable energy consumption and economic growth in the literature. However, a minuscule amount of studies have been conducted on the nexus between hydropower energy consumption and economic growth in the world. For example, Abakah (1993) probed the linkages between three disaggregate sources of energy, i.e., charcoal, petroleum, and hydroelectricity consumption, with economic growth in Ghana during 1976–1990. The empirical results showed that hydroelectricity and petroleum consumption have a positive association with economic growth in the short run and long run, while charcoal consumption has a negative association with economic growth. Okafor (2012) examined the linkages among the selected disaggregate energy, i.e., coal, hydro, and oil consumption and economic growth in Nigeria and South Africa, spanning the period 1970–2010. The results of the Granger causality test indicated that coal consumption and economic growth are Granger causes in South Africa, while coal consumption Granger causes economic growth in Nigeria. However, hydropower energy use and economic growth Granger causes each other in Nigeria and South Africa. Ziramba (2013) proved the nexus between hydroelectricity consumption and economic growth in three African countries, namely, Egypt, South Africa, and Algeria, over the period 1980–2009. Their findings indicated that hydroelectricity consumption promotes economic growth in both Egypt and South Africa. The author also found that hydroelectricity consumption and economic growth are Granger causes to each other in Algeria, while economic growth Granger causes hydroelectricity consumption in South Africa. However, no causal linkage is detected between hydroelectricity consumption and economic growth in Egypt. Ohler and Fetters (2014) reported that hydroelectricity consumption positively contributes to economic growth in 20 OECD countries during 1990–2008. Further, Granger causality test results documented hydroelectricity consumption and economic growth Granger causes to each other in both the short run and long run. Solarin and Ozturk (2015) investigated the causal linkages between hydroelectricity consumption and economic growth in seven Latin American countries during 1970–2012. The long-run estimates of without structural break revealed that hydroelectricity consumption has positively associated with economic growth in Brazil, Peru, and Venezuela, while negatively in Colombia and Ecuador. However, hydroelectricity consumption promotes economic growth for all the countries except Venezuela with two structural break analyses. Their causality test results without break revealed hydroelectricity consumption Granger causes economic growth for all the six countries except Chile in the long run. Their findings from two structural break analyses confirmed hydroelectricity consumption and economic growth are Granger causes each other in Argentina and Venezuela, whereas hydroelectricity consumption Granger causes economic growth in Brazil, Chile, Colombia, Ecuador, and Peru, respectively. Apergis et al. (2016) reported that economic growth promotes hydroelectricity consumption in the top 10 hydroelectricity-consuming countries. The Granger causality test results indicated economic growth Granger causes hydroelectricity consumption in the pre-1988 period, whereas hydroelectricity consumption and economic growth are Granger causes each other in the post-1988 period in both the short run and long run. They suggested that bidirectional linkage not only was established between hydroelectricity consumption and economic growth but also created a more significant impact on economic growth via the increasing role of hydroenergy source for the break years 2000 and 2009. Bildirici (2016) examined the nexus between hydropower energy consumption and economic growth in OECD and non-OECD high-income countries, spanning the period 1980–2011. The empirical results confirmed that hydropower energy consumption reduces economic growth in Brazil, Canada, Finland, Mexico, and the USA, while increases economic growth in Turkey. The results of the Granger causality test revealed that hydropower energy consumption Granger causes economic growth in OECD countries with high income. Further, in the short run, the study also found that economic growth Granger causes hydropower energy consumption in Brazil, the USA, Finland, Mexico, and Turkey. Finally, the author detected hydroelectricity consumption and economic growth are Granger causes each other in the long run.

Hydropower energy consumption, economic growth, and CO_2 emissions

In the literature, there is evolving concern regarding the nexus between hydropower energy consumption and economic growth. However, investigating the impact of hydropower energy use on CO_2 emissions is very scarce, although hydropower use can improve the environmental quality. In recent years, a minuscule amount of available literature probed the relationship among the hydropower energy consumption, economic growth, and CO_2 emissions in the developed and developing countries. For instance, Bildirici (2014) explored the linkages among the hydropower energy consumption, environmental pollution, and economic growth in 15 countries. The results from the Toda-Yamamoto causality test revealed unidirectional causality running from hydropower energy consumption to economic growth in Austria, from economic growth to hydropower energy consumption in Germany, and an absence of any causality between hydropower energy consumption and economic growth in the UK. However, bidirectional causality is established between hydropower energy consumption and economic growth in the rest of the countries. Furthermore, the author also found no causality between hydropower energy consumption and CO_2 emissions in Belgium, Iceland, and the UK, while a unidirectional causality exists from CO_2 emissions to hydropower energy consumption in the rest of the countries. Further, Lau et al. (2016) explored the nexus among the hydroelectricity consumption, economic growth, and CO_2 emissions in Malaysia, spanning the period 1965–2010. The short-run results revealed that unidirectional causal linkage exists from hydroelectricity consumption to CO_2 emissions. However, in the long run, unidirectional causality runs from economic growth and hydroelectricity consumption to CO_2 emissions. Bildirici and Gökmenoğlu (2017) investigated the relationship among hydropower energy consumption, economic growth, and CO_2 emissions in G7 countries during 1961–2013. Their empirical results revealed unidirectional causality running from hydropower energy consumption to economic growth in overall and bidirectional causality between hydropower energy consumption to economic growth in few G7 countries. The authors also detected CO_2 emissions Granger causes hydropower energy consumption in the first, second, and third regimes, while hydropower energy consumption Granger causes CO_2 emissions in some of the G7 countries. Recently, Solarin et al. (2017) examined the linkages among the hydroelectricity consumption, urbanization, economic growth, and CO_2 emissions in India and China during 1965–2013. Their long-run results revealed that economic growth and urbanization have a positive association with CO_2 emissions, while hydroelectricity consumption has a negative association on it in both India and China. The findings from the Granger causality test showed that there exists a unidirectional causality running from hydroelectricity consumption to CO_2 emissions, from economic growth to hydroelectricity consumption, and from hydroelectricity consumption to CO_2 emissions in the short run. However, a bidirectional causality is established between hydroelectricity consumption and CO_2 emissions and hydroelectricity consumption and economic growth in both India and China in the long run. Furthermore, the authors also found the presence of environmental Kuznets curve (EKC) in both countries. Most recently, Ummalla and Samal (2018) documented that hydropower energy consumption increases economic growth and reduces CO_2 emissions in the long run. Their empirical results confirmed unidirectional causality running from hydropower energy consumption to economic growth in the short run, while bidirectional causality among the hydropower energy consumption, economic growth, and CO_2 emissions in the long run. However, they did not find the existence of EKC in China during 1965–2016.

Based on the above literature, it was confirmed that empirical results differ regardless of the country selection, the data period, the frequency of observations, and the econometric techniques of probing the nexus among variables. However, there are hardly any studies which have investigated the linkages among hydropower energy consumption, economic growth, and CO_2 emissions in a time-series framework. To the best of our knowledge, this is the first study which explores the nexus among hydropower energy consumption, economic growth, and CO_2 emissions in a panel of BRICS countries, spanning the period 1990–2016.

Data and methodology

Data

The present study used yearly data for the BRICS countries (namely Brazil, Russia, India, China, and South Africa) during 1990–2016. The considered variables of the present study include per capita hydropower (HYD) energy consumption in million tons oil equivalent (Mtoe), per capita GDP (GDP) (constant 2010 US$), per capita carbon dioxide (CO_2) emissions in million metric tons. The data on HYD and CO_2 are obtained from the BP Statistical Review of World Energy 2017, whereas population and GDP data are retrieved from the World Development Indicators (WDI) online database. All the selected variables are transferred into natural logarithms.

Methodology

The main objective of the study is to investigate the short-run and long-run nexus among the hydroelectricity, economic growth, and CO_2 emissions in the BRICS countries. To fulfil the objective, our study employs the panel ARDL bounds testing approach. Further, panel quantile regression was applied to probe the effects of independent variables on economic growth and CO_2 emissions at their different quantile levels. The simple framework of the model can be written as follows:

$$\begin{aligned}\mathrm{lnGDP}_{it} = {} & \alpha_1 + \beta_1 \mathrm{lnHYD}_{it} + \beta_2 \mathrm{lnCO}_{2it} + \beta_3 lnPOP_{it} \\ & + e_{1it} \end{aligned} \tag{1}$$

$$\begin{aligned}\mathrm{lnCO}_{2it} = {} & \alpha_2 + \beta_4 \mathrm{lnHYD}_{it} + \beta_5 \mathrm{lnGDP}_{it} + \beta_6 lnPOP_{it} \\ & + e_{2it} \end{aligned} \tag{2}$$

where GDP_{it}, HYD_{it}, CO_{2it}, and POP_{it} denote per capita GDP, per capita hydropower energy consumption, per capita CO_2 emissions, and population, respectively. The subscript i ($i = 1 \ldots. N$) and $t(t = 1 \ldots. T)$ represent country and time period, respectively. Finally, e_{1it} and e_{2it} are the two residual terms which are assumed to be normally distributed.

Cross-sectional dependence

We first aim to identify whether the given series is cross-sectional dependent or independent. Heterogeneity may exist across the countries for the considerable variables. Therefore, the prerequisite panel econometric tests are required before commencing analysis[3]. Henceforth, this study employs Pesaran's (2004) cross-sectional dependence (CD) test which takes into account both issues. The null hypothesis of cross-sectional independence is tested against the alternative hypothesis of cross-sectional dependence. If we reject the null hypotheses, it suggests that there is a presence of cross-sectional dependence among all of the variables.

Panel unit root tests

With the existence of cross-sectional dependence, we did not apply the first-generation unit root tests such as IPS and LLC because it does not address the issue of cross-sectional dependence. Therefore, we employ the Pesaran (2007) CADF and CIPS panel unit root tests in our analysis. It is worth noting that both of these panel unit root tests produce more reliable and accurate results in the presence of both cross-sectional dependence and heterogeneity across the sample countries[4]. These unit root tests were used to verify the order of integration among the variables. The null hypothesis of a unit root is tested against the alternative hypothesis of no unit root.

Panel ARDL model

In this paper, we apply the panel ARDL model with a country fixed effect and the period fixed effect propounded by Pesaran et al. (1999) to investigate the short-run and long-run relationship among the hydropower energy consumption, economic growth, CO_2 emissions, and population in the BRICS countries. This method also helps to estimate the consistent and efficient estimators by eliminating the problem of endogeneity. The specified model can be written as follows:

$$\begin{aligned}\Delta \ln GDP_{it} = \delta_0 &+ \sum_{i=1}^{q} \delta_{1i} \Delta lnGDP_{i,t-1} + \sum_{i=1}^{q} \delta_{2i} \Delta lnHYD_{i,t-1} \\ &+ \sum_{i=1}^{q} \delta_{3i} \Delta lnCO_{2i,t-1} + \sum_{i=1}^{q} \delta_{4i} \Delta lnPOP_{i,t-1} \\ &+ \delta_5 \ln GDP_{i,t-1} + \delta_6 \ln HYD_{i,t-1} \\ &+ \delta_7 \ln CO_{2i,t-1} + \delta_8\, lnPOP_{i,t-1} + e_{1it}\end{aligned} \tag{3}$$

$$\begin{aligned}\Delta \ln CO_{2it} = \beta_0 &+ \sum_{i=1}^{q} \beta_{1i} \Delta lnCO_{2i,t-1} + \sum_{i=1}^{q} \beta_{2i} \Delta lnHYD_{i,t-1} \\ &+ \sum_{i=1}^{q} \beta_{3i} \Delta lnGDP_{i,t-1} + \sum_{i=1}^{q} \beta_{4i} \Delta lnPOP_{it-1} \\ &+ \beta_5 \ln CO_{2i,t-1} + \beta_6 \ln HYD_{i,t-1} \\ &+ \beta_7 lnGDP_{i,t-1} + \beta_8 lnPOP_{i,t-1} + e_{2it}\end{aligned} \tag{4}$$

where q is the lag order, e_{1it} and e_{2it} are the error terms which are assumed to be identically and independently distributed. Equations (3) and (4) can be transformed into an error correction model (ECM) to Eqs. (5) and (6) as follows:

$$\begin{aligned}\Delta \ln GDP_{it} = \delta_0 &+ \sum_{i=1}^{q} \delta_{1i} \Delta lnGDP_{i,t-1} + \sum_{i=1}^{q} \delta_{2i} \Delta lnHYD_{i,t-1} + \sum_{i=1}^{q} \delta_{3i} \Delta lnCO_{2i,t-1} + \sum_{i=1}^{q} \delta_{4i} \Delta lnPOP_{i,t-1} \\ &+ \xi \left(\ln GDP_{i,t-1} + \pi_1 \ln HYD_{i,t-1} + \pi_2 \ln CO_{2i,t-1} + \pi_3 lnPOP_{i,t-1} \right) + e_{1it}\end{aligned} \tag{5}$$

$$\begin{aligned}\Delta \ln CO_{2it} = \beta_0 &+ \sum_{i=1}^{q} \beta_{1i} \Delta lnCO_{2i,t-1} + \sum_{i=1}^{q} \beta_{2i} \Delta lnHYD_{i,t-1} + \sum_{i=1}^{q} \beta_{3i} \Delta lnGDP_{i,t-1} + \sum_{i=1}^{q} \beta_{4i} \Delta lnPOP_{it-1} \\ &+ \xi \left(\ln CO_{2i,t-1} + \theta_1 \ln HYD_{i,t-1} + \theta_2 lnGDP_{i,t-1} + \theta_3 lnPOP_{i,t-1} \right) + e_{2it}\end{aligned} \tag{6}$$

where ξ is the speed of the adjustment parameter. π_1, π_2, and π_3 are the long-run coefficients of per capita hydropower energy consumption, per capita CO_2 emissions, and population, respectively in Eq. (5), while θ_1, θ_2, and θ_3 are the long-run coefficients of per capita hydropower energy consumption, per capita GDP, and population, respectively, in Eq.

[3] Several authors (e.g., Alam et al. 2015; Alam et al. 2017; Paramati et al. 2016; Paramati et al. 2017a) argue the cross-sectional dependence and heterogeneity in their analysis.

[4] The previous studies (e.g., Dogan et al. 2017; Mallick et al. 2016; Paramati et al. 2017a) used the CADF and CIPS cross-sectional unit root tests in their empirical analysis.

(6). γ_{1i}, γ_{2i}, γ_{3i}, and γ_{4i} and α_{1i}, α_{2i}, α_{3i}, and α_{4i} denote the short-run coefficients in Eqs. (7) and (8). Therefore, the panel ARDL (p, q, k, and g) models are written as:

$$\begin{aligned}\Delta \mathrm{lnGDP}_{it} &= \gamma_0 + \sum_{i=1}^{p} \Delta\gamma_{1i}\Delta lnGDP_{i,t-1} + \sum_{i=1}^{q} \Delta\gamma_{2i}\Delta lnHYD_{i,t-1} \\ &+ \sum_{i=1}^{k} \Delta\gamma_{3i}\Delta lnCO_{2i,t-1} + \sum_{i=1}^{g} \Delta\gamma_{4i}\Delta lnPOP_{i,t-1} \\ &+ \xi\left(\mathrm{lnGDP}_{i,t-1} + \pi_1 \mathrm{lnHYD}_{i,t-1} + \pi_2 \mathrm{lnCO}_{2i,t-1} + \pi_3 lnPOP_{i,t-1}\right) + e_{1it}\end{aligned} \tag{7}$$

$$\begin{aligned}\Delta \mathrm{lnCO}_{2it} &= \alpha_0 + \sum_{I=1}^{p} \Delta\alpha_{1i}\Delta lnCO_{2i,t-1} + \sum_{i=1}^{q} \Delta\alpha_{2i}\Delta lnHYD_{i,t-1} \\ &+ \sum_{i=1}^{k} \Delta\alpha_{3i}\Delta lnGDP_{i,t-1} + \sum_{i=1}^{g} \Delta\alpha_{4i}\Delta lnPOP_{it-1} \\ &+ \xi\left(\mathrm{lnCO}_{2i,t-1} + \theta_1 \mathrm{lnHYD}_{i,t-1} + \theta_2 lnGDP_{i,t-1} + \theta_3 lnPOP_{i,t-1}\right) + e_{2it}\end{aligned} \tag{8}$$

Panel quantile regression

We have applied the fixed effect panel quantile regression model to explore the impact of hydropower energy use on economic growth and CO_2 emissions in the BRICS countries throughout the conditional distribution. The advantages of the panel quantile regression model are as follows: (a) it is an extension of classical ordinary least square (OLS) method of conditional mean which enables to estimate with different points of conditional probability distribution of dependent variables. (b) This method also takes into account the heterogeneous structure of the different levels of growth and CO_2 emissions as the OLS does not consider it. (c) It minimizes the problem of outlier observations and issues related to heavy distributions. (d) It is a more efficient method than the ordinary least square (OLS) estimators if the error terms are not normally distributed. (e) It enables us to assess the conditional heterogeneous covariance effects of CO_2 emissions and economic growth. (f) It also helps to investigate the impact of the hydropower energy consumption on economic growth and CO_2 emissions at different levels of the conditional distribution of the dependent variables. In quantile regression, the conditional distribution of dependent variable is divided into different quantiles, where the 50th quantile represents the median (Hübler 2017). Therefore, we can represent the τth quantile as the conditional distributions of dependent variables (per capita economic growth and CO_2 emissions), and given the set of independent variables X_{it}, the equation can be specified as:

$$Q_\tau\left(\frac{lnGDP_{it}}{X_{it}}\right) = \alpha_\tau + \beta_\tau X_{it} + \alpha_\tau \mu_{it} \tag{9}$$

$$Q_\tau\left(\frac{lnCO_{2,it}}{X_{it}}\right) = \alpha_\tau + \beta_\tau X_{it} + \alpha_\tau \mu_{it} \tag{10}$$

where, in Eqs. (9) and (10), lnGDP_{it} and $\mathrm{lnCO}_{2,\ it}$ are the natural logarithms of per capita economic growth and CO_2 emissions of country i in time period t, and X_{it} denotes the vector of three independent variables, namely, per capita hydropower energy consumption, CO_2 emissions, and population, respectively, and vice versa for Eq. (10). u_{it} represents unobservable factors. The coefficients in Eqs. (9) and (10) are estimated minimizing the absolute value of residuals by using the following objective functions:

$$\begin{aligned}Q_\tau(\beta_\tau) &= \min_\beta \sum_{i=1}^{n} \left[\left|lnGDP_{it} - \beta_\tau X_{it}\right|\right] \\ &= \min_\beta \left[\sum_{i:lnGDP_{it} \geq \beta X_i}^{n} \tau\left|lnGDP_{it} - \beta_\tau X_{it}\right| + \sum_{i:lnGDP_{it} < X_{it}}^{n} (1-\tau)\left|lnGDP_{it} - \beta_\tau X_{it}\right|\right]\end{aligned} \tag{11}$$

The same procedure follows when the CO_2 emission is a dependent variable. Koenker (2004) estimated the vector of individual effects using shrinkage methodology which does not capture the unobserved factors with fixed effects regression model and later on, Canay (2011) found that Koenker's methodology is computationally intensive; therefore, he introduced a two-step procedure of a fixed effect panel quantile regression model. In the first stage, the conditional mean of u_{it} is estimated and the estimated coefficients are to be calculated to obtain individual fixed effects. In the second stage, estimated individual fixed effects would be deducted from the original dependent variable and finally, standard estimation of quantile regression is used. Our empirical analysis is carried out using the above methodology of Canay (2011). Further, some of the previous studies have applied quantile regression to panel data in their analysis (Apergis et al. 2018; Gozgor et al. 2018; Zhu et al. 2018).

Empirical results and analysis

Preliminary results

The annual average growth rate (in percent) of selected variables for individual countries is presented in Table 1. The highest growth rate of output is experienced in China (9.634) followed by India (6.593), while the lowest growth rate is experienced by Russia (0.690). Similarly, the annual growth rate of CO_2 emissions is higher in the case of India (5.332) and China (5.331) and lowest and negative in Russia (− 1.552). Among the BRICS countries, the growth rate of hydropower energy consumption is highest in South Africa (32.032) and China (9.217) followed by India (3.127) and lowest in Russia (0.719). Further, South Africa and India have positive and highest average growth rate of the population, whereas the growth rate of Russia (− 0.085) is negative during the sample period 1990–2016. In general, it is observed from

Table 1 Annual average growth rate, 1990–2016 (percent)

Variable	Brazil	Russia	India	China	South Africa
GDP	2.296	0.690	6.593	9.634	2.377
HYD	2.468	0.719	3.127	9.217	32.032
POP	1.295	− 0.085	1.645	0.777	1.648
CO_2	3.104	− 1.552	5.332	5.331	1.434

The growth rate was calculated using original data

Table 1 that the highest average growth rate of output and CO_2 emissions are occupied by China and India. However, hydropower energy consumption and the population are highest in the case of South Africa. Further, the annual average growth rate of all the considered variables is lowest and negative in Russia.

The mean statistics of individual countries of the BRICS are reported in Table 2. The highest per capita output belongs to China (28.732) and Brazil (28.167) followed by Russia (27.835), India (27.638), and South Africa (26.428). It suggests that there is a consistent development of per capita output across the sample countries. The per capita hydropower energy consumption is higher in China (4.368) and Brazil (4.252) than Russia (3.648) and India (3.031), whereas hydropower energy consumption is lowest and negative in South Africa (− 1.351). The average per capita CO_2 emissions in China (8.485) and Russia (7.382) are higher than those in South Africa (5.921) and Brazil (5.775). The population is highest in China (20.965) and India (20.814) in comparison with Russia (18.795) and South Africa (17.648) during the sample study period.

We also presented the summary statistics of panel dataset in Table 3. The results show that the average economic output across the sample countries is 27.76%. It implies that selected countries have a significant economic outcome during the study period. The average population is about 19.44%, while CO_2 emissions are 6.92%. Finally, hydropower energy consumption accounts for 2.78%. It suggests hydropower energy use remains relatively low, but it is significantly growing in a panel of the BRICS countries.

Table 2 Mean statistics for individual countries, 1990–2016

Country	GDP	HYD	POP	CO_2
Brazil	28.167	4.252	19.008	5.775
Russia	27.835	3.648	18.795	7.382
India	27.638	3.031	20.814	7.039
China	28.732	4.368	20.965	8.485
South Africa	26.428	−1.351	17.648	5.921

HYD per capita hydropower energy consumption in million tons oil equivalent, *GDP* per capita real GDP in constant 2010 US$; *$CO_2$* per capita carbon dioxide emissions in million tons oil equivalent, *POP* total population

Results of cross-sectional dependence tests

Before applying any econometric techniques which deal with panel data analysis, one should always check whether there is a presence of cross-sectional dependence or independence among the variables. The results of conventional unit root tests are spurious and misleading if the variables are found to be cross-sectional dependence because it is based on the assumption of cross-sectional independence. Hence, we employed the cross-sectional dependence (CD) test propounded by Pesaran (2004) in order to investigate the presence of cross-sectional dependence and heterogeneity problem associated in our study. The CD test results are shown in Table 4. The results reveal that the null hypothesis of cross-sectional independence is significantly rejected against the alternative hypothesis of cross-sectional dependence at the 1% level of significance. It suggests that there is a presence of cross-sectional dependence among all of the variables.

Results of panel unit root tests

Since conventional unit root tests are not suitable in the presence of cross-sectional dependence across the sample, we have utilized Pesaran's (2007) CADF and CIPS cross-sectional augmented panel unit root tests which account for cross-sectional dependence. The CADF and CIPS tests results are reported in Table 5. The results indicate that the data series is stationary at the level for population and CO_2 emissions variables which follows I (0), while other variables, namely, economic growth and hydropower energy consumption, are stationary at the first difference which follows I (1). However, all of these variables reject the null hypothesis of non-stationary at the first difference. Based on these findings, we conclude that the considered variables have different orders of integration, i.e., I (0) and I (1). Therefore, we applied the panel ARDL model to examine the short-run and long-run relationship among hydropower energy consumption, economic growth, and population and CO_2 emissions in the BRICS countries.

Results of panel ARDL model

To examine the short-run and long-run relationship among the variables, we have employed the panel ARDL model. This

Table 3 Panel summary statistics

Variable	Mean	Std. dev.	Minimum	Maximum
GDP	27.760	0.885	26.098	29.882
HYD	2.789	2.177	− 3.410	5.572
POP	19.446	1.275	17.420	21.044
CO_2	6.921	1.051	5.284	9.129

Table 4 Cross-sectional dependence test results

Variable	GDP	HYD	POP	CO_2
Pesaran CD test	14.73***	6.68***	3.89***	5.46***
P value	0.000	0.000	0.000	0.000

***Indicates the rejection of null hypothesis of cross-sectional independence (CD test) at the 1% significance level

test can provide more robust and reliable results even in the presence of different orders of integration in the model. The results of long-run and short-run estimates based on panel ARDL model are reported in Table 6. When economic growth is a dependent variable, the results of long-run estimates show that hydropower energy consumption, CO_2 emissions, and population are positively associated with economic growth. It implies that a 1% increase in hydropower energy consumption, CO_2 emissions, and population increases economic growth by 0.038%, 0.349%, and 0.834%, respectively. Our results are consistent with those of Ziramba (2013) in Egypt and South Africa and Solarin and Ozturk (2015) in seven Latin American countries. The ECM coefficient is negative (− 0.629) but not significant. Moreover, in the short run, the results also revealed that hydropower energy consumption promotes economic growth. More technically, a 1% increase in hydropower energy consumption increases economic growth by 0.098% and 0.048% in the lagged periods.

When CO_2 emission is a dependent variable, economic growth increases CO_2 emissions while hydropower energy consumption and population reduce CO_2 emissions. It indicates that a 1% rise in economic growth increases CO_2 emissions by 0.282%, while a 1% increase in hydropower energy consumption and population decreases CO_2 emissions by − 0.227% and − 1.375, respectively. This suggests that high economic growth plays a very significant role in promoting CO_2 emissions which may be due to rapid industrialization

Table 5 Panel unit root test results

Variable	CADF		CIPS	
	Ztbar	*P* value	Ztbar	*P* value
GDP	− 0.968	0.166	3.126	0.999
HYD	0.779	0.782	− 0.619	0.267
POP	− 5.982***	0.000	− 6.905***	0.000
CO_2	− 1.396*	0.081	0.813	0.791
ΔGDP	− 1.998**	0.023	− 2.939***	0.001
ΔHYD	− 7.111***	0.000	− 6.518***	0.000
ΔPOP	− 1.821**	0.034	0.729	0.767
ΔCO_2	− 3.745***	0.000	− 4.230***	0.000

Δ is the first difference term. *, **, and ***indicate the rejection of null hypothesis of unit root at the 10%, 5%, and 1% significance levels, respectively

Table 6 Panel ARDL estimation results

$GDP = f(HYD, CO_2, POP)$			$CO_2 = f(HYD, GDP, POP)$		
Variable	Coefficient	Prob.	Variable	Coefficient	Prob.
Long-run equation			Long-run equation		
HYD	0.038**	0.021	HYD	− 0.227*	0.076
CO_2	0.349***	0.000	GDP	0.282**	0.020
POP	0.834***	0.000	POP	− 1.375**	0.037
Short-run equation			Short-run equation		
COINTEQ01	− 0.629	0.409	COINTEQ01	− 0.452***	0.000
D(GDP(− 1))	0.261	0.549	$D(CO_2(-1))$	− 0.129	0.522
D(GDP(− 2))	− 0.012	0.953	$D(CO_2(-2))$	− 0.101	0.625
D(GDP(− 3))	0.300**	0.014	$D(CO_2(-3))$	− 0.172	0.327
D(HYD)	0.040	0.585	D(HYD)	− 0.063	0.405
D(HYD(− 1))	0.083	0.333	D(HYD(− 1))	− 0.031	0.739
D(HYD(− 2))	0.098**	0.011	D(HYD(− 2))	− 0.004	0.938
D(HYD(− 3))	0.048*	0.084	D(HYD(− 3))	− 0.010	0.742
$D(CO_2)$	0.031	0.949	D(GDP)	0.381	0.225
$D(CO_2(-1))$	− 0.025	0.944	D(GDP(− 1))	0.034	0.856
$D(CO_2(-2))$	0.152	0.260	D(GDP(− 2))	0.213	0.139
$D(CO_2(-3))$	0.030	0.854	D(GDP(− 3))	0.158	0.422
D(POP)	− 175.520	0.244	D(POP)	− 181.966	0.154
D(POP(− 1))	306.328	0.252	D(POP(− 1))	379.017	0.152
D(POP(− 2))	− 228.693	0.233	D(POP(− 2))	− 233.877	0.312
D(POP(− 3))	38.855	0.230	D(POP(− 3))	− 7.741	0.937
Constant	5.630	0.429	Constant	12.605***	0.000

*, **, and ***indicate the rejection of null hypothesis of unit root at the 10%, 5%, and 1% significance levels, respectively. The lag length is chosen based on AIC

and urbanization in recent periods, while hydropower energy consumption helps to mitigate CO_2 emissions in the BRICS countries. Our results are similar with those of Solarin et al. (2017) in India and China, and contradict those of Ummalla and Samal (2018) in China. The ECM coefficient is negative (− 0.452) and statistically significant at the 1% level. In the short run, we have observed that hydropower energy consumption and population have a negative impact on CO_2 emissions, while economic growth has a positive impact on it at the insignificant level.

In sum, regarding the panel ARDL test results on all the considerable variables, we can highlight that hydropower energy consumption, CO_2 emissions, and population are considered the significant drivers in order to achieve higher economic growth in the BRICS countries. The economic growth and population raise CO_2 emissions, while hydropower energy use reduces it. Therefore, governments and policymakers should take appropriate policy initiatives, namely, shifting tax incentives and invest fund on hydropower energy projects through foreign direct investment and foreign institutional investment in order to promote hydropower energy use rather than non-renewable energy sources. The increase in investment in hydropower energy projects increases the energy generation capacity and meets the demand for hydropower energy consumptions to mitigate CO_2 emissions without compromising in achieving higher economic growth in the BRICS countries.

Results of panel quantile regression (PQR) estimates

The results of panel quantile regression (PQR) estimates are reported in the upper panel of Table 7 when economic growth is considered a dependent variable. The results of 10th, 20th, 30th, 40th, 50th, 60th, 70th, 80th, 90th, and 95th percentiles are represented in conditional growth distributions. The impact of hydropower energy consumption on economic growth is heterogeneous across quantiles. The marginal impact of hydropower energy consumption on economic growth is higher at the higher quantile levels. The hydropower energy consumption significantly promotes economic growth at the 1% level of significance across the quantiles (except the 10th quantile level). It demonstrates that a 1% rise in hydropower energy consumption promotes economic growth by 0.214–0.319%. More technically, whether in low-income countries or high-income countries, based on these findings, we urge that hydropower energy consumption is a primary source of energy for enhancing economic growth in the BRICS countries over the period.

Next, regarding the CO_2 emission variable, we can see that there is a presence of the heterogeneous impact of CO_2 emissions on economic growth across the quantile in the conditional distribution of economic growth. The impact of CO_2 emissions on economic growth is positive and insignificant at the first three quantile levels, namely, 10th, 20th, and 30th, while the coefficients are positive and significant at the higher quantile levels (60th–95th quantiles) which indicates that the influence of CO_2 emissions on economic growth is positive. It implies that a 1% increase in CO_2 emissions promotes economic growth by 0.336–0.473% in high-income countries. The marginal impact of CO_2 emissions on economic growth is higher at the higher quantiles of income. From these results, we can see that the high-income countries are more reliant on fossil fuels, in turn to high CO_2 emissions which has a severe impact on climate change, to achieve their high growth targets. However, we can suggest that high-income countries should mitigate CO_2 emissions by consuming renewable energy sources without compromising economic growth. In other words, high-income countries should invest more funds on the development of energy infrastructure, setting of new less-energy intensive industries, and spending on research and development (R&D) which can combat CO_2 emissions and also boost economic growth. Regarding population variable, the impact of population on economic growth is different across quantiles. The coefficients of population are negative and insignificant in most of the quantiles. However, it is negative and significant in higher quantiles, namely, 90th and 95th quantiles. These findings imply that an increase in the population reduces the economic growth. It suggests that the population retards economic growth in the BRICS countries.

The results of panel quantile regression (PQR) estimates are represented in the lower panel of Table 7 when CO_2 emissions are considered a dependent variable. We also observe that the influence of hydropower energy consumption on CO_2 emissions is heterogeneous in the conditional distribution of CO_2 emissions. The impact of hydropower energy consumption on CO_2 emissions is negative and significant at the 5% level at the lower quantile levels (i.e., 10th, 20th, 30th, and 40th quartiles). These empirical findings demonstrate that hydropower energy consumption plays a significant role in mitigating CO_2 emissions in lower CO_2 emissions countries. However, coefficients became insignificant in 50th and 60th quantiles. Further, the coefficients of hydropower energy consumption are positive and significant on CO_2 emissions in higher quantiles (i.e., 80th, 90th, and 95th quantiles). It suggests that hydropower energy consumption promotes CO_2 emissions in higher CO_2 emission countries. In other words, these countries are heavily consuming non-renewable energy rather than renewable energy for their economic activities. Therefore, the use of hydropower energy does not help mitigate CO_2 emissions in high-CO_2 emission countries. Further, coefficients of economic growth are positive and significant at the 1% levels on CO_2 emissions across the quantiles. These results suggest that whether in low-CO_2 emission or high-CO_2 emission countries, economic growth has significantly increase emissions. Moreover, the findings also revealed that coefficients of the population are significant and positive at the 1% level across the quantiles. From these results, we can report that the population has significantly enhanced emissions in the BRICS countries.

Conclusion and policy implications

In the recent period, there is a concern on global warming and climate change among the policymakers and environmental scientists, which are mainly caused by combustion of conventional energy sources for achieving the high economic growth target, rapid industrialization, and rising population. Therefore, many international organizations and individual countries in the world have taken it as the early warning system and started promoting renewable energy sources in order to mitigate CO_2 emissions in a side and meet the demand for energy on another side. Given the above background, in this paper, we aim to explore the effects of hydropower energy consumption on economic growth and CO_2 emissions in the BRICS countries, spanning the period 1990–2016. For this

Table 7 Panel quantile regression (PQR) results

Variable	10th	20th	30th	40th	50th	60th	70th	80th	90th	95th
GDP= f (HYD, CO_2, POP)										
Constant	25.773***	27.818***	26.921***	26.694***	25.985***	26.641***	27.200***	27.821***	28.618***	28.236***
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
HYD	0.214	0.342***	0.337***	0.344***	0.327***	0.322***	0.339***	0.348***	0.336***	0.319***
	0.225	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.0000	0.000
CO_2	0.336	0.037	0.101	0.170**	0.180**	0.302***	0.366***	0.425***	0.468***	0.473***
	0.436	0.564	0.102	0.015	0.016	0.006	0.001	0.000	0.000	0.000
POP	− 0.075	− 0.081	− 0.050	− 0.059	− 0.019	− 0.088	− 0.137	− 0.186	− 0.236**	− 0.214**
	0.325	0.108	0.311	0.313	0.069	0.471	0.356	0.167	0.035	0.047
Pseudo *R*-squared	0.599	0.606	0.603	0.591	0.578	0.573	0.590	0.627	0.702	0.737
Adjusted *R*-squared	0.590	0.597	0.594	0.582	0.966	0.563	0.580	0.618	0.695	0.731
CO_2 = f (HYD, GDP, POP)										
Constant	− 31.298***	− 29.334***	− 28.878***	− 28.029***	− 22.446***	− 20.837***	− 16.658***	− 13.063***	− 11.514***	− 11.871***
	0.000	0.000	0.000	0.002	0.000	0.000	0.000	0.0000	0.000	0.000
HYD	− 0.402***	− 0.416***	− 0.407***	− 0.396***	− 0.085	− 0.053	0.012	0.079**	0.114***	0.099***
	0.0000	0.000	0.000	0.000	0.219	0.420	0.802	0.034	0.000	0.000
GDP	0.922***	0.864***	0.854***	0.846***	0.975***	0.870***	0.695***	0.556***	0.540***	0.567***
	0.000	0.000	0.002	0.006	0.000	0.000	0.000	0.000	0.000	0.000
POP	0.671***	0.659***	0.650***	0.619***	0.140**	0.209**	0.242**	0.251***	0.192***	0.177***
	0.000	0.000	0.000	0.000	0.053	0.017	0.012	0.005	0.009	0.004
Pseudo *R*-squared	0.462	0.455	0.442	0.422	0.450	0.469	0.516	0.584	0.657	0.672
Adjusted *R*-squared	0.449	0.443	0.429	0.409	0.437	0.456	0.505	0.575	0.649	0.665

** and ***Imply the significance levels at the 5% and 1%, respectively

purpose, we have applied several panel econometric methodological approaches.

The empirical findings based on the panel ARDL model manifest that in the long run, hydropower energy consumption, CO_2 emissions, and population promote economic growth. However, hydropower energy consumption and population reduce CO_2 emissions, while economic growth positively contributes to CO_2 emissions. These results are similar to the findings of Solarin et al. (2017) in China and India. However, it contrasts with findings of Ummalla and Samal (2018) in China. In the short run, hydropower energy consumption has a positive association with economic growth, while hydropower energy consumption and population have a negative association with CO_2 emissions, and economic growth has a positive impact on it at the insignificant level. These outcomes are similar with Solarin et al. (2017) in China and India.

Furthermore, our panel quantile regression results indicate that the effects of independent variables on economic growth and CO_2 emissions are heterogeneous across the quantiles. When economic growth is a dependent variable, the marginal impact of hydropower energy consumption on economic growth is positive and significant at the 1% level at all the quantile levels (except the 10th quantile). It implies that hydropower energy consumption has a substantial positive impact on economic growth in low- and high-income countries. Next, CO_2 emissions have a positive and significant impact on economic growth at the low and high quantile levels (i.e., 40th–95th quantile). Finally, an increase in the population reduces the economic growth at higher quantiles (namely, 90th and 95th quantiles) in BRICS countries.

When CO_2 emission is a dependent variable, hydropower energy consumption plays a significant role in mitigating CO_2 emissions in lower CO_2 emission countries (i.e., 10th, 20th, 30th, and 40th quantiles). However, hydropower energy consumption promotes CO_2 emissions at the higher quantile levels (i.e., 80th, 90th, and 95th quantiles) in higher CO_2 emission countries. Further, coefficients of economic growth are positive and significant on CO_2 emissions across the quantiles. Besides, the findings also revealed that higher population enhances the CO_2 emissions across quantiles in the BRICS countries. Based on the empirical findings, we observed that hydropower energy consumption positively affects the economic growth and it shows that hydropower energy is the driving force of economic growth. Similarly, use of the hydropower energy negatively affects CO_2 emissions which postulates that hydropower energy is the potential determinant of mitigating CO_2 emissions. Therefore, the benefits of this type of energy consumption help to cut down CO_2 emissions in line with the goal of sustainable economic growth. Hence, our findings of the paper imply that policymakers of the BRICS countries should reduce CO_2 emissions by using hydropower energy without reliance on fossil fuels in order to meet their energy demands and sustainable economic growth.

Based on the above findings, we highlight the following important policy implications. (1) The hydropower energy consumption is considered an essential driver to achieve rapid economic growth, and it also helps in mitigating CO_2 emissions in the BRICS countries. Therefore, governments and policymakers should frame appropriate policies in favor of the deployment of hydropower energy projects. (2) Any conservation hydropower energy policies will have a negative impact on economic growth. Therefore, expansionary of hydropower energy policies is useful for the BRICS countries. (3) Since expansionary hydropower energy policies are beneficial to the countries, it should be considered a feasible policy and also substituting it for fossil fuel to mitigate CO_2 emissions (Solarin and Ozturk 2015). (4) Policy makers should also promote hydropower energy generation and consumption by introducing appropriate incentives, e.g., tax rebates and subsidies (Apergis et al. 2016). (5) Financing in hydropower energy projects through the stock market developments, foreign direct investment (FDI), and official development assistance (ODA) will promote hydropower energy generation which is a solution for addressing global warming and climate change. (6) Governments of the BRICS countries should encourage public-private partnership investments in hydropower energy projects. (7) These economies should also introduce investment subsidies and tax incentives to attract investors in energy projects to ensure energy security and stability. (8) As suggested by the Paris Summit, developed countries should do financial support to developing countries, and BRICS development bank also increases more funds and allocates among the BRICS countries for adaption of innovations and technologies in hydropower energy generation and mitigation of CO_2 emissions. Finally, since hydropower energy use has a positive impact on economic growth and negative impact on CO_2 emissions, the BRICS countries should follow the expansionary hydropower policies for better sustainable economies in the world.

The present study is conducted on the BRICS countries. However, in light of awakening global awareness towards mitigating CO_2 emissions and sustainable economic growth, future studies should be conducted on developed and developing countries to capture the larger impact of hydropower energy consumption. Furthermore, researchers can examine the impact of hydropower energy consumption on economic growth and CO_2 emissions in these countries by incorporating other variables like institutional quality, R&D, and financial development in the model.

References

Abakah EM (1993) A review of economic growth and energy consumption in a developing country: Ghana. *OPEC Energy Review* 17(1):47–61

Alam MS, Paramati SR (2015) Do oil consumption and economic growth intensify environmental degradation? Evidence from developing economies. *Applied Economics* 47(48):5186–5203

Alam MS, Miah MD, Hammoudeh S, Tiwari AK (2018) The nexus between access to electricity and labour productivity in developing countries. *Energy Policy* 122:715–726

Alam MS, Paramati SR, Shahbaz M, Bhattacharya M (2017) Natural gas, trade and sustainable growth: empirical evidence from the top gas consumers of the developing world. *Applied Economics* 49(7):635–649

Alam MS, Paramati SR, Shahbaz M, Bhattacharya M (2015) Dynamics of natural gas consumption, output and trade: empirical evidence from the emerging economies. In: Discussion paper 21/15. Monash University, Department of Economics

Apergis N, Payne JE (2010a) Renewable energy consumption and economic growth: evidence from a panel of OECD countries. *Energy Policy 38*(1):656–660

Apergis N, Payne JE (2010b) Renewable energy consumption and growth in Eurasia. *Energy Economics 32*(6):1392–1397

Apergis N, Payne JE (2011) The renewable energy consumption–growth nexus in Central America. *Applied Energy 88*(1):343–347

Apergis N, Can M, Gozgor G, Lau CKM (2018) Effects of export concentration on CO_2 emissions in developed countries: an empirical analysis. *Environmental Science and Pollution Research* 25(14):14106–14116

Apergis N, Chang T, Gupta R, Ziramba E (2016) Hydroelectricity consumption and economic growth nexus: evidence from a panel of ten largest hydroelectricity consumers. *Renewable and Sustainable Energy Reviews 62*:318–325

Banerjee A, Marcellino M, Osbat C (2004) Some cautions on the use of panel methods for integrated series of macroeconomic data. *Econometrics Journal* 7(2):322–340

Ben Aïssa MS, Ben Jebli M, Ben Youssef S (2014) Output, renewable energy consumption and trade in Africa. *Energy Policy 66*:11–18

Bhattacharya M, Awaworyi Churchill S, Paramati SR (2017) The dynamic impact of renewable energy and institutions on economic output and CO_2 emissions across regions. *Renewable Energy* 111:157–167

Bhattacharya M, Paramati SR, Ozturk I, Bhattacharya S (2016) The effect of renewable energy consumption on economic growth: evidence from top 38 countries. *Applied Energy 162*:733–741

Bildirici M (2016) The relationship between hydropower energy consumption and economic growth. *Procedia Economics and Finance 38*:264–270

Bildirici ME (2014) Hydropower energy consumption, environmental pollution, and economic growth. *The Journal of Energy and Development 40*(1/2):189–208

Bildirici ME, Gökmenoğlu SM (2017) Environmental pollution, hydropower energy consumption and economic growth: evidence from G7 countries. *Renewable and Sustainable Energy Reviews 75*:68–85

BP Statistical Review of World Energy (2017) BP statistical review of world energy, London

BRICS Energy Indicators (2015), BRICS energy indicators, Ministry of Mines and Energy, Namibia. Retrived from http://www.mme.gov.

br/documents/10584/3580500/06+-+BRIC+Energy+Indicators+%28year+-+2015%29+%28PDF%29/470882ae-364b-4d37-8463-8f1220016315?version=1.2.

Canay IA (2011) A simple approach to quantile regression for panel data. *The Econometrics Journal 14*(3):368–386

Dogan E (2015) The relationship between economic growth and electricity consumption from renewable and non-renewable sources: a study of Turkey. *Renewable and Sustainable Energy Reviews 52*: 534–546

Dogan E, Seker F, Bulbul S (2017) Investigating the impacts of energy consumption, real GDP, tourism and trade on CO_2 emissions by accounting for cross-sectional dependence: a panel study of OECD countries. Current Issues in Tourism 20(16):1701–1719

Gozgor G (2016) Are shocks to renewable energy consumption permanent or transitory? An empirical investigation for Brazil, China, and India. *Renewable and Sustainable Energy Reviews* 66:913–919

Gozgor G (2018) A new approach to the renewable energy-growth nexus: evidence from the USA. *Environmental Science and Pollution Research* 25(17):16590–16600

Gozgor G, Lau CKM, Lu Z (2018) Energy consumption and economic growth: new evidence from the OECD countries. *Energy* 153:27–34

Hsiao C (2007) Panel data analysis—advantages and challenges. TEST 16(1):1–22

Hübler M (2017) The inequality-emissions nexus in the context of trade and development: a quantile regression approach. Ecological Economics 134:174–185

IEO (2016) International Energy Outlook. U.S. International Energy Administration, Washington, DC

Inglesi-Lotz R (2016) The impact of renewable energy consumption to economic growth: a panel data application. *Energy Economics 53*: 58–63

IPCC, 2011. IPCC Special report renewable energy sources. Abu Dhabi, United Arab Emirates.

Ito K (2017) CO_2 emissions, renewable and non-renewable energy consumption, and economic growth: evidence from panel data for developing countries. *International Economics 151*:1–6

Koçak E, Şarkgüneşi A (2017) The renewable energy and economic growth nexus in Black Sea and Balkan countries. *Energy Policy 100*:51–57

Koenker R (2004) Quantile regression for longitudinal data. *Journal of Multivariate Analysis 91*(1):74–89

Kutan AM, Paramati SR, Ummalla M, Zakari A (2018) Financing renewable energy projects in major emerging market economies: evidence in the perspective of sustainable economic development. *Emerging Markets Finance and Trade 54*(8):1761–1777

Lau E, Tan C-C, Tang C-F (2016) Dynamic linkages among hydroelectricity consumption, economic growth, and carbon dioxide emission in Malaysia. *Energy Sources, Part B: Economics, Planning, and Policy 11*(11):1042–1049

Lin B, Moubarak M (2014) Renewable energy consumption – economic growth nexus for China. *Renewable and Sustainable Energy Reviews 40*:111–117

Mallick L, Ummalla M, Jaganath B (2016) Does tourism affect economic growth in Indian states? Evidence from panel ARDL model. *Theoretical and Applied Economics 23*(1):183–194

Marques AC, Fuinhas JA (2012) Is renewable energy effective in promoting growth? *Energy Policy 46*:434–442

Menegaki AN (2011) Growth and renewable energy in Europe: a random effect model with evidence for neutrality hypothesis. *Energy Economics 33*(2):257–263

Ocal O, Aslan A (2013) Renewable energy consumption–economic growth nexus in Turkey. *Renewable and Sustainable Energy Reviews 28*:494–499

Ohler A, Fetters I (2014) The causal relationship between renewable electricity generation and GDP growth: a study of energy sources. *Energy Economics 43*:125–139

Okafor HO (2012) Testing the relationship between energy consumption and economic growth: evidence from Nigeria and South Africa. *Journal of Economics and Sustainable Development* 3(11):111–124

Paramati SR, Apergis N, Ummalla M (2017a) Financing clean energy projects through domestic and foreign capital: the role of political cooperation among the EU, the G20 and OECD countries. *Energy Economics 61*:62–71

Paramati SR, Apergis N, Ummalla M (2018) Dynamics of renewable energy consumption and economic activities across the agriculture, industry, and service sectors: evidence in the perspective of sustainable development. *Environmental Science and Pollution Research 25*(2):1375–1387

Paramati SR, Mo D, Gupta R (2017b) The effects of stock market growth and renewable energy use on CO_2 emissions: evidence from G20 countries. *Energy Economics 66*:360–371

Paramati SR, Ummalla M, Apergis N (2016) The effect of foreign direct investment and stock market growth on clean energy use across a panel of emerging market economies. *Energy Economics 56*:29–41

Pesaran MH (2004) General diagnostic tests for cross section dependence in panels. University of Cambridge, Working paper

Pesaran MH (2007) A simple panel unit root test in the presence of cross-section dependence. *Journal of Applied Econometrics* 22:265–312

Pesaran MH, Shin Y, Smith RP (1999) Pooled mean group estimation of dynamic heterogeneous panels. *Journal of the American Statistical Association 94*(446):621–634

Sadorsky P (2009) Renewable energy consumption and income in emerging economies. *Energy Policy 37*(10):4021–4028

Salim RA, Hassan K, Shafiei S (2014) Renewable and non-renewable energy consumption and economic activities: further evidence from OECD countries. *Energy Economics 44*:350–360

Shahbaz M, Loganathan N, Zeshan M, Zaman K (2015) Does renewable energy consumption add in economic growth? An application of auto-regressive distributed lag model in Pakistan. *Renewable and Sustainable Energy Reviews 44*:576–585

Solarin SA, Ozturk I (2015) On the causal dynamics between hydroelectricity consumption and economic growth in Latin America countries. *Renewable and Sustainable Energy Reviews 52*:1857–1868

Solarin SA, Al-Mulali U, Ozturk I (2017) Validating the environmental Kuznets curve hypothesis in India and China: the role of hydroelectricity consumption. *Renewable and Sustainable Energy Reviews* 80:1578–1587

Ummalla M, Samal A (2018) The impact of hydropower energy consumption on economic growth and CO_2 emissions in China. *Environmental Science and Pollution Research* 25(35):35725–35737

Ummalla M, Samal A (2019) The impact of natural gas and renewable energy consumption on CO2 emissions and economic growth in two major emerging market economies. *Environmental Science and Pollution Research* 26(20):20893–20907

Zhu H, Xia H, Guo Y, Peng C (2018) The heterogeneous effects of urbanization and income inequality on CO_2 emissions in BRICS economies: evidence from panel quantile regression. *Environmental Science and Pollution Research* 25(17):17176–17193

Ziramba E (2013) Hydroelectricity consumption and economic growth nexus: time series experience of three African countries. *European Scientific Journal* 9(1):85–96

Received: 23 December 2019 | Revised: 30 January 2020 | Accepted: 9 March 2020

DOI: 10.1002/pa.2126

ACADEMIC PAPER

WILEY

The impact of clean energy consumption on economic growth and CO_2 emissions in BRICS countries: Does the environmental Kuznets curve exist?

Mallesh Ummalla | **Phanindra Goyari**

School of Economics, University of Hyderabad, Hyderabad, India

Correspondence
Mallesh Ummalla, School of Economics, University of Hyderabad, Hyderabad 500046, India.
Email: mummalla@uohyd.ac.in

This paper examines the impact of clean energy consumption (CEC) on economic growth (EG) and CO_2 emissions (CO_2) within a framework of environmental Kuznets curve (EKC) hypothesis in a panel of BRICS countries for the period 1992–2014. The results indicated that CEC and EG have a significant positive impact on EG, while CO_2 has a negative impact on it. Our results also found that EC and EG increase CO_2 while CEC significantly reduces it. Further, we found that the EKC hypothesis is valid in the BRICS countries. Finally, panel causality test indicated that unidirectional causality running from EC to EG. However, we did not find a causal relationship between CEC and EG. Based on these results, some of the policy implications have proposed for these emerging market economies.

1 | INTRODUCTION

Energy consumption (EC) is a towering functioning factor of economic growth (EG) along with capital and labor for any nation as they are inputs in the production of goods and services. Every stage of economic activities, from production to consumption, the county largely relies on energy. Therefore, energy is the main driving force of economic growth (EG) and industrialization. However, high EC increases higher CO_2 emissions (CO_2). According to the World Bank (2019), the world gross domestic product (GDP) has increased significantly, approximately two times, from $39,170.1 billion (constant 2010 US$) in 1992 to $73,690.3 billion in 2014, with an average annual growth rate of 2.9%. At the same time, global EC has increased from 8,223.6 million tonnes oil equivalent (Mtoe) in 1992 to 12,939.7 Mtoe in 2014, with an average annual growth rate of 2.0%. The massive combustion for energy, especially conventional energy sources, led to environmental issues. Therefore, global CO_2 has increased from 21,354.0 million tons (Mt) in 1992 to 32,844.8 Mt in 2014 (BP, 2018). In search of alternatives to carbon-intensive fossil fuel, clean energy use has the considerable most effective source of energy in the world.

Therefore, international organizations, economists, environmental scientists, and policymakers are alarming the developed and developing countries to shift their EC patterns from nonclean to clean energy sources. In order to reduce CO_2 and control global warming, the demand for clean energy has been increasing in the world. The clean energy consumption (CEC) has many benefits over nonclean energy sources. First, it is noncarbohydrate energy that does not emit CO_2 when generated. Second, clean energy can be widely used in both domestic (solar energy) and industrial sector. Third, development of clean energy projects in rural areas also fills the gap between rural–urban energy in terms of accessible, reliable, and affordable. Fourth, generation of clean energy will reduce the dependence of imported nonclean energies, that is, oil, gas, and coal, and so on. It will stabilize the macroeconomic performance of the economy. Finally, installation of clean energy projects will create job opportunities directly or directly in the economy.

The BRICS countries have accounted for 20.3% of the world GDP, 36.7% of global EC, and contributed 41.9% of global CO_2 in 2014. The fact is that the significant development of clean energy needed; otherwise, these countries will be struck into the insecure, inefficient, and carbon-intensive energy system. To overcome this, the BRICS countries have been heavily investing in clean energy projects. Pao, Li, and Hsin-Chia (2014) also suggested the development of clean energy is a feasible solution for addressing energy security and climate change issues. In 2014, Brazil's CEC accounted for 10.8% of total energy use, Russia's was 8.1%, India's was 2.6%, China's was

5.1%, and South Africa's was 2.6% (World Bank, 2019). Further, in the 2015 Paris Climate Change Conference, these five emerging market economies have signed on Intended Nationally Determined Contribution (INDC) to reduce greenhouse gas (GHG) emissions by 2030.[1]

The significance of accelerating the clean energy sector has attracted attention in the literature. Our study may suggest that four types of hypotheses in CEC and EG nexus. They are: first, *the growth hypothesis* asserts that there is a unidirectional causality running from CEC to EG. Under the growth hypothesis, energy plays a significant positive or negative role in the EG process. In this case, expansionary energy policies will have a positive impact on EG, while any energy conservation policies will have a negative influence on EG. Second, *the conservation hypothesis* suggests that unidirectional causality running from EG to CEC. In this situation, any reduction in CEC will not have a negative impact on EG. Third, *the feedback hypothesis* shows that bidirectional causality between CEC and EG. This relationship postulates that a reduction in CEC retards EG and vice versa. Under this hypothesis, we can observe that the interdependent and complementary nexus between CEC and EG. Lastly, *the neutrality hypothesis* documents that no causal nexus between CEC and EG, therefore reduction in one variable will not influence on another one.

The increase in CEC can mitigate CO_2. This may help to establish the EKC hypothesis between CO_2 and EG in the BRICS economies. The EKC hypothesis postulates that EG stimulates CO_2 initially and then decreases after EG reaches a certain level where a negative relationship exists between these two variables. More specifically, any country's economy starts the development of industrialization to achieve higher EG goals. This industrialization needs massive natural resources (NR), especially energy, and the enormous combustion of energy sources leads to higher CO_2. As the country's EG continues, in the experience of postindustrialization, governments, policymakers, and people start to increase the awareness of environmental quality, energy efficiency, and uses of clean energy sources, resulting in a reduction of CO_2. Therefore, inverted-U shaped relationship can be established between CO_2 and EG. Hence, the main objectives of our study are to answer the following questions: First, does CEC has a positive impact on EG and a negative impact on CO_2? Second, does the EKC exist in BRICS countries?

The significance of accelerating clean energy sector has attracted attention in the literature. A few studies, four research papers only, have explored the nexus between CEC and EG. For example, Aslan and Cam (Aslan & Çam, 2013) in Isreal, Maji (2015) in Nigeria, Pao et al. (2014) in MITS countries (namely, Mexico, Indonesia, South Korea, and Turkey), and Hamit-Haggar (2016) in 11 sub-Saharan African countries. However, only one study has probed the nexus among CEC, EG, and CO_2 emissions in G7 countries (Cai, Sam, & Chang, 2018). More specifically, no study was examined the nexus among CEC, EG, and CO_2 in the BRICS countries. Hence, the novelty of this study is to fulfil this research gap.

This paper contributes significant lines to the existing literature. First, to the best of our knowledge, no previous study has empirically examined the impact of CEC on EG and CO_2 in the BRICS countries. Only a single study has disentangled the nexus among CEC, EG, and CO_2 in G7 countries (Cai et al., 2018). Second, Cai et al. (2018) have conducted on time series data set for their analysis. Nevertheless, we utilize panel data to get a more accurate estimation of model parameters and more temporal and dynamics of the relationship, which cannot be addressed by a single time series data (Hsiao, 2007). Third, they fail to explore the nexus between CO_2 and EG. Therefore, we address the EKC hypothesis in our analysis. Fourth, it applies several panel econometric techniques to answer the research questions empirically.

The main outcomes of our study indicate that CEC, EC, and CAP increase EG, while CO_2 reduces it. The findings also show that EG and EC have a positive impact on CO_2, but CEC significantly reduces CO_2. Further, our results established an inverted U-shaped nexus between CO_2 and EG. In other words, the EKC hypothesis is valid. Finally, we could not develop a causal nexus between CEC and EG in a panel of BRICS countries.

We proceed with the rest of paper as follows. Section 2 devoted to the literature review. Section 3 describes the data and estimation techniques used for this analysis. Section 4 provides empirical findings and discussion. Finally, Section 5 concludes the study with policy implications.

2 | LITERATURE REVIEW

2.1 | Renewable energy consumption, economic growth, and CO_2 emissions nexus

Numerous studies have examined the relationship among renewable energy consumption (REC), EG, and CO_2 across the globe. For example, Saidi and Ben Mbarek (2016) investigated the nexus among REC, EG, and CO_2 in nine developed countries during 1990–2013. They found that REC increases EG and decreases CO_2. Their Granger causality results showed that unidirectional between REC and EG in the short-run, and bidirectional causality between REC and EG and unidirectional causality from EG to CO_2 in the long-run. Bhattacharya, Awaworyi Churchill, and Paramati (2017) examine the impact of REC on EG and CO_2 in 85 developed and developing countries, spanning the period 1991–2012. They found that REC has a positive impact on EG and a negative impact on CO_2. Paramati, Mo, and Gupta (2017) found that REC has a positive impact on economic growth and a negative influence on CO_2 emissions in full panel of G20 countries as well as developed and developing nations of its member countries during 1991–2010. Similar results were documented by Paramati, Sinha, and Dogan (2017) in a panel of Next-11 countries. Sharif, Raza, Ozturk, and Afshan (2019) also revealed that REC has significantly reduced CO_2 emissions while nonrenewable energy consumption (NREC) has increased it in a panel of 74 countries, spanning the period 1990–2015. Further, the nexus among these three variables have been widely scrutinized in the empirical domain in the context of BRICS countries also. For example, Salim and Rafiq (2012) examined the determinants of REC in six emerging market economies, including

Brazil, China, and India. They reported that REC is mainly determined by EG and CO_2 as a panel and in Brazil, China, India, and Indonesia, while mostly by EG in the Philippines and Turkey. Their causality test results showed that bidirectional causality between REC and EG, REC, and CO_2, and unidirectional causality from EG to CO_2 in both Brazil and China. In the case of India, one-way causality from EG and CO_2 to REC, and bidirectional causality between CO_2 and REC. Rafiq, Bloch, and Salim (2014) probed the dynamic relationship among REC, EG, and CO_2 in China and India during 1972–2011. They found that unidirectional causality from REC to EG, and CO_2 to EG and REC in the short-run, while feedback causality among REC, EG, and CO_2 in the long-run in India. In China, they found that unidirectional causality from EG to REC, and CO_2 to REC in the short-run, while EG causes REC, and feedback causality between CO_2 and REC in the long-run. Dong, Sun, Jiang, and Zeng (2018) assessed the relationship among the REC, natural gas consumption (NGC), CO_2, and EG in China during 1993–2016. They found that REC and NGC mitigate CO_2. Further, one-way causality from REC to CO_2 in the short-run, and feedback causality among REC, NGC, and CO_2 in the long-run. But, there was no causal connection between REC and EG. Recently, Kutan, Paramati, Ummalla, and Zakari (2018) found that REC and NREC have a positive impact on EG, and REC reduced CO_2 while NREC increased it in four emerging market economies during 1990–2012. Finally, they reported that one-way causal association from REC to CO_2. Most recently, Ummalla and Samal (2019) investigated the impact of NGC and REC on CO_2 and EG in China and India from 1965 to 2016. They found that one-way causality from REC to EG in India and no causality established between the above-mentioned variables in China in the short-run. Finally, in the long-run, they found that two-way causation among the variables in both countries. Danish, Mahmood, and Zhang (2019) analyzed the impact of NR, REC, and EG on CO_2 in BRICS nations over the period from 1990 to 2015. They established that NR and REC reduced CO_2 in Russia and South Africa, and Brazil, China, India, and Russia, respectively. However, EG has significantly increased CO_2 in all BRICS countries. Further, as a panel, REC and NR did not have any impact on CO_2, but EG has increased CO_2. Finally, they reported that bidirectional causal connection between REC and EG, REC, and CO_2, and unidirectional causal association from CO_2 to EG in these emerging market economies.

2.2 | CEC, economic growth, and CO_2 emissions nexus

There is a growing international consensus that clean energy will play a substantial part in the world's energy transformation to reduce CO_2 and meet the demand for energy. Therefore, some studies have empirically probed nexus among these variables in the literature. Aslan & Çam (2013) inspected the relationship between CEC and EG in Isreal, spanning the period 1985–2009. They found that one-way causality running from CEC to EG. Maji (2015) investigated the impact of CEC on EG in Nigeria during 1971–2011. The author found that CEC has a negative impact on EG. Pao et al. (2014) examined nexus among CEC, nonclean energy consumption and EG in the MITS countries. They found that growth hypothesis in the long-run and feedback hypothesis between CEC and EG in the short-run. Hamit-Haggar (2016) found that one-way causality running from CEC to EG in 11 sub-Saharan African countries, spanning the period 1971–2007.

Recently, a few studies have examined the relationship among CEC, EG, and CO_2 in the world. Paramati, Ummalla, and Apergis (2016) demonstrated that CEC has a significant positive influence on EG and negative on CO_2 in 20 emerging market economies during 1991–2012. However, they did not prove causal nexus between CEC and EG, but CO_2 causes CEC. Paramati, Apergis, and Ummalla (2017) documented that CEC has a positive impact on EG and negative impact on CO_2 across the panels of EU, G20 and OECD economies, spanning the period 1993–2012. Further, they found that CEC causes EG in OECD countries, EG causes CEC in EU countries, and two-way causality between CEC and EG in G20 countries. Most recently, Cai et al. (2018) probed the nexus among CEC, EG, and CO_2 in G7 countries. They found that unidirectional causality is running, from CEC to EG in Canada, Germany and, the US, from CEC to CO_2 in the US, and bidirectional causality between CEC and CO_2 emissions in Germany.

2.3 | EKC analyses for the BRICS nations

Last few decades, ample studies have verified the validity of the EKC in developed and developing countries. For example, Apergis, Can, Gozgor, and Lau (2018) examine the validation of the EKC hypothesis in 19 developed countries during 1962–2010 by incorporating the export concertation index. Their empirical results found that the existence of the EKC hypothesis. Fang, Gozgor, Lu, and Wu (2019) also verify the EKC hypothesis in 82 developing countries by incorporating EC, NRC and trade openness (TOP). Their results supported the EKC hypothesis. However, few studies have tested on the BRICS nations as a panel and country-specific wise. For instance, Pao and Tsai (2011a) studied the nexus between CO_2, EG, and EC in Brazil during 1980–2007. They found that an inverted U-shaped relationship between EG and CO_2, that is, validation of the EKC hypothesis. Pao, Yu, and Yang (2011) also investigated nexus among CO_2, EG, and EC in Russia, spanning the period 1990–2007. They unveiled that there is no evidence of the EKC hypothesis in their analysis. Jayanthakumaran, Verma, and Liu (2012) investigated nexus among CO_2, EG, and EC in China and India during 1971–2007. Their empirical results supported the existence of the EKC hypothesis in both countries. Tiwari, Shahbaz, and Adnan Hye (2013) examined EG and CO_2 nexus in India during 1966–2011 by including coal consumption (CC) and TOP. They found that the EKC hypothesis is valid for India in the short-run and long-run. Further, they reported that bidirectional causality between EG and CO_2, and CC and CO_2. Kohler (2013) also found the same results in South Africa, spanning the period 1960–2009. Govindaraju and Tang (2013) explored the nexus among the CO_2, EG, and CC in China and India during 1965–2009. The results did not support the existence of the EKC hypothesis in both countries. Further, they found that unidirectional causality from EG to CO_2 in China in the short-run and long-run, while only short-run causality detected in the case of India. Boutabba (2014) investigated the EKC hypothesis in the case of India during 1971–2008 by incorporating the role of EC, financial development (FD), and TOP. The author found that evidence of the EKC hypothesis. Solarin, Al-Mulali, and Ozturk (2017) tested the validity of the EKC hypothesis and its nexus with hydropower energy consumption (HEC) and urbanization (URB) in China and India during 1965–2013. Their results supported that the EKC hypothesis in both countries. Further, they revealed that EG and URB significantly increase CO_2, while HEC reduces CO_2 in both countries. Gozgor and Can (2017) also tested the EKC hypothesis in China by incorporating trade and export quality index. Their results supported the EKC hypothesis. Ummalla and Samal (2018) probed the nexus among the CO_2, HEC, and EG in China covering the period 1965–2016. They did not find the EKC hypothesis for China. Finally, they reported that bidirectional causality among the variables. However, Dong et al. (2018) supported the EKC hypothesis in China. Usman, Iorember, and Olanipekun (2019) analyzed the EKC hypothesis in India during 1971–2014 by including EC and democracy (DEM) as well. Their empirical results confirmed the existence of the EKC hypothesis in India. Further, they documented that EC significantly increases CO_2, whereas DEM reduces it.

Tamazian, Chousa, and Vadlamannati (2009) explored the impact of EG, FD, and EC on CO_2 in BRIC nations, namely Brazil, Russia, India, and China, during 1992–2004. The empirical results supported the EKC hypothesis, and the high stages of EG and FD reduce CO_2. Pao and Tsai (2010) examined the relationship among CO_2, EG, and CC in BRIC countries. Their panel estimation result supported the EKC hypotheses in BRIC countries. However, in their country-wise analysis, the EKC hypothesis was found in India and China only. Another study by Pao and Tsai (2011b) analyzed the impact of EG, FD, EC on CO_2 in BRIC countries. Their empirical results supported the EKC hypothesis, and EC and FD have a positive impact on CO_2. Chang (2015) tested the scope for low carbon emission in G7 and BRICS countries during 2000–2010. The author tested the EKC hypothesis by incorporating energy intensity, corban intensity, and carbonization value in their estimations. They found that U-shaped EKC rather than an inverted U-shaped EKC in their study period. However, Chakravarty and Mandal (2016) supported the EKC hypothesis in BRICS countries, spanning the period 1997–2011. Dong, Sun, and Hochman (2017) investigated the nexus among CO_2, EG, NGC, and REC in BRICS countries during 1985–2016. They found that panel and country-specific results were supported the EKC hypothesis. Abdouli, Kamoun, and Hamdi (2018) analyzed the EKC hypothesis in BRICS countries, including Turkey, which was the part of the study during 1990–2014. They found that the existence of the EKC hypothesis in a panel and country-specific (except Russia). Further, they reported that EC increases CO_2, and FD increases CO_2 in a panel, China and Russia while it reduces CO_2 in Turkey. Danish et al. (2019) analyzed the impact of NR, REC, and EG on CO_2 in BRICS countries between the years from 1990 to 2015. Their empirical results supported the EKC hypotheses in a panel and country-specific (except India). They suggested that NR combat CO_2 in Russia, while it increases CO_2 in South Africa. Finally, they found that bidirectional causality link between NR and CO_2.

To sum up, the above review of literature clearly shows that the bulk of studies have discussed the link among REC, EG, and CO_2. However, there was little research has done on the nexus among CEC, EG, and CO_2. Most importantly, clean energy use has neglected in the EKC hypothesis framework. Therefore, to the best of our knowledge, this is the first study that examines the relationship among the CEC, EG, and CO_2 within the EKC hypothesis framework in a panel of BRICS countries during 1992–2014.

3 | DATA AND ESTIMATION TECHNIQUES

3.1 | Data

The current study is selected balanced panel of BRICS countries, namely Brazil, Russia, India, China, and South Africa, spanning the period from 1992 to 2014. The study collects data on CEC as a % of total energy use, EC in Mtoe, CO_2 in millions metric tons, GDP in constant 2010 US$, gross fixed capital formation (constant 2010 US$) is proxy for capital (CAP), total labor force (LAB) in million, and finally, total population (POP) is measured in million. The CEC, EC, CO_2, and GDP are in per capita terms. The data on CEC, GDP, CAP, LAB, and POP are drawn from the WDI, 2018. Similarly, data on EC and CO_2 are collected from the BP, 2018. All variables are converted into natural logarithm form.

3.2 | Estimation techniques

The main aim of study is to probe the effect of CEC on EG and CO_2 and also verity the EKC in these emerging market economies. So, we frame the following equations for the empirical investigation:

$$lnGDP_{it} = \alpha_1 + \beta_1 lnCAP_{it} + \beta_2 lnLAB_{it} + \beta_3 lnCO_{2it} + \beta_4 lnCEC_{it} + \beta_5 lnEC_{it} + e_{1it} \quad (1)$$

$$lnCO_{2it} = \alpha_2 + \beta_6 lnGDP_{it} + \beta_7 lnGDP^2_{it} + \beta_8 lnCEC_{it} + \beta_9 lnEC_{it} + \beta_{10} lnPOP_{it} + \mu_{2it} \quad (2)$$

Where GDP_{it}, CAP_{it}, LAB_{it}, CO_{2it}, CEC_{it}, EC_{it}, GDP^2_{it}, and POP_{it} denote per capita GDP, capital, labor, per capita CO_2 emissions, per capita CEC, per capita energy consumption, square term per capita GDP, and population, respectively. The $\alpha_1$and α_2 are the intercepts, βs are the slope coefficients, i refers to county, and t is the time. Finally, e_{1it} and μ_{2it} are error terms. To verify the EKC hypothesis, we expect per capita GDP is positively link with per capita CO_2 emissions, that is, $\beta_6 > 0$ while square term per capita GDP is negatively link with per capita CO_2 emissions, that is, $\beta_7 < 0$.

3.2.1 | Unit root tests

The first step of any econometric exercise is to explore whether a given series is stationary or not. For this purpose, our study applies two-panel unit root techniques developed by Levin et al. (2002, hereafter LLC) and Im et al. (2003, hereafter IPS).

For the LLC panel unit root test, consider the following panel ADF process:

$$\Delta y_{i,t} = \rho_i y_{i,t-1} + \sum_{j=1}^{\rho_i} \rho_{i,j} \Delta y_{i,t-j} + \varepsilon_{i,t} \tag{3}$$

The LLC (2002) assumes that the persistence parameters ρ_i are common across cross-sections, that is, $\rho_i = \rho$ for all i. Δ shows the first differences, Δy and $\Delta y_{i,\ t-j}$ have the individual regressions with $\Delta y_{i,\ t-j}$ and residuals. j stands for an optimal lag chosen by AIC and SBC. The null hypothesis of a unit root tested over the alternative hypothesis of no unit root, that is, $H_0 : \rho_i = 0$ for all i and $H_1 : \rho_i < 0$ for all i.

The IPS (2003) test is also similar to Equation (3), nevertheless, unlike LLC test, it assumes ρ_i to be heterogeneous across cross-sections. The null and alternative hypothesis are $H_0 : \rho_i = 0$ for all i and $H_1 : \rho_i < 0$ at least one or some of the i, respectively. If the considerable variables are stationary at the first order of integration, that is, I (1), then it suggest that all the selected variables are nonstationary at their levels and become stationary at the first order difference.

3.2.2 | Panel cointegration test

In the next step, we explore the long-run equilibrium relationship among the selected variables. For this purpose, we employ the Fisher–Johanson panel cointegration test proposed by Maddala and Wu (1999). Johanson (Johansen, 1988) proposed two different approaches, namely, trace statistics and maximum eigenvalue statistics. These two statistics help to determine the existence of cointegrating vectors on the nonstationary data series. The trace statistics and maximum eigenvalue statistics are as follows:

$$\lambda_{\text{trace}}(r) = -T \sum_{i=r+1}^{n} \ln\left(1-\hat{\lambda}_i\right)$$

$$\lambda_{\max}(r, r+1) = -T \ln\left(1-\hat{\lambda}_i\right)$$

Where $\hat{\lambda}_i$, T, and r indicate the estimated eigenvalue, number of observations, and number of cointegrating vectors, respectively. The trace statistics test the null hypothesis of at most r cointegrating vector against the alternative hypotheses of full rank $r = n$ cointegrating vector. The null and alternative hypothesis of maximum eigenvalue statistics check r cointegrating vector against the alternative hypotheses of $r+1$ of cointegrating vectors. Fisher–Johanson panel cointegration test is a panel version of the individual Johanson cointegration test. This method is based on the aggregates of p-values of individual Johanson maximum eigenvalues and trace statistics (Maddala & Wu, 1999). If p_i is the p-value from an individual cointegration test for cross-section i, under the null hypothesis of the test statistic for a panel is as follows:

$$-2\sum_{i=1}^{n} \log\left(p_i\right) \tilde{\chi}^2_{2n} \tag{4}$$

In other words, the null hypothesis (H_0) of no cointegration relationship for cross-section i tested against the alternative hypothesis (H_1) of cointegration for cross-section i.

3.2.3 | Panel long-run estimates

After confirming the cointegration relationship among the variables, fully modified ordinary least squares (FMOLS) is applied to estimate the long-run coefficients. The FMOLS approach has proposed by Pedroni (2001a, 2001b) and Pedroni (2004). The main advantages of the FMOLS are that it accounts for both endogeneity and serial correlation problem. He proposed the following equation:

$$W_{i,t} = \alpha_i + \beta_i X_{i,t} + \varepsilon_{i,t} \tag{5}$$

Where $W_{i,\ t}$ and $X_{i,\ t}$ are cointegrated with slope β_i, it may or may not be homogenous across i. In the other way, he developed Equation (5) as follows:

$$W_{i,t} = \alpha_i + \beta_i X_{i,t} + \sum_{k=-k_i}^{k_i} \gamma_{i,k} \Delta X_{i,t-k} + \varepsilon_{i,t} \tag{6}$$

Further, he also considered: $\xi_{i,t} = (\hat{\varepsilon}_{i,t}, \Delta X_{i,t})$ and $\Omega_{i,t} = limT \rightarrow \infty E\left[\left(\frac{1}{T}\right)\left(\sum_{t=1}^{T}\xi_{i,t}\right)\left(\sum_{t=1}^{T}\xi_{i,t}\right)'\right]$ is the long-run covariance for this vector process which can be decomposed into $\Omega_i = \Omega_i^0 + \Gamma_i + \Gamma_i'$ where Ω_i^0 is the contemporaneous covariance and Γ_i is a weighted sum of covariance.

Thus, the FMOLS model can be written as follows:

$$\hat{\beta}^{*}_{\text{FMOLS}} = \frac{1}{N}\sum_{i=1}^{N}\left[\left(\sum_{t=1}^{T}\left(X_{i,t}-\bar{X}_i\right)^2\right)^{-1}\left(\sum_{t=1}^{T}\left(X_{i,t}-\bar{X}_i\right)W^{*}_{i,t}-T\hat{\gamma}_i\right)\right] \tag{7}$$

Where $W^{*}_{i,t} = W_{i,t} - \bar{W}_i - \left(\hat{\Omega}_{2,1,i}/\hat{\Omega}_{2,2,i}\right)\Delta X_{i,t}$ and

$$\hat{\gamma}_i = \hat{\Gamma}_{2,1,i} + \hat{\Omega}^0_{2,1,i} - \left(\hat{\Omega}_{2,1,i}/\hat{\Omega}_{2,2,i}\right)\left(\hat{\Gamma}_{2,2,i} + \hat{\Omega}^0_{2,2,i}\right)$$

3.2.4 | Panel Granger causality test

Finally, this study explores the short-run bivariate Granger causality among these variables by employing a panel Granger causality test. For this purpose, we use the methodology suggested by Dumitrescu and Hurlin (2012). To apply this test, we require stationary data;

hence, we conducted it on the first difference data series of the selected variables. The unique nature of this test is that it takes into account heterogeneity across the nations. This test is based on the average standard of Wald statistics of Granger-non causality tests for individual time series. The causal relationship between Y and X follows the linear model:

$$\Delta y_{i,t} = \alpha_i + \sum_{j=1}^{j} \lambda_i^j \Delta y_{i,t-j} + \sum_{j=1}^{j} \beta_i^j \Delta x_{i,t-j} + \varepsilon_{i,t} \tag{8}$$

$$\Delta x_{i,t} = \alpha_i + \sum_{j=1}^{j} \lambda_i^j \Delta x_{i,t-j} + \sum_{j=1}^{j} \beta_i^j \Delta y_{i,t-j} + \varepsilon_{i,t} \tag{9}$$

Where Δ, α_1, λ^j, and β_i^j indicate first difference, constant term, lag parameter, coefficient, respectively. Dumitrescu and Hurlin (2012) states that "a homogeneous specification of the relation between the variables x and y does not allow interpreting the causality relations if any individual from the sample has an economic behaviour different from that of the others". Under this circumstance, the null hypothesis of $x_{i,\ t}$ does not homogeneous Granger cause $y_{i,\ t}$ can be tested as $H_0 : \beta_i = 0$, $(i = 1, \ldots N)$ against the alternative hypothesis of $x_{i,\ t}$ does not heterogeneous Granger cause $y_{i,\ t}$ $H_0 : \beta_i = 0$, $(i = 1, \ldots N_1)$; H_1: $\beta_i \neq 0$, $(i = N_1 + 1, N_1 + 2, \ldots N)$ (for some cross-sections). In other words, the null hypothesis says no homogenous Granger causality for all the cross sections against alternative hypothesis supports at least one causal relationship in some cross sections. Under the alternative hypothesis, two subgroups of cross-sections are specified. A causality runs from x to y be observed for the first subgroup, but not merely on the same model. No causal nexus between x and y is observed from the second subgroup. The acceptance or rejection of the null hypothesis is based on the average standard of Wald statistics for each country, and it expresses as:

$$W_{N,T}^{Hnc} = \frac{1}{N} \sum_{i-1}^{N} W_{i,T} \tag{10}$$

Where $W_{i,\ T}$ indicates individual Wald statistics for the each ith cross-section.

4 | EMPIRICAL FINDINGS AND DISCUSSION

4.1 | Preliminary analysis

Table 1 provides the annual average growth rate of the selected variables. The highest growth rate of CEC is attained by China (7.20%), followed by Russia (2.13%), and India (0.20%). South Africa and Brazil are experienced the lowest CEC during this period. Similarly, China is the highest energy consumer with an annual growth rate of 7.75%, followed by India (3.55%) and Brazil (2.40%). South Africa and Russia are the lowest energy consumers with an annual growth of 0.18 and −0.54%, respectively. Moreover, CO_2 growth rates are highest in China (5.31%) and India (3.60%), while Russia is the lowest (−1.13%). In the case of GDP, higher growth is achieved by China (9.17%) and India (4.72%) and lower by South Africa (1.49%). In addition, China is also registered the highest growth rate in capital and population, while the lowest is Russia in both variables. Finally, the higher and lower growth rate of labor is occupied by Brazil (2.11%) and Russia (−0.02%), respectively. Overall, Table 1 shows that the annual average growth rates of all consider variables (except labor) are the highest in the case of China. However, the annual average growth rate of EC is higher than the CEC in the BRICS countries during the study period. Therefore, we can argue that still, CEC needs to grow for mitigating CO_2 without compromising EG in these emerging market economies.

4.2 | Results of panel unit root tests

We begin our empirical analysis with panel unit root tests to verify integration properties of the variables using LLC and IPS. These tests help us in the case of selecting suitable empirical techniques. For the all tests, null hypothesis of a unit root is tested over alternative hypothesis of no unit root. These unit root tests results are depicted in Table 2. The results show that all the variables GDP, GDP^2, CAP, LAB, EC, CEC, and CO_2 are nonstationary at the level but it becomes stationary in its first difference.

4.3 | Results of panel cointegration test

After confirming the all variables are stationary at the first difference, we investigate the long-run link among the variables of Equations (1) and

TABLE 1 Annul average growth rate, 1992–2014 (percent)

Variable	Brazil	Russia	India	China	South Africa	Average
CEC	−1.82	2.13	0.20	7.20	−0.88	1.36
EC	2.40	−0.54	3.55	5.75	0.18	2.26
CO_2	2.74	−1.13	3.60	5.31	0.22	2.14
GDP	1.96	2.10	4.72	9.17	1.49	3.88
GDP^2	4.00	4.64	9.69	19.22	3.04	8.11
CAP	4.31	1.72	8.73	16.62	5.39	7.35
LAB	2.11	−0.02	1.69	0.82	1.97	1.31
POP	1.27	−0.15	1.63	5.31	1.49	1.91

Note: The growth rates were calculated using original data.

TABLE 2 Panel unit root test results

Level					Fist difference			
	LLC test		IPS test		LLC test		IPS test	
Variable	Statistic	Prob.	Statistic	Prob.	Statistic	Prob.	Statistic	Prob.
CEC	0.006	0.502	1.556	0.940	−5.194***	0.000	−5.260***	0.000
EC	0.732	0.768	1.775	0.962	−2.453***	0.007	−2.865***	0.002
CO_2	1.239	0.892	1.934	0.973	−1.905**	0.028	−2.342***	0.009
GDP	0.397	0.654	3.315	0.999	−3.236***	0.000	−3.334***	0.000
GDP^2	1.061	0.855	3.771	0.999	−3.011***	0.001	−3.017***	0.001
CAP	−1.058	0.145	1.496	0.932	−2.010**	0.022	−3.154***	0.000
LAB	−3.710	0.000	−1.377	0.084	−2.211**	0.013	−2.196**	0.014
POP	−1.428	0.076	1.185	0.882	−3.185***	0.000	−1.288*	0.098

Note: *, **, and *** indicate the rejection of null hypothesis of unit root at the 10, 5, and 1% significant levels, respectively.

TABLE 3 Johanson–Fisher panel cointegration test results

GDP = f (CAP, LAB, CO_2, CEC, EC)					*CO_2 = f(GDP, GDP^2, CEC, EC, POP)*			
Hypothesized no. of CE(s)	Trace test	Prob.	Mag-eigen test	Prob.	Trace test	Prob.	Mag-eigen test	Prob.
None	226.2***	0.000	128.0***	0.000	251.6***	0.000	127.9***	0.000
At most 1	137.4***	0.000	71.56***	0.000	167.6***	0.000	87.89***	0.000
At most 2	85.37***	0.000	47.74***	0.000	112.9***	0.000	62.43***	0.000
At most 3	46.41***	0.000	26.82***	0.002	65.62***	0.000	42.59***	0.000
At most 4	29.81***	0.000	25.37***	0.004	35.01***	0.000	33.24***	0.000
At most 5	18.03**	0.054	18.03**	0.054	15.68	0.109	15.68	0.109

Note: ** and *** indicate the rejection of null hypothesis of no cointegration at the 10 and 1 significant levels, respectively.

(1) and (2) using the Fisher–Johanson panel cointegration test. The results of panel cointegration test are reported in Table 3. These results confirm that the null hypothesis of no cointegration is rejected for the trace test and max-eigen test in both Equations (1) and (2). It demonstrates that there an existence of a long-run equilibrium relationship among the selected variables in both equations in these emerging market economies.

4.4 | Panel estimates of long-run economic growth and CO_2 emissions elasticities

The panel cointegration test does not show the nature of cause and effect nexus among EG, CAP, LAB, CO_2, CEC, and EC. Therefore, this study applies the panel FMOLS technique to examine the impact of selected independent variables on EG and CEC in the BRICS countries. The results of FMOLS long-run estimates are displayed in Table 4.

The outcomes confirm that a 1% increase in CEC, EC, and CAP raise 0.209, 1.278, and 0.447% of EG, respectively, while a 1% increase in CO_2 reduces EG by 1.080% in the BRICS countries. More specifically, CEC, EC, and LAB are positively affect EG, while CO_2 is negatively affect it. This results suggest that increasing CEC raises EG and significantly reduces CO_2. Therefore, governments and policymakers should encourage CEC in the total energy mix in these emerging market economies. This outcome is in line with Paramati et al. (2016) and Paramati, Apergis, and Ummalla (2017), who point

TABLE 4 Panel results of FMOLS estimator

Variable	Coefficient	*t*-Statistic	Prob.
GDP = f (CAP, LAB, CO_2, CEC, EC)			
CAP	0.447***	15.874	0.000
LBR	−0.048	−0.444	0.657
CO_2	−1.080***	−3.762	0.000
CEC	0.209***	3.472	0.000
EC	1.278***	3.998	0.000
CO_2 = f(GDP, GDP^2, CEC, EC, POP)			
GDP	0.346***	2.661	0.009
GDP^2	−0.023***	−3.323	0.001
CEC	−0.118***	−4.420	0.000
EC	1.077***	32.874	0.000
POP	−0.117*	−1.676	0.096

Note: * and *** indicate the significance level at the 10 and 1%, respectively.

out that CEC has a significant positive impact on EG and negative influence on CO_2 in their studies. Similarly, this findings is also consistence with Hamit-Haggar (2016) who find that a 1% increase in CEC raises EG by 0.093% in sub-Saharan African countries during 1971–2017, but this finding contrasts with Maji (2015) who find that a 1% increase in CEC reduces EG by 0.713% in Nigeria during 1971–2011.

The long-run estimates of CO_2 reveal that a 1% rise in EC increases CO_2 by 1.077%, while CEC reduces CO_2 by 0.118%. It indicates that EC has a significant positive impact on CO_2, while CEC has a negative impact on CO_2. These findings are in line with our expectations that clean energy sources can be consider as the most effective substitute for other nonclean energy sources. In other words, an increase in CEC combat CO_2 in BRICS countries. These empirical results are corroborated with Paramati et al. (2016) and Paramati, Apergis, and Ummalla (2017) who conclude that EC is significantly increases CO_2 while CEC substantially reduces CO_2 in their studies. The other variable POP also helps to reduce CO_2. However, coefficients of GDP and square GDP are positive and negative, respectively. It indicates the existence of the EKC hypothesis in a panel of these emerging market economies. This implies that per capita CO_2 emissions go up in the early stage but eventually declines when per capita GDP rises over the period. Similar finding was found by Dong et al. (2017), Abdouli et al. (2018), and Danish et al. (2019) in the case of BRICS countries.

4.5 | Time-series analysis of long-run economic growth and CO_2 emissions elasticities

We already explored panel data analysis of long-run EG and CO_2 elasticities in the above section. Here we aim to examine the time-series analysis of long-run EG and CO_2 elasticities for each of the individual countries across a panel. This analysis is more important to understand the impact of CEC on EG and CO_2 and to verify the existence of the EKC hypothesis in individual countries. The country-specific results of FMOLS estimator are reported in Table 5 when EG is a dependent variable. Table 5 shows that CEC has a significant positive impact on EG in both Russia (0.736%) and India (0.130%) countries. In contrast, CEC is negatively associated with EG in Brazil (−0.344%) and China (−0.163%). This indicates that a 1% increase in CEC will increase EG by 0.736% in Russia and 0.130% in India, while it will decrease EG by 0.344% in Brazil and 0.163% in China. In the remaining country, that is, South Africa, CEC does not have either a positive or negative impact on EG. Similarly, CO_2 has a negative impact on EG in Brazil (−0.441%) and China (−2.610%), while a positive impact in India (0.523%). However, EC has a significant positive association with EG in China (2.966%) only. Finally, CAP has a significant positive impact on EG in these individual emerging market economies.

The country-specific results of FMOLS estimator are reported in Table 6 when CO_2 is dependent variable. The results show that CEC has a significant negative impact on CO_2 in individual BRICS countries. More specifically, a 1% increase in CEC reduces CO_2 by 0.504, 0.207, 0.099, 0.054, and 0.048% in Brazil, Russia, India, China, and South Africa, respectively. In addition, EC has a positive and significant influence on CO_2 in all individual countries. Specifically, a 1% increase in EC increases CO_2 by 1.353, 1.002, 0.945, 1.089, and 1.082% in Brazil, Russia, India, China, and South Africa, respectively. These results imply that all individual countries of BRICS should focus more on clean energy use rather than nonclean energy to significantly reduce CO_2. Finally, we did not find the validation of the EKC hypothesis in all five BRICS countries (except China). This finding falls in a

TABLE 5 Country-specific results of FMOLS estimator (dependent variable: GDP)

Country	Variable	CAP	LBR	CO_2	CEC	EC	Adj.R^2
Brazil	Coefficient	0.447***	0.194***	−0.441***	−0.344***	0.299	.989
	t-Statistic	15.874	2.989	−3.277	−3.957	1.310	
	Prob.	0.000	0.008	0.004	0.001	0.208	
Russia	Coefficient	0.462***	−0.652	−0.417	0.736***	0.502	.992
	t-Statistic	8.359	−1.510	−0.628	5.124	0.610	
	Prob.	0.000	0.150	0.5384	0.000	0.550	
India	Coefficient	0.054**	0.739***	0.523**	0.130***	0.298	.997
	t-Statistic	2.093	11.343	2.387	4.545	1.185	
	Prob.	0.052	0.000	0.029	0.000	0.253	
China	Coefficient	0.422***	0.837	−2.610***	−0.163**	2.966***	.998
	t-Statistic	4.783	1.343	−4.299	−2.025	4.295	
	Prob.	0.000	0.198	0.000	0.059	0.000	
South Africa	Coefficient	0.276***	0.070	0.842	−0.038	−1.104	.987
	t-Statistic	5.716	0.555	1.299	−0.765	−1.601	
	Prob.	0.000	0.586	0.212	0.455	0.128	

Note: ** and *** indicate the significance level at the 10 and 5%, respectively.

TABLE 6 Country-specific results of FMOLS estimator (dependent variable: CO_2)

Country	Variable	GDP	GDP^2	CEC	EC	POP	Adj.R^2
Brazil	Coefficient	3.197	−0.209	−0.504***	1.353***	−0.247	.979
	t-Statistic	0.269	−0.326	−4.438	7.538	−0.927	
	Prob.	0.790	0.748	0.000	0.000	0.367	
Russia	Coefficient	1.677	−0.096	−0.207***	1.002***	−0.211	.986
	t-Statistic	1.481	−1.603	−3.561	8.788	−0.382	
	Prob.	0.157	0.128	0.002	0.000	0.707	
India	Coefficient	−2.650***	0.187***	−0.099***	0.945***	0.305**	.999
	t-Statistic	−9.241	9.745	−8.957	26.334	2.899	
	Prob.	0.000	0.000	0.000	0.000	0.010	
China	Coefficient	1.099**	−0.068***	−0.054***	1.089***	−1.217***	.999
	t-Statistic	6.894	−8.173	−5.492	82.150	−3.989	
	Prob.	0.000	0.000	0.000	0.000	0.001	
South Africa	Coefficient	−0.603	0.045	−0.048***	1.082***	−0.200**	.990
	t-Statistic	−0.226	0.304	−3.810	28.053	−2.849	
	Prob.	0.823	0.764	0.001	0.000	0.011	

Note: ** and *** indicate the significance level at the 10 and 5%, respectively.

TABLE 7 Dumitrescu–Hurlin panel causality test results

Equation (1):						
Dependent variable	**Independent variable**					
	GDP	CAP	LBR	CEC	EC	CO_2
GDP	-	0.798 (0.676)	1.045 (0.919)	1.080 (0.954)	2.966** (0.018)	3.111** (0.011)
CAP	1.362 (0.762)	-	0.910 (0.783)	1.308 (0.814)	1.452 (0.676)	1.122 (0.997)
LBR	0.803 (0.681)	0.968 (0.841)		1.140 (0.984)	1.599 (0.544)	0.955 (0.828)
CEC	0.882 (0.756)	1.687 (0.472)	0.278 (0.280)	-	0.127 (0.203)	0.043 (0.167)
EC	1.437 (0.690)	0.749 (0.632)	0.893 (0.767)	0.592 (0.496)	-	2.462** (0.088)
CO_2	1.213 (0.910)	1.621 (0.526)	1.419 (0.707)	0.411 (0.362)	3.461*** (0.002)	-
Equation (2):						
	CO_2	GDP	GDP^2	CEC	EC	POP
CO_2	-	1.213 (0.910)	1.292 (0.830)	0.411 (0.362)	3.461*** (0.002)	1.231 (0.891)
GDP	3.111** (0.011)	-	0.563 (0.473)	1.080 (0.954)	2.966** (0.018)	0.903 (0.778)
GDP^2	3.191*** (0.008)	0.750 (0.633)	-	1.099 (0.974)	3.116** (0.011)	1.337 (0.786)
CEC	0.043 (0.167)	0.882 (0.756)	0.753 (0.635)	-	0.127 (0.203)	1.841 (0.36)
EC	2.462** (0.088)	1.437 (0.690)	1.575 (0.565)	0.592 (0.496)	-	0.666 (0.558)
POP	1.570 (0.570)	2.755** (0.035)	2.838** (0.028)	1.390 (0.734)	1.474 (0.656)	-
Direction of causality						
EC → GDP, GDP ↔ CO_2, EC ↔ CO_2, EC → GDP^2, CO_2 → GDP^2, GDP → POP, GDP^2 → POP						

Note: ** and *** indicate the significance level at the 10 and 5%, respectively.

similar line with the results of Pao et al. (2011), Ummalla and Samal (2018), and Govindaraju and Tang (2013) who did not establish the EKC hypothesis in Russia, China, and China and India, respectively. This finding, however, contradicts with Pao and Tsai (2011a), Jayanthakumaran et al. (2012), Tiwari et al. (2013) and Boutabba (2014), Kohler (2013) in China, China and India, India, South Africa, respectively; who found that an evidence of the EKC hypothesis in their studies.

Based on the above results we can infer that all five countries where CEC has a positive impact on EG and negative impact on CO_2, we suggest that these individual countries should focus more on clean energy use rather than nonclean energy to achieve sustainable economic growth by significantly reducing CO_2. In China, EC has a positive impact on EG but CEC has negative influence on it. However, CEC significantly reducing CO_2 while EC increasing it. It because of China heavily depends on coal consumption which leads to CO_2. Therefore, China's policymakers should promote efficient use of clean energy and also investment in clean energy technologies. Further, the nonexistence of the EKC hypothesis countries should have sound economic and energy policies.

4.6 | Panel causality test results

The presence of long-run cointegration relationship among the variables suggests that there must be one way Granger causality at least. For this purpose, we test the direction of causality among the selected variables by using Dumitrescu and Hurlin (2012) panel causality test. The empirical results of the short-run panel causality test are documented in Table 7. The findings show that EC Granger causes EG and bidirectional causality between EC and CO_2, while CO_2 Granger causes EG. However, we found no causal relationship between CEC and EG and also among EG, CAP, LAB, and CEC in Equation (1). Similarly, from Equation (2), we find that unidirectional causality from EC to EG and bidirectional causality between EC and CO_2, while one-way causality from CO_2 to EG. Further, unidirectional causality from EG to POP. However, we found no causal relationship between CEC and EG. Finally, these results suggest that EC influences EG, and bidirectional casualty between EC and CO_2, but no evidence of causality between CEC and EG. This can be portrayed as EC plays a significant role in EG and this EC stimulates CO_2 in the BRICS countries. However, given the concern on climate change and greenhouse gas emissions, these emerging market economies should encourage clean energy uses by providing tax incentives in clean energy projects without compromising economic growth. This result is in line with Paramati et al. (2016) who found no causality between CEC and EG in 20 emerging market economies. This is inconsistent with Pao et al. (2014) and Hamit-Haggar (2016) who documented unidirectional causality between these two variables in MITS and 11 sub-Saharan African countries, respectively.

5 | CONCLUSION AND POLICY IMPLICATIONS

This study probes the impact of CEC on EG and CO_2 by incorporating CAP, LAB, EC, and POP, and tested the EKC hypothesis in the BRICS countries over the period 1992–2014. We estimated two separate specification models where in the first model, EG is a dependent variable, and in the second model, CO_2 is a dependent variable. For empirical analysis, this study used LLC and IPS unit tests to check the stationary properties of the selected variables. The Johanson–Fisher panel cointegration is applied to examine the long-run equilibrium relationship among the variables. The long-run elasticities of EG and CO_2 were estimated by employing panel FMOLS. Finally, Dumitrescu and Hurlin (2012) panel causality test is used to examine the short-run causal relationship among the variables.

The results of the panel cointegration test confirmed the long-run equilibrium association among the variables in both Equations (1) and (2). The long-run elasticities of EG and CO_2 show that EC, CEC, and CAP have a significant positive impact on EG, while CO_2 has a negative impact on it in a panel of BRICS countries. The findings also show that EG and EC increase CO_2, but CEC reduces CO_2. Further, our results established the existence of the EKC hypothesis in a panel of these emerging market economies. Finally, EC causes EG, but no reverse causality between them. However, we found no causal relationship between CEC and EG in the BRICS nations. This result is in line with Paramati et al. (2016) in 20 emerging market economies. This is inconsistent with Pao et al. (2014) and Hamit-Haggar (2016) in MITS and 11 sub-Saharan African countries, respectively. Based on the above results, we can observe that rapid EG and EC yield higher CO_2, which postulates that these two variables are mainly triggering CO_2 in BRICS countries. However, EC increases CO_2 where CEC reduces it, which indicates that CEC is the potential determinants of mitigating CO_2 emissions. Here, it is importance to note that rapid EG and EC are important to any emerging economies to achieve convergence with advanced countries. But CEC is a vital factor not only to mitigate CO_2 and path to sustainable economic growth, but also to create a healthy environment. Therefore, our findings of the present paper suggest that policymakers of the BRICS countries should cut down CO_2 by consuming clean energy rather than nonclean energy to achieve sustainable economic growth.

From the above empirical analysis, we can draw important policy implications. First, EC and CEC have a positive impact on EG. However, EC increases CO_2, while CEC significantly reduces it. Therefore, the BRICS governments and policymakers should support the development of clean energy so that it not only meet the demand for energy, but also combat CO_2. Second, to accelerate and development of clean energy these emerging market economies should share their knowledge and expertise, strengthen the rules and regulations, and collaborating research, development and demonstration (RD&D) activities. Third, the BRICS countries should attract more domestic and foreign investment in clean energy projects. Ummalla, Samal, and Goyari (2019) also suggested that financing hydropower energy projects will give a solution to environmental issues. Fourth, they should improve the technological innovation in three economic activities (namely, agriculture, industry and services) to reduce CO_2.

The main limitations of the present study are that it is conducted on BRICS countries only and more extended period data on CEC are not available. Despite these limitations, our research has provided valuable policy implications regard to the nexus among CEC, EG, and CO_2 in the context of BRICS countries. However, considering clean energy as an alternative to fossil fuels, a study can be conducted on these variables in developed and developing countries. Finally, the present study considers CEC at the aggregate level for the impact on EG and CO_2, and verify the existence of the EKC hypothesis. Therefore, a future study can be considered CEC at the disaggregated level (i.e., nuclear, hydro, wind, and solar) for both developed and developing countries.

ORCID

Mallesh Ummalla https://orcid.org/0000-0003-3222-3906

ENDNOTE

[1] Brazil's was 37% in 2025 and 43% in 2030 below 2005 levels, Russia's was 25–30% from 1990 levels, India's was 33%–35% from 2005 levels, China's was 60–65% from 2005 levels, South Africa's was 398–614 metric tons of carbon dioxide equivalent during 2025–2030 (Carbon Brief, 2015).

REFERENCES

Abdouli, M., Kamoun, O., & Hamdi, B. (2018). The impact of economic growth, population density, and FDI inflows on CO_2 emissions in BRICTS countries: Does the Kuznets curve exist? *Empirical Economics*, *54*(4), 1717–1742.

Apergis, N., Can, M., Gozgor, G., & Lau, C. K. M. (2018). Effects of export concentration on CO_2 emissions in developed countries: An empirical analysis. *Environmental Science and Pollution Research*, *25*(14), 14106–14116.

Aslan, A., & Çam, S. (2013). Alternative and nuclear energy consumption–economic growth nexus for Israel: Evidence based on bootstrap-corrected causality tests. *Progress in Nuclear Energy*, *62*, 50–53.

Bhattacharya, M., Awaworyi Churchill, S., & Paramati, S. R. (2017). The dynamic impact of renewable energy and institutions on economic output and CO_2 emissions across regions. *Renewable Energy*, *111*, 157–167.

Boutabba, M. A. (2014). The impact of financial development, income, energy and trade on carbon emissions: Evidence from the Indian economy. *Economic Modelling*, *40*, 33–41.

BP (2018) *BP statistical review of world energy*. London.

Cai, Y., Sam, C. Y., & Chang, T. (2018). Nexus between clean energy consumption, economic growth and CO2 emissions. *Journal of Cleaner Production*, *182*, 1001–1011.

Carbon Brief, 2015. Paris 2015: tracking country climate pledges. Available from https://www.carbonbrief.org/paris-2015-tracking-country-climate-pledges

Chakravarty, D., & Mandal, S.-K. (2016). Estimating the relationship between economic growth and environmental quality for the BRICS economies-a dynamic panel data approach. *Journal of Developing Areas*, *50*(5), 119–130.

Chang, M.-C. (2015). Room for improvement in low carbon economies of G7 and BRICS countries based on the analysis of energy efficiency and environmental Kuznets curves. *Journal of Cleaner Production*, *99*, 140–151.

Danish, Baloch, M. A., Mahmood, N., & Zhang, J. W. (2019). Effect of natural resources, renewable energy and economic development on CO_2 emissions in BRICS countries. *Science of the Total Environment*, *678*, 632–638.

Dong, K., Sun, R., & Hochman, G. (2017). Do natural gas and renewable energy consumption lead to less CO_2 emission? Empirical evidence from a panel of BRICS countries. *Energy*, *141*(Suppl. C), 1466–1478.

Dong, K., Sun, R., Jiang, H., & Zeng, X. (2018). CO_2 emissions, economic growth, and the environmental Kuznets curve in China: What roles can nuclear energy and renewable energy play? *Journal of Cleaner Production*, *196*, 51–63.

Dumitrescu, E.-I., & Hurlin, C. (2012). Testing for granger non-causality in heterogeneous panels. *Economic Modelling*, *29*(4), 1450–1460.

Fang, J., Gozgor, G., Lu, Z., & Wu, W. (2019). Effects of the export product quality on carbon dioxide emissions: Evidence from developing economies. *Environmental Science and Pollution Research*, *26*(12), 12181–12193.

Govindaraju, C. V. G. R., & Tang, C. F. (2013). The dynamic links between CO_2 emissions, economic growth and coal consumption in China and India. *Applied Energy*, *104*, 310–318.

Gozgor, G., & Can, M. (2017). Does export product quality matter for CO_2 emissions? Evidence from China. *Environmental Science and Pollution Research*, *24*(3), 2866–2875.

Hamit-Haggar, M. (2016). Clean energy-growth nexus in sub-Saharan Africa: Evidence from cross-sectionally dependent heterogeneous panel with structural breaks. *Renewable and Sustainable Energy Reviews*, *57*, 1237–1244.

Hsiao, C. (2007). Panel data analysis—Advantages and challenges. *Test*, *16*(1), 1–22.

Im, K. S., Pesaran, M. H., & Shin, Y. (2003). Testing for unit roots in heterogeneous panels. *Journal of Econometrics*, *115*(1), 53–74.

Jayanthakumaran, K., Verma, R., & Liu, Y. (2012). CO_2 emissions, energy consumption, trade and income: A comparative analysis of China and India. *Energy Policy*, *42*, 450–460.

Johansen, S. (1988). Statistical analysis of cointegration vectors. *Journal of Economic Dynamics and Control*, *12*(2), 231–254.

Kohler, M. (2013). CO_2 emissions, energy consumption, income and foreign trade: A south African perspective. *Energy Policy*, *63*, 1042–1050.

Kutan, A. M., Paramati, S. R., Ummalla, M., & Zakari, A. (2018). Financing renewable energy projects in major emerging market economies: Evidence in the perspective of sustainable economic development. *Emerging Markets Finance and Trade*, *54*(8), 1761–1777.

Levin, A., Lin, C.-F., & James Chu, C.-S. (2002). Unit root tests in panel data: Asymptotic and finite-sample properties. *Journal of Econometrics*, *108*(1), 1–24.

Maddala, G. S., & Wu, S. (1999). A comparative study of unit root tests with panel data and a new simple test. *Oxford Bulletin of Economics and Statistics*, *61*(S1), 631–652.

Maji, I. K. (2015). Does clean energy contribute to economic growth? Evidence from Nigeria. *Energy Reports*, *1*(0),145–150.

Pao, H.-T., Li, Y.-Y., & Hsin-Chia, F. (2014). Clean energy, non-clean energy, and economic growth in the MIST countries. *Energy Policy*, *67*, 932–942.

Pao, H.-T., & Tsai, C.-M. (2010). CO_2 emissions, energy consumption and economic growth in BRIC countries. *Energy Policy*, *38*(12), 7850–7860.

Pao, H.-T., & Tsai, C.-M. (2011a). Modeling and forecasting the CO_2 emissions, energy consumption, and economic growth in Brazil. *Energy*, *36*(5), 2450–2458.

Pao, H.-T., & Tsai, C.-M. (2011b). Multivariate granger causality between CO_2 emissions, energy consumption, FDI (foreign direct investment) and GDP (gross domestic product): Evidence from a panel of BRIC (Brazil, Russian Federation, India, and China) countries. *Energy*, *36*(1), 685–693.

Pao, H.-T., Yu, H.-C., & Yang, Y.-H. (2011). Modeling the CO_2 emissions, energy use, and economic growth in Russia. *Energy*, *36*(8), 5094–5100.

Paramati, S. R., Apergis, N., & Ummalla, M. (2017). Financing clean energy projects through domestic and foreign capital: The role of political cooperation among the EU, the G20 and OECD countries. *Energy Economics*, *61*, 62–71.

Paramati, S. R., Mo, D., & Gupta, R. (2017). The effects of stock market growth and renewable energy use on CO_2 emissions: Evidence from G20 countries. *Energy Economics*, *66*, 360–371.

Paramati, S. R., Sinha, A., & Dogan, E. (2017). The significance of renewable energy use for economic output and environmental protection: Evidence from the next 11 developing economies. *Environmental Science and Pollution Research*, *24*(15), 13546–13560.

Paramati, S. R., Ummalla, M., & Apergis, N. (2016). The effect of foreign direct investment and stock market growth on clean energy use across a panel of emerging market economies. *Energy Economics*, *56*, 29–41.

Pedroni, P. (2001a). Fully modified OLS for heterogeneous cointegrated panels. In B. H. Baltagi (Ed.), *Nonstationary panels, panel cointegration, and dynamic panels* (Vol. 15, pp. 93–130). Bingley: Emerald Group Publishing.

Pedroni, P. (2001b). Purchasing power parity tests in cointegrated panels. *The Review of Economics and Statistics*, *83*(4), 727–731.

Pedroni, P. (2004). Panel cointegration: Asymptotic and finite sample properties of pooled time series tests with an application to the PPP hypothesis. *Econometric Theory*, *20*(3), 597–625.

Rafiq, S., Bloch, H., & Salim, R. (2014). Determinants of renewable energy adoption in China and India: A comparative analysis. *Applied Economics*, *46*(22), 2700–2710.

Saidi, K., & Ben Mbarek, M. (2016). Nuclear energy, renewable energy, CO_2 emissions, and economic growth for nine developed countries: Evidence from panel granger causality tests. *Progress in Nuclear Energy*, *88*, 364–374.

Salim, R. A., & Rafiq, S. (2012). Why do some emerging economies proactively accelerate the adoption of renewable energy? *Energy Economics*, *34*(4), 1051–1057.

Sharif, A., Raza, S. A., Ozturk, I., & Afshan, S. (2019). The dynamic relationship of renewable and non-renewable energy consumption with carbon emission: A global study with the application of heterogeneous panel estimations. *Renewable Energy*, *133*, 685–691.

Solarin, A. S., Al-Mulali, U., & Ozturk, I. (2017). Validating the environmental Kuznets curve hypothesis in India and China: The role of hydroelectricity consumption. *Renewable and Sustainable Energy Reviews*, *80*, 1578–1587.

Tamazian, A., Chousa, J. P., & Vadlamannati, K. C. (2009). Does higher economic and financial development lead to environmental degradation: Evidence from BRIC countries. *Energy Policy*, *37*(1), 246–253.

Tiwari, A. K., Shahbaz, M., & Adnan Hye, Q. M. (2013). The environmental Kuznets curve and the role of coal consumption in India: Cointegration and causality analysis in an open economy. *Renewable and Sustainable Energy Reviews*, *18*, 519–527.

Ummalla, M., & Samal, A. (2018). The impact of hydropower energy consumption on economic growth and CO_2 emissions in China. *Environmental Science and Pollution Research*, *25*(35), 35725–35737.

Ummalla, M., & Samal, A. (2019). The impact of natural gas and renewable energy consumption on CO_2 emissions and economic growth in two major emerging market economies. *Environmental Science and Pollution Research*, *26*(20), 20893–20907.

Ummalla, M., Samal, A., & Goyari, P. (2019). Nexus among the hydropower energy consumption, economic growth, and CO_2 emissions: Evidence from BRICS countries. *Environmental Science and Pollution Research*, *26* (34), 35010–35022.

Usman, O., Iorember, P. T., & Olanipekun, I. O. (2019). Revisiting the environmental Kuznets curve (EKC) hypothesis in India: The effects of energy consumption and democracy. *Environmental Science and Pollution Research*, *26*(13), 13390–13400.

World Bank (2019). World development indicators, World Bank. Available from https://databank.worldbank.org/reports.aspx?source=world-development-indicators.

AUTHOR BIOGRAPHIES

Mallesh Ummalla is a PhD scholar at the School of Economics in University of Hyderabad, India. He has completed his MA and MPhil in Economics from Pondichery University, India. He has published his research work in Energy Economics, Emerging Markets Finance and Trade, Environmental Science and Pollution Research, and Theoretical and Applied Economics, etc. His research interest includes clean and renewable energy, CO_2 emissions, and developmental issues.

Phanindra Goyaris is a Professor of Economics at the School of Economics in University of Hyderabad, India. Professor Goyari has obtained his PhD degree in Economics from University of Hyderabad, India. Recently, he has completed his Post-Doctoral Research at Texas Christian University, USA. He has published numerous scholarly articles in, among others, Economic and Political Weekly, Agricultural Economics Research Review, The Journal of Developing Areas, Agricultural and Food Economics, Journal of Quantitative Economics, and Environmental Science and Pollution Research.

How to cite this article: Ummalla M, Goyari P. The impact of clean energy consumption on economic growth and CO_2 emissions in BRICS countries: Does the environmental Kuznets curve exist? *J Public Affairs*. 2020;e2126. https://doi.org/10.1002/pa.2126

56th ANNUAL CONFERENCE OF THE INDIAN ECONOMETRIC SOCIETY (TIES)

Madurai Kamaraj University

8 - 10 January 2020

CERTIFICATE

This is to certify that Mr/Ms/Dr. Mallesh ummalla .... of University of Hyderabad, Hyderabad, Telangana .... presented a research paper entitled The impact of clean energy consumption on economic growth and CO2 emissions: Evidence from a panel of BRICS countries in the **56th Annual Conference of The Indian Econometric Society (TIES) held during 08 – 10 January 2020,** organized by School of Economics, Madurai Kamaraj University, Madurai, Tamil Nadu, India.

Prof. N.R. Bhanumurthy	Prof. D. Swamikannan	Dr. S. Pushparaj
Secretary, TIES	Local President	Local Organising Secretary

ICFAI Foundation for Higher Education
(Deemed-to-be-University under Section 3 of the UGC Act, 1956)

IGIDR

IBS
ICFAI BUSINESS SCHOOL
HYDERABAD

AACSB ACCREDITED

13th Doctoral Thesis Conference

8th & 9th October 2020

Certificate of Presentation

This Certificate is Presented to

Mallesh Ummalla

For Presenting the paper titled

Does institutional quality matter for renewable energy consumption and CO2 emissions in BRICS countries?

In 13th Doctoral Thesis Conference organized by IBS Hyderabad

Prof. Sushanta Kumar Mahapatra
Conference Chair

Prof. V Padamavathi
Conference Co-chair

Three Essays in Energy Economics: A Study on BRICS Countries

by Ummalla Mallesh

Three Essays in Energy Economics: A Study on BRICS Countries

ORIGINALITY REPORT

62% −30−22 = 10%
SIMILARITY INDEX

28/12/2020

DR. PHANINDRA GOYARI
Professor
School of Economics
University of Hyderabad
Hyderabad-500046. India

46%
INTERNET SOURCES

57%
PUBLICATIONS

13%
STUDENT PAPERS

PRIMARY SOURCES

1	link.springer.com (Annexure-1) 28/12/2020 Internet Source	−30%
2	Mallesh Ummalla, Phanindra Goyari. " The impact of clean energy consumption on economic growth and CO emissions in BRICS countries: Does the environmental Kuznets curve exist? ", Journal of Public Affairs, 2020 (Annexure-2) Publication	−22%
3	mpra.ub.uni-muenchen.de Internet Source	1%
4	Sudharshan Reddy Paramati, Mallesh Ummalla, Nicholas Apergis. "The effect of foreign direct investment and stock market growth on clean energy use across a panel of emerging market economies", Energy Economics, 2016 Publication	1%
5	www.tandfonline.com Internet Source	1%
	discovery.dundee.ac.uk	

DR. PHANINDRA GOYARI
Professor
School of Economics
University of Hyderabad
Hyderabad-500046. India

These ① and ② are publications of the research scholar, given in Annexure-1 and 2, respectively
28/12/2020

DR. PHANINDRA GOYARI
Professor
School of Economics
University of Hyderabad
Hyderabad-500046. India

PhD Supervisor

6	Internet Source	<1%
7	onlinelibrary.wiley.com Internet Source	<1%
8	www.mdpi.com Internet Source	<1%
9	المالكي ، أمل. "المحددات الاقتصادية لانبعاثات ثاني أكسيد الكربون في المملكة العربية السعودية : الدور والأثر = The Economic Determinants of the Carbon Dioxide Emission in Saudi Arabia : The Role and Impact", King Abdulaziz University : Scientific Publishing Centre, 2020 Publication	<1%
10	www120.secure.griffith.edu.au Internet Source	<1%
11	Submitted to Jawaharlal Nehru University (JNU) Student Paper	<1%
12	Mallesh Ummalla, Asharani Samal, Phanindra Goyari. "Nexus among the hydropower energy consumption, economic growth, and CO2 emissions: evidence from BRICS countries", Environmental Science and Pollution Research, 2019 Publication	<1%
13	editorialexpress.com Internet Source	<1%

14	www.econjournals.com Internet Source	<1%
15	Sudharshan Reddy Paramati, Di Mo, Rakesh Gupta. "The effects of stock market growth and renewable energy use on CO 2 emissions: Evidence from G20 countries", Energy Economics, 2017 Publication	<1%
16	Submitted to National Institute of Technology, Rourkela Student Paper	<1%
17	jedsnet.com Internet Source	<1%
18	pericles.pericles-prod.literatumonline.com Internet Source	<1%
19	Submitted to The University of Manchester Student Paper	<1%
20	www.dallasfed.org Internet Source	<1%
21	Submitted to University of Amsterdam Student Paper	<1%
22	Submitted to Bloomsbury Colleges Student Paper	<1%
23	pdfs.semanticscholar.org Internet Source	<1%

24	mafiadoc.com Internet Source	<1%
25	jfin-swufe.springeropen.com Internet Source	<1%
26	energsustainsoc.biomedcentral.com Internet Source	<1%
27	ir.nctu.edu.tw Internet Source	<1%
28	iaabd.org Internet Source	<1%
29	Submitted to University of Sri Jayewardenepura Nugegoda Sri Lanka Student Paper	<1%
30	hydra.hull.ac.uk Internet Source	<1%
31	ec.europa.eu Internet Source	<1%
32	www.researchgate.net Internet Source	<1%
33	www.asecu.gr Internet Source	<1%
34	Mucahit Aydin, Yunus Emre Turan. "The influence of financial openness, trade openness,	<1%

and energy intensity on ecological footprint: revisiting the environmental Kuznets curve hypothesis for BRICS countries", Environmental Science and Pollution Research, 2020
Publication

35	researchportal.port.ac.uk Internet Source	<1%
36	Ali M. Kutan, Sudharshan Reddy Paramati, Mallesh Ummalla, Abdulrasheed Zakari. "Financing Renewable Energy Projects in Major Emerging Market Economies: Evidence in the Perspective of Sustainable Economic Development", Emerging Markets Finance and Trade, 2017 Publication	<1%
37	Submitted to London School of Economics and Political Science Student Paper	<1%
38	www.inderscienceonline.com Internet Source	<1%
39	Sudharshan Reddy Paramati, Nicholas Apergis, Mallesh Ummalla. "Financing clean energy projects through domestic and foreign capital: The role of political cooperation among the EU, the G20 and OECD countries", Energy Economics, 2017 Publication	<1%

40	www.evwind.es Internet Source	<1%
41	Submitted to uu Student Paper	<1%
42	Submitted to Aristotle University of Thessaloniki Student Paper	<1%
43	Submitted to University of Petroleum and Energy Studies Student Paper	<1%
44	cluteinstitute.com Internet Source	<1%
45	Sudharshan Reddy Paramati, Nicholas Apergis, Mallesh Ummalla. "Dynamics of renewable energy consumption and economic activities across the agriculture, industry, and service sectors: evidence in the perspective of sustainable development", Environmental Science and Pollution Research, 2017 Publication	<1%
46	espace.curtin.edu.au Internet Source	<1%
47	stud.epsilon.slu.se Internet Source	<1%
48	Submitted to University of Nigeria Student Paper	<1%

49	edgar.jrc.ec.europa.eu Internet Source	<1%
50	Submitted to Monash University Student Paper	<1%
51	Ahmed Malumfashi Halliru, Nanthakumar Loganathan, Asan Ali Golam Hassan, Abbas Mardani, Hesam Kamyab. "Re-examining the environmental kuznets curve hypothesis in the economic community of West African states: A panel quantile regression approach", Journal of Cleaner Production, 2020 Publication	<1%
52	Submitted to Graduate Institute of International and Development Studies Student Paper	<1%
53	hdl.handle.net Internet Source	<1%
54	www.afridev.org Internet Source	<1%
55	ethesis.unifr.ch Internet Source	<1%
56	Multinational Business Review, Volume 20, Issue 4 (2012-11-24) Publication	<1%
57	isiarticles.com	

Internet Source

<1%

58	www.atlantis-press.com Internet Source	<1%
59	businessperspectives.org Internet Source	<1%
60	researchbank.rmit.edu.au Internet Source	<1%
61	Submitted to Wawasan Open University Student Paper	<1%
62	Submitted to Yildirim Beyazit Universitesi Student Paper	<1%
63	www.ijcar.net Internet Source	<1%
64	Submitted to uvt Student Paper	<1%
65	eprints.undip.ac.id Internet Source	<1%
66	Submitted to CSU, San Jose State University Student Paper	<1%

Exclude quotes	On	Exclude matches	< 14 words

Exclude bibliography On