Demystifying Energy Growth Connections: Lessons for Public Policy in India

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BY

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Dedicated

to

My Parents

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&

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DECLARATION

I, Mr. Jaganath Behera, hereby declare that this thesis entitled "**Demystifying Energy Growth Connections: Lessons for Public Policy in India**" submitted by me under the supervision of Dr. Alok Kumar Mishra, 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 in 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 Shodhganga/INFLIBNET.

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CERTIFICATE

This is to certify that the thesis entitled "Demystifying Energy Growth Connections: Lessons for Public Policy in India" submitted by Mr. Jaganath Behera bearing registration number 14SEPH10 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. Publication:

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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:

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EC751	Study Area	4	Passed

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Date: 31-01-2022

Dean

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Jaganath Behera

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ABBREVIATION

ADF	Augmented Dickey Fuller
AIC	Akaike Information Criteria
AMECO	European Commission Economic and Financial Affairs Indicators
ARCH	Auto Regressive Conditional Heteroscadasticity
ARDL	Autoregressive Distributed Lag
ATF	Aviation Turbine Fuel
BCM	Billion Cubic Meters
BT	Billion Tones
BTO	Billion Tones
BU	Billion Units
CADF	Cross Sectional Augmented Dickey Fuller
CAGR	Cumulative Annual Growth Rate
CD	Cross Sectional Dependency
CD-ROM	Compact Disc Read Only Memory
CEA	Central Electricity Authority
CKC	Carbon Kuznets Curve
CMT	Cubic Million Tones
CSIR	Council of Scientific and Industrial Research
CUSUM	Cumulative Sum Control Chart
CUSUMSQ	Cumulative Sum of Recursive Residuals and the CUSUM Square

DFE	Dynamic Fixed Effect
DOLS	Dynamic Ordinary Least Square
ECM	Error Correction Model
ECOWAS	Economic Community of West African States
EIA	Energy Information Administration
EKC	Environmental Kuznets Curve
ERS	European Respiratory Society
FAO	Food and Agricultural Organization
FAOSTAT	Food and Agriculture Organization Corporate Database
FDI	Foreign Direct Investment
FE	Fixed Effect
FMOLS	Fully Modified Ordinary Least Square
GDP	Gross Domestic Product
GHGs	Green House Gases
GMM	Generalized Movements Methods
GNI	Gross National Income
GOI	Government of India
GWH	Giga Watt Hour
HQ:	Hannan Quinn
HSDO	High Speed Diesel Oil
IAEA	International Atomic Energy Agency
IBEF	Indian Brand Equity Foundation
ICAR	Indian Council of Agricultural Research

IEA	International Energy Administration
IEA	International Energy Agency
IEO	International Energy Outlook
IEP	Integrated Energy Policy
IES	International Energy Statistics
IFS	International Financial Statistics
IMF	International Monetary Fund
IPCC	Intergovernmental Panel on Climate Change
IRF	Impulse Response Function
JB	Jerque Bera
KOE	Kg Oil Equivalent
LDO	Light Diesel Oil
LM	Lagrange Multiplier
LPG	Liquefied Petroleum Gas
MENA	Middle East and North Africa
MG	Mean Group
MJ	Mega Joules
MMT	Million Metric Tones
MOC	Ministry of Coal
MOPNG	Ministry of Petroleum and Natural Gas
MT	Million Tones
MTOE	Million Tons Oil Equivalent
MWALD	Modified Wald Test Method

NBER	National Bureau of Economic Research
NEA	Nuclear Energy Agency
NLS	Non-linear least Square
NSDP	National Spatial Development Perspective
OECD	Oil Exporting Countries Development
OLS	Ordinary Least Square
OPEC	Oil Petroleum Exporting Countries
PHWR	Pressurized Heavy Water Reactors
PJ	Peta Joules
PMG	Pooled Mean Group
PP	Philips Perron
PPP	Purchasing Power Parity
PSTR	Panel Smooth Transition Regression
RE	Random Effect
SHP	Small Hydro Power
SSA	Sub-Saharan African
TYDL	Toda-Yamamoto Dorado-Lutkepohl
UAE	United Arab Emirates
UNEP	United Nations Environment Programme
USA	United States of America
USDA	United States Department of Agriculture
VAR	Vector Autoregression
VECM	Vector Error Correction Model

WB	World Bank
WDI	World Development Indicators
WEO	World Economic Outlook
WRS	World Research Institute

Demystifying Energy Growth Connections: Lesson for Public Policy in India

Abstract

This thesis explores the relationship between energy consumption and economic growth. Chapter Three, four, five, six and seven examine the linkage between energy consumption and economic growth outcomes by applying different methodologies across spatial dimensions. Chapter three examined the trends and patterns of energy consumption, production, and distribution of the energy sector in India. The empirical evidence of this chapter indicates that energy security for India could be achieved through the constant availability of commercial energy to increase its growth level. Chapter four shows that renewable and non-renewable energy consumption are necessary for economic growth in both developed and developing countries. Chapter five estimated the presence of Environmental Kuznets Curve hypothesis in the context of India. Chapter six studied the impact of Sectoral electricity consumption on economic growth in India. Chapter seven investigated the role of nuclear energy consumption on economic growth in India. The study suggest that nuclear energy consumption has a positive and significant impact on economic growth in India. The thesis concluded with chapter eight.

Key Words: *Energy, Growth, ARDL, Co-integration, P-ARDL, Error Correction, India*

GEL Classifications: $Q_{43,}$ *and* C_{32}

CHAPTER 1

Background, Objectives, and Methodology of the Study

1.1 Background

Human activities are the leading cause of greenhouse gas emissions (GHGs) and linked to climate change in the last two centuries, particularly in the Nineteenth century (CSIR 2009; IPCC 2007B, 2007A). Since the pre-industrial periods, the emission level has been proliferating, soaring the World's oceans and air temperature and risk in sea points (IPCC, 2007B, 2007A, Mackibbin and Wilcoxen 2002). The changing climate conditions are connected to plats and population by various negative externalities (Garnaut 2008; Owen 1997, Wills 2006). Conversely, greenhouse gas emissions are endorsed mainly by using energy to produce goods and services. The ever-increasing amount of worldwide carbon dioxide (CO_2) emissions seems to be intensifying this problem. Since most emissions are mainly from fossil fuels, reducing energy consumption is a direct and efficient way to reduce emissions. However, due to the possible negative impacts on economic growth, especially in developing countries, cutting back on energy use is less travelled.

The expansion of energy-consuming activities in developed and emerging countries leads to two primary concerns. First, the depletion of most easily accessible energy resources, i.e., oil, gas, and coal, and subsequently the problem of global warming caused by the rapidly increasing emissions of greenhouse gases such as carbon dioxide (CO2) and methane. This global nature energy challenge calls for the efficient management and optimum utilisation of renewable energy resources. In layman parlance, renewable energy is commonly defined as energy generated from natural sources such as solar, wind, tide and wave, wood, waste, geothermal, and biomass. Unlike conventional energy, renewable energy is clean, safe, and inexhaustible. This is also known as clean energy and shifting to this will protect the environment and contribute to growth and employment (UNDP, 2011). Therefore, renewable energy consumption-led growth will occupy a leading position across the World. The United Nations' Sustainable Development Goals (SDGs) agenda has set a clear goal (i.e., SDG 7) to achieve sustainable energy through global access to clean energy, ensuring sufficient energy supply, and growing the proportion of renewable energy in the overall global energy mix globally (UN 2015).

In developing countries, natural resources are the primary energy source for economic growth. However, the exhaustive use of natural resources will increase the volume of carbon dioxide (CO_2) emissions which further depletes the environment. The energy-linked restraint of economic growth has been terminated historically by conventional macroeconomic principles (e.g., Solow 1956; Barro & Sala-I-Martin 2003; Mankiw 2006 and Aghion and Howitt 2009). Most ecological economists merely consider the critical importance of energy and disregard the characteristics of other essential contributors like labour and capital (Cleveland et al. 1984; Hall et al. 1986). Efforts have been initiated to incorporate the two approaches, but there is no consensus (e.g., Stern 2001a, and Ayres and Warr 2009).

Much theoretical work has been contributed to economic growth primarily based on the Solow growth model. In recent years, growth models have relied increasingly on endogenous growth theories. A few theoretical studies model a direct link between the environment and growth, energy and growth, and energy and environment. The empirical literature seems to be more abundant. However, the perennial debate over the relationship between economic growth and energy consumption has generated conflicting evidence and remains unresolved (Adewuyi and Awodumi, 2017, Omri, 2013; Ozturk, 2010). Further, energy usage is a more significant concern due to increased imported energy prices. Thus, examining the relationship between output growth and the energy consumption is an initial step for formulating necessary strategies to cut emissions and sustain sustainable economic progress.

To analyze the linkage between energy consumption and economic growth, empirical works have used econometric methods to justify whether energy consumption reasons for economic growth or not. The findings are inadequate. Studies were done by Kraft, and Kraft 1978 and Long 1978 obtained no causality from energy to output. Succeeding studies reported econometric problems and omitted variable biases with early literature (Stern 1993; Karenfil 2009). However, few researchers supported the presence of a causal relationship between energy consumption to economic growth. However, there is no agreement on the findings (Payne 2010c). Most of the findings are inconclusive or have employed different frameworks and alternative methodologies.

Smulders and De Nooji (2003) suggested that reducing energy consumption without technical improvements would negatively affect economic growth. Thus, the policy suggestions regarding energy efficiency and promotion of fuel switching are considered the vital measure of energy preservation to diminish emission (Pereira & Pereira 2010). Formulating policies for this requires proper advancement of technology, a well-developed market structure, and primary factors from the present and historical perspectives. For example, in the case of inter-fuel substitution, it is essential to understand whether technological viabilities exist in the market or technological innovation is necessary. For planning energy efficiency policies in the future, one needs to understand historical tendencies and likely situations for emission reduction. Now the question that arises is; in order to attain the national goal of emission reduction, how much energy efficiency improvement is necessary? It is a fundamental task to understand and maintain the role of energy competence in declining emissions and to choose particular composite indicators that could extend and incorporate energy competence indicators for the aggregate economy.

It is not easy to significantly increase the production of goods and services without raising energy consumption. Finally, the trade-off between emissions and economic well-being must be well understood. On the other hand, the question remains whether emission increases linearly with economic improvement or not. It is an essential research matter, particularly in appraising the current strategies on emission reduction, predicting the future emissions, and the improvement cost. Some studies suggested that there is a possibility of an inverted 'U' shaped linkage between the quality of the environment and per capita GDP. The 'U' shaped relationship between these two variables shows the emission level increases with a rise in income but decreases, showing that emissions would decline as people grow wealthier (Grossman and Krueger 1991; Shafik and Bandyopadhyay 1992). Improvement in the energy consumption efficiency, behavioral changes linked to technological enhancement, population-based factors, and socio-economic factors cause an inverted 'U' shaped path among income and emissions. Nevertheless, Shafik and Bandopadhyay (1992) suggested that "it is possible to grow out of some environmental problems. But there is nothing automatic about these policies and investments must be made to reduce degradation" (P-23).

Several theories and empirical studies have been devoted to analyzing the relationships among various aspects of energy consumption and economic growth, including mechanisms by which energy consumption can sustain development over time (Bartleet and Gounder, 2010; Saud et al., 2018; Shahbaz et al., 2014). while some studies have concluded that any such relationship is weak; another strand of empirical research has unearthed a possible causal relationship between economic growth and energy consumption, leading to the development of four hypotheses: neutrality feedback (see Belke et al., 2011, Dogan, 2015a, Nasreen and Anwar, 2014, Ouedraogo, 2013), conservation (see Fang and Chang, 2016, Narayan and Narayan, 2010) and growth (see Acaravci et al., 2015, Dogan, 2014, Ozturk, 2010) hypotheses.

I. First, the growth hypothesis suggests that increased energy consumption leads to increased economic growth (see Acaravci et al., 2015, Dogan, 2014, Ozturk, 2010).

II. Second, the conservation hypothesis states that rising economic growth leads to increased energy consumption (see Fang and Chang, 2016, Narayan and Narayan, 2010).

III. The third hypothesis, known as the feedback hypothesis, indicates a bidirectional causal relationship between energy consumption and economic growth (see Belke et al., 2011, Dogan, 2015a, Nasreen and Anwar, 2014 Ouedraogo, 2013).

IV. The fourth hypothesis, known as the neutrality hypothesis, shows that energy consumption and economic growth are independent of each other (see Jafari et al., 2012, Kahsai et al., 2012, Menegaki and Tugcu, 2016, Tang and Shahbaz, 2011).

The linkage between energy consumption and economic growth has long been highly correlated. Extensive studies have examined the dynamic linkage between energy use and economic growth. However, no stylized facts have been estimated. Most of the studies have historically focused on developed and newly industrialized countries. Studies on developing countries have only been sporadic. Given the magnitude of India's energy consumption and its robust economic growth, it attracts more and more attention to this line of research, and several studies have also been conducted in recent years. However, a production function framework has not been used in previous studies. This study aims to fill this gap and hopes to shed light on this study area. This model adopts a neoclassical production function with energy incorporation.

The causal linkage between energy use and economic growth has been deeply investigated in the energy economics literature. Many researchers have been motivated on different proxy variables, different econometric techniques, and different countries' periods of study for analyzing the relationship between these two variables. The findings of all these studies have been mixed and based on conflicting results. Dissimilar results also arise because of the various data sets, different countries' characteristics, and alternative econometric techniques. The causal relationship is varied in different countries, and this is due to different nations' characteristics "for example, indigenous energy supplies, altered economic and political histories, changes in institutional activities, diverse culture, and alternative energy policies (Chen et al. 2007, p. 2613). In this context, the key aim of this study is to assess the relationship between renewable and non-renewable energy consumption and economic growth in developed and developing countries. Further, the study attempted to investigate the moderating role of environmental sustainability on the nexus between renewable energy consumption and economic growth in India. The study's novelty lies in contributing solutions for the attainment of the United Nations Sustainable Development Goals (SDGs) and the Agenda 2063 of the African Union.

1.2 Statement of the Problem

Since independence Indian economy transformed from an agriculture-based economy to an expanding economy with increasing industrialization, urbanization, and tertiary sectors, a growing standard of living has been accompanied by increasing energy demand. India has increased its strong resilience to coal and other fossil fuels to meet its energy requirements. However, the rapid growth of population and increasing demand for energy for diversified economic activities depend on substantial energy requirements. The accelerated uses of fossil fuels, rapid industrialization, and deforestation have caused a significant threat to the environment in the form of an increase in greenhouse gases. The increasing greenhouse gases resulted in increased threats (socially and economically) to human sustenance, livelihood, global economy, and climate change. Since the 1990s, the impact of global warming on the world economy has been assessed extensively by researchers. The impacts are the susceptibility of the economic sectors to floods, cyclones, droughts, diseases, decrease in the production of food items, and threat to sustainable development. These are why worldwide organizations attempt to minimize the hazardous impact of global warming and climate change through climate change agreements.

Carbon dioxide is one of the major greenhouse gases in the atmosphere. The carbon dioxide emission level increases day by day because of the burning of fossil fuels. Hence, protecting the environment from these hazardous effects has become a topic in economics. The enormous prospective for economic growth through the misuse of the environment is unquestionable. Dynamic resources have forever been a necessary part of economic growth.

The environment plays an essential role in supporting life. It is pointless to say that if humans destroy the earth's ability to sustain life, the result would be severe. Climate degradation, in principle, ranges a point where further economic growth becomes difficult. Therefore, the human race faces social and economic insecurity because of climate change.

If the greenhouse gas increases continuously, climate change may act as an obstacle to the income of this latter stage. As a result, the global economy faces severe threats from global climate change. An appropriate environmental policy should be adopted now to save the World from the dangerous effect of climate change. One policy that Kuznets suggests is Environmental Kuznets Curve (EKC).

1.3 Objectives

To analyze the trends and patterns of energy consumption, production, and distribution of the energy sector in India.

To examine the role and impact of renewable and nonrenewable energy consumption on economic growth in developed and developing countries.

To investigate the environmental Kuznets curve for carbon emission in India. Furthermore, to analyze if energy consumption matters.

To explore the importance of sectoral electricity consumption on economic growth in India from 1970-2016.

To evaluate the significance of nuclear energy consumption and economic growth in India from 1971 to 2019.

1.4 Data and Methodology

The study uses both time series and cross-sectional data for developing and developed countries. The data is collected from the International Energy Statistics (IES), International Energy Administration (IEA), World Energy Outlook, World Bank Indicators, Indiastata.com, and Indian energy statistics. This study deals with six analytical chapters employing advanced time series and cross-sectional econometric and decomposition tools. The study also employed recent time series techniques with different alternative models and standard diagnostic tests. The methodology and data period details are discussed in each chapter.

Past literature on the linkage between energy consumption and economic growth is conflicting. For instance, in the case of developing countries, the findings are dissimilar for different data periods for some countries. Glasure Lee (1997), Yu and Choi (1985) for Korea and Mashi and Mashi (1998), Marimoto and Hope (2004) for Sri Lanka show different results.

Thus, earlier studies for developing countries produce inconsistent findings. However, these studies also neglect structural breaks and cross-sectional dependency across the countries. The importance of considering the structural breaks in energy consumption series is that energy is highly correlated with economic structures Mark et al. (1994).

1.5 Justification for the research

In the energy economics literature, very few studies have been carried out to investigate the linkage between energy consumption and output in India and developing countries using a multivariate approach. The relationship between energy consumption and output growth still provides mixed results for India. The present study incapacitates the research gaps in the literature by applying different modeling frameworks, larger samples than earlier studies, recent development in econometric methods, and the expansion of the study to comprise discrete energy types and comparison cross country. The analysis of this study supports showing how energy is essential in the growth process and whether a straight measure of energy conservation would be harmful to economic growth for developing and developed countries.

There is a lack of empirical studies on different measures of energy conservation, for instance, inter-fuel substitution and energy efficiency in the context of India. Earlier research is based on very few industrial sectors, and they are outdated in the current context of emission decline methods. This research fills the gap by including more end-use sectors in our study, using recent data sets. This study also takes a pivotal interest in examining the Environmental Kuznets curve hypothesis, which talks about economic growth being a remedy for the environmental problem. Nevertheless, the empirical findings on the EKC studies are still inconsistent in the literature, and the studies related to EKC are scarce in the Indian context. Hence, this study fills the gap by investigating EKC in the Indian context.

1.6 Scope and Significance of the study

In energy economics, literature research in this area has improved in recent times but merely focused on developed countries with very few empirical findings on developing countries, Asian and African economies in particular. However, present literature has disregarded and ineffectively addressed the subject of dynamics and endogeneity in framing the postulated links. Moreover, the existing literature is not decisive in presenting policy recommendations that could be used across countries. Besides these, some researchers studied the output energy nexus and output environmental degradation in an integrated approach, given that energy consumption positively impacts environmental pollution.

The essential purpose of our study is to examine the importance of energy consumption on economic growth, the causal direction, and the interrelationship between the energy conservation and emission reduction goals in India. The scope and significance of this kind of study are enormous and can be used for both theoretical and empirical analysis.

Furthermore, very few studies have investigated the relationship between environmental degradation and per capita income in the context of India. In this way, our analysis will provide new insight into these issues. Also, the present study is helpful to fill the gap in energy literature because there is a lack of general study for India and the developing countries. Moreover, some important variables such as urbanization and openness of trade are included for understanding their impact on environmental pollution.

1.7 Organization of the Study

Our analysis is comprised of eight chapters. The fundamental theoretical framework and broad review of both theoretical and empirical literature on energy consumption, CO2 emission, economic growth, environmental Kuznets curve, and energy-output-pollution nexus hypothesis are discussed in chapter two. The third chapter analyzes the energy production, availability, and consumption of energy resources in India. The fourth chapter studies renewable and nonrenewable energy consumption and economic growth in developed and developing countries. The fifth chapter presents the role of energy consumption, CO2 emission, economic growth, and the environmental Kuznets curve for India. The sixth chapter investigated sectoral electricity consumption and its impact on economic growth in India for the period 1970-2016. The role of nuclear energy consumption on economic growth in India is examined in chapter seven. The final chapter considers the essential findings and draws the main policy implications. The chapter also discourses the limitations and recommends future research plans.

CHAPTER 2

Review of Theoretical and Empirical Literature

2.1 Introduction

Increasing fossil fuel consumption raises carbon dioxide emissions in the atmosphere. Carbon dioxide is the most dangerous anthropogenic greenhouse gas (GHG) which eventually raises the global temperature and causes global warming (IPCC, 2005). International Energy Agency (IEA) reported that the Maximum amount of carbon emission generated due to fossil fuel burning demonstrates two-thirds of the global level. The activities of human being mostly influence the environment. The burning of fossil fuels and biomass generates a huge amount of greenhouse gases that result in climate change and the structure of the environment (IPCC 2001). Rising industrialization and urbanization are now considered two major factors of economic growth; these two factors are highly dependent on energy consumption which leads to environmental degradation. The rising level of energy consumption and greenhouse gases is supposed to lead to manmade disasters. Expansion of service industries raises the demand for energy resulting from the pollution level increases. Environmental degradation, climate change, and depletion of natural resources have become significant concerns to the world.

As compared to fossil fuels renewable energy consumption generates lower and near-zero amounts of greenhouse gas emissions. The transformation of fossil fuel energy consumption to renewable energy could reduce greenhouse gas. Therefore, increasing the consumption of renewable energy slowly reduces pollution emissions.

One of the reasons behind focusing on the topic of energy consumption and economic growth is that consumption of energy has a significant potential impact on economic growth. Nevertheless, the empirical findings on the relationship between the variables are debatable. Ozturk (2010) suggested that the inconsistent result arises due to different reasons. Such as different data sets, different countries, and alternative econometric models. The relationship between energy consumption and economic growth is based on four hypotheses (Soytas and Sari, 2003; Lee, 2006; Ewing et al., 2007; Bowden and Payne, 2010; Apergis and Payne, 2009a; 2011b; Ozturk, 2010; and Payne, 2010.)

1. The first hypothesis is known as the growth hypothesis. This hypothesis shows a unidirectional causality from energy use to economic growth. In the case of the growth hypothesis, adopting a conservation energy policy will hurt growth.
2. The second one is the conservation hypothesis. This hypothesis indicates causality from growth to energy consumption. Here energy conservation policy does not have any effect.
3. The next is the feedback hypothesis. This hypothesis indicates that causal direction runs in bidirection. In this case, energy conservation may reduce the growth level.
4. The fourth hypothesis is known as the neutrality hypothesis. This hypothesis exists when there is an absence of causality in any direction.

In energy studies, energy is considered one of the significant development indicators. The relationship between energy consumption and economic growth needs the researcher's attention. Hence, the nexus between energy use and economic growth literature became popular after the seminal work of Kraft and Kraft (1978).

The energy literature is classified into three aspects. The first aspect deals with the disaggregate analysis of energy consumption. Studies such as Narayan and Smyth, 2008; Chotanawat et al, 2008; Bowden and Payne, 2009; Apergis and Payne, 2009a; Apergis and Payne, 2010b; Kaplan et al, 2001; Eggoh et al, 2011; Belke et al, 2011, and Fuinhas and Marques, 2001 Substantiated the existence of the feedback hypothesis; conservation hypothesis found by Lise and Montfort, 2007; and Huang et al, 2008; the neutral causality found by Soytas et al. 2007. Similarly, the growth and feedback hypothesis was found by Belloumi 2009; and Apergis and Payne, 2009b.

Ozturk et al, 2010 concluded that there is a presence of the conservation and feedback hypothesis; Soytas and Sari, 2006 and 2003 suggested the validity of the feedback, growth, and conservation. Akinola, 2008 examined the existence of the conservation, neutrality, and feedback hypothesis. And Lee 2006 investigated the validity of neutrality, conservation, and feedback hypothesis.

The second aspect of literature deals with renewable energy use and economic growth. For example, Payne (2011) studied the presence of the growth hypothesis. Apergis and Payne (2010c and (2010d) and Apergis and Payne (2011a) examined the feedback hypothesis. The neutrality hypothesis is investigated by Menegaki (2011). Moreover, Chien and Hu (2007), Fang (2011), and Tiwari (2011a) empirically found that increasing the consumption of renewable energy will have a positive impact on growth. Sadorsky (2009) concluded that as the economy grows rapidly there are chances of more renewable energy consumption.

The new aspect of energy literature deals with the role of renewable and non-renewable energy consumption on economic growth. Ewing et al., (2007) explored the impact of different sources of energy and their effects on industrial production in the context of the U.S. from 2001-2005. The method of variance decomposition is used for the analysis. The study found renewable energy explaining the stronger variation of industrial output.

Payne (2009) explored the role of renewable and non-renewable energy consumption and economic growth by using a multivariate framework. The study found that there is an absence of causality between the variables.

Apergis et al. (2010) examined the linkage between nuclear and renewable energy use and economic growth in the context of 19 countries from 1984-2007. The empirical result shows renewable energy has a significant positive effect on growth. On the other hand, nuclear energy has a negative influence on economic growth. The findings also show causality from nuclear and renewable energy to economic growth.

Bowden and Payne (2010) studied the causal linkage between energy use and growth in the case of the U.S. from 1994-2006. The empirical result reveals the absence of a causal relationship between the variables. The result also found causality from residential energy consumption to growth. Conversely, the findings again confirm bi-directional causality from non-renewable energy consumption to the residential sector and commercial sector to GDP.

Tiwari (2011b) examined the effectiveness of renewable and non-renewable energy use on growth in the case of European and Eurasian nations from 1965-2009. The analysis employed the P-VAR model for the analysis and found that renewable energy has a positive effect on economic growth and non-renewable energy harms the GDP growth rate.

Apergis and Payne (2011b) explored the role of renewable and non-renewable energy use on economic growth in the context of 80 nations from 1990-2007. By using a multivariate panel framework, the analysis found that the long-run elasticity for non-renewable energy use is relatively higher. The result also shows bidirectional causality between energy use and economic growth both in the long-run and short-run.

2. 2 Carbon Emission, Energy Use, and Economic Growth

Yildirm et al. (2014) analyzed the linkage between energy consumption and economic growth in the context of 11 nations from 1971-2010. The variables included are GDP per capita, gross capital formation, and energy use per capita (kg oil equivalent) respectively. All the variables were cumulated from World Development Indicators (WDI) 2013. Estimating a tri-variate model the study supported the neutrality hypothesis for all the nations except Turkey. The result also found causality from energy use to economic growth for Turkey. As the growth hypothesis is verified, the energy conservation policy stances a problem to economic growth in Turkey.

Salim et al. (2014) studied the importance of renewable and non-renewable energy on GDP growth in the context of OECD nations from 1980-2011. The analysis used labor force, industrial output, energy consumption both renewable, non-renewable and GDP. The findings of the study indicate a long-run relationship between the variables. The findings also confirm bidirectional causality between industrial output and energy use.

Omari A. (2013) analyzed the linkage between energy use, carbon emission, and economic growth in the context of 14 MENA nations covering the period 1990-2011. The study used per capita real GDP, energy use, financial development, trade openness, carbon emissions, capital stock, urbanization, and total labor force. All the data were cumulated from WDI. By using the generalized method of movements (GMM) the analysis found bidirectional causality between energy use and economic growth. The result also shows a bi-directional causality between economic growth and carbon emission for all the MENA countries.

Tugcu et al, (2012) explored the linkage between renewable and non-renewable energy use and economic growth in the context of G7 nations from 1980-2009. By employing an augmented production function the study decides what kind of energy is essential for G7 nations. The variables included in this study are GDP, energy use, the total number of students admitted in part and full time tertiary and public sectors. By using an ARDL econometric approach the findings suggest that the augmented production function is more dynamic for the energy growth relationship and in the case of classical production function a bi-directional causality is obtained. The result also indicates that the consumption of both renewable and non-renewable energy matters for growth.

Belke et al. (2011) examined the linkage between energy use, energy price, and real GDP in the context of 25 OECD nations covering the period from 1981-2007. All the data were cumulated from International Energy Agency. The principal component analysis method is used for the analysis. The empirical result shows a long-run linkage between energy use and real GDP growth. The result also found bi-directional causality between energy use and economic growth.

Lee and Chiu (2011) studied the relationship between oil price, nuclear energy, and income in the context of six industrial nations (Canada, United States, France, United Kingdom, Japan, and Germany) over the period 1965-2008. By using co-integration, impulse response function, and Toda & Yamamoto causality method the study found that oil price and nuclear energy are substitutes in the case of Canada and the U.S. while they are corresponding in the U.K., Japan and France. The result also reveals causality from real income to nuclear energy consumption in the context of Japan. Further, the study observes the temporary early effects of innovations in real income and oil consumption on nuclear energy consumption.

Apergis and Payne (2012) studied the importance of renewable and non-renewable energy use on economic growth in the context of 80 nations from 1990-2007. The variables used in this study are renewable and non-renewable electricity use, labor force, and real GDP and capital formation. The analysis used panel econometric techniques such as panel unit root test, Pedroni panel co-integration test. The findings of the study show that a long-run linkage exists between the variables. The test result also reveals a bi-directional causality between energy use and economic growth in both the short-run and long-run.

Ouedraogo. S. N. (2013) investigated the linkage between accesses to modern energy, growth, and development for fifteen African ECOWAS nations from 1980-2008. The data includes energy consumption, GDP, International energy prices, and electricity consumption. The data are obtained from World Bank, statistical review of world energy 2010. Using the panel econometric technique the study found that all the variables are moving together in the long run. The analysis also found that there is short-run causality running from GDP to energy consumption and from energy use to GDP. Again the study shows long-run causality from electricity use to GDP. The empirical findings suggest that lack of access to modern energy will affect the growth rate negatively.

Kahsai, et al. (2012) examined the linkage between energy use and economic growth in the context of Sub-Saharan African (SSA) nations from 1980-2007. The analysis classified the countries into two categories middle income and low-income nations. This classification was done by using the World Bank gross national income (GNI) classification criteria. The variables considered for this study are per capita GDP, CPI price, and per capita energy consumption. All the data were obtained from Energy Information Administration (EIA), International Monetary Fund (IMF), and World Economic Outlook (WEO, 2009). The analysis used the panel econometric technique such as panel co-integration, panel unit root, and panel error correction. The result of the study supports the neutrality hypothesis in the short run for low-income countries and bidirectional causality is found in the long run.

Wong, et al. (2013) studied the contribution of energy research and development and energy consumption on economic growth for 20 OECD nations covering the period from 1980-2010. The variables used in this study are real output, labor force, gross fixed capital formation, and fossil fuel consumption. Variables were obtained from World Development Indicators (WDI 2012) and International Energy Agency (IEA, 2012). Renewable energy consumption data were calculated by subtracting fossil fuel consumption and nuclear energy consumption from total energy consumption. The study employed panel dynamic methodologies like panel unit root with cross-sectional dependency and structural tests. The result shows that the role of energy research and development may not be ignored and fossil fuel research and development helps to move forward economic growth more than fossil fuel consumption. The findings again suggested that fossil fuel and capital stock are the main indicators for economic growth, renewable energy encourages real output particularly for the nations without oil reserves.

Apergis and Payne (2009) investigated the linkage between energy use and economic growth for eleven nations from 1991-2005. The variables considered in this study are energy consumption, labor force, gross fixed capital formation, and real GDP. The study employed panel econometric methods such as Pedroni's co-integration and error correction methods. The empirical result shows a long-run linkage between the variables. Further, the study found short-run causality from energy use to economic growth and bidirectional long-run causality between the variables.

Lee and Chien (2010) examined the linkage between energy use and real income growth in G7 countries from 1960-2001. The analysis used the annual data for per capita real GDP, capital stock, and energy consumption. The variables were obtained from World Development Indicators (WDI, 2005) and International Financial Statistics (IFS, 2006). The analysis used Toda & Yamamoto

(1995) causality, variance decomposition, and the impulse response methods. The empirical result found that unidirectional causality exists from energy consumption to real income growth in Canada, U.K., and Italy suggesting that energy conservation policy may negatively affect economic growth. Conversely, the causality result is reversed for Japan and France, indicating that energy conservation policy may be viable for both countries.

Apergis and Payne (2010) analyzed the linkage between energy consumption and growth for 9 South American nations from 1980-2005. By using the panel econometric techniques, they found a long-run linkage between the variables. The result also shows short-run and long-run unidirectional causality from energy use to economic growth.

Apergis and Payne (2010) investigated the role of energy consumption on economic growth in the context of 13 Eurasian nations covering the period 1992-2007. The variables included in this study are real GDP, labor force, real gross fixed capital formation, and renewable energy consumption. By using the panel co-integration and error correction test the result reveals a long-run relationship between the variables. The empirical result confirms both long-run and short-run bidirectional causality between energy use and economic growth.

Chiou-Wei, et al. (2008) analyzed the importance of energy consumption on economic growth for newly industrialized Asian nations and the United States spanning from 1954-2006. The data includes total energy use and real GDP and uses 2000 as the base year. The study applied both linear and non-linear Granger causality for the analysis. The empirical analysis finds no causality for Thailand, South Korea, and the U.S. Nevertheless, in case of Singapore and the Philippines a unidirectional causality was found from economic growth to energy consumption.

Nguyen-Van (2010) proposed a semi-parametric study to explore the linkage between per capita energy use and per capita income growth in the context of 158 nations. The analysis used total per capita primary energy and GDP per capita. All the data were obtained from Energy Information Administration (EIA). By employing a semi-parametric technique the study found the existence of the Environmental Kuznets Curve for energy consumption. The findings suggest that as income increases energy consumption also rises for most of the nations and it is invariant in the case of high-income nations.

Hsu, et al. (2008) explored the stationarity of the energy consumption hypothesis in different regions for 84 countries in five regions for the period 1971-2003. Energy consumption data were sourced from World Development Indicators (WDI, 2006). The study employed the Panel SURADF test. The study concluded that the stationarity of energy consumption will be affected by the differencing among the regions. The result also reveals that traditional panel unit root tests can bias the inferences that are influenced towards stationarity if only a single series is highly stationary.

Lee and Chang (2007) investigated the dynamic role of energy consumption on economic growth in the context of 22 developed and 18 developing nations. The sample period considered is 1965-2002 for the developed countries and 1971-2002 for the developing countries. The study employed panel data stationarity testing with a panel VAR model. The study also used a generalized method of movement technique for the analysis. The result reveals that the energy crisis had an essential impact on both variables in all sample countries. The panel VAR test reveals a bidirectional causal relationship between the variables in developed nations, but the findings indicate causality from economic growth to energy use in developing nations.

Wolde-Rufael (2009) examined the importance of energy consumption on economic growth in the case of 17 African nations covering 1971-2004. The variables include real GDP, total labor force, per capita energy use, and real gross capital formation. The study employed Toda & Yamamoto Granger Causality and variance decomposition analysis. The result shows neutrality hypothesis exists in fifteen out of seventeen nations. While the variance decomposition result shows neutrality hypothesis exists between the energy and income relationship for 11 countries. The findings suggest that in comparison to labor and capital, energy consumption is not a significant aspect of economic growth.

Apergis and Payne (2010) examined the role of nuclear energy consumption and economic growth in the context of 16 nations covering the period 1980-2005. The study used labor force, capital formation, nuclear energy consumption, and real GDP. All the variables were collected from the World Development Indicators, WDI, CD-ROM, and the Energy Information Administration. Using the panel co-integration and error correction methods the result obtained a long-run linkage between the variables. The error correction result indicates bidirectional causality between the variables.

Kebede, et al. (2010) analyzed total energy demand and economic development for 20 Sub-Sahara Africa countries for the period 1980-2004. The study includes real GDP in constant 2000 US dollars collected from (ERS/ USDA, 2008), the population in millions of people collected from (ERS/ USDA, 2007). Energy electricity and oil data for each country are collected from the Energy Information Administration (EIA, 2009), and wood fuel data were sourced from the Food and Agricultural Organization, FAOSTAT (FAO, 2008). All energy use was converted to a million BTUs. Value-added sectoral consumption and urban/rural population data were collected from (The World Bank, 2008). Oil price is the annual average crude oil price in dollars per barrel based on the 2007 oil price collected from Oil Patch Research (2008). All the variables are used in the logarithm form. The empirical result shows wood fuel contributes to 70% of energy consumption. The regression result suggests that energy demand is inverse to GDP, agricultural expansion, population growth, and that price elasticity is less than one. The findings again reveal regional divergence in energy demand and the consumption of commercial energy and economic growth. The analysis suggests that these nations should adopt alternative energy sources and innovate energy-efficient techniques to progress economic growth.

Asafu-Adjaye (2000) examined the role of energy consumption and income in the context of four nations such as Thailand, India, the Philippines, and Indonesia. The analysis includes annual time series data spanning from 1973-1995 for Indonesia and India, and 1971-1995 for the Philippines and Thailand. The study included the variables such as commercial energy consumption, real income, and energy price. The study employed panel econometric techniques and found causality between energy consumption and income in the case of the Philippines and Thailand.

Balcilar et al. (2010) analyzed the causal linkage between energy use and economic growth in the context of G-7 nations. The analysis used the annual data from 1971-2006 in the case of Germany and from 1960-2006 for the rest of the countries. The analysis used the bootstrap Granger non-causality method. The empirical result shows no consistent causal linkage between the variables. Nevertheless, the result also indicates a causal linkage between the variables in the case sub-samples.

Wolde-Rufael & Menyah (2010) examined the role of nuclear energy use on real GDP in the context of 9 developed nations from 1971-2005. By employing the Toda & Yamamoto Granger non-causality test the study found causality from nuclear energy consumption to economic growth in the case of Japan, Switzerland, and the Netherland. The findings also suggest that increasing the consumption of nuclear energy may negatively affect the economic growth in the context of UK, Spain, and USA.

Akinlo, (2008) examined the linkage between energy use and economic growth in the case of 11 Sub-Saharan nations from 1980-2003. By employing the autoregressive distributed lag model, the study found a long-run relationship between the variables in the context of Senegal, Gambia, Sudan, Cote D' Ivoire, Zimbabwe, and Ghana. The result also found that in the context of Sudan, Kenya, Senegal, and Ghana energy consumption has a significant effect on economic growth. The empirical result also supports the bidirectional causality between the variables in the context of Senegal, Gambia, and Ghana.

Narayan & Smyth (2008) investigated the relationship between capital formation, real GDP, and energy consumption for G7 countries over the period 1972-2002. The study includes real GDP per capita, energy consumption per capita, and capital stock. The variables were cumulated from the International Energy Agency (IEA) and World Bank. By employing the panel econometric methods the study found a long-run relationship between the variables. The empirical analysis also shows the capital formation and energy use have a significant effect in the long run.

Apergis & Payne (2009) explored the importance of energy consumption on economic growth in the case of 6 Central American nations from 1980-2004. The analysis used energy consumption, real gross fixed capital formation, real GDP, and labor force. All the variables are sourced from World Bank Development Indicators. By employing the panel econometric technique the study found a long-run linkage between the variables. The causality result indicates causality from energy use to economic growth.

Akkemik & Goksal (2012) analyzed the linkage between energy use and GDP in the context of 79 nations spanning the period from 1980-2007. The study used real GDP, capital input, energy consumption measured in tons of oil equivalent, and labor input. The variables are sourced from World Development Indicators (WDI) and International Energy Agency (IEA). The study employed the recently developed panel causality and found bidirectional causality between the variables for 77 countries while 2 countries found no causality and 1 country confirms unidirectional causality.

Francis, et al. (2007) studied to raise the energy efficiency in the case of Caribbean countries over the period 1971-2002. The study used energy consumption, real fuel price, real gross domestic product, and population. By using a BVAR model the study found that the three Caribbean countries found a bidirectional causality from energy use to real GDP. The result also suggests that the rising growth in energy consumption requires a long-term commitment to start research and development of new energy technologies and market development.

Fuinhas & Marques (2012) investigated the significant role of energy consumption on economic growth in the case of PIGST nations (Portugal, Italy, Greece, Spain, and Turkey) spanning from 1965-2009. The study used primary energy use and GDP. The variables are sourced from European Commission –Economic and Financial Affairs Indicators –AMECO. By employing ARDL econometric technique the study found bidirectional causality between the variables. The result also recommended energy conservation policy may reduce the growth for all the countries.

Wolde-Rufael (2014) examined the role of electricity consumption on economic growth in the case of 18 transition nations throughout 1975-2010. By employing bootstrap panel causality the study found unidirectional causality from electricity use to economic growth in case of the Belarus and Bulgaria. Similarly, causality runs from economic growth electricity use in the case of, Latvia, Russia, Czech Republic and Lithuania. The analysis also found bidirectional causality in the case of Ukraine. The findings suggest that there is very little scope for the electricity-led growth hypothesis.

Soytas and Sari (2003) investigated the linkage between energy use and income in the context of G7 nations. The analysis included per capita GDP and energy use. The variables were obtained from United Nations Statistical Yearbook and World Penn Tables. The study used the times series co-integration and error correction technique for the analysis. The empirical findings suggest that there is bidirectional causality in the case of Argentina. The study also found causality from GDP to energy consumption in the context of Korea and Italy and causality from energy use to GDP in the case of Germany, Turkey, and Japan.

Lee (2005) explored the importance of energy consumption on GDP growth in the context of developing nations from 1975-2001. The study includes energy use, GDP, and gross capital formation. The study employed a recently developed panel unit root test, panel co-integration, and error correction model for the analysis. The empirical result supports the long-run linkage between the variables. The findings again show the short-run and long-run causality from energy use to GDP. The result recommended adoption of energy conservation policy may negatively affect growth in developing countries.

Masih & Masih (1996) examined the linkage between energy consumption and real income for 6 Asian countries. The study used the energy use and income measured in GNP constant prices. The variables were obtained from the Energy Statistical Yearbook and International Financial Statistics (World Bank, 1992). By employing the Granger causality and co-integration method the analysis found a long-run linkage between the variables in the context of India, Pakistan, and Indonesia.

Costantini & Martini (2010) examined the relationship between sectoral energy consumption and economic growth in the context of 71 developing and developed nations. The analysis divided the nations into two groups such as 26 OECD nations and 45 non-OECD nations. The study included energy consumption data for industry, residential, commerce, transport, and public services. Energy consumption data is obtained from International Energy Agency (IEA) publications. Information about the economic performance of different sectors was obtained from the World Bank dataset (WDI). Energy price data are obtained from the IEA statistics and 1978-2005 only for the OECD nations. For the bivariate model, the study considered the data for the period from 1970-2005 in the context of Non-OECD nations and for the OECD nations 1960-2005. By employing the panel co-integration the study found a long-run relationship between the variables.

Damette & Seghir (2013) investigated the linkage between energy use and economic growth in the case of 12 Oil-Exporting nations (7 OPEC and 5 non-OPEC countries). The analysis used annual data spanning from 1990-2010. The variables include energy use and GDP. The analysis employed cross-sectional dependency to avoid the spurious result. The study also employed co-integration and error correction tests. The empirical result found cross-sectional dependence and structural breaks over the year. The result also reveals a long-run linkage between the variables. The result of error correction shows short-run unidirectional causality running from energy consumption to economic growth.

Bruns & Gross (2013) examined the energy type-GDP causality by analyzing whether time series for single types of energy are sufficiently independent of total energy for 65 countries. By employing the Toda and Yamamoto Granger causality the result found that at least one energy type result match 92 % of the countries. Using the probit model the study found that the probability of a match increases with the degree of correlation between an energy type and total energy.

Apergis & Tang (2013) investigated the presence of energy-led growth hypothesis for 85 countries at different stages of economic development covering the period 1975- 2007. The study includes energy consumption, real per capita GDP, urbanization, and labor force. All the variables are sourced from the Data Stream database. The study employed the Toda-Yamamoto- Dorado-Lutkepohl (TYDL) causality test for the analysis. The empirical result suggests that the causality result is mixed among countries. The result also reveals that in comparison to low-income and less developed countries the energy-led growth hypothesis is more supportive to develop and developing countries. Therefore, the analysis suggested that energy conservation policy should focus on less-developed countries.

Ohler & Fetters (2014) tested the linkage between electricity generation and economic growth for 20 OECD nations over the period 1990-2008. The study used gross electricity production (GWh), real GDP, the size of the labor force, and gross fixed capital formation. Energy data were collected from the International Energy Agency's data set on world renewable and waste energy statistics. Renewable electricity generation includes biomass, hydroelectric, geothermal, solar, waste, and wind. The study employed panel econometric methods for the analysis. The empirical result shows the long-run fully modified results are statistically significant. The ECM result supports the feedback hypothesis between real GDP and renewable energy. The cross-sectional dependence test reveals an increase in biomass consumption and waste generation negatively affecting the growth rate in the short run.

Apergis & Payne (2011) studied the linkage between electricity use and economic growth for 88 nations over the period 1990-2006. The analysis classified the countries based on their income; such as low income, lower-middle income, high income, and upper-middle-income nations. The study used real GDP, total labor force, electric power consumption, and gross fixed capital formations. By employing the panel econometric technique the analysis found bidirectional causality between electricity use and real GDP for high and upper-middle-income countries. The findings also show a unidirectional causality from electricity use to economic growth and bidirectional causality for lower-middle-income nations.

Coers & Sanders (2013) explored the importance of energy consumption on economic growth in the context of 30 OECD nations from 1960-2000. The analysis includes per capita GDP, per capita energy use, employment, gross fixed capital formation, and educational attainment. The variables are cumulated from the OECD-STAN database, International Energy Agency (IEA). By employing the panel econometric tools the study found unidirectional causality from capital formation to GDP. The result also reveals that decreasing energy use or adopting energy efficiency is not probably to possess a harmful result on the economic process, except over the short.

Menegaki (2011) studied the role of renewable energy use on economic growth in the case of 27 European nations spanning from 1997-2007. The analysis included per capita real GDP in PPP terms, energy consumption, carbon emissions, and rate of employment. The study employed a random effect model and confirms the absence of causality between the variables. The causality test result reveals a short-run linkage between the variables. The analysis supports the presence of the neutrality hypothesis.

Esso (2010) examined the effect of energy consumption on economic growth in the context of 7 Sub-Saharan nations. The study used the annual data from 1970-2007. The analysis includes per capita energy use and GDP. The data were sourced from the World Bank and African Development Bank. By employing the threshold co-integration and Toda-Yamamoto causality methodology the result confirmed a long-run linkage between the variables. The result again reveals energy consumption has a positive effect on economic growth in all nations before 1988 and the effects were negative after 1988. The analysis also suggests the presence of bidirectional causality in the case of Cote d'Ivoire and causality from real GDP to energy use in the context of Ghana and Congo.

Seale Jr & Soano (2012) investigated the linkage between output, energy, and trade for seven South American nations spanning from 1980-2007. The study included energy consumption, labor force, capital formation, real GDP, and export and import. All the data were cumulated from WDI. By employing the panel econometric method the analysis confirmed a long-run linkage between the variables. The short-run dynamics show the feedback hypothesis between energy use and export. The findings also show causality running from energy use to imports.

Apergis & Payne (2010) studied the impact of energy consumption on economic growth in the context of 9 South American nations from 1980-2005. The study used real GDP, labor force, energy consumption, and real gross fixed capital formation. All the variables are obtained from the World Development Indicators (WDI). The analysis used panel econometric methods. The empirical findings show the long-run linkage between the variables. The findings also support the long-run and short-run growth hypothesis.

Table 2.1: Empirical Literature for developing countries.

Author	Methodology	Time period	Countries	Findings
Ya & Choi (2005)	Granger causality	1954-1976	South Korea	Y → E
			Philippines	E → Y
Morimato & Hope (2004)		1960-1998	Sri Lanka	E ↔ Y
Fatai et al. (2004)	T & Y (1995)	1960-1999	India	E → Y
			Indonesia	
			Thailand	E ↔ Y
			Philippines	
Masih & Masih (1996)	Error Corection Model	1955-1990	Malaysia	Non-cointegrated
			Singapore	
			Philippines	
			India	E → Y
			Indonesia	Y → E
			Pakistan	E ↔ Y
Glasure & Lee		1961-1990	South Korea	E ↔ Y
			Singapore	
Masih & Masih (1998)		1955-1991	Sri Lanka	E → Y
			Thailand	
Yong (2000)		1954-1997	Taiwan	E ↔ Y
Asafu-Adjaye (2000)		1973-1995	India, Indonesia	E → Y
			Thailand	E ↔ Y

			Philippines	
			Turkey	E → Y
Soytas & Sari (2003)		1950-1992	Argentina	E ↔ Y
			South Korea	Y → E
			Turkey	E → Y
			Indonesia, Poland	Non-cointegrated
Oh & Lee (2004)		1970-1999	South Korea	E ↔ Y
Paul & Bhattacharya(2004)		1950-1996	India	E ↔ Y
Jumbe (2004)		1970-1999	Malawi	Y → E

Arac & Hasanov (2014) examined the relationship between energy use and economic growth in the context of Turkey covering the period 1960-2010. The study includes per capita energy consumption and per capita GDP as a proxy for output level. All variables were spanned from the World Development Indicators (WDI). The study used the Smooth Transition Vector autoregressive model for analysis of the data. The empirical findings of the study show that there are large versus small and positive versus negative energy consumption shocks on output growth conversely. The empirical findings also show that the negative shocks are more effective on output than positive shocks.

Dergiades, et al. (2013) examine the linear and non-linear effect of energy consumption on economic growth in the context of Greece from 1960-2008. The study used real GDP and total energy use for analysis. Data were cumulated from WDI and International Energy Agency (IAE). By employing the non-parametric causality the result confirms causality from energy use to economic growth. The empirical result also shows a feedback hypothesis in the case of Greece.

2.3 Carbon Emissions, Economic growth: Environmental Kuznets Curve

The empirical studies related to the relationship between the level of environmental pollution and economic growth are generally understood as EKC (Environmental Kuznets Curve) hypothesis. More precisely, this hypothesis talks about a reversed U-shaped linkage between the level of pollution and income. The fundamental idea of this hypothesis discusses that as capita income increases the level of environmental pollution declines (Shafix and Bandyopadaya 1992; Seldem and Song, 1994; Grossman and Krueger 1995; Galeotti and Lanza 1999; Galeotti et al. 2006; Wagner 2008; Kearsley and Riddel 2010).

Unruch & Moomaw (1998) examined the role of EKC in the context of 137 countries covering the period from 1971 to 1991. The analysis used per capita carbon emissions and per capita GDP for analysis. The empirical findings show that as the per capita income increased continuously, an increase in CO_2 emissions decelerated during the 1980s. The analysis supports the EKC hypothesis over the study period.

Gupta and Alhuwalia (2002) investigated the environmental Kuznets curve by using the Carbon-di-oxide (CO_2) and Sulphur-di-oxide (SO_2) as environmental quality indicators. By employing OLS and Neway West econometric methodology the study estimated the relationship for India covering the period from 1884 to 2000. The result suggests that environmental Kuznets curve exists. The result also found that curves just started falling and the turning point for CO_2 and SO_2 was Rs. 14395 per capita and Rs. 12706 per capita respectively.

Granados and Carpintero (2009) estimated the environmental Kuznets curve for the world economy as a whole spanning the period from 1960-2008. The study included carbon emission and economic growth. The analysis does not support the inverted U-shaped pattern. However, a N-shaped relation was found between the variables. “The study of Vincent (1997), Dinda et al. (2000), Holtz-Eakin & Seldon (1992), Moomaw & Unrub (1997), Hill and Magnanai (2000), Gangadharan and Valenzuela (2001), Agras and Chapman (1999), Ghosh (2010), Candoo and Dinda (2001) comes under the second category as they do not support the existence of environmental Kuznets curve hypothesis”.

Dinda, Candoo & Pai (2000) examined the environmental Kuznets curve hypothesis by applying the panel data set for 33 countries spanning the period from 1979 to 2010. The empirical result of the study found an inverse relationship between sulfur dioxide and gross domestic product and U shaped relationship between suspended particulate and gross domestic product.

Kathuria and Mukherjee (2006) attempted to examine the role of environmental quality and per capita NSDP in the context of 14 major Indian states. The findings show a N-shaped linkage between the variables. This result suggested that economic growth in these states is mostly dependent on the cost of environmental quality.

Bagliani, Bravvo, Dalmazzone (2006) investigated the environmental Kuznets curve using a consumption-based line of enquiring covering the period from 1961 to 2007. The analysis used the ecological footprints data for 148 countries. The study finds no longer any compelling evidence in favor of an inverted U-shaped behavior.

Dinda and Coondo (2005) tested the impact of environmental pollution on economic growth in the context of 88 countries. By using the co-integration and ECM model the study found bidirectional causality between the variables for the world as a whole.

Saboori, et al. (2012) attempted to verify the presence of EKC in the context of Malaysia covering the period from 1980-2009. The variables included in this study are per capita carbon emissions and real GDP. The per capita carbon emission was collected from the U.S. Energy Information Administration (EIA) and real per capita GDP was obtained from World Development Indicators (WDI) for the study period. By employing the ARDL method the analysis found a long-run linkage between the variables in the short run. The findings also show a long-run causality from economic growth to carbon emission.

Apergis (2016) analyzed the existence and non-existence of the EKC for carbon emissions based on data for the 48 contiguous states of the US economy covering the annual period of 1960 to 2010. The study includes real GDP per capita income as a measure of output obtained from OECD national accounts. The analysis employed both panel and time series techniques. The empirical test confirms EKC hypothesis exists in 12 out of 15 nations. But, for the rest of the 3 nations, it exists at certain quintiles.

Shahaz, et al. (2015) tried to examine the EKC hypothesis in the context of Portugal covering the period from 1971-2008. The analysis includes CO_2 emissions as a proxy for carbon emissions, per capita energy consumption (kg oil equivalent), real GDP, trade openness, and urbanization. All the data were obtained from (WDI, 2009). By applying the ARDL model the empirical result confirms the presence of EKC in both the long-run and short-run.

Esteve & Tamarit (2012) investigated the long-run environmental Kuznets curve in the context of the Spanish economy covering the period from 1857 to 2007. By employing the threshold cointegration technique the analysis found non-linearity of the link between the variables. The findings confirm an EKC in the case of the Spanish economy.

Lau, et al. (2014) attempted to test the presence of EKC in the context of Malaysia from 1970 to 2008. The analysis includes annual data for carbon emissions, GDP, and foreign direct investment. All variables are obtained from the World Development Indicators, World Bank. By employing the ARDL bound testing co-integration and causality technique the findings show a reverse U-shaped linkage between the variables in both short-run and long-run.

Managi & Jena (2008) studied the determinants of environmental productivity and EKC in India from 1991-2003. By employing the productivity measurement technique the study found the level of productivity decreases and the presence of EKC in the case of India.

Kanjilal & Ghosh (2013) revisited the linkage between energy use, carbon emission, economic activity, and openness of trade in India covering the period from 1971 to 2008. The variables included energy consumption in kg oil equivalent, CO_2 emission, GDP, and openness of trade. All the variables were sourced from World Development Indicators. By employing the threshold co-integration technique the study found the existence of regime shift or threshold co-integration among the variables and EKC for India.

Anastacio (2017) examined the validity of the EKC hypothesis in the context of North American nations (Mexico, Canada, and the U.S.) covering 1980 to 2008. The variables include CO_2 emissions, income, and electricity consumption. All the variables were sourced from WDI, 2015. By employing the Pedroni panel co-integration, FMOLS, and DOLS panel econometric techniques the study found that there is an inverted U-shaped relationship between the variables. The analysis also confirms causality from energy consumption to carbon emission and from economic growth to carbon emission.

Iwata, et al. (2010) examined the presence of the EKC hypothesis in the case of France from 1960 to 2003. The study includes carbon emission, GDP, electricity production from nuclear sources, urbanization, trade, and energy use. All the data were obtained from WDI. By using the ARDL model the study found the presence of EKC.

Bekhet, et al. (2014) examined the causal linkage between CO_2 emission, energy consumption, economic growth, and population in UAE and Saudi Arabia for the period 1975-2011. The variables used for analysis are CO_2 emissions, real GDP, energy consumption per capita is in kg oil equivalent, and total population. All data were cumulated from WDI, 2013. By using ARDL and Granger causality techniques the result confirms a long-run linkage between the variables. The analysis does not find the EKC in both countries. The findings again indicate carbon emission level increases with the increase in energy consumption in Saudi Arabia in the short run and for UAE only in the long run.

He and Richard (2010) examined the presence of the EKC hypothesis in the context of Canada covering the period from 1948 to 2004. To carry out the analysis the study used time series data on CO_2 emissions which were collected from the World Research Institute (WRI), Washington DC. Other variables like GDP, the population were obtained from Statistics Canada. By employing semi-parametric and flexible nonlinear parametric modeling methods the result found the EKC hypothesis.

Baek, J., (2015) estimated the EKC in the context of Arctic nations spanning from 1960-2010. The variable includes per capita CO_2 emissions, real GDP, and energy consumption kg oil equivalent. Data were cumulated from WDI. By using the ARDL method the empirical result suggests that there is little evidence of EKC in the case of Arctic nations. The result also confirms that economic growth has a positive impact on some Arctic nations. However, energy consumption harms the environment for most nations.

2.4 Concluding Remarks

Economic growth, energy consumption, and increasing carbon emission are one of the most pivotal concerns in the World community. This is a controversial topic with regard to the neoclassical growth model which treats land, labour, capital as major sources of inputs of the production function. However, energy as an input of production function is grossly missing from the production function even though energy serves as a major element of economic growth in the era of liberalization, privatization, and globalization, especially for developing countries.

Natural resources are the major sources of energy for growth. However, the exhaustive use of natural resources will increase the level of carbon dioxide (CO_2) emissions which depletes the environment. A plethora of theoretical literature based on economic growth is based on the Solow growth model. The second strand of literature explores the relationship between economic growth, environment, energy consumption, and environment. A third strand of empirical literature explores the relationship between renewable energy consumption, nonrenewable energy consumption, total energy consumption and economic growth. However, there is no near unanimity on consistent conclusion have not been reached yet.

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CHAPTER 3

Energy Consumption, Production, and Distribution in India: Some Stylized Facts

3.1 Introduction

The energy sector plays a crucial role in India and has received substantial importance at the macroeconomic level and in the provision of public funds for its growth. In the third five-year plan, its share has been increased. Despite constant efforts, the development of the energy sector faces many difficulties in keeping pace with the demand for energy services by individual consuming sectors.

In India, there is a shortage of substantial primary energy reserves keeping pace with the rapid growth of population, vast geographical territory, and increasing final energy demand. Over the years, the energy supply pattern and energy consumption have seen substantial changes. In the total energy supply, the share of commercial fuel has increased from 41% in 1970-71 in tones annually. The annual yield of the crop remains placed at around $370*10^6$ tons, of which nearly $45*10^6$ tonnes are used in the household sector. However, a considerable potential of non-conventional and nonrenewable energy resources exists in the country.

In India, the size of primary commercial energy reserves seems large, whereas the per capita availability is relatively moderate on account of the country's large population. In the future, India should add a significant amount of primary commercial energy to meet the availability of energy for the growing population.

3.2 Present Status of Energy Resources

In the last several decades, India has taken a key interest in producing primary commercial energy. In primary commercial energy, coal is considered the main source of energy. Coal is directly used in industry and indirectly utilized for power generation. Efforts have been made to develop and explore hydrocarbons and have directed a substantial step up in coal and natural gas production. On the other hand, the production of crude oil has been stewing.

3.3 Patterns of Energy Demand in India

The energy demand in India is driven by two socio-economic factors such as overpopulation and domestic products. The rapid growth of the population puts stress on the environment, infrastructure, and natural resources. Furthermore, India has undergone critical structural changes since 1991. The growing impact of the structural change has led to an increase in India's energy consumption. As we know, energy is a necessary input to all production economic activity. Thus, the process of economic progress certainly requires a massive amount of energy consumption. We all know a positive correlation between per capita economic growth and capital energy consumption. Therefore, with the economy's growth, energy consumption in India has also been steadily growing.

Industry accounts for more than half the consumption of commercial energy in India. It is followed by the transport sector which accounts for about a quarter of consumption. However, now with the growing incomes and changing lifestyles, the energy consumption in households is also increasing.

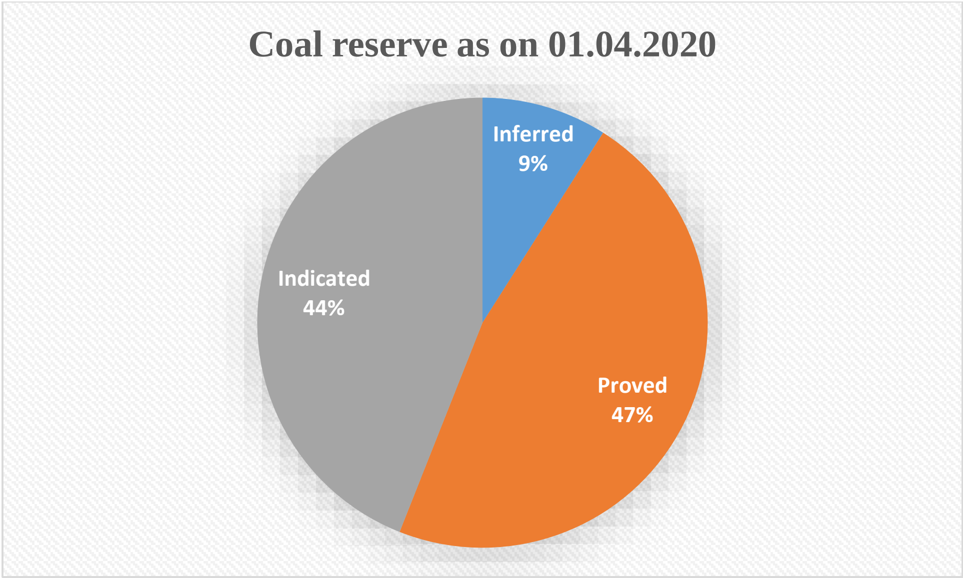
From the Sectoral energy consumption point of view, it is observed that the industrial sector consumes more energy compared to other sectors. In India, the industrial sector consumes nearly 50% of commercial energy. The rising energy consumption in the industrial sector is partly because of investments in essential and energy-intensive industries and partly due to the importance given to the post-development plans to attaining self-reliance.

In India, the domestic sector consumes 45% of total primary energy, with non-commercial biomass fuel having a significant share. Biomass fuel established the predominant energy source in India, particularly for cooking. Biomass fuels contributed 72.3% of the domestic energy and 90% of all rural energy needs. Among the commercial fuels, kerosene and electricity are prominent-being used 43.35 and 55.8% for lighting.

India has a significant deposit record of coal in the world. The total reserve of coal in 2020 was 344.02 BT. The growth rate of coal reserve increased by 5.37% during the year 2020 over 2019. The three highest coal-producing states in India are Odisha, Chhattisgarh, and Jharkhand. These three states account for 70% of the total coal reserve in India.

Figure 3.1: Coal Reserve as on 01.04.2020

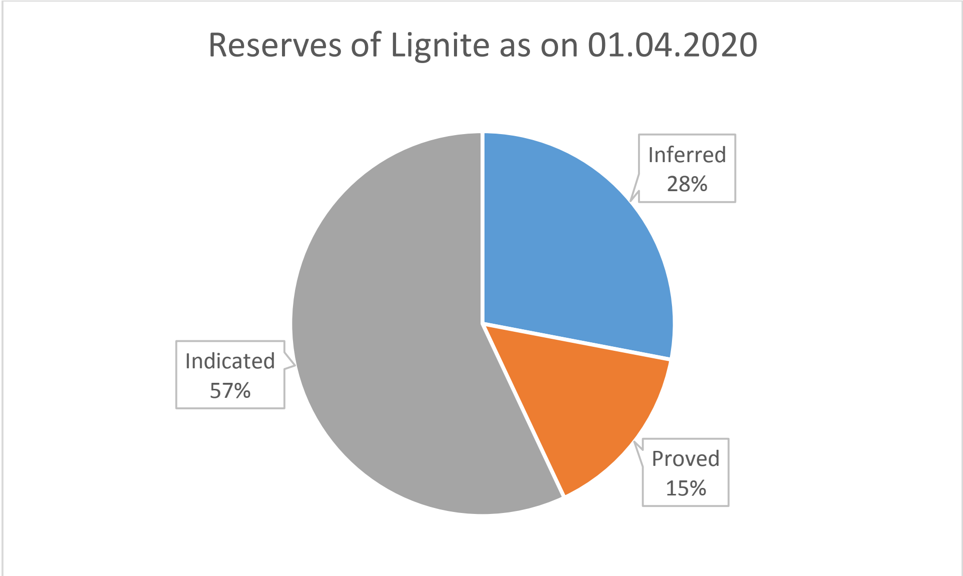
Figure 3.1 reported the reserve of coal in India as on 01.04.2020. It is observed that percentage of inferred coal is 9%, proved coal 47% and indicated 44% respectively.



Source: Author's estimation

Figure 3.2: Reserves of Lignite as on 01.04.2020

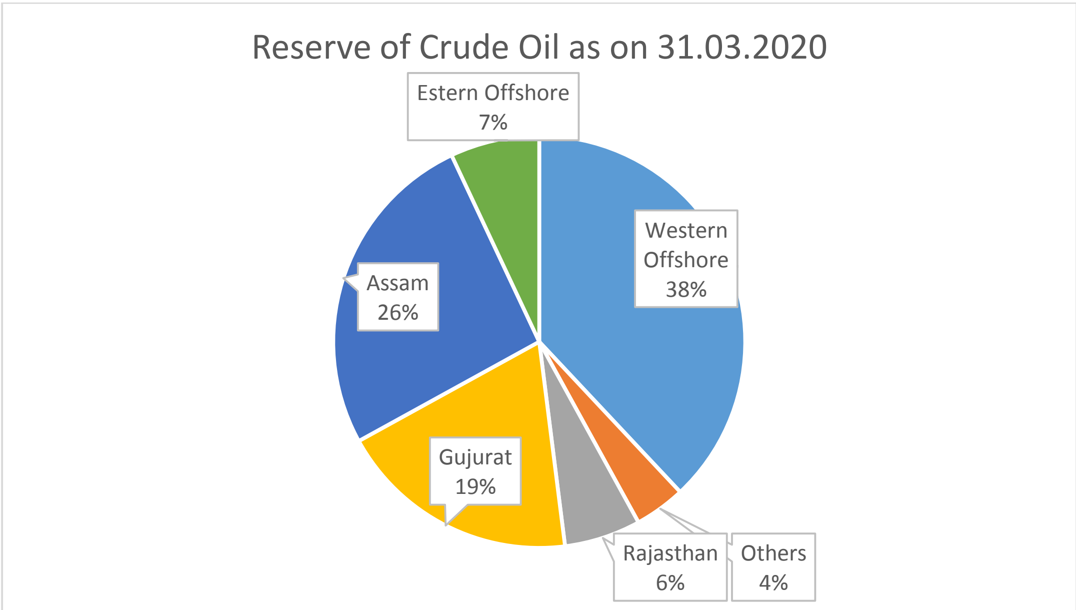
Figure 3.1 reported the reserves of lignite in India as on 01.04.2020. It is observed that percentage of inferred reserve of lignite is 28%, proved lignite 15% and indicated lignite 57% respectively.



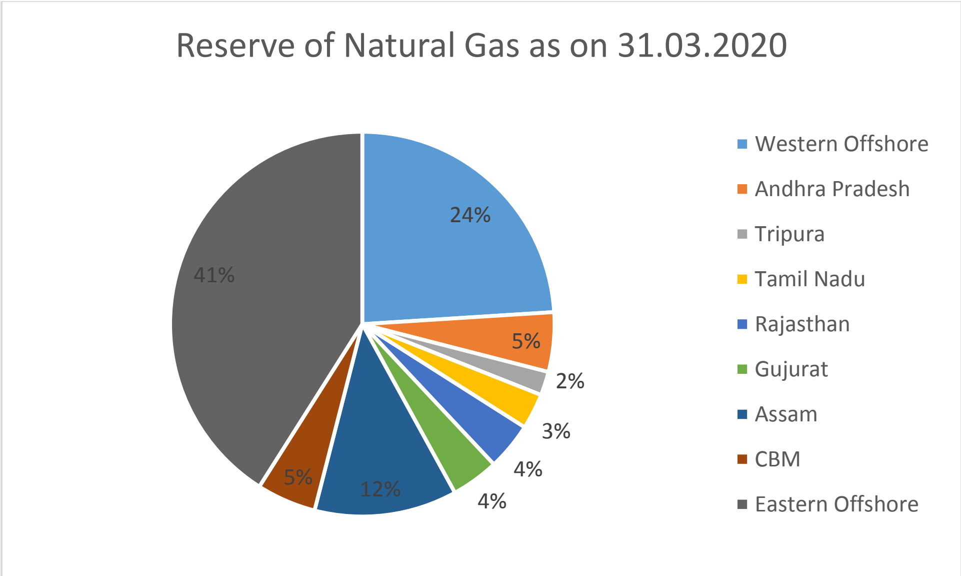
Source: Author's estimation

Figure 3.3: Reserve of Crude Oil as on 31.03.2020

Figure 3.3 shows the calculated reserve of crude oil in India in the year 2020. The estimated reserve of crude oil in India in 2020 is 603.37 MT. The largest crude oil reserve is found in the Western Offshore (39%) and Assam (26%).



Source: Energy statistics India



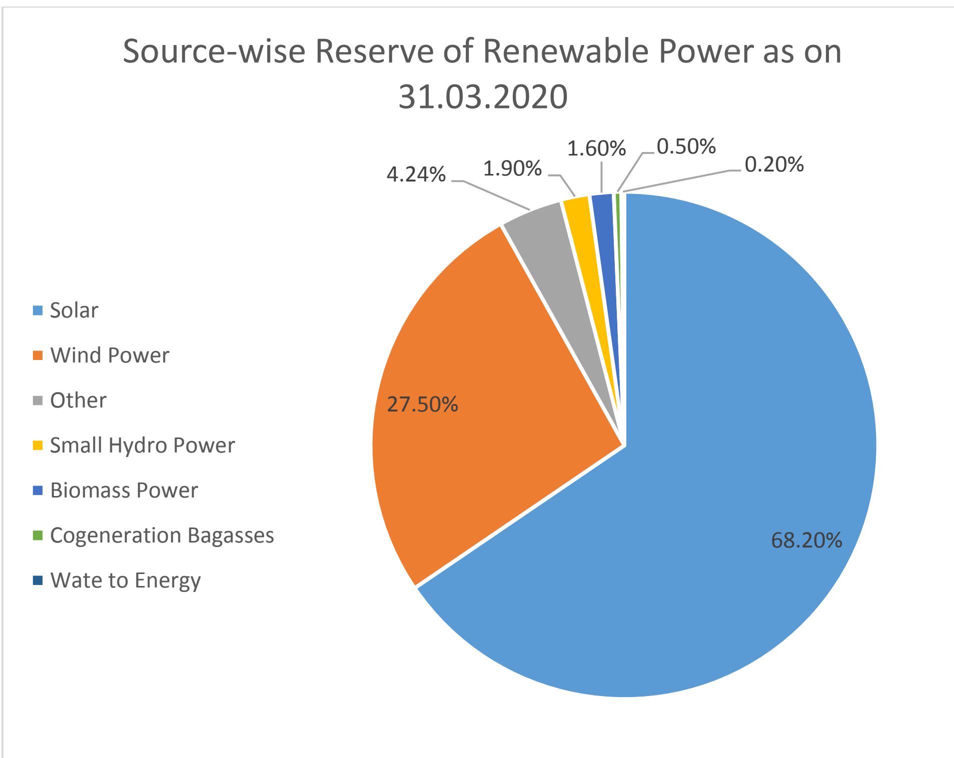
Source: Energy statistics India

Figure 3.4: Reserve of Natural Gas as of 31.03. 2020

The estimated reserve of Natural Gas in India in 2020 was 1371.89 BCM. Maximum reserve of Natural Gas found in Eastern Offshore (41%) and Western Offshore (24%), respectively figure 3.4.

Figure 3.5: Source-wise Reserve of Renewable Power as on 31.03.2020

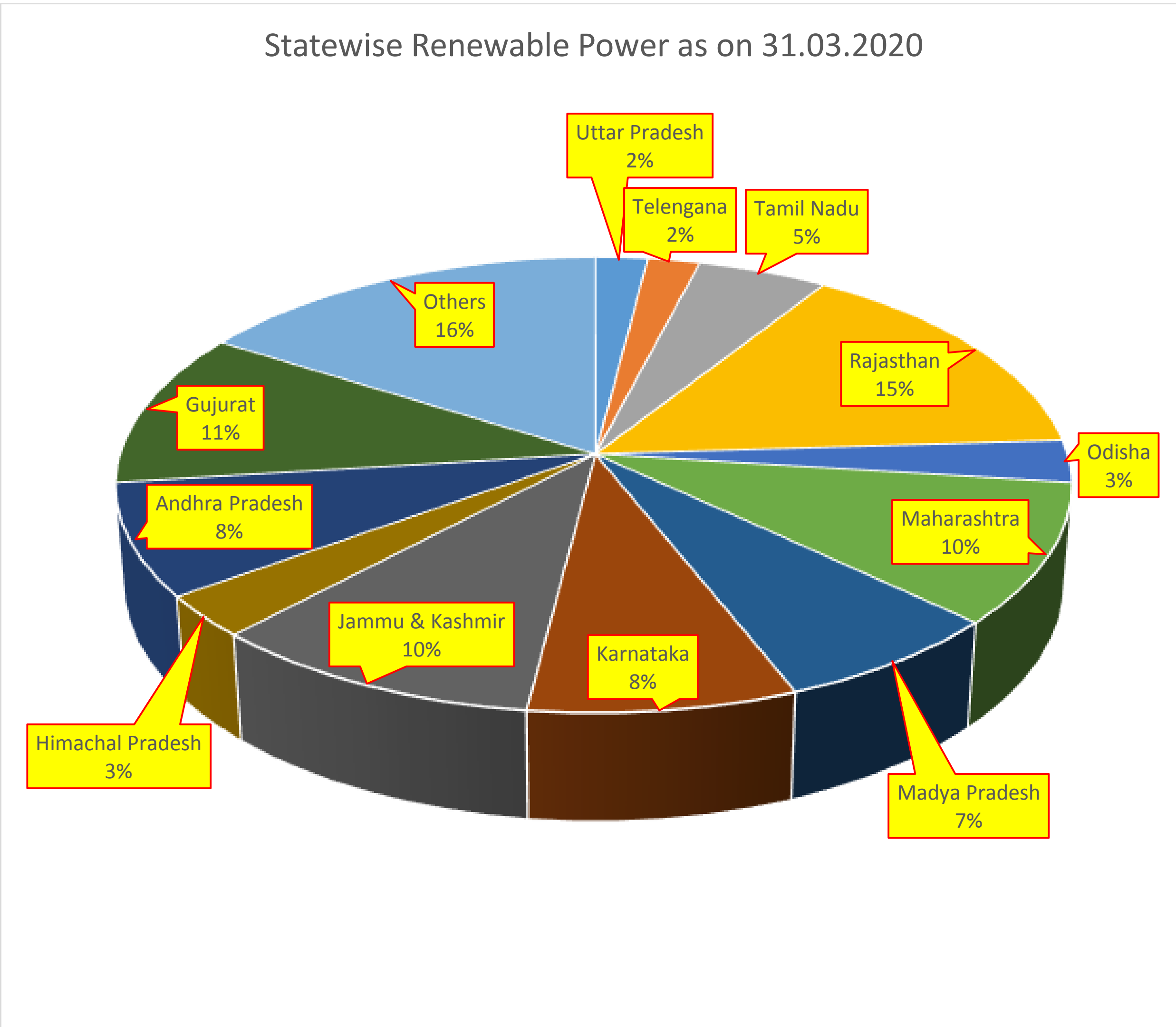
In India, renewable energy is generated from solar, wind, biomass, and small hydro sources. The total potential for renewable power generation in India as of 31.03.2020 was 1,097,465 MW. This comprises solar power of 748990 MW (68.20%), Wind power of 302251 MW (27.50%) at 100m hub height, SHP (small-hydro power) of 21134 MW (1.90%), Biomass power of 17, 536 MW (1.60%) figure 3.5.



Source: Energy statistics India

3.4 Production of Energy Resources

Production of energy is the capture or extraction or manufacture of fuels or energy informs that are ready for general use. Energy production and consequently its availability directly affects future production, imports, exports and investment, all of which have a significant impact on a country's economy. Detailed and high quality energy statistics provide policy makers with the information needed to make informed decisions and evaluate possible trade-offs including planning for global price shocks in energy commodities.



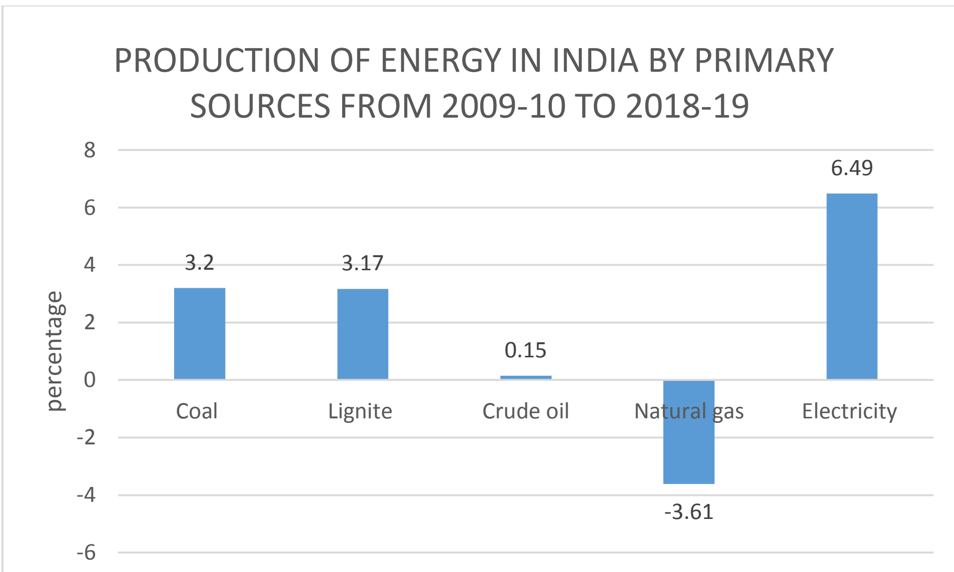
Source: Energy statistics India

Figure 3.6: State-wise Renewable Power as on 31.03.2020

State-wise distribution of renewable power as of 31.03.2020 indicates that Rajasthan has the maximum share of about 15% (162223MW), followed by Gujarat with 11% (122086 MW). Maharashtra and Jammu & Kashmir come next with a 10% share (113925 MW and 112800 MW), respectively figure 3.6.

Figure 3.7: Primary Sources of Energy Production in India from 2009-10 to 2018-19

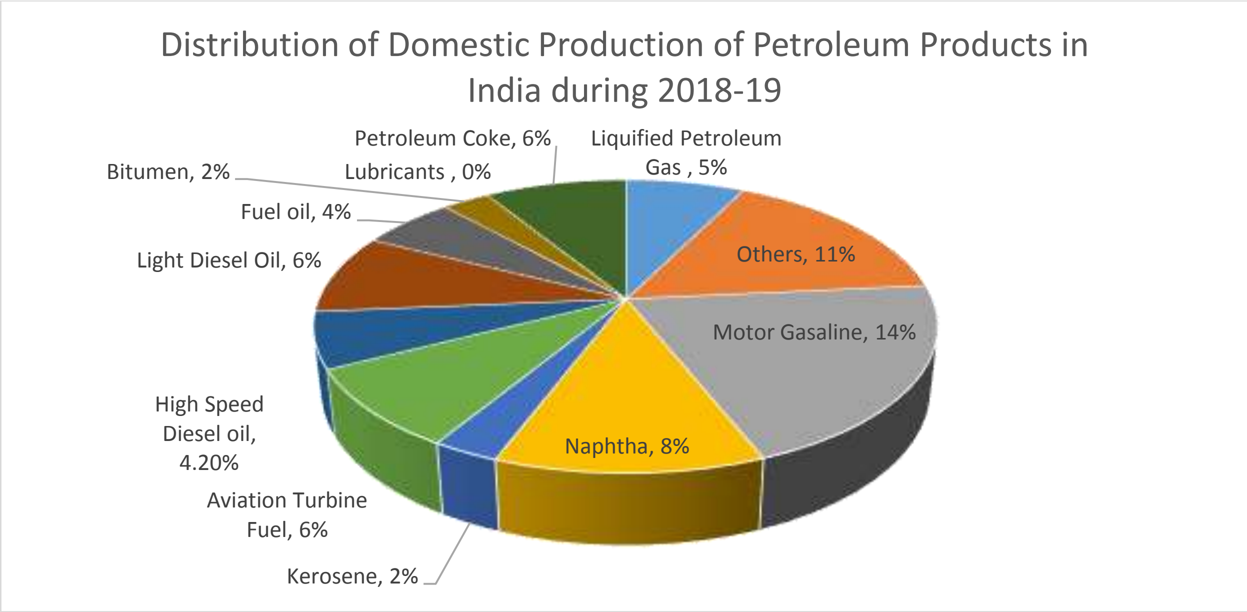
Figure 3.7 indicates primary sources of energy production in India. It is observe that production of electricity is highest followed by lignite whereas natural gas production becomes negative.



Source: Energy statistics India

Figure 3.8 Distribution of Domestic Production of Petroleum Products in India during 2018-19

The estimated distribution of petroleum products in India is highest in case of Motor Gasoline (14%) followed by Naphtha (8%) and Liquefied Petroleum (5%) respectively figure 3.8.



Source: Energy statistics India

3.4.1 Production of Coal, Lignite, Crude Oil, Natural Gas & Electricity

Table 3.1 reports coal production in India during the year 2018-19 was 728.72 MTs. It is presented that coal production trend from 2009-10 to 2018-19 was about 532.04 MTs, it increased to 728.72 MTs with a growth rate of 7.89%.

The production of lignite during 2018-19 was 44.28 MTs. The lignite production declined by 5.06% compared to the previous year, 2017-18 (46.64MTs). During this period, the growth rate was about 2.66%, increasing production from 34.04 MTs in 2009-10 to 44.28 MTs in 2018-19.

During the year 2018-19, crude oil production was 34.2 MT. The production of crude oil declined 4.2% in comparison to the previous year (35.7) 2017-18.

The production of natural gas during the year 2018-19 was 32.87 BCM, and the electricity was 2 99 465.00 Gwh. The growth rate for natural gas and electricity was 0.67% and 12.45 %.

Table 3.1: Production of Primary Sources of Conventional Energy in India

Year	Coal (Million Tons)	Lignite (Million Tons)	Crude Petroleum (Million Tons)	Natural Gas (Billion Cubic Metres)	Electricity Hydro & Nuclear (GWh)
1	2		3	4	5
2005-06	407.04	30.23	32.19	32.20	118,818
2006-07	430.83	31.29	33.99	31.75	132,304
2007-08	457.08	33.98	34.12	32.42	137,344
2008-09	492.76	32.42	33.51	32.85	142,576
2009-10	532.04	34.07	33.69	47.50	125,316
2010-11	532.69	37.73	37.68	52.22	140,524
2011-12	539.95	42.33	38.09	47.56	163,796
2012-13	556.40	46.45	37.86	40.68	146,497
2013-14	565.77	44.27	37.79	35.41	168,931
2014-15	609.18	48.27	37.46	33.66	2,38,908.43
2015-16	639.23	43.84	36.95	32.25	2,24,571.11
2016-17	657.87	45.23	36.01	31.90	2,41, 841.64
2017-18	675.40	46.64	35.68	32.65	2,66,308.30
2018-19	728.72	44.28	34.20	32.87	2,99,465.00
The growth rate of 2018-19 over 2017-18(%)	**7.89**	**-5.06**	**-4.15**	**0.67**	**12.45**
CAGR 2009-10 to 2018-19(%)	**3.20**	**2.66**	**0.15**	**-3.61**	**6.49**

Sources1. Ministry of Coal
2. Ministry of Petroleum & Natural Gas.
3. Central Electricity Authority.

Table 3.2: Production of Coal and Lignite in India

Year	Coal			Lignite	Grand Total
	Coking	**Non-coking**	**Total**		
1	**2**	**3**	**4= 2+3**	**5**	**6=4+5**
2005-06	31.51	375.53	407.04	30.23	437.27
2006-07	32.10	398.74	430.83	31.29	462.12
2007-08	34.46	422.63	457.08	33.98	491.06
2008-09	33.81	457.95	491.76	32.42	524.18
2009-10	44.41	487.63	532.04	34.07	566.11
2010-11	49.55	483.15	532.69	37.73	570.43
2011-12	51.65	488.29	539.94	42.33	582.27
2012-13	51.58	504.82	556.40	46.45	602.86
2013-14	56.82	508.95	565.77	44.27	610.04
2014-15	57.45	551.73	609.18	48.27	657.45
2015-16	60.89	578.35	639.23	43.84	683.08
2016-17	61.66	596.21	657.87	45.23	703.10
2017-18	40.15	635.25	675.40	46.64	722.04
2018-19	41.13	687.59	728.72	44.28	773.00
The growth rate of 2018-19 over 2017-18(%)	**2.45**	**8.24**	**7.89**	**-5.06**	**7.06**
CAGR 2009-10 to 2018-19(%)	**-0.76**	**3.50**	**3.20**	**2.66**	**3.16**

Source: Ministry of Coal, Office of Coal Controller

Production of Petroleum Products

Table 3.3 reports the production of petroleum products in the country. High-speed diesel oil accounted for the maximum share, followed by Motor Gasoline in 2018-19.

Table 3.3: Production of Petroleum Products in India (MTs)

Year	Light distillates			Middle distillates			
	Liquefied Petroleum Gas @	Motor Gasoline	Naphtha$	Kerosene	Aviation Turbine Fuel	High Speed Diesel Oil	Light Diesel Oil
1	2	3	4	5	6	7	8
2005-06	7.71	10.50	16.09	9.24	6.20	47.59	0.92
2006-07	8.41	12.54	18.14	8.63	7.81	53.48	0.80
2007-08	8.79	14.17	17.96	7.97	9.11	58.38	0.67
2008-09	9.16	16.02	16.45	8.39	8.07	62.91	0.61
2009-10	10.33	22.54	18.79	8.70	9.30	73.30	0.47
2010-11	9.71	26.14	19.20	7.81	9.59	78.06	0.59
2011-12	9.55	27.19	18.83	7.86	10.06	82.88	0.50
2012-13	9.82	30.12	17.35	7.87	10.08	91.08	0.40
2013-14	10.03	30.28	18.51	7.42	11.22	93.76	0.42
2014-15	9.84	32.33	17.39	7.56	11.10	94.43	0.36
2015-16	10.57	35.32	17.86	7.50	11.79	98.59	0.43
2016-17	11.33	36.59	19.95	6.04	13.83	102.48	0.63
2017-18	12.38	37.78	20.01	4.41	14.59	107.90	0.56
2018-19	12.79	38.04	19.79	4.07	15.48	110.53	0.70
The growth rate of 2018-19 over 2017-18(%)	**3.31**	**0.69**	**-1.10**	**-7.71**	**6.10**	**2.44**	**25.00**
CAGR 2009-10 to 2018-19(%)	**2.16**	**5.37**	**0.52**	**-7.32**	**5.23**	**4.19**	**4.06**

Source: Ministry of Petroleum & Natural Gas

Table 3.4 presents the production of natural gas in India. Natural gas production increased from 32.65 BCM in 2017-18 to 32.87 BCM in 2018-19, registering a growth of 0.67%.

Table 3.4: Production of Natural Gas in India (in Billion Cubic Meters)

Period	Gross Production	Re-injected	Flared	Net Production
1	2	3	4	5=2-4
2005-06	32.20	4.47	0.88	31.33
2006-07	31.75	4.37	0.96	30.79
2007-08	32.42	4.50	0.94	31.48
2008-09	32.85	4.68	1.09	31.75
2009-10	47.50	5.66	0.98	46.52
2010-11	52.22	5.21	0.97	51.25
2011-2012	47.56	5.31	1.08	46.48
2012-13	40.68	5.40	0.90	39.78

2013-14 2014-15 2015-16 2016-17 2017-18 2018-19	35.41 33.66 32.25 31.90 32.65 32.87	5.59 0.87 1.01 1.01 0.98 0.82	0.77 0.87 0.79 1.01 0.98 0.82	34.64 26.91 25.46 25.03 25.86 26.01
The growth rate of 2018-19 over 2017-18(%)	**0.67**	**3.96**	**-15.60**	**0.55**
CAGR 2009-10 to 2018-19(%)	**-3.60**	**0.65**	**-2.84**	**-4.39**

Source: Ministry of Petroleum & Natural Gas.

Table 3.5 illustrates gross electricity generation in India during 2009-10 was 7, 99, 851 GWh. The electricity generation increased to 13, 71, 779 GWh in 2018-19. The annual growth of electricity was about 5.24%.

Table 3.5 Gross generation of Electricity from Utilities and Non-utilities in India

	(Giga Watt hour=10^6 Kilo Watt hour)							
Year	**Utilities**							
	Thermal				**Hydro**	**Nuclear**	**ORS**	**Total**
	Steam	**Diesel**	**Gas**	**Total**				
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
2009-10	539,586	4,248	96,373	640,208	104,059	18,636	36,947	799,851
2010-11	561,298	3,181	100,342	664,822	114,416	26,266	39,245	844,748
2011-12	612,497	2,649	93,281	708,427	130,511	32,287	51,226	922,451
2012-13	691,341	2,448	66,664	760,454	113,720	32,866	57,449	964,489
2013-14	745,533	1,998	44,522	792,054	134,848	34,228	65,520	1,026,649
2014-15	835,291	1,576	41,075	877,941	129,244	36,102	73,563	1,116,850
2015-16	895,340	551	47,122	943,013	121,377	37,414	65,781	1,167,584
2016-17	944,022	401	49,094	993,516	122,378	37,916	81,548	1,235,358
2017-18	986,591	348	50,208	1,037,184	126,123	38,346	101,839	1,303,493
2018-19	1,022,265	215	49,834	1,072,314	134,894	37,813	126,759	1,371,779

Growth rate of 2018-19 over 2017-18(%)	**3.62**	**-38.19**	**-0.74**	**3.39**	**6.95**	**-1.39**	**24.47**	**5.24**
CAGR 2009-10 to 2018-19 (%)	**6.60**	**-25.79**	**-6.38**	**5.29**	**2.63**	**7.33**	**13.12**	**5.54**

Source: Central Electricity Authority.

Table 3.6 shows the total electricity generation in India from utilities and non-utilities. The total electricity generation from 2018-19 was 15, 46, 779 GWh. In the same year, the total output from non-utilities was 1, 75, .000 GWh.

Table 3.6 Gross generation of Electricity from Utilities and Non-utilities in India

	(Giga Watt hour= 10^6 x Kilo Watt hour)							
Year	**Non-Utilities**							**Grand Total**
	Thermal				**Hydro**	**ORS**	**Total**	
	Steam	**Diesel**	**Gas**	**Total**				
1	**10**	**11**	**12**	**13**	**14**	**15**	**16**	
2009-10	77,416	8,217	19,739	105,372	152	609	106,133	905,984
2010-11	96,657	7,754	15,435	119,846	149	922	120,917	965,665
2011-12	104,863	6,244	21,972	133,079	131	1,178	134,388	1,056,839
2012-13	113,167	8,205	20,769	142,141	118	1,750	144,010	1,108,499
2013-14	118,178	8,866	19,912	146,957	129	1,903	148,988	1,175,637
2014-15	128,401	9,720	21,135	159,256	145	2,656	162,057	1,278,907
2015-16	136,721	8,412	21,083	166,216	110	2,046	168,372	1,335,956
2016-17	137,588	9,182	22,855	169,625	144	2,277	172,046	1,407,404
2017-18	143,868	8,107	25,362	177,337	112	2,328	179,777	1,483,270
2018-19	141,137	7,723	23,785	172,645	97	2,258	175,000	1,546,779
Growth rate of 2018-19 over 2017-18(%)	**-1.90**	**-4.74**	**-6.22**	**-2.65**	**-13.76**	**-3.01**	**-2.66**	**4.28**
CAGR 2009-10	**6.19**	**-0.62**	**1.88**	**5.06**	**-4.38**	**14.00**	**5.13**	**5.49**

to 2018-19 (%)								
Source: Central Electricity Authority.								

3.5 Availability of Coal and Lignite

Table 3.7 reports the total availability of raw coal in the country during 2018-19 was 958.25 MTs, and availability of lignite was 42.72MTs. The coal availability rose 6.94% in the year 2018-19 compared to 2017-18, whereas; the availability of lignite reduced by 9.05% during the same period. The availability of natural gas has not increased significantly. Moreover, an annual growth rate of 2.6 % was reported in natural gas production during 2018-19 over 2017-18.

Table 3.7: Availability of Primary Energy Sources in India

Year	**Coal (MTs)**	**Lignite (MTs)**	**Crude Oil (MTs)**	**Natural Gas (BCMs)**
2009-10	620.39	33.73	192.95	59.41
2010-11	607.06	37.78	201.28	64.16
2011-12	642.63	42.77	209.82	64.45
2012-13	688.75	46.83	222.66	57.36
2013-14	722.57	44.64	227.03	52.37
2014-15	827.52	49.58	226.90	51.30
2015-16	847.58	45.48	239.79	52.51
2016-17	858.58	47.32	249.94	55.70
2017-18	896.09	46.98	256.12	59.17
2018-19	958.25	42.72	260.70	60.75
Growth rate of 2018-19 over 2017-18(%)	**6.94**	**-9.05**	**1.79**	**2.67**
CAGR 2009-10 to 2018-19 (%)	**4.44**	**2.39**	**3.06**	**0.22**

Source: Ministry of Coal, Ministry of Petroleum and natural gas, and CEA.

Table 3.8: Accessibility of Row Coal & Lignite for Consumption in India (in Million Tones)

Periods	COAL					LIGNITE		
	Production (Coking + Non-coking)	Changes Vendible Stock (Closing - Opening)	Imports	Exports	Availability for Consumption	Production	Changes Vendible Stock (Closing - Opening)	Availability for Consumption
1	2	3	4	5	6=2-3+4-5	7	8	9=7-8
2005-06	407.04	10.37	38.59	1.99	433.27	30.23	-0.01	30.24
2006-07	430.83	10.01	43.08	1.55	462.35	31.29	0.48	30.81
2007-08	457.08	2.43	49.79	1.63	502.82	33.98	-0.67	34.65
2008-09	492.76	0.54	59.00	1.66	549.57	32.42	0.58	31.85
2009-10	532.04	17.55	73.26	2.45	585.30	34.07	-0.34	34.41
2010-11	532.69	7.33	68.92	4.41	589.87	37.73	0.05	37.69
2011-12	539.95	1.85	102.85	2.02	638.94	42.33	0.44	41.89
2012-13	556.40	-10.99	145.79	2.44	710.74	46.45	0.44	46.01
2013-14	565.77	-7.87	168.44	2.15	739.92	44.27	0.37	43.90
2014-15	609.18	4.27	217.78	1.24	830.00	48.26	1.32	49.57
2015-16	639.23	5.40	199.88	1.25	843.27	43.84	1.63	45.47
2016-17	657.87	11.53	190.95	1.77	858.58	45.23	2.07	47.32
2017-18	675.40	13.92	208.27	1.50	896.09	46.64	0.33	46.98
2018-19	728.72	-4.40	235.24	1.31	958.25	44.28	-1.54	42.72
The growth rate of 2018-19 over 2017-	**7.89**	**-131.58**	**12.95**	**-12.64**	**6.94**	**-5.06**		**-9.05**

Source: Office of the Coal Controller, Ministry of Coal

3.5.1 Availability of Crude Oil and Petroleum Products

Table 3.9 indicates the availability of crude oil in India in 2018-19 was 260.70 MTs. The table also found a 1.7% increase in the net availability of crude oil during 2018-19 over 2017-18. The crude oil production for the year 2018-19 has reduced 4.15% over the year 2017-18. Production of petroleum products in 2018-19 rose to 262.36 MT from 254.40 MT in 2017-18. The availability of petroleum products is 234.61 MT in 2018-19 from 148.12 MT in 2009-10. The production of natural gas during 2018-19 increased to 32. 05 CMT from 31. 73 CMT in 2017-18. The availability of natural gas is 60.75 CMT in 2018-19 up from 55.97.

Table 3.9: Accessibility of Natural Gas, Petroleum Products and Crude Oil in India

Periods	Crude Oil (MTs)			Petroleum Products(MTs)			Natural Gas (CMTs)		
	Production	Net Imports	Gross Availability	Production @	Net Imports	Gross Availability	Production	Net Imports	Gross Availability
1	**2**	**3**	**4=2+3**	**5**	**6**	**7=5+6**	**8**	**9**	**10-8+9**
2005-06	32.19	99.41	131.60	124.41	-10.02	114.39	31.33	5.06	36.39
2006-07	33.99	111.50	145.49	139.75	-15.96	123.78	30.79	6.81	37.60
2007-08	34.12	121.67	155.79	149.47	-18.38	131.10	31.48	8.32	39.80
2008-09	33.51	132.78	166.28	155.15	-20.38	134.77	31.75	8.06	39.81
2009-10	33.69	159.26	192.95	184.61	-36.31	148.30	46.52	9.15	55.97
2010-11	37.68	163.60	201.28	194.82	-42.26	152.56	51.25	9.93	61.18
2011-12	38.09	171.73	209.82	203.20	-44.99	158.21	46.48	13.21	59.69
2012-13	37.86	184.80	222.66	217.74	-47.63	170.10	39.78	13.14	52.92
2013-14	37.79	189.24	227.03	220.76	-51.15	169.61	34.64	13.03	47.67
2014-15	37.46	189.43	226.89	221.14	-42.63	178.51	33.66	14.09	47.75
2015-16	36.95	202.85	239.80	231.92	-32.23	199.69	32.25	16.58	48.83
2016-17	36.01	213.93	249.94	243.55	-29.23	214.32	30.85	24.85	55.70
2017-18	35.68	220.43	256.11	254.40	-31.37	223.03	31.73	27.44	59.17
2018-19	34.20	226.50	260.70	262.36	-27.75	234.61	32.05	28.69	60.75
The growth rate of 2018-19 over 2017-18(%)	**-4.15**	**2.75**	**1.79**	**3.13**	**-11.55**	**5.19**	**-1.02**	**4.57**	**2.26**

Ministry of Petroleum & Natural Gas.

3.5.2 Availability of Electricity

Table 3.10 shows the availability of electricity in India from 2009-2018. It is observed that the electricity supply rose from 7, 63, 519 GWh in 2009-10 to 12, 96, 235 GWh in 2018-19. The availability of electricity rose by 5.17% in 2018-19 over 2017-18.

Table 3.10: Availability of Electricity in India from 2009-10 to 2018-19

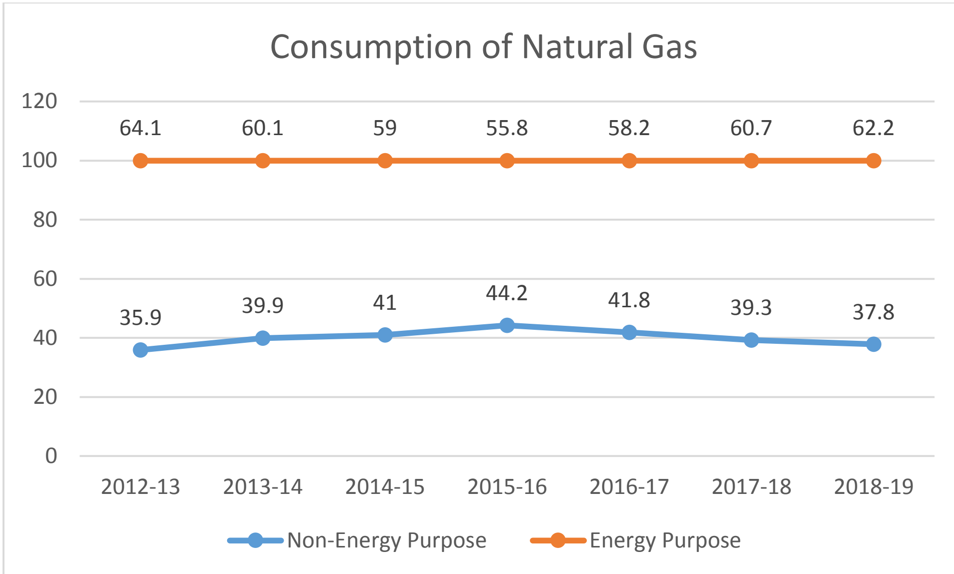
		(in Giga Watt hour = 10^6 Kilo Watt hour)			
Year	**Gross Electricity Generated from Utilities**	**Consumption in Power Station Auxiliaries**	**Net Electricity Generated from Utilities**	**Purchases from Non-Utilities + Net Import from Other Countries**	**Net Electricity Available for Supply**
1	**2**	**3**	**4=2-3**	**5**	**6=4+5**
2009-10	799,851	50,723	749,128	14,391	763,519
2010-11	844,748	52,952	791,796	19,839	811,635
2011-12	922,451	56,499	865,952	15,514	881,466
2012-13	964,489	64,109	900,380	20,849	921,229
2013-14	1,026,649	70,161	956,488	17,948	974,436
2014-15	1,116,850	76,268	1,040,582	13,773	1,054,355
2015-16	1,167,584	79,302	1,088,282	15,947	1,104,228
2016-17	1,235,358	81,044	1,154,314	8,977	1,163,290
2017-18	1,303,455	82,148	1,221,307	11,198	1,232,505
2018-19(P)	1,371,779	85,802	1,285,977	10,258	1,296,235
Growth rate of 2018-19 over 2017-18(%)	**5.24**	**4.45**	**5.30**	**-8.40**	**5.17**
CAGR 2009-10 to 2018-19 (%)	**5.54**	**5.40**	**5.55**	**-3.33**	**5.44**

Source: Central Electricity Authority

3.6 Consumption of Energy Resources

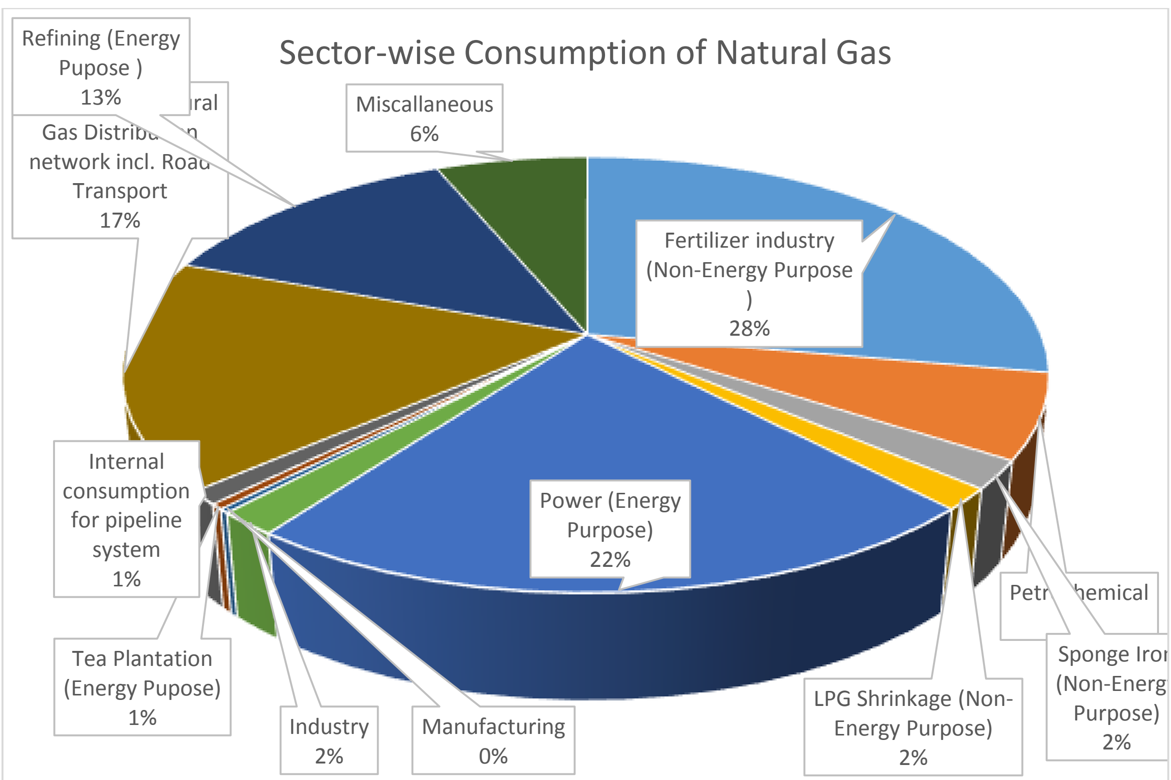
Figure 3.9: Consumption of Natural Gas

Figure 3.9 reported the consumption of natural gas both for non-energy purpose and energy purpose in India. It is observe that the consumption natural gas for energy purpose is reduces over the period. Similarly the consumption of natural gas for non-energy purpose increases but after 2015 it started declining.



Source: Energy statistics India

Figure 3.10: Sector-wise Percentage Consumption of Natural Gas during 2018-19

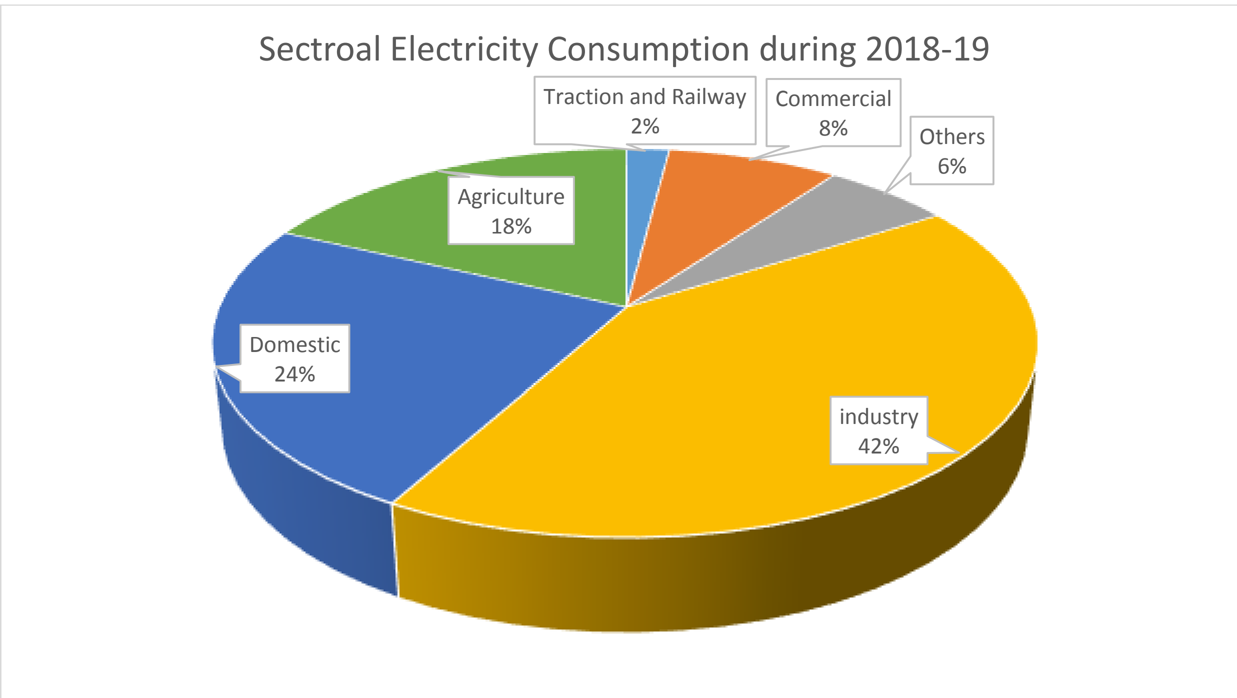


Source: Energy statistics India

Figure 3.10 shows the sector-wise consumption of natural gas in India. It is observe that fertilizer sector uses highest natural gas (28%) followed by power sector (22%), transport (17%) and refining sector (13%) respectively.

Figure 3.11: Sectoral Electricity Consumption during 2018-19

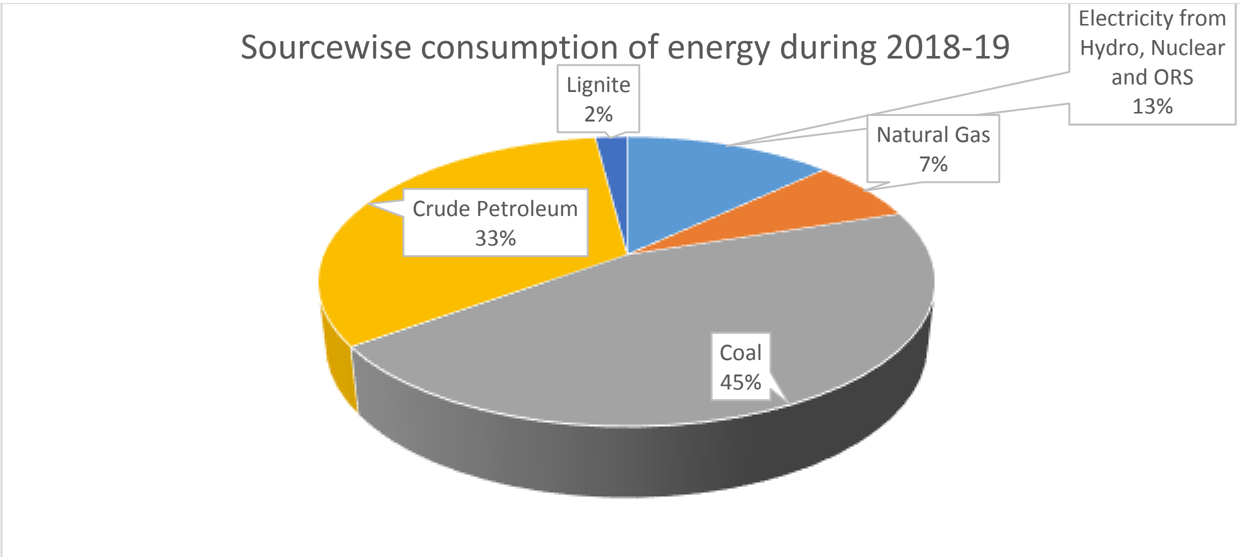
Figure 3.11 indicates consumption of electricity in sector wise in India during 2018-19. Industry uses highest percentage of electricity (42%) followed by domestic (24%), Agriculture (18%) receptively.



Source: Energy statistics India

Figure 3.12: Source-wise Consumption of Energy during 2018-19

Figure 3.12 shows the source wise consumption of energy during 2018-19 in India. The consumption coal energy is highest (45%) followed by crude petroleum (33%), Hydro nuclear (13%), natural gas (7%) respectively.



Source: Energy statistics India

3.6.1 Consumption of Coal and Lignite

Table 3.11 shows the total consumption of raw coal has increased from 587.81 MTs during 2009-10 to 968.25 MTs during 2018-19. The table also reveals consumption of raw coal annual growth 7.76% during 2018-19 over 2017-18. The crude oil consumption rose from 186.55 MMT during 2009-10 to 257.20 MMT during 2018-19. The crude oil consumption increased from 251.93 MMT in 2017-18 to 257.20 MMT in 2018-19, with a growth rate of 2.09%. Similarly, lignite consumption increased from 34.41 MT in 2009-10 to 45.81 MT in 2018-19, with a growth rate of 2.90%.

Table 3.11: Utilization of Conventional Energy Sources in India

Periods	Coal #	Lignite	Crude Oil	Natural Gas (Billion Cubic Metres)	Electricity (GWh)
	(Million Tons)		(MMT)		
1	2	3	4	5	6
2005-06	407.04	30.23	130.11	31.33	411,887
2006-07	430.83	31.29	146.55	30.79	455,748
2007-08	457.08	33.98	156.10	31.48	510,899
2008-09	492.76	32.42	160.77	31.75	562,888
2009-10	587.81	34.41	186.55	46.52	620,251
2010-11	532.69	37.73	196.99	51.25	684,324
2011-12	535.88	41.88	204.12	46.48	755,847
2012-13	567.60	46.31	219.21	39.78	912,057

2013-14	571.89	43.90	222.50	34.64	967,150
2014-15	821.85	46.94	223.24	46.95	9,48.521.67
2015-16	832.46	42.52	232.37	47.85	10,01,190.93
2016-17	837.22	43.16	245.36	55.70	1,061,182.64
2017-18	898.52	46.32	251.93	59.17	1,123,462.86
2018-19	968.25	45.81	257.20	60.75	1,158,310.06
The growth rate of 2018-19 over 2017-	**7.76**	**-1.09**	**2.09**	**2.67**	**3.11**
CAGR 2009-10 to 2018-19 (%)	**5.12**	**2.90**	**3.26**	**0.22**	**6.58**

Source: Ministry of Coal
Ministry of Petroleum & Natural Gas.
Central Electricity Authority.

Table 3.12 reports the consumption of conventional energy in India. The consumption of traditional energy during the year 2013-14 was 24, 071 Peta Joules compared to 23907 peta Joules during 2012-13, registering a growth of 0.70%.

Table 3.12: Utilization of Conventional Energy in India (Peta Joules)

Periods	**Coal & Lignite**	**Crude Petroleum ****	**Natural Gas**	**Electricity ***	**Total**
1	**2**	**3**	**4**	**5**	**6= 2 to 5**
2005-06	7,009	5,448	1,207	1,483	15,146
2006-07	7,459	6,136	1,186	1,641	16,421
2007-08	7,926	6,536	1,213	1,839	17,514
2008-09	8,476	6,732	1,223	2,026	18,457
2009-10	9,137	8,071	1,792	2,233	21,233
2010-11	9,207	8,248	1,974	2,464	21,892
2011-12	9,325	8,547	1,790	2,721	22,383
2012-13	9,909	9,178	1,532	3,283	23,903
2013-14	9,939	9,316	1,334	3,482	24,071
The growth rate of 2013-14 over 2012-	**0.31**	**1.50**	**-12.93**	**6.04**	**0.70**
CAGR 2005-06 to 2013-14(%)	**3.96**	**6.14**	**1.12**	**9.95**	**5.28**

Sources: Ministry of Coal
Ministry of Petroleum & Natural Gas and Central Electricity Authority

Table 3.13 reports per capita energy consumption and energy intensity in India. Per capita energy consumption and energy intensity from 2018-19 were 24453 Mega Joules and 0.2321Mega Joules. The growth rates were 3.63 and -1. 34 respectively.

Table 3.13: Per-capita Energy Consumption (PEC) and Energy Intensity in India

Year	Energy Consumption (in Peta Joules)	Population # (in Million)	GDP # (Rs. Crore) (2004-05 prices)	Per Capita Energy Consumption (in Mega Joules)	Energy Intensity (Mega Joules per rupee)
2005-06	15146	1106	3253073	13694.83	0.4656
2006-07	16421	1122	3564364	14635.85	0.4607
2007-08	17514	1138	3896636	15389.79	0.4495
2008-09	18457	1154	4158676	15994.06	0.4438
2009-10	21233	1170	4516071	18147.99	0.4702
2010-11	21892	1186	4918533	18458.90	0.4451
2011-12	22383	1202	5247530	18621.62	0.4265
2012-13	23903	1217	5482111	19640.72	0.4360
2013-14	24071	1233	5741791	19522.15	0.4192
2014-15	27589	1267	9727490	21775	0.2836
2015-16	28258	1282	10427191	22042	0.2710
2016-17	29397	1299	12,308,193	22630	0.2388
2017-18	30993	1314	13,175,160	23587	0.2352
2018-19	32450	1327	13,981,426	24453	0.2321
The growth rate of 2018-19 over 2017-18(%)	**4.70**	**0.99**	**6.12**	**3.67**	**-1.34**
CAGR 2011-12 to 2018-19(%)	**3.25**	**0.93**	**5.27**	**2.30**	**-1.92**

Source: Ministry of Petroleum

Table 3.14 presents industry-wise consumption of lignite in India. The total consumption of lignite during the year 2018-19 was 45.81 MT compared to 46.32 MT during 2017-18. The growth rate is -1.10.

Table 3.14: Industry-wise Consumption of Lignite in India (in Million Tones)

Year	Electricity	Steel & Washery	Cement	Paper	Textile	Others	Total
1	**2**	**3**	**4**	**5**	**6**	**7**	**8=2 to 7**
2005-06	23.36	-	0.79	0.23	1.11	4.86	30.34
2006-07	23.92	-	0.77	0.22	0.84	5.06	30.80
2007-08	26.76	-	0.96	0.35	0.77	5.83	34.66
2008-09	25.71	-	0.34	0.36	-	6.01	32.42
2009-10	28.14	-	0.38	0.82	-	4.09	33.43
2010-11	29.90	-	0.36	0.84	1.18	6.25	38.53
2011-12	32.06	0.03	1.01	0.63	3.67	4.47	41.88
2012-13	37.20	0.05	1.10	0.69	3.47	3.81	46.31
2013-14	36.48	0.03	1.40	0.66	2.83	2.51	43.90
2014-15	39.47	0.02	1.27	0.65	2.89	2.65	46.95
2015-16	37.81	0.00	0.25	0.44	1.73	1.99	42.21
2016-17	38.82	0.04	0.29	0.53	1.29	2.19	43.16
2017-18	38.84	0.12	1.09	0.76	2.46	3.05	46.32
2018-19	37.67	0.09	1.50	0.60	2.56	3.39	45.81
The growth rate of 2018-19 over 2017-	**-3.01**	**-21.67**	**37.31**	**-20.45**	**4.11**	**11.04**	**-1.10**
CAGR 2009-10to 2018-19(%)	**2.96**		**-14.70**	**-3.00**		**-1.86**	**3.20**

Source: Office of the Coal Controller, Ministry of Coal

Table 3.15 shows the consumption of petroleum products in India. The total consumption of petroleum products during 2015-16 was 184.67 MT compared to 165.53 MT during 2014-15. The growth rate was 16.56%.

Table 3.15: Consumption of Petroleum Products in India (in Million Tones)

Year	Light Distillates			Middle Distillates			
	LPG	Petrol	Naphtha	Kerosene	ATF	HSDO	LDO
1	2	3	4	5	6	7	8
2005-06	10.46	8.65	12.19	9.54	3.30	40.19	0.88
2006-07	10.85	9.29	13.89	9.51	3.98	42.90	0.72
2007-08	12.17	10.33	13.29	9.37	4.54	47.67	0.67
2008-09	12.34	11.26	13.91	9.30	4.42	51.71	0.55
2009-10	13.14	12.82	10.13	9.30	4.63	56.24	0.46
2010-11	14.33	14.19	10.68	8.93	5.08	60.07	0.46
2011-12	15.35	14.99	11.22	8.23	5.54	64.75	0.42
2012-13	15.60	15.74	12.29	7.50	5.27	69.08	0.40
2013-14	16.34	17.13	11.45	7.17	5.51	68.37	0.39
2014-15	18.00	19.08	11.08	7.09	5.72	69.42	0.37
2015-16	19.62	21.85	13.27	6.83	6.26	74.65	0.41
2016-17	21.60	23.76	13.24	5.40	7.00	76.03	0.45
2017-18	23.34	26.17	12.89	3.85	7.63	81.07	0.52
2018-19	24.91	28.28	14.13	3.46	8.30	83.53	0.60
The growth rate of 2018-19 over 2017-18(%)	**6.70**	**8.06**	**9.64**	**-10.03**	**8.74**	**3.03**	**14.19**
CAGR 2009-10 to 2018-19 (%)	**6.61**	**8.24**	**3.38**	**-9.42**	**6.02**	**4.03**	**-2.72**

Source: Ministry of Petroleum

Table 3.16: Consumption of Petroleum Products in India (in Million Tones)

Year	Heavy Ends				Refinery Fuel	Others*	Total
	Fuel Oils	Lubricants	Bitumen	Petroleum Coke			
	9	10	11	12	13	14	15=2 to 14
2005-06	12.83	2.08	3.51	4.93	9.14	4.66	122.36
2006-07	12.62	1.90	3.83	5.44	10.92	5.83	131.67
2007-08	12.72	2.29	4.51	5.95	11.75	5.45	140.70
2008-09	12.59	2.00	4.75	6.17	11.91	4.60	145.51
2009-10	11.63	2.54	4.93	6.59	14.58	5.40	152.39
2010-11	10.79	2.43	4.54	4.98	16.38	4.57	157.42
2011-12	9.31	2.63	4.64	6.14	17.29	4.92	165.43
2012-13	7.66	3.20	4.68	10.14	18.35	5.51	175.40
2013-14	6.19	2.89	4.94	11.65	17.87	6.18	176.06
2014-15	5.96	3.31	5.07	14.56	17.67	5.72	165.53
2015-16	6.63	3.57	5.94	19.30	18.77	6.18	184.67
The growth rate of 2015-16 over 2014-15(%)	**11.26**	**8.05**	**18.52**	**64.09**	**5.05**	**6.88**	**16.56**
CAGR 2005-06 to 2013-14(%)	**-6.23**	**6.51**	**4.47**	**13.50**	**5.57**	**0.58**	**4.34**

Source: Ministry of Petroleum

Table 3.17 reports the sector-wise consumption of petroleum products in India. The sector-wise consumption of petroleum products during 2013-14 was 68, 367 MT compared to 69, 081 MT during 2012-13. The growth rate was -1.03% during 2013-14 over 2012-13.

Table 3.17: Sector-wise Consumption of Selected Petroleum Products in India (Thousand Tones)

Petroleum Product	Year	Transport	Plantation	Power Generation	Industry	Misc. Services	Private Sales	Total
1	2	3	4	5	6	7	8	9=3 to 8
2005-06		4,264	431	498	964	30,151	3,884	40,192
2006-07		4,316	499	433	1,234	34,133	2,279	42,894
2007-08		5,003	504	313	1,241	40,577	31	47,669
2008-09		5,293	490	336	1,310	44,220	62	51,711
2009-10		5,365	594	303	1,502	48,385	94	56,243
2010-11		5,417	616	166	1,440	52,240	193	60,072
2011-12		5,529	684	168	1,649	56,651	70	64,751
2012-13		5,160	617	214	1,628	61,415	47	69,081
2013-14		3,203	429	204	873	63,577	81	68,367
The growth rate of 2013-14 over 2012-13(%)		**-37.93**	**-30.47**	**-4.67**	**-46.38**	**3.52**	**72.34**	**-1.03**
CAGR 2005-06 to 2013-14(%)		**-3.13**	**-0.05**	**-9.44**	**-1.10**	**8.64**	**-34.95**	**6.08**

Source: Ministry of Petroleum

3.6.2 Consumption of Electricity

Table 3.18: Consumption of Electricity by Sectors in India (in Giga Watt Hour) = (10^6 x KiloWatt hour)

Year	Industry	Agriculture	Domestic	Commercial	Traction & Railways	Others	Total Electricity Consumed
1	2	3	4	5	6	7	8=2 to 7
2005-06	151,557	90,292	100,090	35,965	9,944	24,039	411,887
2006-07	171,293	99,023	111,002	40,220	10,800	23,411	455,749
2007-08	189,424	104,182	120,918	46,685	11,108	29,660	501,977
2008-09	209,474	109,610	131,720	54,189	11,425	37,577	553,995
2009-10	236,752	120,209	146,080	60,600	12,408	36,595	612,645
2010-11	272,589	131,967	169,326	67,289	14,003	39,218	694,392
2011-12	352,291	140,960	171,104	65,381	14,206	41,252	785,194
2012-13	365,989	147,462	183,700	72,794	14,100	40,256	824,301
2013-14	386,872	159,144	198,246	76,968	15,182	46,180	882,592
2014-15	4,18,346	1,68,913	2,17,405	78,391	16,177	49,289	9,48,522
2015-16	4,23,523	1,73,185	2,38,876	86,037	16,594	62,976	10,01,191
2016-17	440,206	191,151	255,826	89,825	15,683	68,493	1,061,183
2017-18	468,613	199,247	273,545	93,755	17,433	70,834	1,123,427
2018-19	484,843	207,791	280,454	97,251	16,823	71,149	1,158,310
The growth rate of 2018-19 over 2014-15(%)	**3.46**	**4.29**	**2.53**	**3.73**	**-3.50**	**0.44**	**3.11**
CAGR 2009-10 to 2018-19(%)	**7.43**	**5.63**	**6.74**	**4.84**	**3.09**	**6.87**	**6.58**

Source: Central Electricity Authority.

Table 3.18 reports that electricity consumption increased from 6, 12, 645 GWh during 2009-10 to 11, 58, 310 GWh during 2018-19. It is observed that there is an 11% increase in electricity consumption during 2018-19 over 2017-18.

3.7 Concluding Remarks

India's energy security depends upon the continuous availability of commercial energy sources to sustain its economic growth. The Indian energy sector faces formidable challenges in meeting its energy requirements and supplying an adequate and diverse energy source to consumers sustainably. Reducing the energy intensity of GDP growth following energy efficiency is vital for fulfilling India's energy requirements and enabling its energy security. In this context, energy planning through demand-side management is one of the most viable, feasible, and cost-effective options for our country.

The change due to technology has helped reduce the intensity of both the fuels, i.e., coal and petrol; however, sadly, in the case of electricity, the story is not good. This is primarily because electricity is provided to many sectors, especially agriculture, at a subsidized rate that efficiently prevents usage.

The biggest impediments are a lack of knowledge, know-how, technical skills, and high transaction costs. By adopting new technology, organizational alterations are required to diversify the Indian energy sector by improving energy efficiency. In a diverse country like India, the difference in cost-effectiveness of energy supply and demand is also a hurdle. The lack of information about energy efficiency among small energy users increases their awareness of risk, so different energy users and dealers anticipate unlike rates of profit on investments.

CHAPTER 4

Role and Impact of Renewable and Non-Renewable Energy Consumption on Economic Growth in Developed and Developing Countries

4.1. Introduction

In the last few decades, global warming and climate change have extensively received attention worldwide. At the same time, the developing countries are on the path of the energy revolution to ensure high economic growth. The conventional theories postulate that rapid economic growth requires a heavy amount of energy consumption, which roots higher levels of emission of these, in turn, worsens the environmental pollution and impedes the sustainability of the environment. In this context, researchers and policymakers emphasized how we can relive the dangerous effects of climate change. According to the International Energy Agency (IEA, 2011) Carbon Dioxide (CO_2) was the leading gas compared to other pollutants at the global level in 2010. Over the decades there was wide-reaching and alarming increase in the hazard of global warming, energy crisis, and climate change. This issue becomes a dominant question both economically and politically. The 1997 Kyoto Protocol had the goal of minimizing the greenhouse gases to 5.2% lesser than 1990 during the period 2008-2012. “The Intergovernmental Panel on Climate Change (IPCC, 2007)” estimated 1.1 to 6.4c rises in global heat and an increase in sea level of about 16.5 to 53.8cm by 2100. It will have a tremendous harmful effect on 50% of the world’s populations residing in coastline areas.

In 2002 the Johannesburg summit on sustainable development mentioned the negative effect of energy on the environment irrespective of its key importance as an engine of economic growth. Regardless of the adverse impact of energy use on climate change, still, it is important for production and economic growth. In the past three decades, the relationship between energy consumption and economic growth has been extensively studied. However, this relationship is subject to change because of alterations in the economic organization particularly in energy policy and the government’s involvement in economic activities (Altinay and Karagol, 2004; Lee and Change, in Press). Earlier research on the causal relationship between energy consumption and economic growth is to a certain extent inconsistent at present. Particularly, in the context of developing nations, there are dissimilar results for altered data span for the same country. It is worth noting that the contradictory findings are the product of different experimental models applied for the same country. The main reason for revising energy is that energy plays a crucial role in the recent consideration of the energy-led growth hypothesis. It is observed that economic growth is highly related to energy use as increasing energy consumption leads to a higher level of economic growth. The literature on the linkage between energy consumption and economic growth is still standing in the debate that whether energy can be considered as the input for the production process. The neo-classical school opines that energy has a minimal role in the production process. On the contrary, the ecological economist argues that energy is an important factor in the production function. Hence, there is no consensus on the energy and economic growth nexus, both theoretically as well as empirically.

With finite resources and infinite needs, it is essential to realize the significant linkage between energy use and the environment. The demand for energy consumption at the global level is rising due to the rapid growth of population and faster economic progress in developing countries as their standard of living becomes more energy concerned and consumption-oriented. Accordingly, the questions arise how to fulfill the rising demand for energy in a viable manner. The international community has recognized this for decades but has so far been incapable of affording any significant solutions. Nevertheless, fossil fuels are limited resources, while large supplies do still exist; rushing demand will certainly exhaust their finite supply. More realistically, the effects of energy use and economic growth actions on environmental deprivation and climate change will spur both governments and the international community to act before the supply of fossil fuels is bushed.

If we look at history, two major energy crises were faced by the world's energy market, which unquestionably affected the economic scenario of nearly all the nations and captivated these nations towards recession and instigated to opt for energy-saving methods. Nevertheless, a modification in energy strategy results in a substantial effect on the energy use behavior of the people and this takes fundamental change affected by the presence of energy consumption verge. In the recent past, several economic events took place, and that had a major effect on energy use and expenditure the world over. Some of the major events are; the first oil crisis initiated by the 1973 Arab oil Embargo, in 1978 Iranian revolution rose the oil prices and a higher price rise was seen throughout the late 1970s.

In recent times growing climate change due to carbon emission has become a global threat to all nations. All countries are using both renewable and non-renewable energy to meet their growing energy demands. As we know fossil fuel energy generates a heavy amount of carbon dioxide as a consequence of which it affects the global environment seriously. Particularly it is frequently seen that developing countries are industrialized in nature and growing their economic events and increasing production level. Hence, their demand for energy use has been enlarged in recent years. Therefore, the socioeconomic significance of energy demand has made the recent debate among researchers and development experts. This proposes that developing countries essentially need to be careful about the competent use of energy and the use of different sources of energy (i.e. renewable and non-renewable). Or else, these countries will face bigger challenges from growing CO_2 emissions linked to increased energy consumption.

Based on the above viewpoints, particularly, developing and industrial nations are facing several challenges and consequences. For instance, developing nations are repeatedly facing changing structures of climatic conditions i.e. growing ocean levels, droughts, severe cyclones, tidal waves, etc. which are mainly caused by rising carbon emissions. Therefore, it leads to global warming at global and local altitudes. Now the developing nations understood that the quality of the environment is degraded due to the rise in carbon emission, global warming, and changing climatic conditions. Degradation of the environmental quality not only hampers the life of human beings but also slows down the feasibility of sustainable development. Appealing these tasks, it is noteworthy to claim that changing climatic conditions has become a burning and severe environmental problem in the field of energy and ecological economics. According to the "Intergovernmental Panel on the Climate Change (IPCC, 2006)" carbon emission is considered as one of the impending determinates in growing GHG in the universe. It is estimated that around 76.7% of the total carbon emissions add to GHG emissions. Deforestation, consumption of fossil fuels, and other alternative sources denote 17.3%, 56.6%, and 2.8% correspondingly. This indicates carbon emissions are highly accountable for 76% of the GHG effect. Hence, the rising per capita carbon emission is included as an alternative for determining environmental pollutants, increasing carbon emission creates a key element of changing climatic conditions and global warming and this indicates a severe apprehension at the global level in the current periods. (Hohz-Eakm and Seldon, 1995; Ozturk and Acarpvci, 1995; Kijima et al., 2010; Behera, 2015; Raza et al., 2015; Behera, 2015; Behera, 2016; Behera, 2017) on account of the detrimental effects of changing climatic and global warming, policymakers in developing nations have become progressively interested in decreasing the adverse effect of environmental deprivation on the economy by proposing suitable policy tools such as environmental taxation and increased use of renewable energy.

In light of the increased focus on emission reduction and climate change, it is projected that renewable energy sources will have vital importance in the generation of world energy requirements. According to the United Nations environmental program renewable energy apart from large hydroelectric projects, pretended 53.6 percent of the total gig watt capacity of all energy technologies installed in 2015 (UNEP, 2015). Essentially, renewable energy technologies are becoming much more extensive in both developed and developing countries as they become readily available, reasonable, and more reliable (IEA, 2015b). In 2015, and for the first time, developing economies devoted more money to renewables than developed economies (UNEP, 2015).

International Energy Agency (2007) estimated an average annual growth rate of renewable energy is 6.7% over the period 2005-2030. This indicates the importance of renewable energy consumption to meet future energy requirements. It is observed that very little work has been done on the linkage between renewable energy and income mostly in the context of developing nations. Because developing nations are experiencing rising energy demand and carbon emissions.

With the rising concern over the environmental consequences of Green House Gas emissions from high and volatile energy sources, the geopolitical climate surroundings, fossil fuel production, and renewable energy sources have appeared as a vital component in the world energy consumption mix. According to (International Energy Outlook, 2010), renewable energy is anticipated to be the fastest-growing world energy source. Especially, world renewable energy consumption for electricity generation will rise by an average of 3% per year and renewable energy consumption will increase by 2.6% per year over the period 2007 to 2035. As a consequence, the renewable segment of world electricity generation will upsurge from 18% in 2007 to 32% in 2035. Wind energy and hydroelectricity are expected to have the largest share of total renewable electricity generation of 54% and 36% correspondingly.

Given the role of renewable energy in the debate of a sustainable energy future, it is necessary to realize the relationship between economic growth and renewable energy consumption. In this perspective, the studies on economic growth and energy consumption have been widely studied (Chien and Hu, 2008; Ozturk, 2010; Apergis, et al. 2010; Payne, 2010a, b; Menyab and Wolde-Rafael, 2010; Menegaki, 2011). The relationship between renewable energy consumption and economic growth has only been recently studied. Unlike preceding studies in this area, this study takes the simultaneous use of renewable and non-renewable energy use to distinguish the relative effect of each in the growth process. Another motive, which induces researchers to emphasize this linkage between energy use and economic growth, is the idea of sustainable development. The most important thing is that many countries agreeing on preserving energy and decreasing carbon emissions has augmented the appeal of energy consumption-related studies. On the other hand, the key dynamics of these studies is the consumption of renewable sources. With the rising significance of sustainable development, academicians have become more concerned about the impact of renewable energy, which has originated to be seen as one of the most vital constitutes in the total energy consumption of the world.

International Energy Agency (IEA) and academic researchers have given importance to implementing less carbon, efficient energy techniques deprived of damaging developmental activities. Since, achieving sustainable development is the biggest task for policymakers, however, failing to achieve this objective causes undesirable consequences for the economic systems, for example, unsuitable climate, resources depletion, pollution, and global warming. Generally, CO_2 is most evident in the process where a large amount of energy is being used (Straelen, et al. 2010). Given the importance of renewable energy, our study looks to further examine the role of both renewable and non-renewable energy on economic growth for developed and developing nations with a panel framework.

In recent times, researchers started to include renewable energy under investigation. Unlike earlier empirical researchers, “Apergis and Payne (2010), Tugcu, Ozturk, and Aslan (2012)” include both renewable and non-renewable energy to examine the effects on economic growth. A wealth of studies reproducing the causal relationship between renewable energy consumption and economic growth has been shown for developed and developing nations. For instance, Lee (2005) examined 18 nations by employing a panel error correction model and Alariani (2006) investigated the causal linkage with a panel framework for 6 Gulf cooperation council nations. Stern (2000) employing the VAR econometric method shows a causality from energy use to income from 1948-1994, nevertheless, Thoma (2004) empirically supports Stern's (2000) ideas. Thus, it is observed that developed and developing nations show contradictory findings.

As mentioned, different studies found causality tests are built on country-specific and use the study period of about 20 to 30years. Yet, the findings are dissimilar for different nations besides the analysis period is different in the same nation and also provides different causality results. Therefore, our study pools the data that vary across specific nations. This analysis varies in comparison to earlier literature because we used the new heterogeneous panel co-integration method between energy consumption and economic growth across 18 developing nations.

Most of the developing nations are unable to find the causal linkage between the variables due to short period data span which pulls down the power of unit root results. Most of the nations used annual data set with maximum observations of around 20 to 30 years. Certainly, few studies employed long data spanning periods but these studies neglected the problem of a structural break. In our study, we have considered larger sample periods and applied the heterogeneous panel data techniques to examine the linkage between energy use and economic growth in the context of 18 developing nations.

The rest of the chapter is organized as follows. The theoretical background is explained in section 4.2. Data and period of the study is discussed in 4.3. Methodology is presented 4.4. Empirical resulted is analyzed in section 4.5 followed by concluding remarks and policy implications.

4.2. Theoretical Background

In any economy, both renewable and non-renewable energy consumption is highly connected to economic activity. Nevertheless, among the different sectors of the economy, the industrial sector leads economic events in developed countries, consuming the major portion of energy and producing a substantial amount of carbon dioxide emissions. Very few studies have examined the relationship between energy use and economic growth in developing countries. Nevertheless, their conclusions are rather varied and there is a lack of inferences among economists. Yet, no study so far has explored the link between renewable and non-renewable energy consumption in developed and developing countries. It is essential to identify the links between renewable and non-renewable energy consumption that are liable for the economic growth of developed and developing countries.

Current literature regarding economic growth shows that labor, capital, technology, and energy are the rudimentary elements of economic growth in developed countries. The analytical framework employed here is developed by Liao et al. (2010) and justified by Arbex and Perobelli (2010). Accordingly, this study extends the neo-classical Cobb-Douglas production function by including renewable and non-renewable energy consumption in addition to capital and energy price in estimating the long-run relationship between variables. Salim, et al. (2014) studied the dynamic relationship between renewable and non-renewable energy consumption and industrial output and GDP growth in OECD countries over the period 1980-2011. The empirical result reveals that there is a bidirectional short-run relationship between GDP growth and non-renewable energy consumption in the short and long run while unidirectional causality runs between GDP growth and renewable energy consumption. Although the mainstream neo-classical growth model does not include energy as a factor in the production function that could compel or enable economic growth. The recent literature gives importance to this for substitution of other inputs for energy particularly renewable energy because of high oil price and the fear of so-called 'peak oil.' So optimum adjustment of fuel mix has never been more essential than now, and the economic outcome of decisions regarding energy policy often pivots on substitution between energy sources and other factors of production. Henceforth, correctly estimating and examining the linkages between renewable and non-renewable energy consumption, as well as GDP growth can offer some information for the government as a foundation for setting up suitable policies related to environments like pollution and energy taxes.

To examine the linkage between energy consumption and economic growth for the full sample countries consisting of developed and developing countries the study used the Cobb-Douglas production function as follows.

$$Y_t = A\, E_t^{\alpha}\, EP_t^{\beta} k_t^{\gamma}\, LF_t^{\delta}\, URB_t^{\rho} {CO_2}_t^{\tau} \qquad (1)$$

In this function Y_t is the gross domestic product, E consists of both renewable and non-renewable energy consumption (RE, NRE), EP is the energy price, K is capital, LF is the labor force, URB is the urbanization and CO_2 is the carbon emission correspondingly. According to Liao et al. (2010) and Arbex and Perobelli (2010) energy is categorized into two types, clean energy and non-clean. The production technique uses both resources as a source of energy. Consequently, the above function is adjusted as follows.

$$Y_t = A\, R_t^{\alpha 1}\, N_t^{\alpha 2} EP_t^{\beta} k_t^{\gamma}\, LF_t^{\delta}\, URB_t^{\rho}\, CO_{2t}^{\tau} \qquad (2)$$

The first right term A is called the technology parameter $\alpha 1,\ \alpha 2\ \beta, \gamma, \delta, \rho\ \tau$ are the production elasticities concerning energy consumption, energy price, capital, labor force, urbanization and carbon emission. Largely, the model demonstrates that the gross domestic product (GDP) is described by a set of economic factors such as; labor force, capital, energy price, urbanization which is directly related to the CO_2 emissions. (e.g. Stern, 2000, Ang, 2008; Sharma, 2010, Omri, 2013). If the amount of production elasticities related to the capital, energy consumption, labor force, energy price, urbanization, and CO2 emission equals 1 ($\alpha 1 + \alpha 2 + \beta + \gamma + \delta + \rho + \tau = 1$) the Cobb-Douglas production function gets constant returns to scale. The log liner production function is given by.

$$\begin{aligned} ln(Y_t) = ln(A) + \alpha 1 \ln(RE_t) + \alpha 2 \ln(NRE_t) + \beta \ln(EP_t) + \gamma \ln(k_t) + \delta \ln(LF_t) \\ + \rho \ln(URB_t) + \tau \ln(CO2_t) + \varepsilon_t \qquad (3) \end{aligned}$$

Since our study works with panel data, Eq. (3) can be re-written as follows;

$$\begin{aligned} ln(Y_{it}) = \alpha_{0i} + \alpha_{1i} \ln(RE_t) + \alpha_{1i} \ln(NRE_t) + \alpha_{2i} \ln(EP_t) + \alpha_{3i} \ln(k_t) + \alpha_{4i} \ln(LF_t) + \\ \alpha_{5i} ln\,(URB_t) + \acute{a}_{6i} \ln(CO2_t) + \varepsilon_{it} \qquad (4) \end{aligned}$$

Where the α subscript i=1, ….., 30 signifies the country and t=1, …., T denotes the period from 1990 to 2016. Eq. (4) will be used to estimates the link between energy consumption and economic growth in the full sample countries. The parameter α_{0i} captures the possibility of country-specific fixed effects and deviations from the long-run equilibrium relationship is measured by the estimated residuals ε_{it} (presumed to be independent and identically distributed with zero mean and constant variance). Eq. (3) assumes that energy price, energy consumption, capital, labor force, urbanization, and carbon emission are the driving forces of economic growth. Eq. (3) gives us the long-run elasticities by using the panel ARDL model.

4.3. Data and Period of the Study

To examine the objective the analysis used annual data spanning from 1990 to 2016 for 18 developing and 12 developed countries. The developing countries include South Africa, Poland, Turkey, Argentina, Chile, China, Mexico, Peru, Venezuela, Malaysia, The Philippines, Thailand, India, Pakistan, Sri Lanka, Indonesia, Nigeria, and Kenya. The developed countries consist of

Australia, the United Kingdom, Sweden, the United States, Belgium, Japan, Spain, Netherland, Canada, Switzerland, France, and Italy. The variables used in this analysis are GDP per capita (constant 2010 US dollars), CO2 emission (metric tons per capita) used as a proxy for carbon dioxide emissions, Fossil fuel energy consumption includes oil, natural gas products, coal, and petroleum (% of total) is a proxy for non-renewable energy use. The consumption of Renewable energy in billions of kWh hours includes net geothermal, solar, wind, and biomass energy. Total labor force, urban population (% of total) is an alternative for urbanization. Gross fixed capital formation (constant 2010 US dollars) was used as a substitute for capital stock. Since energy price data is not available for all countries, therefore, we have used consumer price (constant 2010US dollars) as a proxy for energy price. All these variables are used in natural logarithm forms for the analysis. All the data were sourced from World Development Indicators (WDI, 2013), International Energy Agency (IEA), 2014, World Economic Outlook (WEO, 2014), and Energy Information Administration (EIA).

4. 4. Methodology

4. 4. 1 Cross-section Dependency Tests

The current economic scenario of the world revealed that instability in any nation spread to the other countries over external trades and monetary and economic integration (Nazlioglu et al. 2011). Pesaran (2006) suggested that ignorance of cross-sectional dependency may create bias estimation outcomes, therefore, estimation of cross-sectional dependency plays an important role in a panel data methodology "(Boubtane et al.2013; Chang et al. 2013; Chu and Chang, 2012; Nazlioglu et al. 2011)".

"Following Boubtane et al. (2013), Chang et al. (2013), and Kar et al. (2011)" to estimate the cross-sectional dependence, the study employed three different methods. Breusch and Pagan (1980) developed the Lagrange Multiplier (LM) method to test the cross-sectional dependency. This method is based on the following panel data model.

$$lny_{it} = \alpha_i + \beta_i lne_{it} + \varepsilon_{it} \quad for\ i = 1, 2, \dots, N; t = 1, 2, \dots T \qquad (1)$$

Here, lny indicates per capita real GDP, i denotes cross-section dimension, t represents time dimension and α_i is the individual intercept and β_i is slope coefficients that are permissible to change through nations. The test statistics for Breusch and Pagan (1980) LM test is given by:

$$CD_{BP} = T \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \tilde{\rho}^2{}_{ij} \quad (2)$$

Where $\tilde{\rho}_{ij}$the calculated coefficient is derived from the individual OLS results. "Under the null hypothesis of no cross-sectional dependence with a fixed N and large T, CD_{BP} asymptotically follows a chi-squared distribution with N (N-1)/2 degrees of freedom (Boubtane et al. 2013; Chang et al., 2013; Pan et al., in press)."

As indicated by "Pesaran (2004) the CD_{BP} test that has a drawback when N is large, subsequently Pesaran (2004) suggests another Lagrange multiplier (CD_{LM}) statistics for cross-sectional dependence that does not suffer from this problem (Boubtane et al. 2013; Chang et al., 2013)." The CD_{LM} statistics are given as follows.

$$CD_{LM} = \sqrt{\frac{1}{N(N-1)}} \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} (T\tilde{\rho}^2{}_{ij-1}) \qquad (3)$$

Under the null hypothesis of no cross-sectional dependence with T→∞ and then N→∞, CD_{LM} asymptotically follows a normal distribution. Still, this test is likely to display substantial size distortions when N is large relative to T and due to this problem, Pesaran (2004) recommends a new test for cross-sectional dependence (CD) that can be used where N is large and T is small (Change et al., 2013; in press)". This test is shown by:

$$CD = \sqrt{\frac{2T}{N(N-1)}} \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \tilde{\rho}^2{}_{ij} \quad (4)$$

According to 'Pesaran (2004) under the null hypothesis of no cross-sectional dependence with T→∞ and then N→∞ in any order, CD asymptotically follows a normal distribution and is likely to have good small sample properties for both N and T small (Chang et al., 2013)".

4. 4. 2 Friedman's Test

Friedman (1937) suggested a nonparametric test based on Spearman's rank correlation coefficient. The coefficient can be thought of as the regular product-moment correlation coefficient, that is, in terms of the proportion of variability calculated for, except that Spearman's rank correlation coefficient is computed from ranks. In particular, if we define $\{r_i, 1, \ldots\ldots, \quad r_i,\ T\}$ to be the ranks of $\{u, 1, \ldots\ldots, \quad u_i,\ T\}$ [such that the average rank is (T+1/2)], Spearman's rank correlation coefficient equals.

$$r_{ij} = r_{ji} = \frac{\sum_{t=1}^{T}\{r_{i,t} - (T + 1/2)\}\{r_{j,t} - (T + 1/2)\}}{\sum_{t=1}^{T}\{r_{i,t} - (T + 1/2)\}^2}$$

Friedman's statistics are based on the average Spearman's correlation and is given by

$$R_{ave} = \frac{2}{N(N-1)} \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \hat{r}_{ij}$$

Here $\hat{r}_{ij}$ is the residual correlation coefficient. Greater values of R_{ave} shows the occurrence of nonzero cross-sectional correlations. "Friedman shows that $\mathrm{FR} = (\mathrm{T}-1)\{\{\mathrm{N}-1)R_{ave} + 1\}$ is asymptotically χ^2 distributed with T-1 degrees of freedom, for fixed T as N gets large. Originally Friedman devised the test statistic FR to determine the equality of treatment in a two-way analysis of variance."

4. 4. 3 Frees' Test

Frees (1995, 2004) "suggested a statistics that is not subject to this drawback[1]. In particular, the statistic is based on the sum of the squared rank correlation coefficients and equals"

$$R_{ave}^2 = \frac{2}{N(N-1)} \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \hat{r}_{ij}{}^2$$

As indicated by Frees, the meaning of this statistic shows a joint distribution of two individually drawn χ^2 variables. In specific, Frees "represent that

[1] The testing procedure proposed by Sarafidis, Yamagata, and Robertson (2006) is not subject to this drawback either.

$$FRE = N\{R_{ave}^2 - (T-1)^{-1}\} \xrightarrow{d} Q = a\,(T)\left\{x_{1,T-1}^2 - (T-1)\right\} +$$

$$b\,(T)\left\{x_{2,T(T-3)/2}^2 - T(T-3)/2\right\}$$

Where $x_{1,T-1}^2$ and $x_{2,T(T-3)/2}^2$ are independently χ^2 random variables with $T-1$ and $T(T-3)/2$ degrees of freedom, respectively, $a\,(T) = 4\,(T+2)/\,\{5\,(T-1)^2\,(T+1)\}$ and$b\,(T) = 2\,(5T+6)/\,\{5T\,(T-1)\,(T+1)\}$. Thus the null hypothesis is rejected if $R_{ave}^2 > (T-1)^{-1} + Q_q/N$, where Q_q is the appropriate quantile of the Q distribution."

4 .4. 4 Pesaran's Cross-Sectional Augmented Dickey-Fuller (CADF) Test

After confirming cross-sectional dependency, to understand the stationary properties of the variables the study employed the Pesaran Cross-Sectional Augmented Dickey-Fuller (CADF) test (Pesaran, 2007). The presence of cross-sectional dependence can be solved by augmenting the standard Dickey-Fuller regression with cross-sectional averages of lagged levels and first differences of the individual series (Pesaran, 2007). The major benefit of employing this panel second-generation unit root test is its high power of exploring the cross-sectional dependence which induces strong interdependencies between the countries.

The Pesaran CADF equation follows:

$\Delta y_{i,t} = \alpha_i + \beta_i y_{i,t-1} + \gamma_i \bar{y}_{t-1} + \varphi_i \Delta\bar{y}_t + \varepsilon_{it}$ (8)

Where the unit root test hypothesis will be tested based on the OLS results derived from Eq. (8) with t-ratio by t_i (N, T).

The Pesaran CADF test is

CADF = $t_i\,(N,T) = \frac{\Delta y_i\,\bar{m}_w y_{i-1}}{\delta_j\left(y_{i,-1}'\bar{m}_w y_{i-1}\right)^{1/2}}$

Where $\Delta y_i = \left(\Delta y_{i,1}\,,\ \Delta y_{i,2},\ \ldots, \Delta y_{i,T}\right),'$ (9)

$\Delta y_{i,-1} = \left(y_{i,0,}\,y_{i,1,}\ .\ .\ .\ , y_{i,T-1,}\right),'\ \ \tau_T = (1, 1, .\ .\ .\ \ , 1),'$ (10)

$M_w = I_T - \overline{w}(\overline{w},\,\overline{w}\,\overline{w})^{-1}\ \overline{w},'\ \ \overline{w} = (\tau, \Delta\bar{y},\ \bar{y}_{T-1})'$ (11)

$\sigma_i^2 = \frac{\Delta y_i' m_{i,w}\,\Delta y_i}{T-4} m_{i,w} = I_T - \left(G_i\,(G_i{}'\,G_i)^{-1}\,G_i'\ and\ G_i = (\overline{w},\ y_{i-1}\right)$ (12)

4. 4. 5. Panel Autoregressive Distributed Lag Model (P-ARDL)

To examine the long-run relationship between the variables, we have employed a panel autoregressive distributed lag model based on three different estimators such as Mean Group estimator (MG), Pooled Mean Group (PMG), and Dynamic Fixed Effect (DFE). According to Pesaran, Shin, and Smith (1999), an ARDL dynamic heterogeneous panel regression can be written by using the ARDL (p, q) approach where 'p' is the lags of the dependent variable and 'q' is the lags of independent variables. The period t=1, 2, ..., 15 and groups i=1, 2, …., 7, the panel model can be written as follows.

$$y_{it} = \sum_{j=1}^{p} \lambda_{ij}\, y_{i,t-j} + \sum_{j=0}^{q} \delta'_{ij}\, X_{i,t-j} + \mu_i + \epsilon_{it} \qquad (13)$$

Where y is the GDP_{it} dependent variable, X_{it} is the $k \times 1$ vector of explanatory variables for group I (including, re, nre, ep, k, lf and Co_2), N_i denotes the group-specific effects, δ_{it} are the $k \times 1$ coefficient vectors; λ_{ij} are scalar coefficients of the lagged dependent variables.

If the variables in Eq. (9) are, I (1) and co-integrated, formerly the error term is I (0) process for all i. A principal feature of co-integrated variables is their responsiveness to any deviation from long-run equilibrium. This feature implies an error correction model in which short-run dynamics of the variables in the system are influenced by the deviation from equilibrium. Thus it is common to parameterize Eq. (9) into an error correction equation.

$$\Delta y_{it} = \emptyset_i\left(y_{i,t-1} - \theta'_i X_{it}\right) + \sum_{j=1}^{p-1} \lambda^{*}_{ij}\, y_{i,t-1} + \sum_{j=0}^{q-1} \ddot{a}'^{*}_{ij}\, \Delta X_{i,t-j} + \mu_i + \epsilon_{it} \qquad (14)$$

Where $\emptyset_i = -\left(1 - \sum_{j=1}^{p} \lambda_{ij}\right)$, $\theta_i = \sum_{j=0}^{q} \delta_{ij} / (1 - \sum_k \lambda_{ik})$, $\lambda^{*}_{ij} = -\sum_{m=j+1}^{p} \lambda_{im}$ j= 1, 2, …, p-1, and $\delta^{*}_{ij} = -\sum_{m=j+1}^{q} \delta_{im}$ j= 1, 2, …., q-1.

The parameter $\emptyset_i$ is the error-correcting speed of adjustment term. If $\emptyset_i = 0$, then there will be no evidence for a long-run relationship. This parameter is likely to be significantly negative under the prior assumption that the variables show a return to long-run equilibrium. Of particular importance is the vector θ'_i, which contains the long-run relationship between the variables. But more recently, Pesaran, Shin, and Smith (1997, 1999) propose a PMG estimator which combines both average and pooling the residuals. This test incorporates the intercept, short-run coefficients, and different error variances across the groups (like MG estimators). However, it holds the long-run coefficients to be equal across the groups (Like FE estimators).

The MG estimate of the error correction coefficients, $\emptyset_i$, is

$$\widehat{\emptyset} = N^{-1} \sum_{i=1}^{N} \widehat{\emptyset}_i \tag{15}$$

With the variance

$$\hat{\Delta}_{\widehat{\emptyset}} = \frac{1}{N(N-1)} \sum_{i=1}^{N} \left(\widehat{\emptyset}_i - \widehat{\emptyset}\right)^2 \tag{16}$$

The Eq. (10) could be calculated by three altered estimators namely mean group estimator of “Pesaran and Smith (1995), Pooled Mean Group estimator developed by Pesaran, Shin and Smith (1999) and Dynamic Fixed Effect Estimators (DFE).” According to “Pesaran and Shin (1999), panel ARDL can be applied even if the variables follow the different order of integration i.e. I (0) and I (1) or a mixture of both.”

4. 5. Empirical Results

Table 4.1 Descriptive Statistics

	Lnco2	lngdp	lngfcf	lnnre	Lnre
Mean	1.338	9.186	25.386	4.199	3.241
Median	1.688	9.176	25.365	4.365	3.511
Maximum	3.006	11.235	29.117	4.605	8.660
Minimum	-1.610	6.284	21.380	2.561	-2.364
Std. Dev.	1.109	1.391	1.486	0.435	2.432
Skewness	-0.774	-0.317	0.029	-1.939	-0.132
Kurtosis	2.680	1.809	2.998	6.195	2.709
Jarque-Bera	84.375	61.438	0.117	852.445	5.237
Probability	0.000	0.000	0.943	0.000	0.072

The descriptive statistics are reported in table 4.1. It is shown that all the variables except gross fixed capital formation are negatively skewed. Again the result indicates the kurtosis coefficients are higher for non-renewable energy, renewable energy, gross fixed capital formation, and carbon emission. The findings of JB test suggested that the normality problem can be rejected at any conventional level.

The traditional panel unit root tests do not consider the presence of cross-sectional dependence which might give an improper explanation towards the stationary properties of large panel data. To avoid this problem, the present study has employed three alternative cross-sectional dependence tests knows as Pesaran, Free's, and Friedman's cross-sectional dependence tests to check the cross-sectional independence in the developed and developing countries. The result of the cross-sectional dependence test reported in Table 4.2 shows that we reject the null hypothesis of no cross-sectional dependency at 1% level of significance among the variables in all the three alternative tests. It means there is high dependence in all the countries.

Table 4.2 Cross-Sectional Dependence Tests

CD Tests	Fixed Effect Estimation		Random Effect Estimation	
	Statistics	Prob.	Statistics	Prob.
Pesaran's Test	5.240	0.000	5.333	0.000
Free's Test	10.631	Alpha=0.10=0.095 Alpha=0.05=0.124 Alpha=0.01=0.179	10.716	Alpha=0.10=0.095 Alpha=0.05=0.124 Alpha=0.01=0.179
Friedman's Test	50.202	0.000	51.145	0.000

From the above cross-sectional dependence test we observe that there is cross-sectional dependence among the variables. Now we have used the panel second-generation unit root test i.e. Pesaran Cross-Sectional Augmented Dickey-Fuller (PCADF) panel unit root test to check stationary properties of the variables. The PCADF result reported in Table 4.3 shows that the variables attain the stationarity at a different order of integrations i.e. I (0) and I (1). In other words, most of the variables become stationary after the first difference and at the same time, some variables like non-renewable energy and gross fixed capital formation variables attain stationarity in the level.

The Table 4.3 shows the Pesaran cross-sectional Augmented Dickey-Fuller panel unit root test which indicates that all the variables become stationary at different orders i.e. I (0) and I (1). Like the time series analysis when the variables have a different order of integration to check the long-run relationship among the variables, we applied the Autoregressive distributed lag model. According to Pesaran and Shin (1999), panel ARDL can be applied even if the variables follow the different order of integration i.e. I (0) and I (1) or a mixture of both. Here, in this study to check the long-run and short-run dynamics among the variables we have employed three different panel autoregressive distributed lag models. Such as Pooled Mean Group (PMG) estimator, mean Group (MG) estimator, and Dynamic Fixed Effect Model (DFE).

Table 4.3 Pesaran's Cross-Sectional Augmented Dickey-Fuller (CADF) Test Result

	Constant		constant & trend	
Variable	T-bar	p-value	T-bar	p-value
lngdp	-1.917	0.175	-1.858	0.996
lnco2	-0.708	1.000	-2.125	0.861
lnnre	-0.976	1.000	-2.740	0.006***
lnre	-1.958	0.122	-2.124	0.964
lngfcf	-2.192	0.007***	-2.352	0.403
Δlngdp	-2.788	0.000***	-3.203	0.000***
Δlnco2	-3.314	0.000***	-3.409	0.000***
Δlnnre	-3.467	0.000***	-3.489	0.000***
Δlnre	-3.210	0.000***	-3.757	0.000***
Δlngfcf	-3.308	0.000***	-3.365	0.000***

Note: The critical values are -2.34, -2.17 and 2.07 at 1%, 5% and 10% respectively with constant -2.88, -2.69 and -2.59 at 1%, 5% and 10% respectively with constant and trend. The ***, **, and * indicates 1%, 5% and 10% level of significance.

Table 4.4 Panel ARDL Model Results (Pooled Mean Group, Mean group, and Dynamic Fixed Effect Estimators)

Dep.	Pooled Mean Group			Mean Group			Dynamic Fixed Effect		
Var. d.lngdp	Coeff.	Z-stat.	P-value	Coeff.	Z-stat.	P-value	Coeff.	Z-stat.	P-value
Long run									
Lnco2	-.15 (.03)	-4.32	0.00**	.27 (.31)	0.86	0.38	.13 (.12)	1.09	0.27
lnnre	.66 (.18)	3.64	0.00**	-.52 (.70)	-0.74	0.45	.75 (.37)	2.00	0.04*
lnre	.66 (.05)	11.80	0.00**	.25 (.10)	2.36	0.01*	-.01 (.03)	-0.46	0.64
lngfcf	.22 (.03)	6.42	0.00**	.15 (.13)	1.13	0.26	.47 (.05)	8.97	0.00**
Short run									
EC	-.03 (.01)	-2.18	0.03*	-.31 (.03)	-9.02	0.00**	-.04 (.00)	-5.69	0.00**
d1.lnco2	.03 (.09)	1.99	0.04*	.04 (.02)	1.56	0.12	.01 (.01)	1.38	0.16
d1.lnnre	-.06 (.04)	-1.22	0.22	-.09 (.07)	-1.25	0.21	-.00 (.03)	-0.27	0.78
d1.lnre	.04 (.02)	2.17	0.03*	.00 (.02)	0.12	0.90	.02 (.01)	2.58	0.01*
d.lngfcf	.21 (.01)	11.60	0.00**	.14 (.02)	6.88	0.00**	.19 (.00)	24.98	0.00**
Intercept	-.11 (0.08)	-1.40	0.16	.54 (.52)	1.03	0.30	-.29 (.08)	-3.38	0.00**

Note: **, * indicates significance level at 1% and 5%. ( ) parenthesis shows the standard errors. [ ] denotes the p-values of Hausman test. EC is error correction term.

The above Table 4.4 represents the Pooled Mean Group, Mean Group, and Dynamic Fixed Effect estimation results. According to Pesaran and Shin (1999) pooled mean group estimator restricts the long-run results to be equal to the cross-section but allows for the short-run coefficients and error variance to differ across groups on the cross-section. While Mean Group estimation is an unrestricted model compare to Pooled Mean Group in which short-run and long-run results may vary in each country. Table 4.4 shows the long-run and short-run coefficients between economic growth lngdp and other variables, and the speed of adjustment for all the three different estimation results. In the long run, as can be seen, the results show that carbon emission has a negative and statistically significant impact on economic growth in all the countries. Whereas, nonrenewable energy, renewable energy, and capital stock have a positive and statistically significant impact on economic growth in all the countries at 1 percent level of significance. Comparing the long-run results with the mean group and dynamic fixed effect results we found that capital stock, renewable and nonrenewable energy consumption has a positive and statistically significant impact on economic growth in all the countries.

The speed of adjustment reflected by the coefficient of convergence is negative and significant in all three estimators, indicating that there is no omitted variable bias. The short-run result indicates that carbon emission, capital stock, and renewable energy consumption show the short-run causality with economic growth. The short-run result of the mean group found causality from capital stock to economic growth and the result of the dynamic fixed effect model reveals that renewable energy and capital stock shows short-run causality with economic growth.

Table 4. 5 Hausman Test

Hausman Test	Statistics	Probability
PMG, MG	6.15	0.18
MG, DFE	0.00	1.00

To measure efficiency and consistency among the estimator (PMG, MG, and DFE) the Hausman test has been applied. The validity of long-run homogeneity restrictions across all countries, and hence the efficiency of PMG estimator over MG and DFE estimator, is examined by Hausman test. In table 4.5, we found that the Hausman test result accepts the null hypothesis of homogeneity restrictions on the long-run regression, which indicates that PMG is more efficient than MG and DFE.

4.6. Concluding Remarks and Policy Implications

This study validates the relevance of energy consumption including both the promotion of renewable and nonrenewable energy for the correction of GHG levels both for developed and developing countries. By using the latest development of panel econometric tools the empirical result of the study shows that there is a cross-sectional dependence among the variables. The result of the Pesaran Cross-sectional Augmented Dickey-Fuller (PCADF) panel second-generation unit root test suggests that all the variables attain stationarity at a different order of integration i.e. I (0) and I (1). In other words, except for nonrenewable energy and gross fixed capital formation, all other variables attained stationarity at first difference. Since the study found a different order of integration, the analysis employed panel ARDL to examine the long-run and short-run linkage. The panel ARDL model confirms that in the long run carbon emission has a negative and statistically significant impact on economic growth in all the countries. Whereas, nonrenewable energy, renewable, and capital stock have a positive and statistically significant impact on economic growth in all the countries at 1 percent level of significance.

The speed of adjustment reflected by the coefficient of convergence is negative and significant in all the three estimators (PMG, MG, and DFE), indicating that there is no omitted variable bias. The short-run result reveals that carbon emission, capital stock, and renewable energy consumption show the short-run causality with economic growth. The short-run result of the mean group found causality from capital stock to economic growth and the result of the dynamic fixed effect model found that renewable energy and capital stock show short-run causality with economic growth. The efficiency and consistency among the estimators (PMG, MG, and DFE) are measured by the Hausman test. The Hausman test result accepts the null hypothesis of homogeneity restrictions in the long-run regression, which indicates that PMG is more efficient than MG and DFE.

The empirical result of our study provides policymakers a better understanding of the nexus between energy consumption and economic growth to formulate energy policy in these countries. The important policy implications of this study suggest that all countries should use both renewable and non-renewable energy to achieve their targeted growth rate. At the same time the policymakers of these countries should give importance to reduce carbon emissions for the sustainability of the environment and give more importance to use renewable energy which will help to maintain energy security, energy efficiency and environmental sustainability for all these countries.

CHAPTER 5

Environmental Kuznets Curve for Carbon Emission in India

5.1 Introduction

India is one of the rapidly developing economies in the world. International Monetary Fund (IMF) accounts India is the 11th largest in terms of nominal GDP in the world and 3rd largest by purchasing parity (PPP). India's industrial and agriculture sector accounts for 28.6% and 14.6% of the country's GDP while the service sector contributes 57.2% respectively. Nevertheless, "there is widespread inequality as 42% of the Indian population survives under $1.25 a day (Planning Commission of India). To provide an acceptable standard of living and economic wellbeing India needs to grow more than 8% for the next couple of decades (Integrated Energy Policy, IEP document, Planning Commission, GOI).

Inadequate energy supply affects India's economic growth badly. However, India is considered the 5th largest consumer of energy in the international rankings. In the year 2009, India's per capita energy consumption is 650 koe (kg oil equivalent) which is far below the world average. International Energy policy estimated that India is expected to raise its major energy supply 3 to 4 times by 2031 to keep GDP growth eight percent. Because of the huge availability of coal reserves, India's 55 percent energy supply rests on coal energy. However, coal is considered an unclean fuel as consumption of coal emits a huge amount of carbon dioxide. At the international level, India is considered the 4th largest carbon emitter after the USA, China, and Russia. However, in terms of per capita CO_2 emission India is significantly below the world average. Therefore, the Indian economy is facing the challenges between economic progress and environmental security like other developing nations.

At the early stage of economic growth, the EKC hypothesis indicates a direct linkage between environmental pollution and economic growth but the level of pollution declines after reaching a certain level of economic growth. Therefore, the Environmental Kuznets Curve hypothesis shows an inverted U-shaped linkage between pollution and economic growth. The shape of the EKC curve is based on three effects such as composition effect, technical effect, and scale effect. At the beginning phase of industrialization, the level of pollution will be high due to heavy economic activity. This effect is considered a scale effect. When the level of economic activity rises, organizations adopt cleaner technology, as a consequence the pollution levels declines. This effect is known as a technological effect. When the organizations produce intensive goods in the production method the composition effects take place.

5.1.1 EKC Studies Specific to India

Literature by Khanna and Zilbermen (2001) and Bhattacharya & Ghoshal (2009) obtained the EKC hypothesis in their study; though Dietzenbacher and Mukhopadhyay (2007) Mukhopadhyay and Chakrobarty (2005) have denied the presence of EKC hypothesis. Managi & Jena (2007) empirically establish the presence of EKC in the case of India. Jayanthakumaran et al. (2012) empirically found that there is no linkage between CO2 emission and economic growth.

5.1.2 Theoretical Background

Most EKC studies suggested that in the early stage of economic growth the environmental quality declines and successively improves in the well along. The analysis also found that environmental pollution surges quicker than the increase in income in the initial stage of economic growth and reduces with the rise in income level.

Possible explanations for the EKC are seen in the following ways.

I. The transformation of economic activity from agrarian structure to polluting industrial stage to a progressive clean service economic structure.
II. Higher income of the inhabitants will increase the performance for environmental quality.

The presence of EKC in the literature has been questioned on various grounds. Some of them are quality parameters namely local pollutants, which indicate the presence of the Environmental Kuznets Curve. Nevertheless, past literature could not predict the level of income in which the level of environmental pollution will decline.

The key motivation of this study is based on whether economic growth is a solution or problem of environmental pollution.

The initial study found an inverted U-shaped hypothesis in the NBER working paper by Grossman and Kruegar (1991). This hypothesis defined the ‘U’ curve as the Intensity Use Hypothesis. This states that the intensity of material use diminishes beyond a certain level of income.

Kuznets (1955) investigated the linkage between per capita income and income inequality. The study shows that in the initial stage both the variables show a positive direction but then it reaches the turning point where it starts declining. This linkage between the two variables is characterized in the form of a bell-shaped curve. This bell-shaped curve is known as the Kuznets curve. After the 1990's this Kuznets curve got a new insight into the EKC literature. This EKC defined the per capita income and environmental pollution follows the inverted U-shape. Later this "U" shaped relationship between environmental pollution and per capita income came to be known as Environmental Kuznets Curve. A set of studies like Grossman and Kruger (1991); Shafik and Bandyppadhyay (1992) Panayotou (1993) initially examined an inverted U-shaped relationship between per capita income and pollution. Panayotou (1993) created this relationship as the Environmental Kuznets Curve or EKC Hypothesis.

In the initial phase of economic growth, environmental problems, and awareness is low and insignificant. The development of environmental-friendly technologies is not available. As a consequence pollution level rises with increasing per capita income for a certain level beyond which the quality of the environment increases so as income. As economic progress takes place with the strength of sectoral development the waste generation limit increases. When the economy achieves a higher level of development, environmental awareness, better technology, environmental regulation, and the level of environmental expenditure rises. As a result of which the level of environmental pollution gradually diminishes and the quality of the environment is boosted.

This EKC hypothesis deals with a process of dynamic change. The analysis of EKC hypothesis is unambiguous about the time factor. The EKC studies have been examined empirically and various econometric tools have been employed for single and multi-countries as well. In this study, the EKC hypothesis was studied with yearly data from 1970-2016.

The EKC studies have been examined empirically and various econometric tools have been employed both for single and multiple nations. In this study, the EKC hypothesis examines the relationship between carbon emission, energy consumption, economic growth, population density, and trade liberalization with yearly data from 1971 to 2016.

The remainder of this chapter is prepared as follows: Review of literature described in the second section. Data and variables are given in the third section. Model selection is presented in the fourth section. Empirical results are explained in the fifth section and concluding remarks are discussed in the sixth section.

5.2 Review of Literature

Kanjilal & Ghosh (2013) examined the presence of EKC hypothesis in the context of India from 1971-2008. The variable of the study includes per capita energy use, carbon emission, GDP and trade openness. All the variables were collected from World Development Indicators. By employing the threshold co-integration approach the empirical result found that carbon emission is highly elastic concerning real per capita income and energy consumption in India. The study also suggests that there is a long-run relationship between the variables.

Jalil & Mahmud (2009) investigated the environmental Kuznets curve hypothesis between carbon emission and GDP growth in the context of China from 1975- 2005. The variables include energy consumption, carbon emission, foreign trade, and income for the analysis. By employing the Granger causality and autoregressive distributed lag model the empirical result shows the existence of the EKC hypothesis in the study period in the context of China. The findings also reveal that unidirectional causality runs from economic growth to carbon emission.

Ahmed and Long (2012) studied the presence of EKC hypothesis in the case of Pakistan throughout 1971-2008. The study used economic growth, CO_2 emission, energy consumption, and trade liberalization, and population density for the analysis. All the variables are sourced from WDI. The study used the ARDL and error correction econometric model. The empirical result suggests that the U-shaped relationship is found both in the short-run and long-run between carbon emission and economic growth. The findings reveal that energy consumption and economic growth cause environmental pollution in Pakistan. Furthermore, the result also indicates population density harms the environment whereas, the openness of trade supports improving the environment.

He and Richard (2010) investigated the Environmental Kuznets Curve hypothesis in the context of Pakistan for 1971-2009. The variables included in this study are per capita carbon emission, real GDP per capita, and squared of real GDP, energy use, and trade openness. Carbon emission and energy consumption data are obtained from World Development Indicators (WDI). The real GDP and trade openness data are cumulated from The Economic Survey of Pakistan (2008-09).

By using the ARDL cointegration and Granger causality test, the result shows that the long-run linkage among the variables and the study supports the presence of the EKC hypothesis in the context of Pakistan. The result also shows unidirectional causality from economic growth to carbon emissions. Rising energy consumption raises carbon emissions in the short-run as well as in the long-run. However, the openness of trade helps to decline carbon emissions in the long run.

Bekhet (2014) examined the existence of EKC and the causal linkage between energy consumption, carbon emission, and population in UAE and Saudi Arabia countries for the period 1975-2011. The variable includes CO_2 emission per capita in metric tons, real GDP per capita in constant 2005 US dollars, energy consumption per capita in kt of oil equivalent, and the total population. The study employed the ARDL econometric model. All variables are sourced from WDI. The empirical result found that EKC is not applied in both countries UAE and Saudi Arabia. The co-integration result confirms that there is a long-run linkage among the variables. The result also reveals unidirectional causality from GDP to CO_2 emission. Energy consumption increases CO_2 emission both in the short-run and long-run in Saudi Arabia but in the UAE case only in the long run.

Aslanidis and Iranzo (2009) re-addressed the linkage between per capita income and pollution in 77 Non-OECD developing nations spanning from 1971-1997. The analysis includes per capita carbon dioxide emission and national income. The methodology used by the study is Non-linear Least Square (NLS) and Panel Smooth Transition Regression (PSTR) model for the analysis. The empirical result shows the absence of EKC in the context of all these nations.

Table 5. 1 Summary of Review of Literature

Authors	**Country**	**Time Period**	**Methodology**	**EKC Hypothesis**
Ang (2008)	Malysia	1971-1999	VECM, GC	NO
Halicioglu (2009)	Turkey	1960-2005	ARDL, GC	YES
Iwata et al. (2010)	France	1960-2003	ARDL	YES

Fodha, and Zaghdcod (2010)	Tunisia	1961-2004	VECM, GC	YES
Saboori et al. (2011)	Malaysia	1980-2009	ARDL, VECM, GC	YES
Tiwari (2011)	India	1971-2007	VAR, GC	YES
Shahbaz et al. (2012)	Pakistan	1971-2009	ARDL, GC	YES
Kareem et al. (2012)	China	1971-2008	VECM, GC	NO
Shahbaz et al. (2013)	Romania	1980-2010	ARDL	YES
Tiwari et al. (2013)	India	1966-2011	ARDL, VECM, GC	YES
Jali & Mahmud (2009)	China	1975-2005	ARDL, GC	YES
Ahmed & Long (2012)	Pakistan	1971-2008	ARDL	YES
He & Richard (2010)	Canada	1948-2004	Semiparametric flexible parametric	YES
Ang (2007)	France	1960-2000	ARDL, VECM	YES
Soytas et al. (2007)	USA	1960-2004	Toda-Yamamoto GC	NO
Ang (2008)	Malaysia	1971-1999	VECM, Granger Causality	No
Chebbi (2010)	Tunisia	1971-2004	VECM, Impulse Response (IRF)	No

Halicioglu (2009)	Turkey	1960-2005	ARDL, Granger causality	YES
Ghosh(2010)	India	1971-2008	ARDL, Johansen Juselius	YES
Ahmed & Long (2012)	Pakistan	1971-2008	ARDL	YES
Alam et al. (2012)	Bangladesh	1972-2006	ARDL	YES
Esteve & Tamarit (2012)	Spain	1857-2007	Threshold Co-integration Test	YES
Fosten et al. (2012)	UK	1850-2002	Non-linear threshold co-integration and Error Correction Test	YES
Fosten et al. (2012)	United States	1900-2000	Ordinary Least Square (OLS)	YES
Saboori et al. (2012)	Malaysia	1980-2009	ARDL	YES
Giovanis (2013)	UK	1991-2009	Dynamic Panel Data	No
Saboori and Sulaiman(2013)	Malaysia	1980-2009	ARDL, Johansen Juselius	YES
Shabbaz et al. (2013)	South Africa	1965-2008	ARDL	YES
shabbza et al (2013)	1980-2009	Malaysia	VECM, GC Test	YES
Farhani et al (2014)	1971-2008	Tunisia	ARDL	YES
Lau et al.(2014)	Malaysia	1970-2008	ARDL, GC	YES

Yong & Zhao (2014)	India	1970-2008	GC & Directed Acyclic Graphs (DAG)	YES
Multi-Country Analysis				
Pao & Tsai (2010)	BRIC COUNTRIES	1971-2005	VAR &ECM	YES
Jounky (2010)	36 High inocme countries	1980-2005	VECM	YES
Orubu & omotor (2011)	47 African Countries	1990-2002	Longitudinal Panels data	YES
Arouri et al. (2012)	12 MENA Countries	1981-2005	Bootstrap Panel & co-integration techniques	YES
Wang (2013)	150 nations	2005-2011	Ordinary Least Square (OLS)	No
Apergis and Payne (2014)	7 Central American Countries	1980-2010	Panel co-integration Test	YES
Apergis and Payne (2014)	189 countries	1990-2011	Panel Fully Modified Least Square (OLS)	Yes
Farhani et al (2014)	10 MENA Countries	1990-2010	Panel data Method	YES'
Cowan et al (2014)	The BRICS Countries	1990-2010	Panel Causality Test	YES
Menash (2014)	6 African Countries	1980-2000		
Onafowora & Owoye(2014)	8 countries	1970-2010	ARDL	only for 2 countries

5. 3 Description of Variables, Data, and Period of Study

In this study, we have used annual data spanning the period from 1971 to 2016 in the context of India. The variables used in this study are GDP per capita in constant 2010 US $ as a proxy for economic growth, square of per capita GDP, per capita energy consumption (kg of oil equivalent), Trade openness, per capita CO2 emission metric tons, and Foreign Direct Investment (FDI). All the variables are sourced from World Development Indicators (WDI) website. All the variables were used after logarithm transformation.

5.4 Model Specification

To examine the long-run relationship among the variables the analysis used the linear logarithmic quadratic functional form.

$$CO_2 = \alpha_0 + \beta_{01}Y_t + \beta_{02}Y_t^2 + \beta_{03}E_t + \beta_{04} T_t + \beta_{05}FDI_t + \epsilon_t \quad (1)$$

t = defined time period = 1, 2,…..n,

Where ϵ_t is the error term, T defined as foreign trade.

"If the EKC hypothesis is true, the expected sign of β_{01} is positive and β_{02} is negative. The statistical significance of β_{02} implies a monotonically increasing relationship between per capita carbon emission and income. The coefficient of per capita energy use β_{03} is expected to be positive as higher energy consumption leads to higher carbon emissions. The expected sign of β_{04} is mixed depending mainly on the development stage and environmental aspects of the production process of an economy. In the case of the developed economy the sign is expected to be negative because a developed economy prefers to import pollution-intensive products from developing economies where environmental protection law is less stringent. Due to this reason, the expected sign for a developing economy is positive (Grossman and Krueger, 1991)". "The expected sign of T_t is also dependent on if the economy is export and import oriented. The coefficient of T_t can be negative in a developing economy if majority of its manufacturing products are imported from a developed country."

5. 4. 1 ARDL Bound Testing Co-integration Approach

The ARDL model estimates the unrestricted error correction model. The model representation is shown in equation 2.

$$\Delta CO_2 = \alpha_0 + \sum_{i=1}^{n} b_{1i}\Delta CO_{2t-i} + \sum_{i=1}^{n} b_{2i}\Delta Y_{t-i} + \sum_{i=1}^{n} b_{3i}\Delta Y_{t-i}^2 + \sum_{i=1}^{n} b_{4i}\Delta E_{t-i} + \sum_{i=1}^{n} b_{5i}\Delta T_{t-i} + \sum_{i=1}^{n} b_{6i}\Delta FDI_{t-i} + \delta_1 CO_{2t-1} + \delta_2 Y_{t-1} + \delta_3 Y_{t-1}^2 + \delta_4 E_{t-1} + \delta_5 T_{t-1} + \delta_6 FDI_{t-1} + \epsilon_{1t} \quad (2)$$

F-test is employed to test whether a co-integration linkage exists between the variables. The null hypothesis of no co-integration among the variables in Eq- (2) is $H_0;\ \delta_1 = \delta_2 = \delta_3 = \delta_4 = \delta_5 = \delta_6 = 0$, against$H_1;\ \delta_1 \neq \delta_2 \neq \delta_3 \neq \delta_4 \neq \delta_5 \neq \delta_6 \neq 0$, which is signified as FCO_2 (CO_2/Y, Y^2, E, T, FDI).

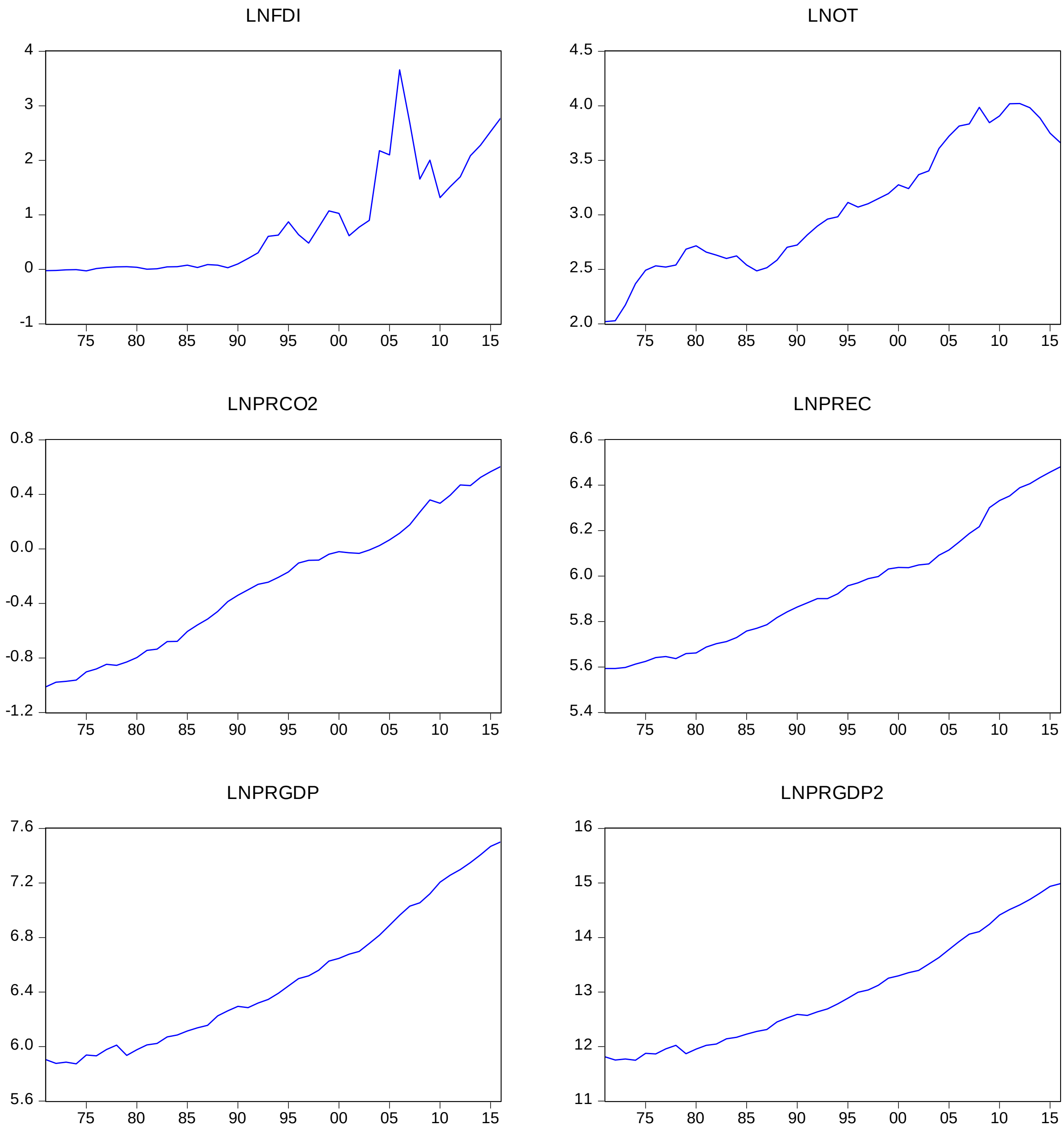
5. 4. 2 Unrestricted Error Correction Test

To know the short-run dynamics we have estimated the error correction model (ECM), the equation as follows

$$\Delta CO_2 = \alpha_0 + \sum_{i=1}^{n} b_{1i}\Delta CO_{2t-i} + \sum_{i=1}^{n} b_{2i}\Delta Y_{t-i} + \sum_{i=1}^{n} b_{3i}\Delta Y_{t-i}^2 + \sum_{i=1}^{n} b_{4i}\Delta E_{t-i} + \sum_{i=1}^{n} b_{5i}\Delta T_{t-i} + \sum_{i=1}^{n} b_{6i}\Delta FDI_{t-i} + \delta_1 CO_{2t-1} + \delta_2 Y_{t-1} + \delta_3 Y_{t-1}^2 + \delta_4 E_{t-1} + \delta_5 T_{t-1} + \delta_6 FDI_{t-1} + \theta\, ECT_{t-i} + \epsilon_{1t} \quad (3)$$

Here, the ECT_{-I} is the error correction term, and in the end, we estimate the stability of coefficients sum (CUSUM) and cumulative sum square (CUSUMSQ).

Figure 5.1 Variable Plots



5. 5 Empirical Results and Interpretation

The summary statistics are reported in table 5.2. The table shows the coefficient of skewness is greater than zero for all variables. The coefficient of kurtosis is relatively high in the case of foreign direct investment. The result also indicates JB test rejects the null hypothesis of normal distribution for all the variables.

Table 5.2 Descriptive Statistics

	LNFDI	LNOT	LNPRCO2	LNPREC	LNPRGDP	LNPRGDP2
Mean	0.82	3.05	-0.26	5.94	6.49	12.99
Median	0.54	2.97	-0.22	5.91	6.36	12.73
Maximum	3.65	4.02	0.60	6.48	7.50	14.98
Minimum	-0.03	2.01	-1.01	5.59	5.87	11.74
Std. Dev.	0.97	0.59	0.48	0.27	0.50	1.01
Skewness	1.06	0.21	0.07	0.44	0.52	0.51
Kurtosis	3.13	1.85	1.82	2.07	2.00	2.00
Jarque-Bera	8.79	2.89	2.66	3.15	3.97	3.97
Probability	0.01	0.23	0.26	0.20	0.13	0.13

The co-movement analysis is presented in the following table 5.3. The result of correlation statistics indicates that there is a high correlation between the variables.

Table 5. 3 Co-movement Analysis

Variables	LNFDI	LNOT	LNPRCO2	LNPREC	LNPRGDP	LNPRGDP2
LNFDI	1					
LNOT	0.87* [12.10] (0.00)	1				
LNPRCO2	0.84* [10.34] (0.00)	0.94* [19.52] (0.00)	1			
LNPREC	0.86* [11.31] (0.00)	0.94* [19.98] (0.00)	0.98* [46.51] (0.00)	1		
LNPRGDP	0.88* [12.86] (0.00)	0.95* [21.42] (0.00)	0.97* [32.55] (0.00)	0.99* [71.25] (0.00)	1	
LNPRGDP2	0.88* [12.86] (0.00)	0.95* [21.50] (0.00)	0.97* [32.60] (0.00)	0.99* [71.24] (0.00)	0.99* [2931.12] (0.00)	1

Note: [ ] shows' statistics and ( ) indicates 'P' values and * indicates 1% level of significance

The unit root test is shown in table 5. 4. The result of the unit root test indicates that all the variables are integrated of order 1 i.e. I (1). This result provides strong evidence to investigate the long-run linkage between the variables by using the ARDL bound testing method which is independent of the order of integration.

Table 5. 4 Unit Root Test

Variables	ADF Test		PP Test	
	Level	**First Difference**	**Level**	**First Difference**
lnprgdp	3.68 (1.00)	-6.01* (0.00)	4.93 (1.00)	-6.04* (0.00)
lnprgdp2	3.55 (1.00)	-6.03* (0.00)	4.30 (1.00)	-6.06* (0.00)
lnprco2	0.88 (0.99)	-6.31* (0.00)	0.83 (0.99)	-6.33* (0.00)
lnprec	3.20 (1.00)	-5.04* (0.00)	2.80 (1.00)	-5.18* (0.00)
lnot	-1.62 (0.46)	-2.84* (0.06)	-1.50 (0.52)	-4.64* (0.00)
lnfdi	-0.84 (0.79)	-7.54* (0.00)	-0.72 (0.82)	-7.51* (0.00)

Note: * shows 1% level of significances. ( ) denoted the probability value

Table 5.5 shows the unknown structural break unit root test result while employing the Augmented Dickey-Fuller (ADF) structural break. The result shows that in the presence of structural break the variables are found to be non-stationary. The structural break was found in 1993, 2005, 2004, 1988, and 2003.

Table 5.5 Unit Root Test with Unknown Structural Break

Variables	ADF Test at Level		ADF Test at First Difference	
	Statistics	Break Date	Statistics	Break Date
lnprgdp	0.87 (0.99)	1993	-7.59** (0.01)	1993
Lnprgdp2	0.76 (0.99)	1993	-7.59** (0.01)	1993
$Lnprco_2$	-0.84 (0.99)	2005	-6.84** (0.01)	2008
lnprec	-0.20 (0.99)	2004	-6.99** (0.01)	2009
lnot	-2.86 (0.75)	1988	-5.85** (0.01)	2013
Lnfdi	-3.69 (0.28)	2003	-8.33** (0.01)	2004
Significance				
CV 1%	-4.94			
CV 5%	-4.44			
CV 10%	-4.19			

Note: ** show the significance at 5% and ( ) parenthesis indicates the probability values

The long-run results are reported in table 5. 6. The result reveals that energy consumption has a positive impact on carbon emission. An increase in energy consumption will increase CO_2 emissions. Furthermore, economic growth has a positive impact on carbon emissions. High economic growth leads to high emissions. The negative coefficient of square GDP suggests the existence of the EKC hypothesis. The result shows that a 1 percent rise in economic growth will decrease carbon emission by 2.56% in the long run. While the negative sign of the square term seems to corroborate the decline of CO_2 emission and a higher level of economic growth. The long-run result also reveals that openness of trade and foreign direct investment does not have any impact on CO_2 emission.

Table 5. 6 Long-run & Short-run Analysis

Dependent Variables: $lnCO_2$			
Long-run Results			
Variables	**Coefficients**	**T-statistics**	**P-value**
Lnprec	2.56	14.57	0.00*
Lnprgdp	3.25	8.79	0.00*
Lnprgdp2	-0.27	-11.78	0.00*
Lnot	-0.00	-0.09	0.92
Lnfdi	0.02	1.16	0.12
C	-24.88	-30.43	0.00*
Short-run Results			
Variables	**Coefficients**	**T-statistics**	**P-value**
D (lnprec)	1.86	7.86	0.00*
D (lnprgdp)	8.41	4.75	0.00*
D (lnprgdp2)	-0.70	-4.81	0.00*
D (lnot)	-0.09	-1.75	0.09
D (lnfdi)	0.00	0.30	0.76
$ECT_{(T-1)}$	-1.02	-3.75	0.00*

Note: * shows the 1% level of significance

The ECM_{T-1} short-run results are presented in Table 5. 6. The short-run elasticity of CO_2 emission, concerning energy consumption, is positive and significant. The positive sign of per capita energy consumption is indicating that in India for each one percent increase in energy consumption per capita CO_2 emission also increases by 1.86 percent. Economic growth is another positive significant factor in the short-run which shows that increase in economic growth leads to more carbon emission. However, the square of economic growth is a negative and significant variable. The negative sign of the square of economic growth supports the existence of an environmental Kuznets curve in India. The openness of trade is negative and insignificant in the short-run and the foreign direct investment is positive and insignificant in the short run. The statistical significance of the error correction term ECT_{t-1} with an appropriate sign (-) is an indication of the speed of adjustment towards the long-run equilibrium after dis-equilibrium in the short run. This indicates that any deviation from the long-run equilibrium between CO_2 emission and other variables is corrected in each period and restored to the long-run equilibrium level after disequilibrium in the short run.

Table 5.7 Diagnostics Test of Error Correction Model

Tests	F-statistics	Prob.
Breusch Godfrey Serial Correlation LM Test	3.16	0.06
Breusch Pagon Godfrey- Heteroskedasticity Test	0.79	0.70
Heteroskedasticity Test: ARCH	1.82	0.18
Heteroskedasticity Test: Glejser	0.99	0.50

Table 5.7 reports the diagnostics test result which shows that the error correction model is free from serial correlation, autoregressive conditional heteroscedasticity, and functional from. And the model is well specified.

The empirical results of the ARDL bound testing result are shown in table 5. 8. The ARDL result shows that the estimated F-statistics is greater than the critical values of both upper bound and lower bound. This ARDL result confirms that there is a long-run equilibrium relationship between the variables.

Table 5. 8 ARDL Result for Co-integration

F-Statistics	Optimal Lag Order	Lower Bound I (0)	Upper Bound I (1)
		Critical Values	Critical Values
5.688*	4, 4, 2, 2, 3, 1	3.74 (1%)	5.06 (1%)
		2.86 (5%)	4.49 (5%)
		2.45 (10%)	3.52 (10%)

Note: * Indicates 1% level of significance

Table 5. 9 ARDL Diagnostic Test

Tests	F-statistics	Prob.
Breusch Godfrey Serial Correlation LM Test	2.09	0.14
Breusch Pagon Godfrey- Heteroskedasticity Test	0.88	0.59
Heteroskedasticity Test: ARCH	0.27	0.60
Heteroskedasticity Test: Glejser	0.72	0.74

The ARDL diagnostic test result is reported in table 5. 9. Table 5. 9 reveals that the ARDL bound testing approach is free from serial correlation, autoregressive conditional heteroscedasticity, and functional form and the model is well specified.

5. 6 Concluding Remarks and Policy Suggestions

The major objective of this chapter is to investigate the existence of an environmental Kuznets curve hypothesis in the context of India. The study employed the autoregressive distributed lag model over the period 1971 to 2016. The empirical result of the co-movement analysis found that there is a high correlation between the variables. The ordinary least square result confirms that economic growth has a positive and significant impact on carbon emission. The OLS result initially confirms that there is an existence of an environmental Kuznets curve for India. The ARDL bounds testing result suggests that there is a long-run equilibrium relationship among the variables when carbon emission is the dependent variable. The long-run co-integration result reveals that energy consumption has a positive impact on carbon emission. The negative square of GDP indicates the existence of the EKC hypothesis in India. This confirms that the negative sign of the square GDP coefficient suggests the presence of the EKC hypothesis in India. The error correction result shows that the positive sign of per capita energy consumption is indicating that in India for each 1 percent increase in energy consumption per capita CO_2 emission also increases by 1.86 percent. The statistical significance of the error correction term ECT_{t-1} with an appropriate sign (-) is an indication of the speed of adjustment towards the long-run equilibrium after disequilibrium in the short run.

CHAPTER 6

Sectoral Electricity Consumption and Economic Growth in India

6. 1 Introduction

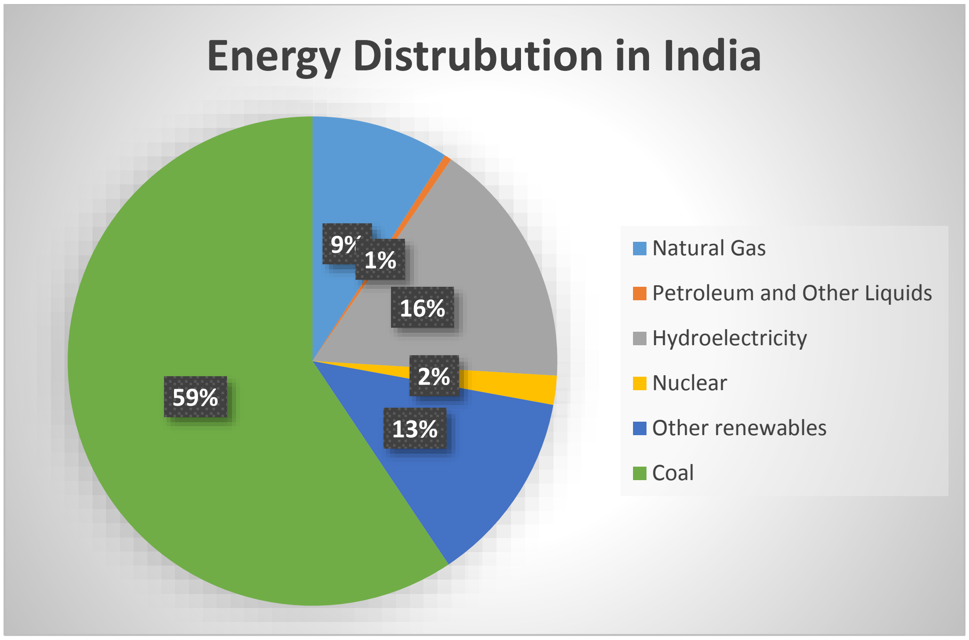
As the energy sector plays a very important role in the economic development process, it is pertinent to study the aggregate impact of energy in Indian sectors. Last three decades from the ground-breaking study of Kraft and Kraft (1978) examining the linkage between energy consumption and economic growth, the causal relationship between these variables is debatable (Ozturk, 2010; Payne, 2010). Studies (like e.g. Stern, 2000; Shiu and Lam, 2004; Narayan and Singh, 2007; Abosedra et al., 2009; Tang, 2009; Shahbaz et al., 2011; Tang and Tan, 2012) suggested that electricity consumption causes economic growth. Whereas many researchers empirically found that electricity does not Granger causes economic growth (e.g. Abosedra and Baghestani, 1989; Yu and Jin, 1992; Cheng, 1995; Ghosh, 2002; Narayan and Smyth, 2005; Marathe, 2007; Binh, 2011; Mahmoodi and Mahmoodi, 2011).

However, most of the studies have considered a fragmentary method to explore the relationship between these variables. Past studies on the linkage between these variables largely focused on the comprehensive level. Very few pieces of literature concentrated on the sectoral level analysis in the context of lower-middle-income nations like India. India is considered one of the emerging economies in the world. The contribution of agriculture, industry and service, construction, and manufacturing sectors to GDP in the year 2016-17 was 17.32 percent, 29.02 percent, and 53.66 percent respectively. Nevertheless, the economic structure has moved steadily from agriculture to the industry and service sector.

Around 600 million people in India live without electricity. And 700 million use biomass as their major source for cooking. India’s electricity generation capacity is fifth in the world. India’s installed capacity stands at 2,50,256 MW at the end of 30 July 2014. The contribution of central, state and private sectors are 39.37%, 28.73%, and 31.88% respectively.

Figure 6.1: Energy Distribution in India

Figure 6.1 presented the energy distribution in India. It is estimated that coal contributes 59% followed by hydroelectricity 16% and natural gas 13% respectively.



Source: Energy statistics India

The growing Indian economy needs higher electricity consumption. India is considered as fourth-largest energy consumer after China, the US, and Russia. In the year 2010-11, electricity consumption in India was estimated to be about 51% of the total energy consumption. Coal and lignite were 25% and crude petroleum 24% respectively. To achieve 8% GDP growth, the electricity supply should rise by 10% annually in India. India pertains to 1.8% of the world's GDP and 5.3% of the world's energy consumption. Coal is considered the main source of commercial energy and accounts for 60% of primary energy use in India. Whereas, natural gas and oil account for 35% of primary commercial energy use. India consumes 3% of the world's total energy. India is considered as 6^{th} largest energy consumer and accounts for 5% of the total world's energy demand. India imports around 70% of petroleum and petroleum products.

With the development of the energy sector in India, inter-fuel substitution has been taking place from traditional energy sources like firewood, coal, and oil to electricity in various sectors. Increasing developmental activities call for the enlargement of the commercial, industry, and transport sectors. In all these sectors, electricity is utilized as a fundamental input because of its unpolluted and competent nature. The consumption of electricity in the agriculture and transport sector improved the economic condition of India. The consumption of electricity in both sectors has been increasing with an annual growth rate of 15 percent from 1970 to 1995. Under such a situation, one could rationally believe that economic growth helps to boost electricity use in India. India is considered the fourth prime consumer and third-biggest producer of electricity in the world, having an installed power capacity of 330, 860.58 GW in 2017. Moreover, India has the fifth-largest installed ability in the world. However, India's energy sector has been suffering from a prolonged shortage of electricity supply. Moreover, the electricity sector in India deals with heavy damages of about 20-25 percent in comparison to the world average of 6-9 percent because of power theft, environmental problems, and excessive auxiliary consumption. According to the International Energy Agency, 2012 report around 400 million population lived with access to electricity in India and 836 million population depend on conventional biomass for cooking. In the case of primary energy consumption, India is considered the fourth-largest consumer in the world. In the year 2009-10 primary energy consumption in India was 316.29 (Mtoe). In comparison to the world level, India's average level of energy consumption is low. In the year 2009 the per capita energy use in India was 585 (Kgoe) as against the world average of 1802 (Kgoe). In 2009, the per capita energy use was 751 Kwh in India against the world average of 2099 Kwh. So, the demand for energy in India rises over the years to meet the minimum energy requirements of the population. The report of the Integrated Energy Policy (IEP) suggested that to achieve the growth rate of 8 percent, the country requires to upsurge the supply of primary energy 3 to 4 times and electricity generation capacity 5 to 6 times.

In India, around 68 percent of the inhabitants still reside in rural regions, and they are mostly dependent on non-commercial energy bases like biomass, firewood which are mainly used for cooking and lighting purposes. In the year 2009-10, the 66th round consumer expenditure survey showed that 76 percent of Indian rural households used firewood as the key cooking energy and 33.54 percent population used kerosene as primary lighting fuel. Hence, the consumption of commercial fuel in India would be much lower in comparison to the total consumption of biomass.

In the 13th five-year plan the GOI planned for capacity addition of around 100GW. In the year 2017, the GOI declared the intention to establish an asset reform firm for management of the strained assets in the power sector. “This would help in the transfer of stressed power generation assets of power projects, which would then be auctioned. Power consumption is projected to increase from 1160.1 TWh in 2016 to 1894.7 TWh in 2022.” (Source: IBEF; Indian Brand Equity Foundation) and the electricity production of 1160.1 BU in 2017, the nation perceived growth around 4.72 percent over the previous fiscal year. “Generation of electricity rose to 902.9 BU in April-December 2017. Production of electricity rose at a 7.03 CAGR over the financial year 10-17. The power minister in the year 2017 launched an application GARV-II, to afford electricity in rural areas in India. In India 16,064 villages were electrified out of 18,452 up to May 1, 2018.

Table 6.1 reports the consumption of electricity by different important sectors in India. This table indicates that there is an increasing trend in electricity consumption for the period 1970-2015. The electricity consumption in the industrial sector is generally more as compared to the agriculture and service sectors. The industrial sector consumed 1,51,551 GWh in the year 2005, whereas in the agriculture sector 90,292 GWh, the domestic sector 1,00,090 GWh, commercial sector 25,965 GWh, and Railway sector 90,292 GWh was consumed respectively. After one decade, the electricity consumption in the industrial sector was increased 4, 23, 523 Gwh, Agriculture sector 1, 73, 185 Gwh, Domestic sector 2, 38, 876, Commercial sector 86, 037, and Railway sector 16, 594 Gwh respectively. From the above figures, it is observed that there is a rising trend in electricity consumption in all the sectors. Therefore, it is essential to consider electricity as a key input of production in all sectors. Hence, this is worthwhile to study the linkage between electricity consumption and economic growth at the sectoral level in the context of India.

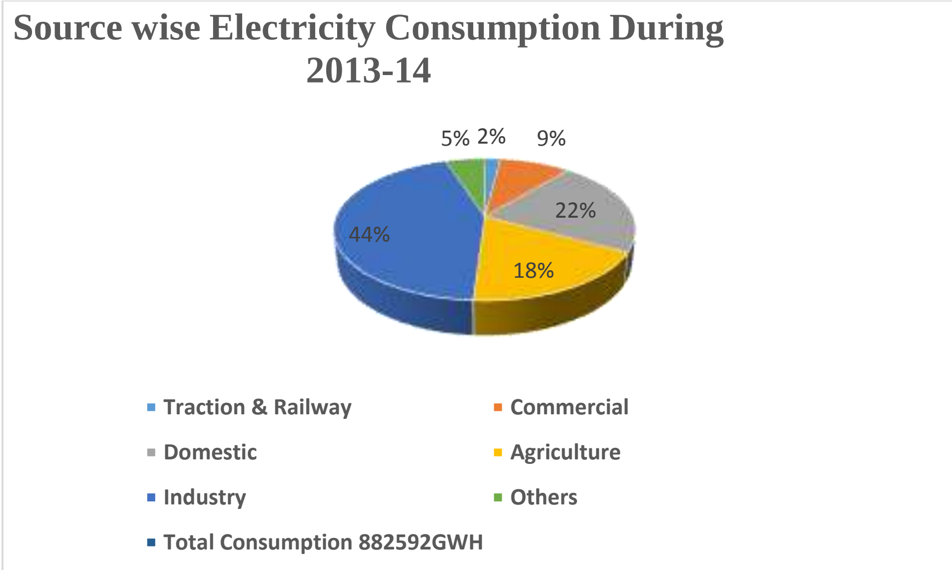
Table 6. 1: Sectoral Electricity Consumption in India (Gwh) = (10^6 * Kwh)

Year	Indu.	Agri.	Dome.	Comm.	Traction &	Other	Total Electrici
1	2	3	4	5	6	7	8=2 to 7
2005-06	151,557	90,292	100,090	35,965	9,944	24,039	411,887
2006-07	171,293	99,023	111,002	40,220	10,800	23,411	455,749
2007-08	189,424	104,182	120,918	46,685	11,108	29,660	501,977
2008-09	209,474	109,610	131,720	54,189	11,425	37,577	553,995
2009-10	236,752	120,209	146,080	60,600	12,408	36,595	612,645
2010-11	272,589	131,967	169,326	67,289	14,003	39,218	694,392
2011-12	352,291	140,960	171,104	65,381	14,206	41,252	785,194
2012-13	365,989	147,462	183,700	72,794	14,100	40,256	824,301
2013-14	386,872	159,144	198,246	76,968	15,182	46,180	882,592
2014-15	4,18,34	1,68,913	2,17,405	78,391	16,177	49,289	9,48,522
2015-16(p)	6	1,73,185	2,38,876	86,037	16,594	63,976	10,01,19
Distribution (%)	**42.30**	**17.30**	**23.86**	**8.59**	**1.66**	**6.29**	**100.00**
The growth rate of 2015-16	**1.24**	**2.53**	**9.88**	**9.75**	**2.58**	**27.77**	**5.55**
CAGR 2005-06	**9.47**	**5.75**	**7.97**	**7.90**	**4.39**	**10.40**	**8.19**

Source: Central Electricity Authority.

Figure 6. 2: Source wise Electricity Consumption during 2013-14

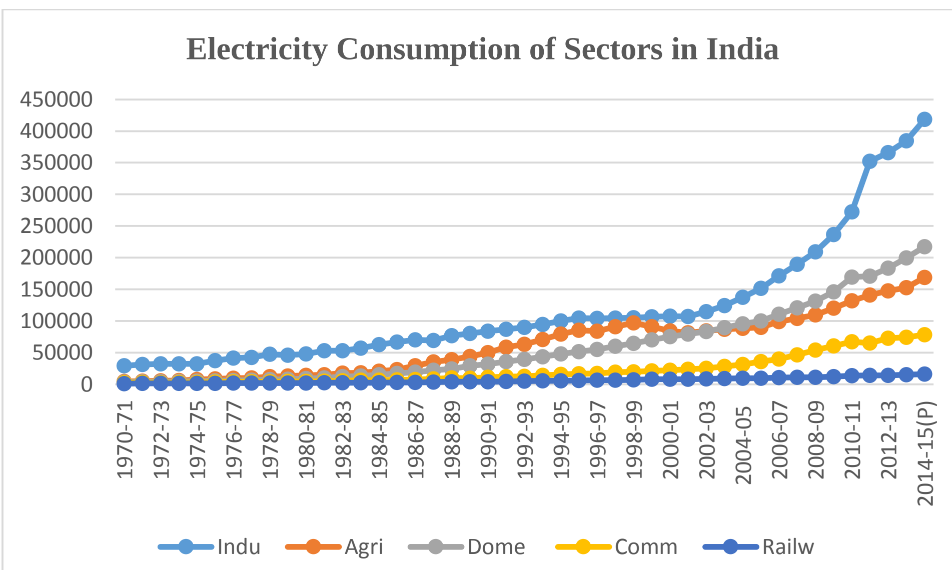
Figure 6.2 shows source wise consumption of electricity in India. It is estimated that industry accounts highest consumption of electricity (44%), domestic sector (22%), agriculture sector (18%) followed by commercial sector (9%) respectively.



Source: Central Electricity Authority

Figure 6.3: Electricity Consumption of Sectors in India 1970-2015

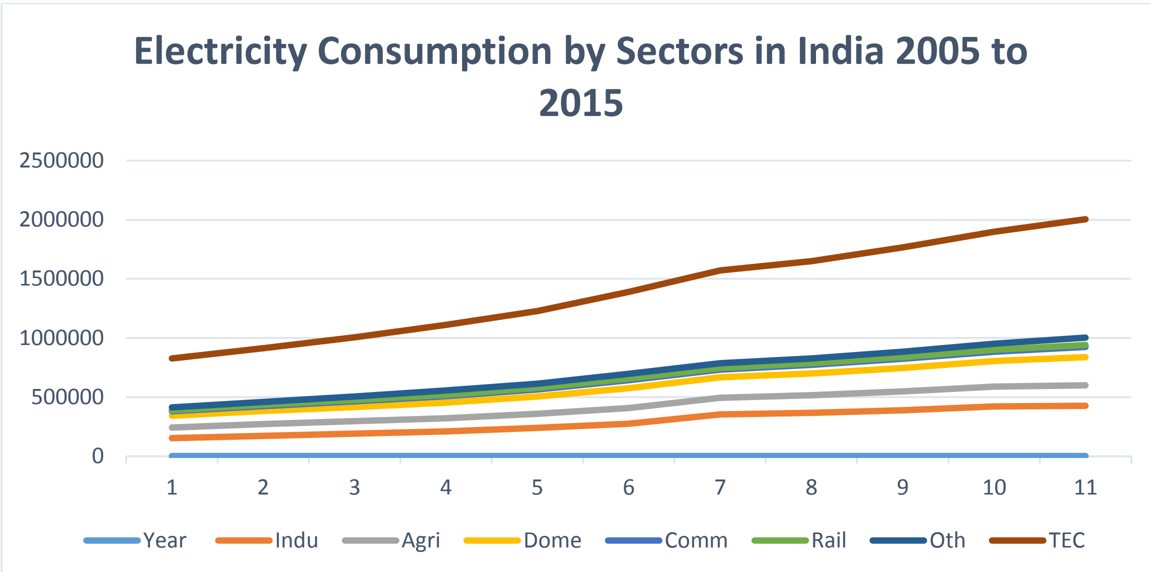
Figure 6.3 shows the patterns of sectoral electricity consumption in India during 1971-2015. It is observe that the consumption of electricity in industrial sector increases at an increasing rate. Similarly in all other sector the electricity consumption is also increases during this period.



Source: Authors estimation

Figure 6.4: Electricity Consumption by Sectors in India 2005 to 2015

Figure 6.4: shows the patterns of sectoral electricity consumption in India during 2005-2015. It is observe that the consumption of electricity in industrial sector increases at an increasing rate. Similarly in all other sector the electricity consumption is also increases during this period.



Source: Authors Estimation

Table 6. 2 Gross Production of Electricity in India (Gwh) = 10^6 x Kwh)

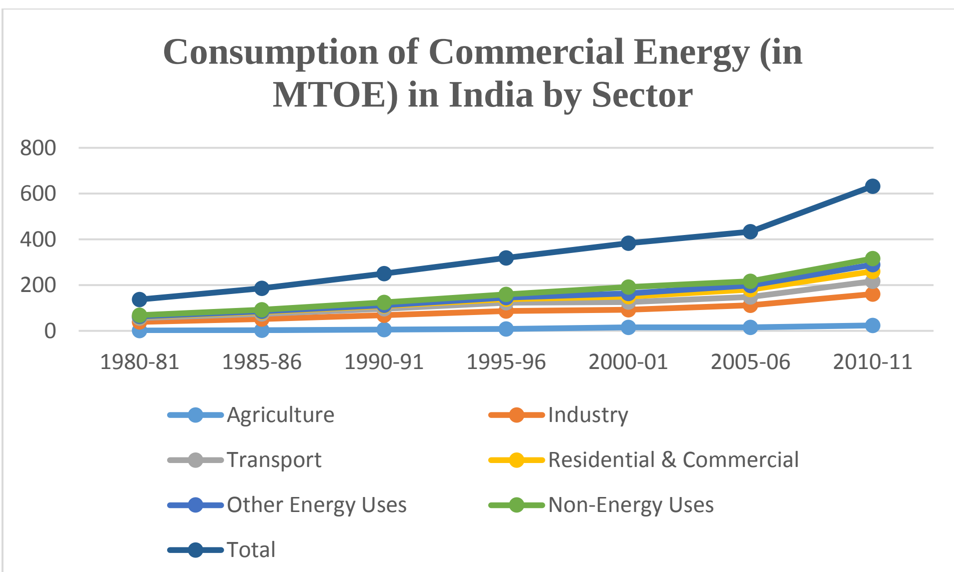
Table 6.2 shows the production of electricity in India from utilities and non-utilities. The growth rate of electricity production from utilities is 4.46 and from non-utilities 5.84. The growth rate of grand production increased from 6.01 to 6.07 during 2005-2013.

Year	Utilities				Non-Utilities	Grand Total
	Thermal	Hydro	Nuclear	Total		
1	2	3	4	5 = 2 to 4	6	7=5+6
2005-06	505,001	101,494	17,324	623,819	73,640	697,459
2006-07	538,350	113,502	18,802	670,654	81,800	752,454
2007-08	585,282	120,387	16,957	722,626	90,477	813,103
2008-09	617,832	113,081	14,713	745,626	95,905	841,531
2009-10	670,965	106,680	18,636	796,281	109,693	905,974
2010-11	704,323	114,257	26,266	844,846	114,224	959,070
2011-12	708,427	130,511	32,287	922,451	128,172	1,050,623
2012-13	817,225	113,720	32,866	963,811	148,000	1,111,811
2013-14(p)	853,683	134,731	34,200	1,022,61	156,642	1,179,256
The growth rate of	**4.46**	**18.48**	**4.06**	**6.10**	**5.84**	**6.07**
CAGR 2005-06	**6.01**	**3.20**	**7.85**	**5.65**	**8.75**	**6.01**

Source: Central Electricity Authority.

Figure 6. 5: Consumption of Commercial Energy (in MTOE) in India by Sector

Figure 6.5 reported the consumption of commercial energy by Indian sector. It is observe that all the sectors consumption of commercial energy increases over the period of time. The consumption is highly increased in all the sectors particularly during the period 2005-2010.



Source: Energy statistics India

Table 6. 3: Final Electricity Energy Consumption across Various Sectors in India

It is estimated that the consumption of electricity by industrial sector is high followed by residential sector, agriculture respectively.

Sectors	Electricity/ Power
Agriculture	10.27
Industry	21.34
Transport	1.07
Residential	12.20
Commercial	5.07
Other Energy Uses	2.38
Non-Energy Uses	-

Source: CEA (2011); MoC (2010); MoPNG (2010)

Table 6.4: Electricity Generated (from utilities), Distributed, Sold, and Lost in India. (in GWh) = ((10^6 x Kwh)

Table 6.4 shows the generation of electricity from utilities in India. It is observe that generation of electricity increases and the sold also increases over the years. The loss of electricity in transmission increases and remains stable 2011-12.

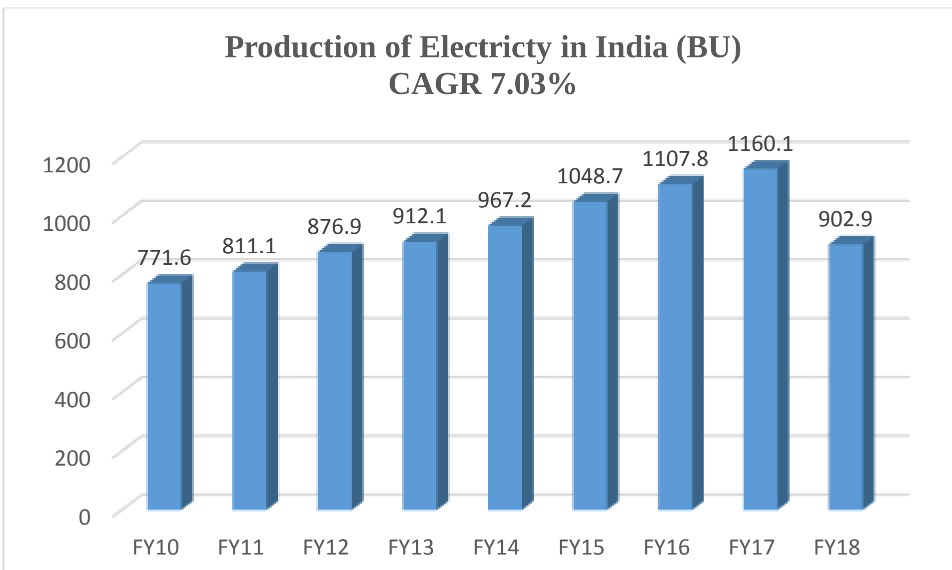
Year	Gross Electricity Genera	Consumption in Power Station	Net Electricity Generate	Purchases from Non-Utilities	Net Electricity Availabl	Sold to Ultimate Consumers	Loss in transmissio	Loss in transmissio
1	**2**	**3**	**4=2-3**	**5**	**6=4+5**	**7**	**8=6-7**	**9**
2005-06	623,819	41,970	581,849	10,345	592,194	411,887	180,14	30.42
2006-07	670,654	43,577	627,077	11,931	639,008	455,749	183,01	28.64
2007-08	722,626	45,531	677,095	12,685	689,780	501,977	187,62	27.20
2008-09	746,626	47,573	699,053	14,181	713,234	553,995	178,42	25.02
2009-10	796,281	49,706	746,576	14,391	760,967	612,645	193,45	25.42
2010-11	844,846	52,952	791,894	19,839	811,733	694,392	194,53	23.97
2011-12	922,451	56,499	865,952	15,516	811,506	685,194	208,40	25.68
2012-13	963,722	59,799	903,923	20,577	924,500	824,301	226,39	24.49
2013-	1,022,61	62,250	960,364	20,577	980,941	882,592	226,00	23.04

The growth rate	**6.11**	**4.10**	**6.24**	**0.00**	**6.11**	**7.07**	**-0.17**	**-5.91**
CAGR 2005-06	**6.37**	**5.05**	**6.46**	**8.98**	**6.51**	**9.99**	**2.88**	**-3.41**

Source: Central Electricity Authority.

Figure 6.6: Production of Electricity in India (BU)

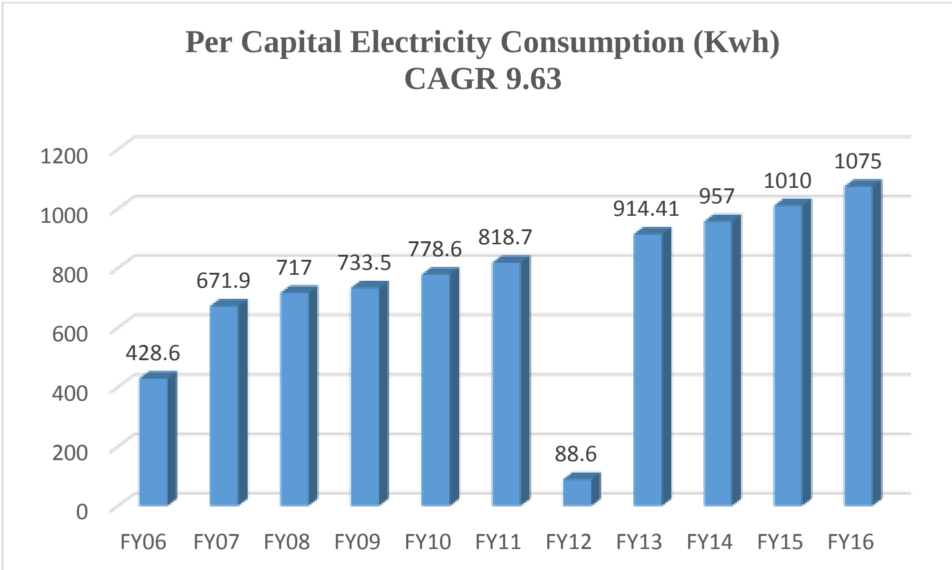
Figure 6.6 shows the production of electricity in India during 2010-18. The production of electricity is increasing and its was highest in the year 2018 then its starts decline.



Notes: FY: Indian Financial Year (April –March), BU- Billion Units

Source: BP Statistical Review, Ministry of Power, Aranca Research.

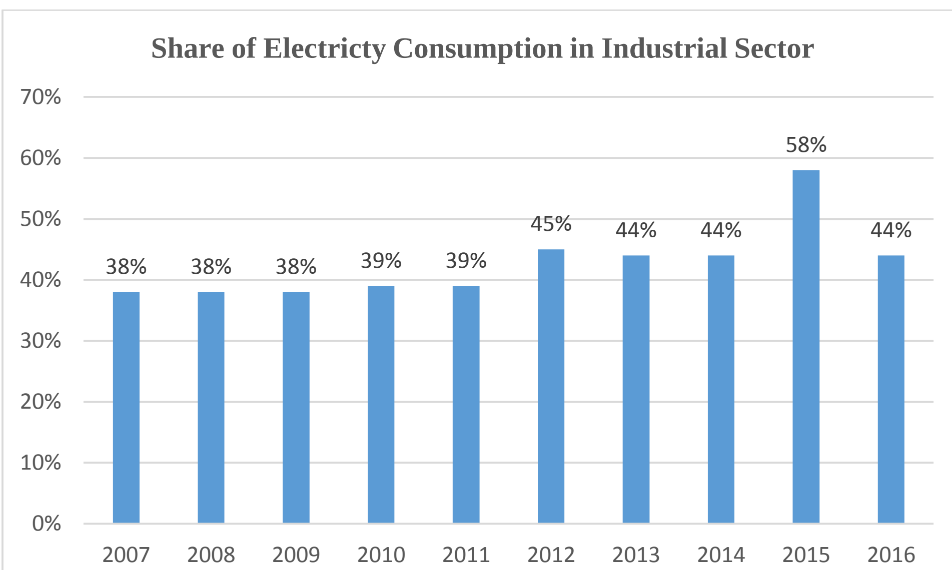
Figure 6.7: Per Capital Electricity Consumption (Kwh)



Notes: Source: CEA, Aranca Research

In India per capita consumption of electricity rose at a CAGR of 9.36 percent during 2006-2016, and reached 1075 Kwh in 2016.

Figure 6.8: Share of Electricity Consumption in Industrial Sector



Note: Twh-Terawatt Hours

Source: Aranca Research, Ministry of Statistics, and Program Implementation.

Figure 6.8 shows that the consumption electricity in industrial sectors. It is observe that share of electricity is increases in industrial sector over the years. It reaches the highest level in the year 2015 then starts declining.

Studies on the causal relationship between energy consumption and economic growth results are varied in the aggregate level because of the problem of aggregation bias. For instance, Abid and Sebri (2012) empirically found the energy-led growth hypothesis at the aggregate level while the same analysis discards the hypothesis at the sectoral level. Bowden and Payne (2009) and Zachariadia (2007) examined the neutrality hypothesis at the aggregate level, even though, the study found some causality at the aggregate level. Besides, the difference between the aggregate and sectoral studies, Zachariadis and Pashourtidou (2007), Bowden and Payne (2010), Zaman et al. (2011) investigated the linkage between energy use and economic growth at the sectoral level and empirically concluded that the causality result is unreliable among sectors.
Striving by the significance of the above studies and policymakers, our study explored the linkage between electricity use and economic growth at the sectoral level in the context of India for the period 1970-2016.

6. 2 Previous studies on electricity consumption and economic growth

6. 2. 1 Country-specific studies on electricity consumption and economic growth nexus

Huang (1993), Holtedahl & Joutz (2004), and Ghosh (2004) investigated the linkage between electricity consumption and economic growth. The findings suggested a positive causality from electricity consumption to economic growth. Huang (1993) studied the linkage between electricity consumption and economic growth in the context of China covering the period 1950-1980. The empirical result did not find any causal linkage between the variables. Holtedahl and Joutz (2004) studied the relationship in the context of Taiwan spanning the period 1955-1996. The result of the study shows that the relative price elasticity was inelastic and the long-run income elasticity demand is unity. Ghosh (2009) investigated the linkage between electricity supply, real GDP, and employment in India over the period 1970-71 and 2005-06. By employing the autoregressive distributed lag model the analysis found a long-run relationship between the variables. The findings indicate there is long-run and short-run causality running from real GDP to employment. Studies such as Fergson et al. (2000), Narayan et al. (2007), Narayan and Smyth (2009), and Yoo (2009) investigated the linkage between the variables and found that the results are contradictory. Fergson et al. (2000) examined the linkage between electricity consumption and economic development for 100 nations. The result of the study shows a high correlation between the variables for rich nations than poor countries. Narayan et al. (2007) studied the income and price elasticity for residential electricity demand for G7 countries over the period 1978-2003. By using the panel data methodology the analysis found that the residential electricity demand is price elastic and income inelastic in the long run. Narayan and Smyth (2009) explored the linkage between electricity consumption, GDP, and exports for Middle Eastern nations. The empirical findings show that there are feedback effects between these variables for the panel as a whole. Yoo and Lee (2009) studied the linkage between electricity use and economic growth for 88 countries spanning the period 1975-2004. The result of the study shows there is a statistically significant relationship between per capita electricity consumption and income.

The overall results of the above analysis suggest that most of the findings show inconsistent outcomes and there is no unanimity about the direction of causality between the variables. The conclusion obtained from the literature is vital for formulating policy in energy economics. The analysis also indicates this issue still deserves further investigation in the disaggregate and Sectoral levels.

This study contributes to the existing literature in two ways. First, studies related to India examined the relationship between the variables and the directional causality with bivariate and ignore the role of sectoral evidence. Lutkepohl (1982) argued the findings of Granger causality with bivariate analysis generate biased outcomes because of the omission of important variables. Furthermore, Gross (2012) concluded that the empirical findings at the aggregate level are inadequate for policy suggestions basically at the sectoral level. To overcome this issue, our study used multi variables to examine the relationship in the context of India at the sectoral levels. By using multivariable, our study escapes from omitted variables bias and prescribes significant policy suggestions. Behera (2015) explored the linkage between energy consumption and economic growth in the case of India from 1970-71 to 2011-12. By using the Granger causality the result found a causal linkage from economic growth to energy consumption. The result also supports the conservation hypothesis. Behera (2015) studied the linkage between energy use and economic growth in a disaggregate method in the context of India over the period 1970 to 2011. By using the VAR decomposition and Granger causality method the study confirms that there is a bidirectional relationship between electricity consumption and economic growth and lignite consumption and economic growth. Behera (2016) explored the linkage between energy use and economic growth in the case of China from 1978 to 2012. By using the state space econometric method the analysis shows no long-run relationship between the variables. The result supports the presence of the neutrality hypothesis in the case of China. Behera (2017) studied the output, energy, and pollution hypothesis in the case of India over the period 1970-2010. By employing the cointegration and error correction model the empirical result shows a long-run equilibrium relationship among the variables. The result also indicates economic growth has a positive and significant impact on energy consumption. The findings also indicate a unidirectional causality from economic growth to energy consumption. Behera and Mishra (2019) studied the linkage between renewable and non-renewable energy use and economic growth in the case of G7 nations spanning the period from 1990-2015. By employing the panel ARDL model the result confirms the short-run causality between non-renewable energy use and economic growth.

6. 3 Data and sources of variables

The current analysis employed annual data spanning the period from 1970-2016. The variable includes per capita GDP (in the constant US $ 2010), obtained from World Development Indicators (WDI), World Bank. The sectoral electricity data for agriculture, industry, residential and commercial are obtained from the Indian Council of Agricultural Research. All the variables are converted to a natural logarithm for a smooth estimation process.

6. 4 Model Specification

6. 4. 1 Unit Root Test

In the time series analysis stationary test plays a very significant role. To examine the stationary properties of the variable our study employed the ADF and PP tests. This stationary test helps to avoid specious and bias results. To eradicate such problems this study used unit root tests.

$$\Delta Y_t = \alpha + \alpha_2 Y_{t-1} + \sum_{i=1}^{p} \beta_i \, \Delta Y_{t-1} + \varepsilon_t \qquad (1)$$

Here the choice variables are Y; the first difference operator is Δ, $\alpha\ and\ \beta$ are constant parameters; ε_t is the error term. The Akaike Information Criteria (AIC) is chosen to select the lags. To examine the order of integration the equation includes the second difference on lagged first. The second difference lags p follows as

$$\Delta^2 Y_t = \theta_1 \Delta Y_{t-1} + \sum_{i=1}^{p} \theta_i \ \Delta^2 Y_{t-1} + \epsilon_t \qquad (2)$$

Where the second difference operator is Δ^2, $\theta_1$and $\theta_i$are constant parameter; ϵ_t is the stochastic process for stationary. To test the stationarity, ADF and PP models are applied to equations 1 and 2. The null hypothesis H_0: $\alpha_2 = 0$ against H_1: $\alpha_2 \neq 0$ and H_0: θ_1=0 against H_1: $\theta_1 \neq 0$ correspondingly, which indicates non-stationary of both Y_{t-1} and ΔY_{t-1}.

6. 4. 2 The Cointegration model

The cointegration test is employed to examine the long-run association between the variables. The Johansen (1988, 1991) maximum likelihood method is employed to investigate the cointegration among the variables.

$$\Delta \mathrm{Y} = \mu + \gamma_1 \mathrm{Y}_{t-1} + \gamma_2 \mathrm{X}_{t-2} + \cdots\cdots\cdots + \gamma_{k-1}\mathrm{X}_{t-k+1} + \pi \mathrm{Y}_{t-k} + \varepsilon_t \;\cdots\cdots\cdots\cdots (3)$$

Where Yt is the vector of the first-order integrated variables; γ_i are coefficient matrices; ε_t is the error term which is independently and normally distributed. The max eigenvalue and trace statistics were obtained by Johansen (1991) for checking the integrating vectors in the VAR. If π is of rank r (0 < r < 5), formerly it can be disintegrated as: π =αβ ′, where α (5Xr) and β (5Xr); and the equation (2) can be defined as:

$$\Delta \mathrm{Y} = \mu + \gamma_1 \mathrm{Y}_{t-1} + \gamma_2 \mathrm{X}_{t-2} + \cdots\cdots\cdots + \gamma_{k-1}\mathrm{X}_{t-k+1} + \alpha(\beta^1 \mathrm{Y}_{t-k}) + \varepsilon_t \;\cdots\cdots\cdots\cdots (4)$$

In equation (4), the ‘α’s are the error correction coefficients that indicate the speed of adjustment towards the long-run equilibrium. β vector is unrestricted. “Unless there is a unique cointegrating vector (i.e. r =1), the matrix of cointegrating vectors, as it stands, can’t be identified as typical long-run economic relationships. This is as any linear combination of cointegrating vectors forms another linear stationary relationship”. Therefore, the VAR can be written as follows.

$$\Delta \mathrm{Y} = \mu + \pi \mathrm{Y}_{t-\rho} + \sum_{i=1}^{k-1} A_i \,\Delta \mathrm{Y}_{t-i} + \varepsilon_t \;\cdots\cdots\cdots\cdots (5)$$

And from the vector of residual, we create two likelihood ratio statistics. The one is trace statistics, which is shown as

$$\lambda_{Tra} = -\gamma \sum_{i=r+1}^{n} \mathrm{Log}\left(1 - \hat{\lambda}_i\right) \;\cdots\cdots\cdots\cdots (6)$$

Where, $\widehat{\lambda}_{r+1,} \ldots \ldots . \widehat{\lambda}_{n}$, *are (n-r)* estimated Eigenvalues. The null hypothesis is to verify that there are at most r unique cointegration vectors. The second statistic is the Max-eigenvalue, which is indicated as follows

$$\lambda_{Max} = -\gamma \operatorname{Log}(1 - \widehat{\lambda}_{i}) \cdots\cdots\cdots\cdots (7)$$

"The null hypothesis for this test is that there are r cointegrating vectors inY_t. For both statistics, the alternative hypothesis is that there are g > r cointegration vectors inY_t. Johansen and Juselius (1990) suggested that the trace test may lack power over the maximal eigenvalue test. Nevertheless, the trace test is more robust to the non-normality of errors."

6. 4. 3 Lag Selection Criteria

The model selection criteria are used to define the lag selection for the VAR (P) model. The common way to fit VAR (P) models with orders P=0, …, 0_{max} and define the value of P which minimizes some model selection criteria. The VAR (P) model has the following form.

$$\ln(p) = \ln\left|\widetilde{\sum(p)}\right| + C_r . \varphi\,(n, p)$$

"$\widetilde{\sum(p)} = T^{-1} \sum_{T=1}^{T} \widehat{\varepsilon_t}\, \hat{\acute{\varepsilon}_t}$ is the residual covariance matrix without a degree of freedom correction from a VAR (p) model, T is a sequence indexed by the sample size T, and (n, p) is a penalty function that penalizes large VAR (P) models."

The three information criteria are AIC, BIC, and HQ.

$$AIC\,(p) = \ln\left|\widetilde{\sum(p)}\right| + \frac{2}{T}\, pn^2$$

$$BIC(p) = \ln\left|\widetilde{\sum(p)}\right| + \frac{lnT}{T}\, pn^2$$

$$HQ\,(p) = \ln\left|\widetilde{\sum(p)}\right| + \frac{2 \ln lnT}{T}\, pn^2$$

"Where AIC overestimates the order with positive probability asymptotically, the BIC and HQ criteria guess the order consistently under fairly general conditions if the true order p is less than or equal to p_{max}."

6. 4. 4 Vector Error Correction Model

The dynamics of long-run and short-run causality are examined by the VECM model. The VECM model is shown in the following form.

$$"\Delta AGRI = \delta_1 + \sum_{k=1}^{p-1} \alpha_{11,k}\ \Delta AGRI_{1,t-k} + \sum_{k=1}^{p-1} \alpha_{12,j}\ \Delta COMM_{2,t-k} + \sum_{k=1}^{p-1} \alpha_{13,l}\ \Delta DOME_{3,t-k} + \sum_{k=1}^{p-1} \alpha_{14,m}\ \Delta GDP_{4,t-k} + \sum_{k=1}^{p-1} \alpha_{15,n}\ \Delta INDU_{5,t-k} + \sum_{k=1}^{p-1} \alpha_{16,o}\ \Delta TEC_{6,t-k} \sum_{h=1}^{r} \alpha_{1,h}\ EC_{h,t-1} + \varepsilon_{1t} \quad (7.1)"$$

$$"\Delta COMM = \delta_2 + \sum_{k=1}^{p-1} \alpha_{21,k}\ \Delta AGRI_{1,t-k} + \sum_{k=1}^{p-1} \alpha_{22,j}\ \Delta COMM_{2,t-k} + \sum_{k=1}^{p-1} \alpha_{23,l}\ \Delta DOME_{3,t-k} + \sum_{k=1}^{p-1} \alpha_{24,m}\ \Delta GDP_{4,t-k} + \sum_{k=1}^{p-1} \alpha_{25,n}\ \Delta INDU_{5,t-k} + \sum_{k=1}^{p-1} \alpha_{26,o}\ \Delta TEC_{6,t-k} \sum_{h=1}^{r} \alpha_{2,h}\ EC_{h,t-1} + \varepsilon_{2t} \quad (7.2)"$$

$$"\Delta DOME = \delta_3 + \sum_{k=1}^{p-1} \alpha_{31,k}\ \Delta AGRI_{1,t-k} + \sum_{k=1}^{p-1} \alpha_{32,j}\ \Delta COMM_{2,t-k} + \sum_{k=1}^{p-1} \alpha_{33,l}\ \Delta DOME_{3,t-k} + \sum_{k=1}^{p-1} \alpha_{34,m}\ \Delta GDP_{4,t-k} + \sum_{k=1}^{p-1} \alpha_{35,n}\ \Delta INDU_{5,t-k} + \sum_{k=1}^{p-1} \alpha_{36,o}\ \Delta TEC_{6,t-k} \sum_{h=1}^{r} \alpha_{3,h}\ EC_{h,t-1} + \varepsilon_{3t} \quad (7.3)"$$

$$"\Delta GDP = \delta_4 + \sum_{k=1}^{p-1} \alpha_{41,k}\ \Delta AGRI_{1,t-k} + \sum_{k=1}^{p-1} \alpha_{42,j}\ \Delta COMM_{2,t-k} + \sum_{k=1}^{p-1} \alpha_{43,l}\ \Delta DOME_{3,t-k} + \sum_{k=1}^{p-1} \alpha_{44,m}\ \Delta GDP_{4,t-k} + \sum_{k=1}^{p-1} \alpha_{45,n}\ \Delta INDU_{5,t-k} + \sum_{k=1}^{p-1} \alpha_{46,o}\ \Delta TEC_{6,t-k} \sum_{h=1}^{r} \alpha_{4,h}\ EC_{h,t-1} + \varepsilon_{4t} \quad (7.4)"$$

$$"\Delta INDU = \delta_5 + \sum_{k=1}^{p-1} \alpha_{51,k}\ \Delta AGRI_{1,t-k} + \sum_{k=1}^{p-1} \alpha_{52,j}\ \Delta COMM_{2,t-k} + \sum_{k=1}^{p-1} \alpha_{53,l}\ \Delta DOME_{3,t-k}$$
$$+ \sum_{k=1}^{p-1} \alpha_{54,m}\ \Delta GDP_{4,t-k} + \sum_{k=1}^{p-1} \alpha_{55,n}\ \Delta INDU_{5,t-k}$$
$$+ \sum_{k=1}^{p-1} \alpha_{56,o}\ \Delta TEC_{6,t-k} \sum_{h=1}^{r} \alpha_{5,h}\ EC_{h,t-1} + \varepsilon_{5t} \qquad (7.5)"$$

$$"\Delta TEC = \delta_6 + \sum_{k=1}^{p-1} \alpha_{61,k}\ \Delta AGRI_{1,t-k} + \sum_{k=1}^{p-1} \alpha_{62,j}\ \Delta COMM_{2,t-k} + \sum_{k=1}^{p-1} \alpha_{63,l}\ \Delta DOME_{3,t-k}$$
$$+ \sum_{k=1}^{p-1} \alpha_{64,m}\ \Delta GDP_{4,t-k} + \sum_{k=1}^{p-1} \alpha_{65,n}\ \Delta INDU_{5,t-k}$$
$$+ \sum_{k=1}^{p-1} \alpha_{66,o}\ \Delta TEC_{6,t-k} \sum_{h=1}^{r} \alpha_{6,h}\ EC_{h,t-1} + \varepsilon_{6t} \qquad (7.6)"$$

"Where, $h_{,\ t-1}$ EC is the h^{th} error correction term, the residuals from the h^{th} cointegration equation, lagged one period, and α_{ij}, k describes the effect of the k^{th} lagged value of variable j on the current value of the variable" i: I .j = AGRI, COMM, DOME, GDP, INDU, TEC. The VECM model shows the short-run and long-run causality. In the above setting (Equation 7.1, 7.2, 7.3, 7.4, 7.5, 7.6), long-run Granger causality among the variables in the presence of cointegration is evaluated by testing the null hypothesis is thatα_j, h =0 for h=1, …, r, whereas the short-run Granger causality from $AGRI_i$ to Variable $AGRI_j$ is calculated by testing the null hypothesis thatα_{ij}, 1= ……….,α_{ij}, p-1=0, using F statistics.

6. 4. 5 The Toda-Yamamoto Granger Causality Test

A modified Wald Test method (MWALD) is employed to test the causality suggested by Toda and Yamamoto (1995). This model helps to estimate the problem linked with the normal Granger causality model. "The Toda and Yamamoto (1995) approach fit a standard vector autoregressive model in the levels of the variables. (rather than the first difference, as the case with the Granger causality test), thereby minimizing the risk associated with the possibility of wrongly identifying the order of integration of the series (Marvotas & Kelly, 2001)". "The simple idea of this methodology is to artificially augment the correct VAR order, k, by the maximal order of integration, d_{max}. Once this is done, a ($k + d_{max}$) the order of VAR is estimated, and the coefficients of the last lagged d_{max} vector are ignored (see Caporale & Pittis, 1999; Rambaldi & Doran, 1996; Rambaldi, 1997; Zapata & Rambaldi, 1997)". To employ Toda & Yamamoto (1995) model, we denote the model in the succeeding VAR system.

$$"AGRI_t = \alpha_0 + \sum_{i=1}^{k} \alpha_{1i}\, AGRI_{t-i} + \sum_{j=k+1}^{d_{max}} \alpha_{2j}\ AGRI_{t-j} + \sum_{i=1}^{k} \theta_{1i}\ COMM_{t-i} + \sum_{j=k+1}^{d_{max}} \theta_{2j}\ COMM_{t-j} + \sum_{i=1}^{k} \varphi_{1i}\ DOME_{t-i} + \sum_{j=k+1}^{d_{max}} \varphi_{2j}\ DOME_{t-j} + \sum_{i=1}^{k} \beta_{1i}\ GDP_{t-i} + \sum_{j=k+1}^{d_{max}} \beta_{2j}\ DOME_{t-j} + \sum_{i=1}^{k} \rho_{1i}\ INDU_{t-i} + \sum_{j=k+1}^{d_{max}} \rho_{2j}\ INDU_{t-j} + \sum_{i=1}^{k} \gamma_{1i}\ TEC_{t-i} + \sum_{j=k+1}^{d_{max}} \gamma_{2j}\ TEC_{t-j} + \varepsilon_{1t} \qquad (7.7)"$$

$$"COMM_t = \lambda_0 + \sum_{i=1}^{k} \lambda_{1i}\, COMM_{t-i} + \sum_{j=k+1}^{d_{max}} \lambda_{2j}\ COMM_{t-j} + \sum_{i=1}^{k} \varpi_{1i}\ AGRI_{t-i} + \sum_{j=k+1}^{d_{max}} \varpi_{2j}\ AGRI_{t-j} + \sum_{i=1}^{k} \phi_{1i}\ DOME_{t-i} + \sum_{j=k+1}^{d_{max}} \phi_{2j}\ DOME_{t-j} + \sum_{i=1}^{k} \psi_{1i}\ GDP_{t-i} + \sum_{j=k+1}^{d_{max}} \psi_{2j}\ GDP_{t-j} + \sum_{i=1}^{k} \upsilon_{1i}\ INDU_{t-i} + \sum_{j=k+1}^{d_{max}} \upsilon_{2j}\ INDU_{t-j} + \sum_{i=1}^{k} \Theta_{1i}\ TEC_{t-i} + \sum_{j=k+1}^{d_{max}} \Theta_{2j}\ TEC_{t-j} + \varepsilon_{2t} \qquad (7.8)"$$

$$
"DOME_t = \varpi_0 + \sum_{i=1}^{k} \varpi_{1i}\, DOME_{t-i} + \sum_{j=k+1}^{d_{max}} \varpi_{2j}\ COMM_{t-j} + \sum_{i=1}^{k} \Gamma_{1i}\ AGRI_{t-i}
+ \sum_{j=k+1}^{d_{max}} \Gamma_{2j}\ AGRI_{t-j} + \sum_{i=1}^{k} \xi_{1i}\ COMM_{t-i} + \sum_{j=k+1}^{d_{max}} \xi_{2j}\ COMM_{t-j}
+ \sum_{i=1}^{k} \omega_{1i}\ GDP_{t-i} + \sum_{j=k+1}^{d_{max}} \omega_{2j}\ GDP_{t-j} + \sum_{i=1}^{k} \varrho_{1i}\ INDU_{t-i}
+ \sum_{j=k+1}^{d_{max}} \varrho_{2j}\ INDU_{t-j} + \sum_{i=1}^{k} \iota_{1i}\ TEC_{t-i} + \sum_{j=k+1}^{d_{max}} \iota_{2j}\ TEC_{t-j}
+ \varepsilon_{3t} \qquad (7.9)"
$$

$$
"GDP_t = \tau_0 + \sum_{i=1}^{k} \tau_{1i}\, GDP_{t-i} + \sum_{j=k+1}^{d_{max}} \tau_{2j}\ GDP_{t-j} + \sum_{i=1}^{k} \chi_{1i}\ AGRI_{t-i} + \sum_{j=k+1}^{d_{max}} \chi_{2j}\ AGRI_{t-j}
+ \sum_{i=1}^{k} \zeta_{1i}\ COMM_{t-i} + \sum_{j=k+1}^{d_{max}} \zeta_{2j}\ COMM_{t-j} + \sum_{i=1}^{k} o_{1i}\ DOME_{t-i}
+ \sum_{j=k+1}^{d_{max}} o_{2j}\ DOME_{t-j} + \sum_{i=1}^{k} \varepsilon_{1i}\ INDU_{t-i} + \sum_{j=k+1}^{d_{max}} \varepsilon_{2j}\ INDU_{t-j}
+ \sum_{i=1}^{k} \kappa_{1i}\ TEC_{t-i} + \sum_{j=k+1}^{d_{max}} \kappa_{2j}\ TEC_{t-j} + \varepsilon_{4t} \qquad (7.10)"
$$

$$"INDU_t = \Omega_0 + \sum_{i=1}^{k} \Omega_{1i} INDU_{t-i} + \sum_{j=k+1}^{d_{max}} \Omega_{2j}\ INDU_{t-j} + \sum_{i=1}^{k} \Phi_{1i}\ AGRI_{t-i} + \sum_{j=k+1}^{d_{max}} \Phi_{2j}\ AGRI_{t-j} + \sum_{i=1}^{k} \Upsilon_{1i}\ COMM_{t-i} + \sum_{j=k+1}^{d_{max}} \Upsilon_{2j}\ COMM_{t-j} + \sum_{i=1}^{k} \Pi_{1i}\ DOME_{t-i} + \sum_{j=k+1}^{d_{max}} \Pi_{2j}\ DOME_{t-j} + \sum_{i=1}^{k} \psi_{1i}\ GDP_{t-i} + \sum_{j=k+1}^{d_{max}} \psi_{2j}\ GDP_{t-j} + \sum_{i=1}^{k} \varepsilon_{1i}\ TEC_{t-i} + \sum_{j=k+1}^{d_{max}} \varepsilon_{2j}\ TEC_{t-j} + \varepsilon_{5t} \qquad (7.11)"$$

$$"TEC_t = \tau_0 + \sum_{i=1}^{k} \tau_{1i} TEC_{t-i} + \sum_{j=k+1}^{d_{max}} \tau_{2j}\ TEC_{t-j} + \sum_{i=1}^{k} \Theta_{1i}\ AGRI_{t-i} + \sum_{j=k+1}^{d_{max}} \Theta_{2j}\ AGRI_{t-j} + \sum_{i=1}^{k} \varrho_{1i}\ COMM_{t-i} + \sum_{j=k+1}^{d_{max}} \varrho_{2j}\ COMM_{t-j} + \sum_{i=1}^{k} \chi_{1i}\ DOME_{t-i} + \sum_{j=k+1}^{d_{max}} \chi_{2j}\ DOME_{t-j} + \sum_{i=1}^{k} \Delta_{1i}\ GDP_{t-i} + \sum_{j=k+1}^{d_{max}} \Delta_{2j}\ GDP_{t-j} + \sum_{i=1}^{k} \epsilon_{1i}\ INDU_{t-i} + \sum_{j=k+1}^{d_{max}} \epsilon_{2j}\ INDU_{t-j} + \varepsilon_{6t} \qquad (7.12)"$$

6. 5 Empirical Analysis

6. 5. 1 Summary Statistics

The statistical summary is reported in table 6.5. The result shows the skewness of coefficients, this is used as a sign of asymmetry. The result shows that except for agriculture and the domestic sector all the variables skewed positively. The Kurtosis coefficients are quite significant in the context of GDP and industry. The test result also shows that the JB test rejects the null hypothesis of normal distribution at any convenient confidence level for all the variables.

Table 6.5: Summary Statistics

	AGRI	COMM	DOME	GDP	INDU	TEC
Mean	10.66	9.57	10.46	6.47	11.48	12.26
Median	11.16	9.55	10.67	6.33	11.45	12.38
Max	12.13	11.34	12.40	7.52	13.15	13.91
Min	8.40	7.85	8.25	5.86	10.29	10.68
S.D	1.11	1.09	1.29	0.51	0.78	0.94
Skewness	-0.57	0.10	-0.22	0.56	0.48	-0.01
Kurtosis	1.97	1.79	1.76	2.05	2.43	1.91
JB	4.60	2.92	3.37	4.22	2.42	2.31
Prob.	0.10	0.23	0.18	0.12	0.29	0.31

6. 5. 2 Co-movement Analysis

Table 6.6 represents the co-movement test result. The correlation matrix indicates that there is a high pair-wise correlation among all the variables.

Table 6.6: Co-movement Analysis

Variables	AGRI	COMM	DOME	GDP	INDU	TEC
AGRI	1					
COMM	0.95* 21.26 0.00	1				
DOME	0.98* [37.63] (0.00)	0.98* [46.12] (0.00)	1			
GDP	0.89* [13.10] (0.00)	0.98* [34.75] (0.00)	0.95* [20.75] (0.00)	1		

INDU	0.91* [15.67] (0.00)	0.98* [33.66] (0.00)	0.95* [22.95] (0.00)	0.98* [35.79] (0.00)	1	
TEC	0.97* [27.96] (0.00)	0.99* [07.03] (0.00)	0.99* [65.96] (0.00)	0.97* [26.96] (0.00)	0.98* [35.35] (0.00)	1

Note: * indicates the 1 percent level of significance, [ ] shows the t values and parenthesis ( ) denotes the probability values.

6. 5. 3 Unit Root Test

The unit root test result is reported in table 6.7. The unit root test result shows the null hypothesis cannot be rejected at their levels for all the variables. But, the null hypothesis is rejected at their first difference for all the variables. Hence, all variables are integrated of order one i.e. I(1). Therefore, this unit root test result helps to examine the long-run relationship between the variables by using the co-integration methodology.

Table 6.7: Unit Root Test

Variables	ADF Test		PP Test	
	Level	First Difference	Level	First Difference
GDP	4.30 (1.00)	-5.38* (0.00)	4.94 (1.00)	-5.46* 0.00
INDU	2.47 (1.00)	-4.80* (0.00)	1.99 (0.99)	-4.88* (0.00)
AGRI	-2.63 (0.09)	-4.07* (0.00)	-2.79 (0.06)	-4.02* (0.00)
DOME	-2.24 (0.19)	-5.72* (0.00)	-1.73 (0.40)	-5.39* (0.00)
COMM	0.08 (0.96)	-7.07* (0.00)	0.09 (0.96)	-7.07* (0.00)
TEC	0.28 (0.97)	-4.47* (0.00)	0.25 (0.97)	-4.54* (0.00)

Note: * indicates 1 percent level of significance and the parentheses ( )' shows the probability values.

6. 5. 4 Lag Order Selection Criteria

Table 6.7 reports that all variables attain stationarity at their first difference. Hence, the study used the co-integration test to verify the long-run linkage between the variables. As we know the co-integration test is dependent on the Maximum Likelihood method with the VAR model. Therefore, before the use of VAR, it is essential to know the lag length. The following table 6.8 indicates that the optimal lag is selected as three.

Table 6.8: Lag Order Selection Criteria

Lag	LogL	LR	FPE	AIC	SC	HQ
0	236.72	NA	1.12	-10.48	-10.24	-10.39
1	613.24	633.24	2.17	-25.96	-24.26*	-25.33*
2	639.26	36.66	3.74	-25.51	-22.34	-24.33
3	700.10	69.14*	1.56*	-26.64*	-22.01	-24.96

Note: * indicates lag order selected by the criterion

6. 5. 5 Co-integration Analysis

Table 6.9 reported the co-integration result. The co-integration test result indicates that the null hypothesis of no co-integration is rejected at 0.05 significance level. The test result observes that the trace statistics and Eigenvalue statistics show two co-integrating vectors. Therefore, the result concluded that long-run equilibrium relationship exists among the variables.

Table 6.9: Cointegration Test

Unrestricted Cointegration Rank Test (Trace)				
Null Hypothesis	Eigenvalue	Trace Statistics	0.05 C. V	Prob.**
r=0*	0.77	181.31	95.75	0.00
r = 1*	0.59	116.73	69.81	0.00
r ≤ 2*	0.51	77.93	47.85	0.00
r ≤ 3*	0.41	46.79	29.79	0.00
r ≤ 4*	0.34	23.97	15.49	0.00
r ≤ 5*	0.12	5.51	3.84	0.01
Unrestricted Cointegration Rank Test (Maximum Eigenvalue)				
Null Hypothesis	Eigenvalue	Max Eigen Statistics	0.05 C.V	Prob.**
r = 0*	0.77	64.55	40.07	0.00
r ≤ 1*	0.59	38.81	33.87	0.01
r ≤ 2*	0.51	31.13	27.58	0.01
r ≤ 3*	0.41	22.82	21.13	0.02
r ≤ 4*	0.34	18.45	14.26	0.01
r ≤ 5*	0.12	5.51	3.84	0.01

Source: Authors estimation. Note: * denotes the rejection of null hypothesis at the 0.05 level of significance and ** indicates Mackinnon- Haug-Michelis (1999) p values.

6. 5. 6 Error Correction Model

The error correction model determines the short-run and long-run linkage between the variables. The following table 6.10 indicates the error correction result. The test result shows the correct negative sign for the agriculture sector. The value for agriculture, domestic, and industry is significant.

The findings show the behavior of electricity consumption in the agriculture, domestic and industrial sector implies that any short-run shock will not deviate from the equilibrium adjustment in the long run.

Table 6.10: Error Correction Result

Error Correction	D(AGRI)	D(COMM)	D(DOME)	D(GDP)	D(INDU)	D(TEC)
CointEq1	-0.581	-0.009	-0.132	0.288	0.335	0.113
	(0.185)	(0.196)	(0.103)	(0.078)	(0.158)	(0.089)
	[-3.131]	[-0.049]	[-1.279]	[3.688]	[2.116]	[1.276]

Source: Authors estimation, Note: 'p' value in parenthesis and't' value in brackets.

6. 5. 7 Vector Error Correction Model for Short-run Analysis

Table 6.11: Vector Error Correction Result

	D(AGRI)	D(DOME)	D(DOME)	D(GDP)	D(INDU)	D (TEC)
D(AGRI(-1))	0.190	0.062	0.220	0.197	0.308	0.240
	(0.289)	(0.306)	(0.162)	(0.122)	(0.248)	(0.139)
	[0.658]	[0.202]	[1.361]	[1.616]	[1.244]	[1.724]
D(AGRI(-2))	0.081	0.160	0.046	-0.1	0.069	0.095
	(0.291)	(0.308)	(0.163)	(0.123)	(0.249)	(0.140)
	[0.280]	[0.520]	[0.285]	[-0.818]	[0.278]	[0.681]
D(COMM(-1))	-0.211	-0.026	0.144	0.337	0.585	0.321
	(0.204)	(0.215)	(0.114)	(0.086)	(0.174)	(0.098)
	[-1.033]	[-0.124]	[1.265]	[3.912]	[3.351]	[3.269]
D(COMM(-2))	-0.353	0.104	0.005	0.286	0.471	0.231
	(0.213)	(0.225)	(0.119)	(0.090)	(0.182)	(0.102)
	[-1.658]	[0.462]	[0.046]	[3.176]	[2.585]	[2.255]
D(DOME(-1))	-0.346	-0.168	0.094	0.389	0.914	0.431
	(0.448)	(0.473)	(0.250)	(0.189)	(0.383)	(0.215)
	[-0.771]	[-0.355]	[0.377]	[2.058]	[2.383]	[2.000]
D(DOME(-2))	0.012	0.312	0.027	-0.018	0.467	0.460
	(0.454)	(0.480)	(0.254)	(0.191)	(0.388)	(0.218)
	[0.028]	[0.651]	[0.107]	[-0.097]	[1.202]	[2.111]
D(GDP(-1))	1.124	0.087	0.262	-0.404	-0.179	0.089
	(0.561)	(0.593)	(0.314)	(0.237)	(0.480)	(0.269)

	[2.001]	[0.147]	[0.834]	[-1.707]	[-0.372]	[0.333]
D(GDP(-2))	0.388	0.212	-0.014	-0.414	-0.994	-0.487
	(0.516)	(0.545)	(0.288)	(0.218)	(0.441)	(0.248)
	[0.752]	[0.389]	[-0.049]	[-1.902]	[-2.250]	[-1.963]
D(INDU(-1))	-0.584	-0.247	0.255	0.629	1.193	0.482
	(0.573)	(0.605)	(0.320)	(0.242)	(0.490)	(0.275)
	[-1.018]	[-0.408]	[0.797]	[2.601]	[2.433]	[1.751]
D(INDU(-2))	-0.245	0.568	-0.285	0.154	0.983	0.612
	(0.593)	(0.626)	(0.331)	(0.250)	(0.507)	(0.285)
	[-0.413]	[0.906]	[-0.858]	[0.615]	[1.937]	[2.147]
D(TEC(-1))	0.857	0.658	-0.627	-1.21	-1.909	-0.871
	(1.124)	(1.187)	(0.628)	(0.474)	(0.961)	(0.540)
	[0.762]	[0.554]	[-0.998]	[-2.549]	[-1.985]	[-1.613]
D(TEC(-2))	0.491	-1.399	0.272	0.0185	-1.464	-0.999
	(1.186)	(1.253)	(0.663)	(0.500)	(1.014)	(0.569)
	[0.414]	[-1.116]	[0.411]	[0.037]	[-1.443]	[-1.754]
C	0.032	0.062	0.064	0.012	-0.03	-0.002
	(0.037)	(0.039)	(0.020)	(0.015)	(0.031)	(0.017)
	[0.881]	[1.591]	[3.130]	[0.814]	[-0.971]	[-0.145]

6. 5. 8 Error Correction Diagnostic Test

Table 6.12 reports the diagnostics test result which shows that the error correction model is free from autoregressive conditional heteroscedasticity, serial correlation, and functional form. And the used model is well established.

Table 6.12 Error Correction Diagnostic Test

Diagnostic Tests	F-statistics	Prob.
Breusch-Godfrey LM Test	2.72	0.082
Heteroskedasticity Test: Breusch Pagan Godfrey	1.396	0.216
Heteroskedastictiy Test: Glejser	1.51	0.167
Heteroskedastictiy Test: ARCH	0.27	0.600

6. 5. 9 Toda & Yamamoto Granger Non-causality Test

Table 6.13 reports the result of the Toda & Yamamoto test. This result suggested a unidirectional causality from electricity consumption of the agriculture sector to the domestic sector, commercial sector to domestic sector, industrial sector to commercial sector, and total energy consumption to the domestic sector. The findings confirm a unidirectional causality from the commercial sector to GDP, agriculture sector to industry, commercial & domestic sector to the industrial sector. Finally, the result also shows a unidirectional causality from the commercial sector to the total energy sector.

Table 6.13 Toda & Yamamoto Granger Causality Result

Dependent variable: AGRI			
Excluded	Chi-sq	df	Prob.
COMM	2.569	3	0.462
DOME	1.203	3	0.752
GDP	1.177	3	0.758
INDU	1.596	3	0.660
TEC	1.122	3	0.771
All	10.391	15	0.794
Dependent variable: COMM			
Excluded	Chi-sq	df	Prob.

AGRI	2.178	3	0.536
DOME	1.524	3	0.676
GDP	0.830	3	0.842
INDU	3.347	3	0.341
TEC	3.551	3	0.314
All	10.378	15	0.795
Dependent variable: DOME			
Excluded	Chi-sq	df	Prob.
AGRI	14.291	3	0.002
COMM	22.458	3	0.000
GDP	1.642	3	0.649
INDU	11.216	3	0.010
TEC	15.937	3	0.001
All	39.537	15	0.000
Dependent variable: GDP			
Excluded	Chi-sq	df	Prob.
AGRI	2.113	3	0.549
COMM	18.238	3	0.000
DOME	0.330	3	0.954
INDU	0.752	3	0.860
TEC	1.332	3	0.721
All	45.636	15	0.000
Dependent variable: INDU			
Excluded	Chi-sq	df	Prob.
AGRI	7.579	3	0.055
COMM	15.444	3	0.001
DOME	13.404	3	0.003
GDP	2.400	3	0.493
TEC	6.526	3	0.088
All	38.239	15	0.000

Dependent variable: TEC			
Excluded	Chi-sq	df	Prob.
AGRI	4.550	3	0.207
COMM	8.989	3	0.029
DOME	6.821	3	0.077
GDP	1.418	3	0.701
INDU	5.396	3	0.144
All	19.531	15	0.190

6. 6 Concluding Remarks and Policy Suggestions

The current study investigated the sectoral electricity use and economic growth in the case of India from 1970 to 2016. The findings of the analysis show a high correlation between the variables. The result of the unit root shows all the variables are integrated of order one. The result of co-integration suggests a long-run relationship among the variables. The error correction result confirmed that in the case of shocks in the short-run there is no problem with long-run adjustments. The Toda & Yamamoto Granger causality result reveals a unidirectional causality from electricity consumption of the agriculture sector to the domestic sector, commercial sector to domestic sector, industrial sector to commercial sector, and total energy consumption to the domestic sector. The result also found that there is unidirectional causality from the commercial sector to GDP, agriculture sector to industry, commercial and domestic sector to the industrial sector. Finally, the result also found unidirectional causality from the commercial sector to the total energy sector.

The policy implication of the analysis suggests that at the sectoral levels, electricity consumption is necessary to increase the productivity in agriculture, commercial and industrial sectors in India as these sectors are highly electricity-based compared to other sectors. However, to avoid the supply crunch of electricity India should ensure an adequate supply of electricity to the required sectors. To avoid the energy crisis, government should consider power generation on a priority basis for tax relief. And the government should provide a rebate to the energy sector to encourage investment in the power sector.

CHAPTER 7

Nuclear Energy Consumption and Economic Growth in India

7. 1 Introduction

Nuclear energy is considered the essential source of energy supply for most nations (Fiore, 2006; Toth and Ragner, 2006). It is estimated that in the 1970's around 25% of the world's electricity remained produced from oil and it declined to 7.2% in 2002. Nuclear energy consumption increased to 16.6%, and nuclear energy captivated 75% of the reduction in oil contribution (Toth and Ragner, 2006).

International Energy Agency (2003) estimated that the growth of nuclear energy increases particularly in the year 2020-2040, suggesting a 14-fold rise in world nuclear energy generation in the period 2000-2050 (Toth and Ragner, 2006). According to the Nuclear Energy Agency (NEA, 2002) nuclear energy saves 1200 million tons of carbon dioxide emissions annually or around 10% of entire carbon emissions from the energy consumption in OECD nations. It is demanded that the setup of nuclear power plants have a wide influence to mitigate the GHG emissions. Recently nuclear power protects 10% of carbon emissions from world energy consumption (Adamantiades and Keseides, 2009).

The lack of alternative energy sources and variation in energy prices forced us to find out different sources of nuclear and renewable energy. In the current situation, nuclear energy has become a very important energy source because it does not produce carbon dioxide and helps to reduce environmental pollution. Expanding alternative energy and discovering steady, clean, and safe sources of energy supply come to be a vital task for energy policy makers for several nations (Fiore, 2006; Toth and Ragner, 2006; Elliot, 2007; Ferguson, 2007). To enhance energy security most of the nations increase the supply of renewable energy and minimize the dependency on imported oil and reduce the volatility of oil imports (Toth and Ragner, 2006, Villancourt et al. 2008)

Many studies believe that nuclear energy is near carbon-free energy and is also considered as a solution to global warming and energy security (Elliot, 2007; Ferguson, 2007). According to the International Energy Agency (IEA) nuclear energy is fascinating fresh attention for a rising assortment of energy supplies to enhance energy security and helps to produce little carbon to fossil fuels. Hence, the significance of nuclear energy as an impending source of energy security and carbon-free nature needs supplementary exploration to examine the causal linkage between nuclear energy consumption and economic growth. Consumption of nuclear energy not only provides energy security but also helps in maintaining environmental sustainability.

The current environmental challenges faced by India and other growing economies are focused on the growing sectoral energy demand, low-cost energy supply, and at the same time to minimize the harmful effects of GHG associated with economic progress. The excess use of non-renewable energy produces a huge amount of carbon emissions and this becomes a greater source of global warming. To reduce the use of non-renewable energy and its detrimental effect on the environment widely attracted the search for new alternative energy sources (Ohlan, 2016). To maintain sustained economic growth without raising carbon emission in emerging economies becomes an important apprehension about environmental deprivation. An emerging economy like India has become the 3rd largest economy in terms of nominal GDP and has the potential to grow quickly in the near future. However, the growth of the Indian economy is mainly determined by the dirtiest energy consumption. India has become the 3rd largest carbon emitter next to China and the United States.

At the global level, India's share of carbon emissions is 6.56 percent. Though India gains 18 % of the world population, however, the share of oil, gas, and coal reserves are 0.6%, 0.4%, and 7% correspondingly. Consequently, the energy import dependency is increasing day by day. India is producing 70% of its electricity by utilizing fossil fuels. In the total energy consumption, coal and oil contribute 40% and 24% respectively. Besides, the share of oil is 31% of the total import. Hence, in the coming years, the energy demand is predicted to increase to fulfill the requirements of economic growth (Vidyarthi, 2013). Regardless of the adequate availability of fossil fuel energy, the demand for imported energy is projected to rise 53% of India's total energy consumption by 2030. The volatility of international energy prices and disruption of global energy supply creates a larger vulnerability to the Indian energy sector. Therefore, India needs to develop alternative energy sources to fulfill the required energy demand in the immediate future.

In India, though the consumption of primary energy has considerably risen in absolute terms, the per capital consumption of energy is comparatively lower than many emerging nations. To sustain the present economic growth India needs rising energy security with energy efficiency and active policy for reducing the negative effect of carbon emissions. Energy security has to turn into a major challenge for Indian policymakers as it helps to reach the potential growth rates of 9-10% in the future. The consumption of energy in India has increased at a rate of 4.5% and the production by 2.4% of the world's total energy production, but India consumes about 3.3% of the world's total energy. Rising energy consumption is a key factor to boost economic growth. But this has environmental implications.

Hence, nuclear energy is considered the most essential alternative energy source for India to fulfill the energy requirement. Nuclear energy is the 4th largest production basis of electricity in India. Currently, India has 21 nuclear reactors operating in 7 plants, having an installed capacity of 6780MW. However, these nuclear plants generate 3.5% of India’s electricity. In the year 1970 first nuclear power plant was established. Presently, India has 6 nuclear power reactors and 2 are in process. In nuclear energy consumption, India’s rank is 4th at the international level. International Atomic Energy Agency (IAEA) reported that India is ranked is 12th in terms of power production from nuclear energy sources in 2015. But, in terms of the number of reactors India holds 6th position at the global level. To strengthen the nuclear power India has signed 123 nuclear contracts with the United States.

In the coming decades, nuclear energy is considered an important energy source due to its heavy prospective for growth, zero-emission nature, and reliable nature of production. The increasing development of nuclear power not only solves the connectivity problems of Indians but also provides a greater platform to mitigate climate change by reducing carbon emissions.

The government of India Plans to generate 25 percent of electricity from nuclear power by 2050. In the year 2011, it was estimated that nuclear power targets were set at 14.6 GB and 27.5 GB in 2020 and 2032 respectively. Though nuclear power gives only 2 percent of power generation capacity, still nuclear energy has significant importance on the overall energy mix in India. The GOI has also prepared to increase nuclear energy from 6.7 GW to 63 GW by 2032. Further, the government is also willing to sanction Rs. 3000 crore per annum to construct 10 pressurized Heavy Water Reactors (PHWR) in 10 years. These expected plans will help India to declare itself as a nuclear manufacturing hub.

Without adequate energy power, it is hard to believe India is a global power. In the year 2015 in the Paris Climate Change Conferences, India dedicated itself to raising its non-fossil fuels from 30 to 40 percent by 2030. The government of India is also projected to install 175 GW renewable power capacity by 2022.

“The combination of several factors mentioned above makes nuclear energy a credible alternative source of energy and one of the potential panaceas for greenhouse gas reductions, its enormous risks are also equally substantial (Fiore, 2006; Toth and Rogner, 2006; Elliot, 2007; Ferguson, 2007; World Energy Council, 2007; Squassani, 2009). These include nuclear terrorism, operational safety, and radioactive waste disposal (See, Toth and Ragner, 2006; IEA, 2008).” As a consequence of the alarm of nuclear explosion and health hazards, many nations have discontinued the use of their nuclear power as a source of future energy.

In the energy literature, different studies explored the linkage between energy consumption and carbon emission. However, very few researchers explored the importance of nuclear energy consumption on economic growth.

This chapter tries to investigate the effect of nuclear energy use on carbon emission and economic growth in the case of India. Though in the last two decades various researchers analyzed the role of energy consumption on economic growth in the context of India, very few studies discussed nuclear energy in the case of India. This analysis gives new insight into the nuclear energy literature in comparison to past studies. The beauty of the study is that large sample data sets and with important control, variables have been taken to provide comprehensive findings for the study period.

7. 2 Review of Literature

Destek (2015) studied the causal linkage between nuclear energy use and economic growth for different sample periods. By employing the bootstrap rolling window causality the findings show nuclear energy consumption has a significant effect on economic growth in the case of Canada only. The result also reveals that in the context of the UK no causal relationship is established between the variables.

Alam A. (2013) studied the relationship between nuclear energy consumption and economic growth in the context of 25 developing and developed nations for the period 1993-2010. By employing the panel causality and error correction econometric model the analysis found a short-run causality from carbon emission to economic growth. The result also shows that the consumption of nuclear energy affects carbon emissions and a short-run causality is obtained from economic growth to carbon emissions.

Apergis and Payne (2010) examined the role of nuclear energy consumption on economic growth in the context of 16 nations from 1981-2005. The study employed panel econometric methods for the analysis of the variables. The empirical findings of the study show a bi-directional causality between economic growth and nuclear energy use. Further, the analysis reveals causality from nuclear energy use to economic growth.

Yoo and Ku (2009) studied the importance of nuclear energy use on economic growth in six nations namely, Switzerland, Korea, France, Pakistan, Germany, and Argentina. The analysis used annual data spanning from 1985-2005. By using the time series econometric technique the study found inconsistent results for the six countries. The result also reveals economic growth affects nuclear energy use in the case of Pakistan and France. Conversely, the findings again show causality from nuclear energy use to economic growth in the context of Korea.

Wolde-Rufael (2010) explored the linkage between nuclear energy consumption and economic growth in India from 1969-2006. By employing the bound testing co-integration and Granger causality econometric method the empirical result shows that economic growth is influenced by nuclear energy consumption.

Heo, et al. (2011) examined the causal linkage between nuclear energy consumption and economic growth in India from 1969-2006. The study includes GDP constant 2010 US$ and nuclear energy uses in million terms of oil equivalent. By employing the co-integration and error correction test the study found that a unidirectional causality between nuclear energy use and economic growth.

Rani and Kumar (2017) analyzed the effect of nuclear energy consumption on carbon emission in India from 1969-2014. The study includes nuclear energy use, non-renewable energy, carbon emission, and trade openness for analysis. The finding shows that nuclear energy use cuts carbon emission whereas non-renewable energy increases carbon emission.

Al-Mulali (2014) studied the effects of nuclear energy use on economic growth for 30 nuclear energy-consuming nations from 1990-2010. The findings reveal that nuclear energy has a positive long-run impact on economic growth for all countries.

Back (2016) examined the impact of renewable and nuclear energy use on carbon emission in the context of the U.S. for the period 1960 to 2010. The empirical findings of the analysis indicate nuclear energy use minimizes the rate of carbon emissions whereas renewable energy use increases the carbon emissions.

Menyah & Wolde-Rufael (2010) explored the causal linkage between carbon emissions, renewable energy, nuclear energy, and economic growth in the context of the U.S. from 1960-2007. By employing the modified causality test the study found causality from nuclear energy consumption to carbon emission.

Ozcan & Ari (2015) investigated the role of nuclear energy consumption on economic growth for 15 OECD nations for the period 1980-2012. By using the bootstrap causality test the study found the presence of neutrality hypothesis for 10 nations. The result also found no causality between nuclear energy consumption and economic growth.

Naser (2015) explored the importance of nuclear energy consumption on economic growth in the context of four industrial nations namely France, U.S., Japan, and Canada for the period 1965-2010. By using the Toda & Yamamoto Granger causality method the empirical result found a causality from nuclear energy consumption to economic growth in the case of Japan. The findings again reveal no causality in the case of the U.S. and Canada.

Lee and Chiu (2011) explored the dynamic linkage between oil price, economic growth, oil use, and nuclear energy use for developed nations from 1971-2006. By employing the panel data methods the study found that oil price has a positive impact on nuclear energy consumption in the long run. The result also shows that real income has a positive effect on nuclear energy in the long run. Further, the findings indicate a unidirectional causality from oil price and economic growth to nuclear energy use.

Al-Mulali (2014) explored the importance of nuclear energy consumption on GDP growth and carbon emissions in the context of 30 major nuclear energy-consuming nations covering the period from 1990-2010. By using the panel data methods the findings show that nuclear energy consumption has a significant impact on GDP growth in the long run while the consumption of nuclear energy has a neutral effect on carbon emissions. The findings also reveal that nuclear energy consumption has a positive short-run causal linkage with GDP growth.

Naser (2014) studied the linkage between nuclear energy use, economic growth, oil consumption, and oil price in the context of four emerging nations (Russia, India, Korea, and China) for the period 1965-2010. The analysis used the modified Granger causality method and found that world crude oil price plays an important role in determining the economic growth in these nations. The result also shows a causality from oil consumption to GDP growth in the case of India. Again, the findings suggest that nuclear energy use encourages economic growth in both South Korea and India.

Wolde-Rufael & Menyab (2010) examined the linkage between nuclear and renewable energy use, carbon emission, and real GDP in the context of the U.S. covering the period from 1960-2007. By employing the method of modified Granger causality the result shows a unidirectional causality from nuclear energy consumption to carbon emission. The result also suggests that nuclear energy helps to mitigate carbon emissions.

Chiu & Lee (2011) investigated the dynamic linkage between oil price, nuclear energy consumption, oil consumption, and real income for six industrialized nations from 1965-2008. The analysis used co-integration, Granger causality, forecast error variance decomposition methods. The empirical results of the study show oil price and nuclear energy consumption as substitutes in the case of the U.S. and Canada while they are complementary in the context of France, Japan, and the U.K. Further, the result also reveals a causality from real income to nuclear energy consumption in Japan.

Chang and Chu (2012) examined the role of energy consumption in promoting economic growth in the context of G-6 nations from 1971-2010. By employing bootstrap panel Granger causality the result shows a causality from nuclear energy to economic growth in the case of Japan, the UK, and the US. The result also found a causality from economic growth to nuclear energy consumption in the context of the U.S. The result again confirms that there is an absence of causal linkage between nuclear consumption and economic growth in the case of Canada, France, and Germany.

Kayhan, et al. (2011) examined the causal linkage between nuclear energy consumption and economic growth in the context of OECD nations from 1980-2007. The study includes nuclear energy use, capital, growth, and labor force. By employing the panel econometric techniques the result shows that there is no causality between nuclear energy use and economic growth in 11 nations out of 14 countries.

Chaibi and Omri (2014) analyzed the causal relationship between renewable and nuclear energy consumption and economic growth for 17 developing and developed nations. The analysis employed the dynamic panel econometric techniques. The empirical findings show causality from nuclear energy consumption to economic growth in the case of Sweden, Canada, Bulgaria, and the Netherlands. The result also reveals bi-directional linkage in the context of the USA, Pakistan, Brazil, Argentina, and France. Further, the study supports the neutral causality in the case of the U.K. India, Japan, Finland, Hungary, and Switzerland.

Taylor and Payne (2008) investigated the linkage between nuclear energy use and GDP growth in the context of the U.S. from 1957-2006. By using the Toda &Yamamoto Granger causality technique, they found no causality between the variables supporting the neutrality hypothesis of energy consumption.

Ari and Ozcan (2015) explored the causal relationship between nuclear energy consumption and economic growth for 15 OECD nations for the period 1980-2012. The analysis used the bootstrap causality method. The empirical findings indicate no causality between the variables and support a neutrality hypothesis for 10 nations out of 15 countries. The results also reveal causality between growth and nuclear energy consumption.

7. 3 Data and Period of the Study

The present study used annual data spanning the period from 1971-2019. The analysis includes GDP per capita (constant 2010 US dollar), Foreign Direct Investment (FDI, current US $), nuclear energy consumption % of total energy, and CO2 emissions (metric tons per capita). All the variables are cumulated from World Development Indicators (WDI), World Bank. All the variables were converted into natural logarithm form.

7. 4 Model Specification

7. 4. 1 Unit Root Test

In the time series analysis stationary test plays a very significant role. To examine the stationary properties of the variable our study employed the ADF and PP tests. This stationary test helps to avoid specious and bias results. To eradicate such problems this study used unit root tests.

$$\Delta Y_t = \alpha + \alpha_2 Y_{t-1} + \sum_{i=1}^{p} \beta_i \Delta Y_{t-1} + \varepsilon_t \qquad (1)$$

Here the choice variables are Y; the first difference operator is Δ, α and β are constant parameters; ε_t is the error term. The Akaike Information Criteria (AIC) is chosen to select the lags. To examine the order of integration the equation includes the second difference on lagged first. The second difference lags p follows as

$$\Delta^2 Y_t = \theta_1 \Delta Y_{t-1} + \sum_{i=1}^{p} \theta_i \; \Delta^2 Y_{t-1} + \epsilon_t \qquad (2)$$

Where the second difference operator is Δ^2, $\theta_1$and $\theta_i$are constant parameter; ϵ_t is the stochastic process for stationary. To test the stationarity ADF and PP model are applied to equations 1 and 2. The null hypothesis H_0: $\alpha_2 = 0$ against H_1: $\alpha_2 \neq 0$ and H_0: θ_1=0 against H_1: $\theta_1 \neq 0$ correspondingly, which indicates non-stationary of both Y_{t-1} and ΔY_{t-1}.

7. 4. 2 Lag Selection Criteria

The model selection criteria are used to define the lag selection for the VAR (P) model. The common way to suitable VAR (P) methods with orders P = 0, …, 0_{max} and define the value of P which reduces certain model selection conditions. The VAR (P) method has the following form.

$$\ln(p) = \ln\left|\widetilde{\sum(p)}\right| + C_r . \varphi\,(n, p)$$

"$\widetilde{\sum(p)}$ = T^{-1} $\sum_{T=1}^{T} \widehat{\varepsilon_t}\, \acute{\widehat{\varepsilon_t}}$ is the residual covariance matrix without a degree of freedom correction from a VAR (p) model, T is a sequence indexed by the sample size T, and (n, p) is a penalty function that penalizes large VAR (P) models."

The three information criteria are AIC, BIC, and HQ.

$$AIC\ (p) = \ln\left|\widetilde{\sum(p)}\right| + \frac{2}{T}\, pn^2$$

$$BIC(p) = \ln\left|\widetilde{\sum(p)}\right| + \frac{lnT}{T}\, pn^2$$

$$HQ\ (p) = \ln\left|\widetilde{\sum(p)}\right| + \frac{2\ln lnT}{T}\, pn^2$$

"Where AIC overestimates the order with positive probability asymptotically, the BIC and HQ criteria guess the order consistently under fairly general conditions if the true order p is less than or equal to p_{max}."

7. 4. 3 Long-run Model

To explore the long-run linkage among the variables the analysis employed the following liner logarithmic form.

$$LNGDP_t = \alpha_0 + \beta_{01}LNFDI_t + \beta_{02}LNCO2_t + \beta_{03}LNCEC_t + \epsilon_t \quad (1)$$

Where t = time period =1, 2,..n.

7. 4. 4 ARDL Bound Testing Cointegration Approach

The ARDL model estimates the unrestricted error correction model. The model representation is shown in equation 2.

$$\Delta LNGDP = \alpha_0 + \sum_{i=1}^{n} b_{1i}\Delta LNGDP_{t-i} + \sum_{i=1}^{n} b_{2i}\Delta LNFDI_{t-i} + \sum_{i=1}^{n} b_{3i}\Delta LNCO2_{t-i} + \sum_{i=1}^{n} b_{4i}\Delta LNCEC_{t-i} + \delta_1 LNGDP_{t-1} + \delta_2 LNFDI_{t-1} + \delta_3 LNCO2_{t-1} + \delta_4 LNCEC_{t-1} + \epsilon_{1t} \quad (2)$$

F-test is employed to test whether a co-integration linkage exists between the variables. The null hypothesis of no co-integration among the variables in Eq- (2) is $H_0;\ \delta_1 = \delta_2 = \delta_3 = \delta_4 = 0$, against $H_1;\ \delta_1 \neq \delta_2 \neq \delta_3 \neq \delta_4 \neq 0$, which is signified as F LNGDP (LNGDP/LNFDI, LNCO2, and LNCEC).

7. 4. 5 Unrestricted Error Correction Test

To know the short-run dynamics we have estimated the error correction model (ECM), the equation as follows

$$\Delta LNGDP = \alpha_0 + \sum_{i=1}^{n} b_{1i}\Delta LNGDP_{t-i} + \sum_{i=1}^{n} b_{2i}\Delta LNFDI_{t-i} + \sum_{i=1}^{n} b_{3i}\Delta LNCO2_{t-i} + \sum_{i=1}^{n} b_{4i}\Delta LNCEC_{t-i} + \delta_1 LNGDP_{t-1} + \delta_2 LNFDI_{t-1} + \delta_3 LNCO2_{t-1} + \delta_4 LNCEC_{t-1} + \theta ECT_{t-i} + \epsilon_{1t} \quad (3)$$

7. 5 Empirical Results

7. 5. 1 Co-movement analysis

The co-movement result is reported in table 7.1. From table 7.1, it is observed that a high pairwise correlation exist between the variables.

Table 7.1: Co-movement Analysis

	LNGDP	LNFDI	LNCO2	LNCEC
LNGDP	1.00			
LNFDI	0.94 [19.53] (0.00)	1.00		
LNCO2	0.98 [37.07] (0.00)	0.95 [20.87] (0.00)	1	
LNCEC	0.62 [5.27] (0.00)	0.42 [3.08] (0.00)	0.54 [4.28] (0.00)	1.00

Note: * indicates the 1 percent level of significance, [ ] shows the t values and parenthesis ( ) denotes the probability values.

7. 5. 2 Unit Root Test

Table 7.2 reports the unit root test results. The unit root test result reveals that the null hypothesis cannot be rejected at their levels for all the variables. But, at their first difference, the null hypothesis is rejected for all the variables and hence, it is observed that all the variables are integrated of order 1 that is I (1). Thus, the unit root test result helps to investigate the long-run relationship between the variables by using ARDL bound testing method which is autonomous of the order of integration.

Table 7.2: Unit Root Test

Variables	ADF Test		PP Test	
	Level	First Difference	Level	First Difference
lngdp	3.82	-6.37*	5.80	-6.39*

	(1.00)	(0.00)	(1.00)	(0.00)
Lnco2	0.85 (0.99)	-6.77* (0.00)	0.81 (0.99)	-6.78* (0.00)
lncec	-0.92 (0.77)	-8.76* (0.00)	-0.65 (0.84)	-8.76* (0.00)
lnFDI	-1.11 (0.70)	-7.30* (0.00)	-0.95 (0.75)	-9.69* (0.00)

Note: * shows 1 percent level of significance and the parenthesis ( ) specifies the probability values

7. 5. 3 Lag Order Selection Criteria

Table 7.2 reported that all data attained stationarity in the first difference. Hence, the study used the co-integration test to verify the long-run linkage between the variables. As we know, the co-integration test is constructed on the Maximum Likelihood estimation with the VAR model. Therefore, before the use of VAR, it is essential to know the lag length. The following table 7.4 indicates that the optimal lag is one.

Table 7.3: Lag Order Selection Criteria

Lag	LogL	LR	FPE	AIC	SC	HQ
0	17.19	NA	6.07	-0.65	-0.49	-0.59
1	221.52	357.56*	4.97*	-10.07*	-9.23*	-9.77*
2	234.65	20.36	5.89	-9.93	-8.41	-9.38
3	239.97	7.17	1.07	-9.39	-7.20	-8.60

Note: * shows lag order

7. 5. 4 ARDL Cointegration Test

Table 7.4 reported the long-run results. The long-run result reveals that FDI has a positive and substantial effect on economic growth. An increase in foreign direct investment increases economic growth. The result further shows that carbon emission has a positive impact on economic growth. This indicates the country requires a huge amount of energy of consumption to boost its economic growth. Furthermore, the findings show that nuclear energy consumption has a positive and statistically noteworthy influence on economic growth. This result suggests India requires a heavy amount of nuclear energy to raise its economic growth. Moreover, more use of nuclear energy consumption cuts the carbon emission.

The short-run result is presented in the following table 7.4. The short-run result shows that carbon emission and nuclear energy use have a progressive and statistically substantial effect on economic growth in the short run. The statistical significance of the error correction term ECT_{t-1} with a negative sign indicates the speed of adjustment towards the long-run equilibrium after disequilibrium in the short run. This indicates that any unconventionality from the long-run equilibrium between the variables is corrected in each period and restored to the long-run equilibrium subsequently disequilibrium in the short-run.

Table 7.4: ARDL Long-run and Short-run Result

Depd. –GDP	Long-run Result			
Variables	Coeff.	S.E	t-stat.	Prob.
LNFDI	0.05	0.02	2.13	0.03**
LNCO2	0.81	0.18	4.48	0.00*
LNCEC	0.36	0.16	2.16	0.03**
C	5.39	0.68	7.92	0.00*
Short-run Result				
Variables	Coefficient	S.E	t-stat.	Prob.
CointEq (-1)	-0.15	0.05	-3.05	0.00*
D(LNFDI)	0.00	0.00	0.23	0.81
D(LNCO2)	0.28	0.12	2.35	0.02**
D(LNCEC)	0.17	0.04	3.63	0.00*

Note: * and ** indicates 1% and 5% levels of significance.

The findings of the ARDL bound testing result are reported in table 7.5. The ARDL result shows that the estimated F-statistics are higher than the critical values of both upper bound and lower bound. This ARDL result confirms that there is a long-run equilibrium relationship between the variables.

Table 7.5: ARDL Model for Cointegration Test

F-statistics	**Significance Level**	**Lower Bound I(0)**	**Upper Bound I(1)**
		Critical Values	Critical Values
7.22*	1%	4.29	5.61
	2.5%	3.69	4.89
	5%	3.23	4.35
	10%	2.72	3.77

Note: * indicates 1% level of significance.

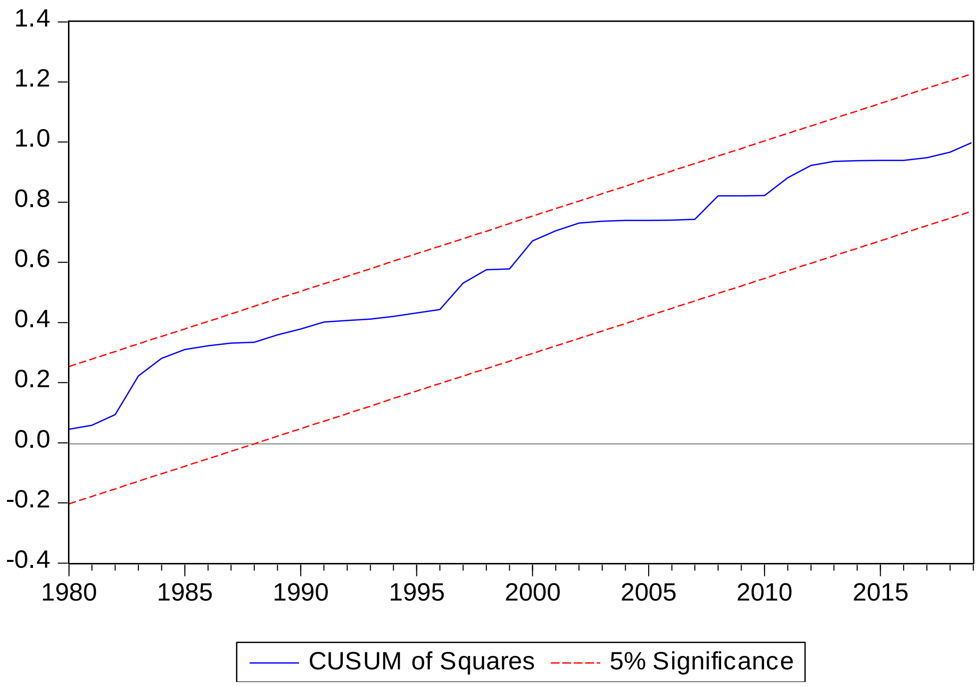
Table 7.6: Diagnostic Result

Tests	**F-stat.**	**Prob.**
Breusch-Godfrey Serial Correlation LM Test	0.22	0.79
Heteroskedasticity Test: Breusch-Pagan-Godfrey	0.39	0.90
Heteroskedasticity Test: Glejser	0.20	0.98
Heteroskedasticity Test: ARCH	0.06	0.79

Table 7.6 reports the ARDL diagnostic test result. The result of the diagnostic test shows that ARDL bound testing approach is free from serial correlation, autoregressive conditional heteroscedasticity, and functional form, and the method is highly specified.

Figure 7.1: CUSUM Squares Test

The CUSUM Squares test shows that the model is stable and free from instability bias figure 7.1.



7. 6 Concluding Remarks and Policy Suggestions

The chapter explored the importance of nuclear energy consumption and economic growth in India covering the period from 1971-2019. The result of the analysis shows a high pairwise correlation between the variables. The result of the unit root test indicates all the variables attained stationarity after the first difference and they are integrated of order one. The study employed ARDL model of co-integration which is independent of the order of integration. The result of ARDL model suggests that FDI has a positive and statistically substantial effect on economic growth in India. This suggests India requires a huge amount of energy use to boost its economic growth. The findings again reveal that nuclear energy consumption has a positive and statistically substantial influence on economic growth. This suggests that India should use a heavy amount of nuclear energy to raise its economic growth. Furthermore, increasing the consumption of nuclear energy helps to mitigate carbon emissions in India. The short-run findings reveal that carbon emission and nuclear energy use have a positive and statically substantial effect on economic growth in the short run. The statistical significance of the error correction term ECT_{t-1} with a negative sign is an indication of the speed of adjustment towards the long-run equilibrium subsequently disequilibrium in the short-run.

Furthermore, the bound testing result of the co-integration test suggests that the estimated F-statistics is higher than the critical values of both higher bound and lower bound. This result of bound testing confirms a long-run equilibrium linkage among the variables. The diagnostic test result suggests that the model is free from serial correlation, ARCH, and functional forms and the model is well specified. The CUSUM squares test found that the model is stable and free from instability bias.

The policy implication of the study suggests that India should raise the consumption of nuclear energy to meet the growing demand for energy requirements. Moreover, in comparison to fossil fuel energy, nuclear energy consumption helps to mitigate carbon emissions and protect the environment. To avoid an energy crisis India should develop nuclear power reactors to achieve the targeted growth rates. Moreover, the study also suggests that India should increase the FDI flow because FDI will help to transfer new ideas, managerial expertise, and transfer of advanced technology to domestic firms. This will help to cut down the carbon emissions and boosts economic growth in India.

CHAPTER 8

Conclusion and Policy Implications

8.1 Key Findings and Policy Implications

The significant empirical findings of the study are presented in the following manner based on the research questions of chapter one.

The first objective of our study, which was to examine the trends and patterns of energy use, production, and distribution of the energy sector in India, is presented in chapter 3. The empirical evidence of chapter 3 indicates that energy security for India could be achieved through the constant availability of commercial energy to increase its growth level. The Indian energy sector faces terrible tasks in supporting an adequate amount of energy supply and developing alternative energy sources to meet its growing energy demand. Increasing energy efficiency and reducing the energy intensity of GDP growth help India meet its current energy challenges. In this context, energy planning through demand-side management is one of the most viable, feasible, and cost-effective options for our country.

The change due to technology has helped reduce the intensity of both the fuels, i.e., coal and petrol; however, sadly, in the case of electricity, the story is not good. This is primarily because electricity is provided to several sectors, especially agriculture, at a subsidized rate which efficiently prevents usage of the same.

It can well be observed that the previous energy policies fail to allocate the energy efficiency, consumption, and production of energy. However, there are many obstacles to increasing energy efficiency; like lack of technological know-how, training, shortage of capital, market imperfections, entrepreneurial inefficiency, and existing legislation. The biggest impediments are the external costs of energy use and subsidized, traditional legislation and rules, and heavy transaction costs.

Improvement in energy efficiency could be achieved by adopting advanced technology and structural changes in organizations. In a diverse country like India, a discrepancy of profit expectations of energy demand and supply is also a hurdle. The lack of awareness about energy efficacy among minor energy consumers increases risk sensitivities. Moreover, different energy users and dealers anticipate the diverse rate of return on investments.

The study's second objective was to investigate the role of renewable and non-renewable energy

use on economic growth in 29 developed and developing nations, which is discussed in chapter 4. The empirical findings of chapter 4 show that this study validates the relevance of energy use, including both renewable and non-renewable energy, to correct GHG levels both for developed and developing nations. By employing the latest development of panel econometric tools, the empirical findings of the study show cross-sectional dependence among the variables. The result of the Pesaran Cross-sectional Augmented Dickey-Fuller (PCADF) panel second-generation unit root test suggests that all the variables attain stationarity at a different order of integration, i.e., I (0) & I (1). In other words, all other variables earned stationarity at first difference except for non-renewable energy and gross fixed capital formation. Since the study found a different order of integration, we have employed the panel autoregressive distributed lag model to examine the long-run and short-run relationship. The panel ARDL model confirms that in the long run, carbon emission has a negative and statistically significant impact on economic growth in all the countries. Whereas non-renewable energy, renewable, and capital stock have a positive and statistically significant impact on economic growth in all the countries at one percent level of significance.
The speed of adjustment reflected by the coefficient of convergence is negative and significant in all the three estimators (PMG, MG, and DFE), indicating no omitted variable bias. The short-run result reveals that carbon emission, capital stock, and renewable energy consumption show the short-run causality with economic growth. The short-run consequence of the mean group found causality from capital stock to economic growth. The dynamic fixed effect model found that renewable energy and capital stock show short-run causality with economic growth. The Hausman test measures the efficacy and reliability among the estimators (PMG, MG, and DFE). The Hausman test result accepts the null hypothesis of homogeneity restrictions in the long-run regression, which indicates that PMG is more efficient than MG and DFE.

The empirical result of our study provides policymakers a better understanding of the nexus between energy consumption and economic growth to formulate energy policy in these countries. The important policy implications of this study suggest that all the countries should use both renewable and non-renewable energy to achieve their targeted growth rate. At the same time, the policy makers of these countries should give importance to reducing carbon emissions for the sustainability of the environment and give more priority to using renewable energy, which will help maintain energy security, energy efficiency, and environmental sustainability for all these countries.

The third objective of the study was to examine the existence of the environmental Kuznets curve hypothesis in the case of India, which is analyzed in chapter 5. Chapter 5 employed co-movement analysis and found that there is a high correlation between the variables. The ARDL bounds testing result suggests a long-run equilibrium relationship among the variables when carbon emission is the dependent variable. The long-run cointegration result reveals that energy consumption positively impacts carbon emission. The negative square of GDP indicates the existence of the EKC hypothesis in India. This confirms that environmental pollution rises primarily with economic growth but reduces after the income touches a calming point. The error correction result with a positive sign of per capita energy consumption indicates that in India, for each 1 percent increase in energy consumption, per capita CO_2 emission also increases by 1.86 percent. The statistical significance of the error correction term ECT_{t-1} with an appropriate sign (-) indicates the speed of adjustment towards the long-run equilibrium after disequilibrium in the short run.

The policy recommendation of the study suggested that India should increase its energy consumption to meet the growing energy demand and boost its economic growth. At the same time, India should encourage investment in energy infrastructure and address the uneconomical energy use. The study also suggests that India design good environmental policies to pave the low carbon emission path. Further, energy market reforms, the inclusion of cleaner technology, development of alternative renewable energy sources, transfer of technology, and international collaboration helps India to monitor a low carbon emission and achieve a sustainable growth path. Promoting further uses of renewable energy seems to be the ideal way to combat global warming and reduce carbon emissions. This will enable to promote of energy security further.

The fourth objective of the study was to examine the sectoral electricity consumption and economic growth in India. An empirical study from 1970 to 2016 is presented in chapter 6. The empirical analysis of chapter 6 suggests a high pairwise correlation between the variables. The unit root test result shows that all the variables are integrated into order one. The cointegration result indicates a long-run equilibrium relationship among the variables. The error correction result confirmed no problem for adjustment in the long run in case of shocks in the short run. The Toda-Yamamoto Granger causality result reveals that there is unidirectional causality from electricity consumption of agriculture sector to domestic sector, commercial sector to domestic sector, industrial sector to commercial sector, and total energy consumption to the domestic sector. The result also found unidirectional causality from the commercial sector to GDP, agricultural sector to industry, commercial and domestic sector to industrial sector. Finally, the result found unidirectional causality from the commercial sector to the entire energy sector.

From the policy implication point of view, the study suggests that at the sectoral levels, electricity is essential to boost productivity in agriculture, commercial and industrial sectors in India because they are more electricity-based sectors compared to the other sectors. However, to avoid the supply crunch of electricity, India should ensure a sufficient electricity supply to the essential sectors. The government should also consider the power generation sector on a priority basis for tax relief or rebates to improve the energy sector's investment climate to eliminate the energy crisis.

The fifth objective of the study was to evaluate the importance of nuclear energy consumption and economic growth in India, covering the period from 1971-to 2019 discussed in chapter 7. The result of the analysis shows a high pairwise correlation between the variables. The unit root test result indicates that all the variables attain stationarity after the first difference and are integrated of order one. The study employed the ARDL model, which is independent of the order of integration. The result of the ARDL model suggests that FDI has a positive and statistically significant effect on economic growth in India. This suggests India requires a huge amount of energy to boost its economic growth. The findings reveal that nuclear energy consumption has a positive and statistically substantial influence on economic growth. This suggests that India should use heavy nuclear energy to raise its economic growth.

Furthermore, increasing the consumption of nuclear energy helps to mitigate carbon emissions in India. The short-run findings reveal that carbon emission and nuclear energy use have a positive and statistically substantial effect on economic growth in the short run. The statistical significance of the error correction term ECT_{t-1} with a negative sign indicates the speed of adjustment towards the long-run equilibrium subsequently disequilibrium in the short-run.

Furthermore, the bound testing result of the cointegration test suggests that the estimated F-statistics is higher than the critical values of both higher bound and lower bound. This result of bound testing confirms a long-run equilibrium linkage among the variables. The diagnostic test result suggests that the model is free from serial correlation, ARCH, and functional forms, and the model is well specified. The CUSUM squares test found that the model is stable and free from instability bias.

The policy implication of the study suggests that India should raise the consumption of nuclear energy to meet the growing energy demand. Moreover, compared to fossil fuel energy, nuclear energy consumption helps mitigate carbon emissions and protect the environment. India should develop nuclear power reactors to avoid an energy crisis to achieve the targeted growth rates. Moreover, the study also suggested that India should increase the FDI flow because FDI will help transfer new ideas, managerial expertise, and advanced technology to domestic firms. This will help cut down the carbon emissions and boosts economic growth in India.

8.2 Research Shortcoming and Way for Further Study

Though the recent study has been analyzed to use as many explanations as possible and employed the most recent developed econometric tools and methods, this study still has certain shortcomings. The limitation of this study is the limited sample size because of the inaccessibility of data on renewable energy use. Furthermore, this study examined the linkage between both renewable and non-renewable energy use and economic growth at an aggregate level. This might be a challenge to collect disaggregated data on renewable and non-renewable energy use. If disaggregate data could be obtained, it would be an effective research area for upcoming studies. An additional way of forthcoming study would be to investigate the linkage between diverse bases of energy and output and altered segments that could offer policymakers to consider the problem of energy substitution.

Energy prices are well recognized as operational features on energy use to understand the impact of energy consumption on economic growth. Nevertheless, because of the unavailability of the prices for the precise energy categories, such aspects have not been studied on renewable and non-renewable energy use in this study.

"The result from the time series model in this research should be interpreted with caution due to limited sample size. The relationship between energy, GDP, and CO_2 emissions may have changed over time. Such changes could not be investigated due to the limited sample period Vaona (2010)”

"Lindmark (2002) investigated the EKC pattern in long-run historical perspective for CO_2 emissions in Sweden for 150 years. Similar tasks can be performed in India and other countries if reliable and longer time series can be constructed and made available for energy consumption and other variables. There could be significant variations of the coefficients across countries due to the variation in local policies on emission reduction. This can also be explored in future research."

The analysis also reported the unavailability of sectoral prices for particular energy. Hence, such energy deals with a variety of products, and there are possible changes in the demand and use of each product within a sector. So, being based on a single price might affect the elasticity of substitution.

A higher frequency data, preferably monthly or quarterly, would provide better results. Likewise, specific utility data related to a particular sector could be effectively helpful for a higher level of aggregation and inter-fuel substitution. Decomposing energy to sub-type to conduct a more detailed investigation of causality will give better policy information.

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ORIGINAL PAPER

Renewable and non-renewable energy consumption and economic growth in G7 countries: evidence from panel autoregressive distributed lag (P-ARDL) model

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Abstract

This paper aims to investigate the relationship between renewable and non-renewable energy consumption and economic growth in the G7 countries (Canada, France, Germany, United Kingdom, Italy and the United States) for the period of 1990–2015. The study used the Pesaran CADF panel second generation unit root test to verify the stationary properties of the variables. To examine the short-run and long-run dynamics the study employed panel autoregressive distributed lag (P-ARDL) model. The empirical findings suggest that there is a presence of cross-sectional dependency among the variables. The panel ARDL model confirms that energy price, labor force, and capital stock have positive and statistically significant long-run impact on economic growth in the G7 countries. The short run dynamics of the result recommend that there is a short run causality between non-renewable energy consumption and economic growth and capital stock to economic growth. The Hausman test found that PMG is more efficient than MG and DFE.

Keywords Energy · Renewable · Non-renewable · Carbon emission · Economic growth · PMG · MG · Panel ARDL · G7

JEL classification Q43 · C32

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1 Introduction

The relationship between energy consumption and economic growth is one of the most important topics in the energy economics literature. One of the basic reasons for focusing on this topic is that energy consumption indicates considerable promise in understanding the role of energy consumption in economic growth through production or consumption approach. In the recent times growing climate change due to carbon emission became a global threat to all the nations. All countries are using both renewable and non-renewable energy to meet their growing demands for energy. We all know that, fossil fuel energy generates the greatest amount of carbon dioxide as a result of which it degrades the global environment seriously. Especially, it is frequently seen in G7 countries that are industrialized in nature and expanding their economic actions and increasing production level. The studies based on G7 countries (Soytas and Sari 2003, 2006 and Narayan and Smyth 2008) found that energy consumption leads to economic growth in the G7 countries. Hence, their demand for energy consumption has increased in the recent years. Therefore, the socioeconomic significance of energy demand has created the recent debate among researchers and development practitioners. This proposes that G7 countries need to be cautious about the efficient use of energy and the use of different sources of energy (i.e. renewable and non-renewable). Otherwise, these countries will face greater challenges from rising CO_2 emissions linked to increased energy consumption.

In this perspective, the consequence of the challenges is multifolds for developing and industrial countries of the world. For instance, developing countries are often experiencing climate change (i.e. rising sea levels, cyclones, droughts and flood), which is primarily caused by rising CO_2 emissions and thereby leads to global warming at the regional and global levels. Developing countries also face the loss of environmental quality due to increased CO_2 emissions, climate changes, and global warming. Environmental degradation not only hampers the viability of sustainable economic development in the long run, but also adversely affects the quality of life and living standards of people in the economy. Taking these challenges together, one can claim that climate change is reflected as an urgent and serious environmental issue in the field of energy and ecological economics. In the recent statistics of the Intergovernmental Panel on the Climate Change (IPCC 2006), CO_2 emission is one of the most potential determinants in increasing greenhouse gas (GHG) emissions in the world, as it accounts for 76.7% of total GHG emissions. A fossil fuel energy mix, deforestation and other sources contribute 56.6%, 17.3%, and 2.8% respectively. This shows that carbon dioxide is largely responsible for more than 76% of the greenhouse effect. Therefore, the issue of growing per capita CO_2 emissions is used as one of the proxy indicators for measuring environmental pollutants. The growing CO_2 emissions constitutes a major ingredient of global warming and climate change and has become a serious concern worldwide in recent years (Holtz-Eakin and Seldom 1995; Ozturk and Acaravie 2010; Kijima et al. 2010; Behera 2015a, b; Raza et al. 2015; Behera 2015a, b; Behera 2016, 2017). Because of the harmful effects of global warming and climate change, policy makers in developing countries have become progressively interested in decreasing the adverse effect of environmental degradation on the economy by suggesting suitable policy tools such as environmental taxation and increased use of renewable energy.

According to the International Energy Agency (2007) renewable energy (like solar, wind, geothermal, wave and tidal), at an average annual growth rate of 6.7% is expected to become the fastest growing segment of the energy industry over the period 2005–2030.Based on the significant role that renewable energy consumption is starting to play in satisfying future energy needs, it is surprising that too little research has been performed on the empirical modeling of the relationship between renewable energy consumption and income.

With the growing concern over the environmental consequences of Green House Gas emissions from fossil fuels, high and volatile energy prices and the geopolitical climate surrounding fossil fuel production, renewable energy sources have emerged as an important component in the World energy consumption mix. According to International Energy Outlook 2010, renewable energy is projected to be the fastest-growing World energy sources. Specifically, World renewable energy use for electricity generation will grow at an average rate of 3% per year and renewable energy consumption will increase by 2.6% per year over the period from 2007 to 2035. As a result, the renewable share of World electricity generation will increase from 18% in 2007 to 32% in 2035. Hydroelectricity and wind energy are projected as the largest share of total renewable electricity generation at 54% and 36% respectively.

Given the importance of renewable energy in the discussion of a sustainable energy future, it is important to understand the dynamics of renewable energy consumption and economic growth. In this context, the literature on energy consumption and economic growth has been widely examined (Chien and Hu 2008; Ozturk 2010; Apergis et al. 2010; Payne, 2010a, b; Menyab and Wolde-Rufael 2010; Menegaki 2011). Studies on renewable energy consumption have been undertaken only recently. Unlike previous studies in this area, this study takes the simultaneous use of renewable and non-renewable energy consumption to differentiate the relative impact of each in the growth process. Another reason, which prompts researchers to focus on this link between energy consumption and economic growth, is the vision of sustainable development. The fact that many countries agreed on preserving energy and decreasing CO_2emissions has increased the attractiveness of energy consumption related studies. However, the key dynamics of these studies is the consumption of renewable sources. With the growing importance of sustainable development, academicians have become more interested in the effects of renewable energy consumption, which has begun to be seen as one of the most vital components in the total energy consumption of the World.

In this regard, this study aims at investigating the long-run and short-run dynamics between renewable and non-renewable energy consumption and economic growth. And creating a comparison between renewable and non-renewable energy sources to determine which type of energy consumption is essential for economic growth in the G7 countries for the period 1990–2015. The reason for choosing G7 economies is that, they are the ones who consumed 36.6% of World Total energy production and caused 33.7% of World's total CO_2 emissions, over the period 2000–2008 (WDI, World Development Indicator 2012). The other reason for choosing G7 countries is that, they are considered as the most industrialized in the world economy because of their potential output contribution to the world gross domestic product (GDP), the share of energy demand and the share of CO_2 emissions to world energy demand. In this way, it is obvious that they function in the world economy as a recognized group that influence an open global economy and successive implementation of environmental policies.

The main contributions of this paper are as follows: First, the study used the panel cross-sectional dependency test. The study also employed the panel second generation unit root test proposed by Pesaran Cross -sectional Augmented Dickey- Fuller (CADF) test which is more robust than other traditional unit root tests. Secondly, The study used the panel Autoregressive Distributed Lag Model (P-ARDL) by Pesaran et al. (1999). The panel ARDL includes: Pooled Mean Group (PMG), Mean Group (MG) and Dynamic Fixed Effect (DFE) estimators to check the short run and long run dynamics among the variables. Thirdly, the study used a Cobb-Douglas Production Function Framework, including the new variables like energy price, renewable and non-renewable energy consumption, labor force, and capital stock which is the solitary contribution of this paper.

The remainder of the paper is structured as follows; Section 2 presents the review of literature. In section 3, we discuss the analytical framework. Data and period of the study have been put forth in Section 4. Methodology is reported in section 5. The empirical results are provided in section 6 and finally section 7 concludes.

2 Review of literature

In the energy economics literature, there have been a number of studies done on the causal relationship between energy consumption and economic growth. The energy literature has become popular since the seminal work of Kraft and Kraft (1978). They found that increased GNP leads to increase energy consumption in U.S.

If we look at the energy literature, it is possible to classify the literature broadly into three types. The first part includes the studies which investigate the disaggregate energy consumption and economic growth. The studies included in this category are Chontanawat et al. (2008), Apergis and Payne (2009), Bowden and Payne (2009) and Apergis and Payne (2010b) which verified the presence of growth hypothesis. Belke et al. (2011), Fuinhas and Marques (2011) Apergis and Payne (2010a) Eggoh et al. (2011) proved the validity of the feedback hypothesis. Lise and Montfort (2007) and Huang et al. (2008) demonstrated the validity of conservation hypothesis and Soyts et al. (2007) verified the validity of neutrality hypothesis.

The second category of the studies investigates the association between renewable energy consumption and economic growth. Paynhe (2011) examined the validity of growth hypothesis; Apergis and Payne (2010c, d), (2011a) proved the validity of feedback hypothesis. Moreover, Chien and Hu (2007), Fang (2011) and Tiwari (2011a) pointed out that an increase in the consumption of renewable energy sources positively contributes to economic growth, while, Sadorsky (2009) examined that the higher growth of the economy, will lead to more renewable energy consumption.

The third line of studies focuses on decomposing the effects of renewable and non-renewable energy consumption on economic growth. Ewing et al. (2007) studied the effects of different bases of energy consumption on industrial output in the US for the period 2001–2005. By employing variance decomposition technique in VAR specification, the study found that about 9.5% of the forecast error variance of industrial production, non-renewable energy consumption explains 10% of forecast error variance of industrial production. In contrast, the consumption of renewable energy sources clarifies only about 2.5% of the forecast error variance of industrial production, specifying consumption of non-renewable energy sources are stronger in explaining the variation of industrial production compared to consumption of renewable energy sources. Payne (2009) examined the causal relationship between renewable and non-renewable energy consumption and real GDP in the US over the period 1949–2006. By using Toda-Yamamoto Granger causality with the multivariateframework, the result found that no causal relationship exists between renewable and non-renewable energy consumption and economic growth, showing the presence of neutrality hypothesis. Apergis et al. (2010) studied the causal relationship between carbon emissions, nuclear energy consumption, renewable energy consumption, and economic growth for a group of 19 developed and developing countries for the period 1984–2007. By employing a panel error correction model, the study found that there is statistically significant long-run relationship between the variables. The findings also reveal that renewable energy consumption has a positive and statistically significant influence on economic growth, whereas nuclear energy consumption has a negative one. The short run causality reveals the bidirectional causality between renewable and nuclear energy consumption and economic growth. Bowden and Payne (2010) investigated the sectoral causal relationship between renewable and non-renewable energy consumption and economic growth in the US for the period of 1949–2006. Using the Toda-Yamamoto causality, the study found that there is no causality between renewable energy consumption in the commercial and industrial sector and real GDP which supports the neutrality hypothesis. However a positive unidirectional causality exists from residential renewable energy consumption to real GDP, indicating the presence of growth hypothesis. Lee and Lee (2010) analyzed the total energy and electricity demand function in 25 OECD countries. The analysis used annual data for the period 1978 to 2004. By employing panel cointegration and causality technique the subject found that total energy demand is income and price inelastic. The result also shows unidirectional causality from income and electricity price to electricity consumption. In the end, the survey indicates that the requirement for total energy and electricity in OECD countries is driven mostly by strong economic growth, while consumers are largely inelastic to price alterations. Costantini and Martini (2010) investigated the causal relationship between economy and vigor for a large sample of developed and developing nations and four distinct energy sectors. The study is based upon the information on 71 countries, divided into two groups; OECD with 26 countries and non-OECD with 45 countries. All the variables are sourced from IEA and WDI. By applying the panel cointegration and error correction model the empirical findings suggest that alternative country samples hardly affect the causal relations, especially in a multivariate and multi sector framework. Tiwari (2011b) studied the relative performance of renewable and non-renewable energy consumption on economic growth in European and Eurasian countries for the period 1965–2009. By using VAR methodology, the study found that the growth rate of non-renewable energy consumption has a negative impact on the growth rate of GDP while, the growth rate of renewable energy consumption has a positive impact on the growth rate of GDP. Apergis and Payne (2011b) analyzed the relationship between renewable and non-renewable energy consumption and economic growth for 80 countries over the period 1990–2007. The empirical result concludes that although the long run elasticity estimate for non-renewable energy consumption is relatively higher, whichever renewable or non-renewable energy consumption matters for economic growth. The result also shows that there is a long-run relationship between the variables with a bidirectional causal relationship between renewable and non-renewable energy consumption and economic growth.

Beckmann et al. (2014a, b) examined whether a cross-sectional perspective on monetary policy is capable of explaining movements in global commodity prices. Their results show that the impact of a global liquidity measure on different commodity prices is significant and varies over time. They also found that one regime approximately accounts for times where commodity prices significantly adjust to disequilibria, while the second regime is characterized by either a weak or no commodity price adjustment. Their study further indicates that global liquidity also reacts to disequilibria in a specific regime demonstrates the two-way causality between monetary policy and commodity prices. In another paper, Beckmann et al. (2014a, b) studied the spot and future prices of energy commodities by employing the data from the Dow Jones UBS commodity index. They examined both the long-run relationship between spot and future energy commodity prices and also tested the smooth transition models to explore whether the adjustment of spot returns to the forward premium follows a nonlinear path. The core finding of the study reveals that the predictive power of futures prices can be observed only if previous volatility or the basis has been low. Hence, past relative volatility is important for the present price discovery function.

3 Theoretical background

In any economy, both renewable and non-renewable energy consumption is toughly connected to the level of economic activity. Nevertheless, among the different sectors of the economy, the industrial sector leads economic activities in G7 countries, consuming the major portion of energy and producing a substantial amount of carbon dioxide emissions. Very few studies have investigated the relationship between energy consumption and economic growth in the G7 countries. However, their conclusions are rather varied and there is a lack of consensus among economists. Yet, no study so far has explored the link between renewable and non-renewable energy consumption of the G 7 countries. It is essential to identify the links between renewable and non-renewable energy consumption, that are responsible for the economic growth of G7 countries.

Recent literature regarding economic growth shows that labor, capital, technology and energy are the rudimentary elements of economic growth in developed countries. The analytical framework employed here is developed by Liao et al. (2010) and justified by Arbex and Perobelli (2010). Accordingly, this study augments the neo-classical Cobb-Douglas production function by including renewable and non-renewable energy consumption in addition to capital and energy price in estimating the long run relationship between variables. Salim et al. (2014) examined the dynamic relationship between renewable and non-renewable energy consumption and industrial output and GDP growth in OECD countries over the period 1980–2011. The empirical result reveals that there is a bidirectional short-run relationship between GDP growth and non-renewable energy consumption in the short and long-run while a unidirectional causality exists between GDP growth and renewable energy consumption. But the mainstream neo-classical growth model does not include energy as a factor in the production function that could constrain or enable economic growth. The recent literature gives importance to this for the substitution of other inputs for energy, particularly renewable energy because of high oil price and the fear of so-called 'peak oil.' Therefore an optimum adjustment of fuel mix has never been more essential than now, and the economic outcome of decisions regarding energy policy often hinges on substitution between energy sources and other factors of production. Hence, correctly estimating and analyzing the linkages between renewable and non-renewable energy consumption, energy price and labor force as well as GDP growth can provide some information for the government and form the base for setting up suitable policies related to environment like pollution and energy taxes.

To examine the linkage between energy consumption and economic growth in G7 countries the study used Cobb-Douglas production function as follows:

$$Y_t = A\, E_t^{\alpha} EP_t^{\beta} K_t^{\gamma} LF_t^{\delta} CO2_t^{\tau} \tag{1}$$

In this function, Y_t is the gross domestic product, E consists of both renewable and non-renewable energy consumption (RE, NRE), EP is the energy price, K is capital, LF is the labor force and CO_2 is the carbon emission respectively. According to Liao et al. (2010) and Arbex and Perobelli (2010) energy is categorized into two types, clean energy (renewable) and non-clean (non-renewable). The production procedure uses both resources as a source of energy. Consequently the above function is adjusted as follows.

$$Y_t = A\, R_t^{\alpha 1} N_t^{\alpha 2} EP_t^{\beta} k_t^{\gamma} LF_T^{\delta} CO2_t^{\tau} \tag{2}$$

The first right term A is called the technology parameter $\alpha 1$, $\alpha 2$, β, γ, δ, τ are the production elasticities with respect to energy consumption, energy price, capital, labour force and carbon emission respectively. Overall, the model illustrates that the gross domestic product (GDP) is explained by a set of economic factors such as; labour force, capital, energy price which is directly related to the CO_2 emissions. (e.g. Stern 2000, Ang 2009; Shrama 2010, Omri 2013). If the sum of production elasticities related to the capital, energy consumption, labor force, energy price and CO_2 emission equals to 1 ($\alpha 1 + \alpha 2 + \beta + \gamma + \delta + \tau = 1$) the Cobb-Douglas production function gets constant returns to scale. The log linear production function is given by:

$$\begin{aligned} ln(Y_t) = ln(A) + \alpha 1 \ln(RE_t) + \alpha 2 \ln(NRE_t) + \beta \ln(EP_t) \\ + \gamma \ln(k_t) + \delta \ln(lf_t) + \tau \ln(co2_t) + \varepsilon_t \end{aligned} \tag{3}$$

Since our study works with panel data, the Eq. (3) can be re-written as follows;

$$\begin{aligned} ln(Y_{it}) = \alpha_{0i} + \alpha_{1i} \ln(RE_t) + \alpha_{2i} \ln(NRE_t) + \alpha_{3i} \ln(EP_t) \\ + \alpha_{4i} \ln(k_t) + \alpha_{5i} \ln(lf_t) + \alpha_{6i} \ln(co2_t) + \varepsilon_{it} \end{aligned} \tag{4}$$

Where the α subscript i = 1, ….., 6 represent the country and t = 1, …., T denotes the time period from 1990 to 2015. The Eq. (4) will be employed to estimate the link between energy consumption and economic growth in the G7 countries. The parameter α_{0i} captures the possibility of country specific fixed effects and deviations from the long run equilibrium relationship are measured by the estimated residuals ε_{it} (assumed to be independent and identically distributed with zero mean and constant variance). The Eq. (3) assumes that energy price, energy consumption, capital, labor force and carbon emission are the driving forces of economic growth. Eq. (3) gives us the long run elasticities by using the panel ARDL model.

4 Data source and period of the study

In this study, we used annual data covering the period from 1990 to 2015 for G7 countries. These are Canada, France, Germany, the United Kingdom (UK), Italy, Japan, and the United States (U. S.). The variables used in this study are GDP per capita (constant US$) 2005 as a proxy for economic growth. CO_2 emission (Metric tons per capita) is used as a proxy for carbon dioxide emission, fossil fuel energy consumption (% of total) is used as a proxy for non-renewable energy consumption. Renewable energy consumption (% of total final energy consumption) is a proxy for renewable energy consumption, gross fixed capital formation is a proxy for capital stock,[1] energy price and total labor force. All these variables are used in the natural logarithm form for the analysis. All the data were obtained from an OECD statistics database, International Energy Administration (IEA) and World Development Indicators (WDI 2013).

5 Methodology

Different studies on the relationship between energy consumption and growth nexus frequently work with non-stationary variables in levels. The Spurious result is a common problem in the regression, to eliminate this problem, it is necessary to test for the cross-sectional independence in the errors for the stationarity and the long run relations of variables. Before examining the presence of unit roots in the series, the study employed two tests that rely on the assumption of cross-sectional dependence in the errors. Since our cross section is very less than time series, we have applied Breusch and Pagan (1980) LM test to check the cross-sectional dependence. This test helps to identify the appropriate panel unit root tests that need to be applied. The first generation panel unit root tests rely on the assumptions of cross-sectional independence among the countries. Whereas, the second generation unit root tests are based on the hypothesis of cross-sectional independence between units existing in the empirical literature. The cross-sectional dependence on the errors may commonly arise because of the existence of common shocks (e. g. the recent Global financial crisis, oil shocks) and unnoticed components. This hypothesis is more likely to be validated in the panel data models because G7 countries have experienced a higher economic and financial integration process during the last decades.

5.1 Breusch-Pagan LM test for cross section dependency

In the fixed n case and as $T \rightarrow \infty$, the Breusch and Pagan (1980) LM test can be applied to test for the cross-sectional dependence in panels under the null hypothesis that the test statistics is asymptotically Chi-square distributed with n (n-1)/2 degrees of freedom. Nevertheless, this test is not applicable when $n \rightarrow \infty$.

[1] Capital stock data are not readily available in official statistics. Therefore, we use the gross fixed capital formation as a proxy for capital stock. See (Soytas, Sari, and Ewing, (2007).

Considering the following heterogeneous panel data model

$$y_{it} = x_{it}^{'}\beta_i + u_{it} \quad \text{For } i = 1, \ldots, N; t = 1, \ldots, T, \ldots \tag{5}$$

Where i indicates the cross-sectional units and t are the time series observations,y_{it} is the dependent variable and x_{it}denotes the exogenous regressor of dimension of K×1 with slope parameters β_i that are allowed to vary across i. $u_{it}$is allowed to be cross-sectionally dependent, but is uncorrelated with x_{it}.

Let $U_t = (u_{1t}, \ldots, u_{nt})'$. Then n×1vectors $U_1, U_2, \ldots, U_T$are assumed to be $iid\ N(o, \Sigma_u)$ over time. Let σ_{ij} be the (i, j) the element of the $n \times n$ matrix Σ_u. The error u_{it} (i = 1, …, n; t = 1, …, T) are cross sectionally dependent if Σ_u is non-diagonal, i.e. $\sigma_{ij} \neq 0$ for i≠j. The null hypothesis for cross sectional dependence can be written as:

$$H_0 : \sigma_{ij} = 0 \text{ for } i \neq j.$$

Or equivalently as

$$H_0 : p_{ij} = 0 \text{ for } i \neq j. \tag{6}$$

Where p_{ij} is the correlation coefficients of the errors with $p_{ij} = \frac{\sigma_{ij}}{\sqrt{\sigma_i^2 \sigma_j^2}}$ under the alternative hypothesis, there is at least one non-zero correlation coefficientp_{ij}, i.e. $H_a : p_{ij} \neq 0$ for some i≠j. The OLS estimator of y_{it} or x_{it} for each i, denoted by $\widehat{\beta}_i$ is consistent. The corresponding OLS residuals $\widehat{u_{it}}$ defined by $\widehat{u_{it}} = y_{it} - x_{it}^{'}\widehat{\beta}_i$are used to compute the sample correlation $\widetilde{p_{\iota J}}$ as follows:

$$\widetilde{p_{\iota J}} = \left(\sum_{t=1}^{T} \hat{u}_{it}^2\right)^{-1/2} \left(\sum_{t=1}^{T} \hat{u}_{jt}^2\right)^{-1/2} \sum_{t=1}^{T} \widehat{u_{it}}\, \widehat{u_{jt}} \tag{7}$$

In the fixed n case and as T → ∞, the Breusch and Pagan's (1980) LM test can be applied to test for the cross-sectional dependency in heterogeneous panels. In this case, it is given by

$$LM_{BP} = T \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \widetilde{p_{\iota J}}^2$$

This is asymptotically distributed under the null as a χ^2 with n (n-1)/ 2 degrees of freedom. However, this Breusch-Pagan LM test statistics is not applicable when N → ∞.

5.2 Pesaran's cross-sectional augmented dickey-fuller (CADF) test

After confirming cross-sectional dependency, to understand the stationary properties of the variables the study employed Pesaran Cross-Sectional Augmented Dickey-Fuller (CADF) test (Pesaran 2007). The presence of cross-sectional dependence can be solved by augmenting the standard Dickey-Fuller regression with cross-sectional averages of lagged levels and first differences of the individual series (Pesaran 2007). The main benefit of applying this panel second generation unit root test is its high power of exploring the cross-sectional dependence which induces strong interdependencies between the countries.

The Pesaran CADF equation follows:

$$\Delta y_{i,t} = \alpha_i + \beta_i y_{i,t-1} + \gamma_i \overline{y}_{t-1} + \varphi_i \Delta \overline{y}_t + \varepsilon_{it} \tag{8}$$

Where the unit root test hypothesis will be tested based on the OLS results derived from Eq. (8) with t-ratio by t_i (N, T).

The Pesaran CADF test is

$$\mathrm{CADF} = t_i(N,T) = \frac{\Delta y_i \overline{m}_w y_{i-1}}{\delta_j \left(y'_{i,-1} \overline{m}_w y_{i-1} \right)^{1/2}}$$

Where

$$\Delta y_i = \left(\Delta y_{i,1}, \quad \Delta y_{i,2}, \quad \ldots, \Delta y_{i,T} \right),' \tag{9}$$

$$\Delta y_{i,-1} = \left(y_{i,0,} y_{i,1,} \quad . \quad . \quad . \quad , y_{i,T-1,} \right), \quad ' \tau_T = (1, 1, \quad . \quad . \quad . \quad , 1),' \tag{10}$$

$$M_w = I_T - \overline{w} \left(\overline{w}, \overline{w}\, \overline{w} \right)^{-1} \overline{w}', \overline{w} = \left(\tau, \Delta \overline{y}, \overline{y}_{T-1} \right)' \tag{11}$$

$$\sigma_i^2 = \frac{\Delta y_i' m_{i,w}\, \Delta y_i}{T-4}\, m_{i,w} = I_T - \left(G_i \left(G_i{}' G_i \right)^{-1} G_i' \; and \; G_i = \left(\overline{w}, y_{i-1} \right) \right. \tag{12}$$

5.2.1 Panel autoregressive distributed lag model (P-ARDL)

To examine the long-run relationship between the variables, we have applied panel autoregressive distributed lag model based on three different estimators such as Mean Group estimator (MG), Pooled Mean Group (PMG) and Dynamic Fixed Effect (DFE). According to Pesaran et al. (1999), an ARDL dynamic heterogeneous panel regression can be written by using ARDL (p, q) approach where ‘p’ is the lags of the dependent variable and ‘q’ is the lags of independent variables. The time period t = 1, 2,. .. .., 15 and groups i = 1, 2, …., 7, the panel model can be written as follows.

$$y_{it} = \sum_{j=1}^{p} \lambda_{ij} y_{i,t-j} + \sum_{j=0}^{q} \delta'_{ij} X_{i,t-j} + \mu_i + \epsilon_{it} \tag{13}$$

Where y is the GDP_{it} dependent variable, X_{it} is the $k \times 1$ vector of explanatory variables for group I (including, re, nre, ep, k, lf and CO_2), N_i denotes the group specific effects, δ_{it} are the $k \times 1$ coefficient vectors; λ_{ij} are scalar coefficients of the lagged dependent variables.

If the variables in Eq. (9) are, I (1) and cointegrated, formerly the error term is an I (0) process for all i. A principal feature of cointegrated variables is their responsiveness to any deviation from long-run equilibrium. This feature implies an error correction model in which short-run dynamics of the variables in the system are influenced by the deviation from equilibrium. Thus it is common to parameterize Eq. (9) into an error correction equation.

$$\Delta y_{it} = \varnothing_i \left(y_{i,t-1} - \theta_i^{'} X_{it} \right) + \sum_{j=1}^{p-1} \lambda_{ij}^{*} y_{i,t-1} + \sum_{j=0}^{q-1} \delta_{ij}^{'*} \Delta X_{i,t-j} + \mu_i + \epsilon_{it} \tag{14}$$

Where

$$\varnothing_i = -\left(1 - \sum_{j=1}^{p} \lambda_{ij}\right), \theta_i = \sum_{j=0}^{q} \delta_{ij} / \left(1 - \sum_k \lambda_{ik}\right), \lambda_{ij}^{*} = -\sum_{m=j+1}^{p} \lambda_{im} \text{ j} =$$

$$1, 2, \ldots, \text{p}-1, \text{and } \delta_{ij}^{*} = -\sum_{m=j+1}^{q} \delta_{im} \text{ j} = 1, 2, \ldots., \text{q}-1.$$

The parameter $\varnothing_i$ is the error correcting speed of adjustment term. If$\varnothing_i = 0$, then there would be no evidence for a long run relationship. This parameter is expected to be significantly negative under the prior assumption that the variables show a return to a long run equilibrium. Of particular importance is the vector$\theta_i^{'}$, which contains the long run relationship between the variables. But more recently Pesaran, Shin and Smith (1997, 1999) proposed a PMG estimator which combines both average and pooling the residuals. This test incorporates the intercept, short run coefficients, and different error variances across the groups (like MG estimators). However, it holds the long run coefficients to be equal across the groups (like FE estimators).

The MG estimate of the error correction coefficients,$\varnothing_i$, is

$$\widehat{\varnothing} = N^{-1} \sum_{i=1}^{N} \widehat{\varnothing}_i \tag{15}$$

With the variance

$$\widehat{\Delta}_{\widehat{\varnothing}} = \frac{1}{N(N-1)} \sum_{i=1}^{N} \left(\widehat{\varnothing}_i - \widehat{\varnothing} \right)^2 \tag{16}$$

The Eq. (10) can be estimated by three different estimators such as mean group estimator of Pesaran and Smith (1995), Pooled Mean Group estimator developed by Pesaran et al. (1999) and Dynamic Fixed Effect Estimators (DFE). According to Pesaran, Shin and Smith (1999), panel ARDL can be applied even when the variables follow the different order of integration i.e. I (0) and I (1) or a mix of both.

6 Empirical results

The traditional panel unit root tests do not consider the presence of cross-sectional dependence which might give an improper interpretation towards the stationary properties of large panel data. To overcome this problem, the present study has employed the Breusch and Pagan (1980) LM cross- sectional dependence test to check cross-sectional independence in the G7 countries. Since our cross-sectional units are less than time series, we have applied the Breusch and Pagan (1980) LM cross-sectional dependence test. The result of cross-sectional dependence test is reported in Table 1 which shows that we reject the null hypothesis of no cross-sectional dependency at 1percen level of significance among the variables. It means there is high dependence in the G7 countries.

From the above cross-sectional dependence test we observe that there is cross-sectional dependence among the variables. Now we employ the panel second generation unit root test i.e. Pesaran Cross-Sectional Augmented Dickey-Fuller (PCADF) panel unit root test to check stationary properties of the variables. The PCADF result reported in Table 2 shows that the variables attained stationarity at different orders of integration i.e. I (0) and I (1). In other words, most of the variables become stationary after the first difference and at the same time some variables like carbon emission and labor force variables attain stationarity in the level.

Table 2 indicates the Pesaran cross-sectional Augmented Dickey-Fuller panel unit root test which shows that all the variables become stationary at different orders i.e. I (0) and I (1). Like the time series analysis, when the variables have a different order of integration, to check the long-run relationship among the variables we applied the Autoregressive distributed lag model. According to Pesaran, Shin and Smith (1999), panel ARDL can be applied even if the variables follow the different order of integration i.e. I (0) and I (1) or a mixture of both. Here, in this study to check the long run and short run dynamics among the variables we have employed three different panel autoregressive distributed lag models such as Pooled Mean Group (PMG) estimator, Mean Group (MG) estimator and a Dynamic Fixed Effect Model (DFE).

Table 3 represents the Pooled Mean Group, Mean Group, and Dynamic Fixed Effect estimation results. According to Pesaran, Shin and Smith (1999) pooled mean group estimator restricts the long run results to be equal to the cross-section but allows for the short run coefficients and error variance to differ across groups on the cross section. Whereas, Mean Group estimation is an unrestricted model compare to Pooled Mean Group in which short run and long run results may vary in each country. Table 3 shows the long run and short run coefficients between economic growth (lngdp) and other variables, and the speed of adjustment for all the three different estimation results. In the long run, as the results show, three variables namely energy price, labor force and

Table 1 Breusch-Pagan LM test for cross section dependency

Test	Statistic	Prob.
Breusch-Pagan LM	92.47	0.00*

* indicates significant at 1% level

Table 2 Pesaran's cross-sectional augmented dickey-fuller (CADF) test result

	Constant		Constant & Trend	
Variable	T-bar	*p* value	T-bar	p value
lnep	−0.98	0.98	−1.05	1.00
lngdp	−1.99	0.26	−2.68	0.14
lnco2	−2.66	0.00***	−3.05	0.00***
lnre	−1.24	0.91	−3.31	0.00***
lnnre	−1.25	0.91	−1.02	0.99
Lnlf	−4.1	0.00***	−4.11	0.00***
Lnk	−1.44	0.80	−1.59	0.97
Δlnep	−2.39	0.04**	−1.53	0.98
Δlngdp	−3.23	0.00***	−3.31	0.00***
Δlnco2	−4.48	0.00***	−4.95	0.00***
Δlnre	−4.04	0.00***	−3.98	0.00***
Δlnnre	−2.84	0.00***	−3.62	0.00***
Δlnlf	−3.51	0.00***	−3.59	0.00***
Δlnk	−2.75	0.00***	−2.78	0.08*

The critical values are −2.34, −2.17 and 2.07 at 1%, 5% and 10% respectively with constant −2.88, −2.69 and − 2.59 at 1%, 5% and 10% respectively with constant and trend. The ***, **, and * indicates 1%, 5% and 10% level of significance

capital stock have positive and statistically significant impact on economic growth in the G7 countries at 1% significance level. The result shows that 1% increase in energy price will increase the economic growth level by around 0.48% in G7 countries and 1% increase in the labor force can generate 1.33% economic growth in G 7 countries. Besides this, 1% increase in the capital increases economic growth in G7 countries by around 3.16%. Comparing the long run result with Mean Group and Dynamic Fixed Effect results we found that energy price positively affects the economic growth in the G7 countries.

The speed of adjustment reflected by the coefficient of convergence is negative and significant in all the three estimators, indicating that there is no omitted variable bias. The short run result shows that non-renewable energy consumption and capital show short run causality with economic growth. The short run result of mean group shows there is a short run causality between capital and economic growth and the DFE estimator shows there is a short-run causality from non-renewable energy consumption to economic growth and capital stock to economic growth.

However, to measure efficiency and consistency among the estimator (PMG, MG and DFE) the Hausman test has been applied. The validity of long-run homogeneity restrictions across G7 countries, and hence the efficiency of PMG estimator over MG and DFE estimator, is examined by Hausman test. The Hausman test result accepts the null hypothesis of homogeneity restrictions on the long-run regression, which indicates that PMG is more efficient than MG and DFE.

Table 3 Panel ARDL model results (pooled mean group, mean group, and dynamic fixed effect estimator)

Dep. Var. d.lngdp	Pooled Mean Group			Mean Group			Dynamic Fixed Effect		
	Coeff.	Z-stat.	*P* value	Coeff.	Z-stat.	*P* value	Coeff.	Z-stat.	*P* value
Long run									
lnep	0.48 (0.11)	4.17***	0.00	0.86 (0.27)	3.18***	0.00	0.94 (0.33)	2.86***	0.00
lnco2	0.19 (0.22)	0.87	0.38	−0.52 (1.32)	−0.40	0.69	0.72 (0.53)	1.37	0.16
lnre	−0.03 (0.07)	−0.39	0.69	−0.10 (0.46	−0.22	0.82	−0.16 (0.14)	−1.12	0.26
lnnre	−1.59 (1.16)	−1.38	0.16	1.07 (1.50)	0.72	0.47	−1.13 (0.83)	−1.36	0.17
lnlf	1.33 (0.40)	3.27***	0.00	1.01 (3.00)	0.34	0.73	1.50 (1.07)	1.40	0.16
lnk	3.16 (0.67)	5.37***	0.00	−0.47 (1.15)	−0.41	0.67	1.41 (0.70)	2.00**	0.04
Short run									
EC	−0.23 (0.06)	−3.58***	0.00	−0.37 (0.09)	−4.04***	0.00	−0.22 (0.04)	−4.63***	0.00
d1.lnep	−0.18 (0.10)	−1.87	0.06	−0.39 (0.15)	−2.68***	0.00	−0.16 (0.10)	−1.57	0.11
d1.lnco2	0.05 (0.14)	0.35	0.72	0.20 (0.50)	0.41	0.68	0.05 (0.23)	0.23	0.81
d1.lnre	−0.04 (0.11)	−0.41	0.68	−0.12 (0.19)	−0.62	0.53	0.10 (0.07)	1.39	0.16
d1.lnnre	0.84 (0.41)	2.01**	0.04	−0.48 (0.58)	−0.83	0.40	1.10 (0.46)	2.36**	0.01
d1.lnlf	0.98 (1.50)	0.65	0.51	−0.21 (1.65)	−0.13	0.89	0.88 (0.60)	1.47	0.14
d1.lnk	0.69 (0.20)	3.43***	0.00	1.51 (0.57)	2.62***	0.00	0.74 (0.26)	2.77***	0.00
Intercept	−3.04 (0.80)	−3.79***	0.00	−1.84 (23.26)	−0.08	0.93	−4.09 (4.37)	−0.93	0.35
Hausman Test	PMG, MG 9.30 [0.15]				MG, DFE 0.00 [1.00]				

***, ** indicates significance level at 1% and 5%. () parenthesis shows the standard errors. [] denotes the *p*-values of Hausman test. EC is error correction term

Table 4 Dependent variable (lngdp) Dynamic Ordinary Least Square (DMOLS)

Variables	Coefficient	Std. Error	T-statistics	Prob.
lnep	.965	.090	10.65	0.000**
$\ln co_2$	.959	.043	22.02	0.000**
lnre	−.051	.024	−2.08	0.037*
lnnre	1.255	.100	12.43	0.000**
lnlf	.424	.016	25.63	0.000**
lnk	−1.548	.223	−6.93	0.000**

R-squared =0.83

Adj. R-squared = 0.44

**, * indicates significant at 1% and 5% respectively

Normally in the long run analysis, there is a possibility of serial correlation and the endogeneity problem takes place. To avoid these problems, the study used DOLS methodology to correct such kind of problems. Kao et al. (1999) discussed the properties of the OLS estimator and suggested that the bias-corrected OLS estimator does not improve over the OLS estimator in general. Therefore, both FMOLS and DOLS may be more promising in co-integrated panel regressions. Nevertheless, Kao and Chiang (2000) defined that both the OLS and Fully Modified OLS (FMOLS) reveal small sample bias and that the DOLS estimator seems to outperform both estimators. In the Table 4, the panel DOLS result found that energy price, carbon emission, nonrenewable energy and labor force have a positive and statistically significant impact on economic growth in the G7 countries. However, renewable energy and capital stock have a negative and a statically significant impact on economic growth in the G7 countries.

7 Concluding remarks

The present study examined the relationship between renewable and non-renewable energy consumption and economic growth in the G7 countries (Canada, France, Germany, the United Kingdom, Italy, Japan, and the United States) covering the period from 1990 to 2015. The study employed the Breusch and Pagan (1980) LM test to check the cross-sectional dependence among the variables. The Pesaran Cross-Sectional Augmented Dickey- Fuller (CADF) panel second generation unit root test is used to verify the stationary properties of the variables. The study also employed the panel autoregressive distributed lag model (P-ARDL) consisting three alternative estimators such as Pooled Mean Group (PMG), Mean Group (MG) and Dynamic Fixed Effect (DFE) estimators to check the long run and short run dynamics among the variables. Finally, we used the Hausman test to measure efficiency and consistency among the estimators.

The empirical result of Breusch and Pagan (1980) LM test confirms that there is cross-sectional dependency among the variables. The panel unit root test suggests that there are different order of integration of variables. Since the variables are stationary in the different order, we have employed the panel autoregressive distributed lag model (P-ARDL). The panel ARDL model confirms that three variables, namely energy price, labor force and capital have a positive and statistically significant impact on economic growth in the G7 countries at 1% significance level. Comparing the long run result with Mean Group and Dynamic Fixed Effect results we found that energy price has a positive and statistically significant impact on economic growth in the G7 countries. The speed of adjustment reflected by the coefficient of convergence is negative and significant in all the three estimators indicating that there is no omitted variable bias. The short run result shows that non-renewable energy consumption and capital show the short run causality with economic growth. The short run result of mean group confirms that there is a short-run causality between capital and economic growth and the DFE estimator demonstrates there is a short-run causality from non-renewable energy consumption to economic growth and capital stock to economic growth. Finally, The Hausman test result accepts the null hypothesis of homogeneity restrictions on the long-run regression, which indicates that PMG is more efficient than MG and DFE.

The empirical result of our work provides policymakers with a fuller apprehension of the link between energy consumption and economic growth to formulate energy policy in the rural regions. The important policy implication of this work suggests that all these countries should use both renewable and non-renewable energy to achieve their targeted growth rate. From our empirical result, it is observed that non-renewable energy consumption and carbon emission has a positive and significant impact on economic growth in the G7 countries. There is no doubt that the G7 countries have become more among energy intensity in the world. Policymakers in these countries often tend to regard energy as a gene that determines economic growth. Hence, to avert a negative force on economic growth, these countries must take in the necessary efforts to increase investment in energy infrastructure and more strictly enact energy conservation policies to slim down the redundant unused of energy. The G7 countries should also advance their industries to use new super technologies to cut down carbon emissions, which will serve to hold environmental sustainability for all these nations.

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Environmental Kuznets curve and India: Evidence from autoregressive distributed lag model

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Abstract. *The present study examined the presence of Environmental Kuznets Curve hypothesis in the context of India. The study employed the autoregressive distributed lag model over the period 1971 to 2016. The negative square of GDP indicates that the existence of the EKC hypothesis in India. This confirms that the negative sign of the square GDP coefficient suggests that the presence of the EKC hypothesis in India. The statistical significance of the error correction term ECTt-1 with an appropriate sign (-) is an indication of the speed of adjustment towards the long-run equilibrium after disequilibrium in the short run.*

Keywords: energy consumption, EKC, ARDL, cointegration, error correction, India.

JEL Classification: C3, Q4.

1. Introduction

India is one of the rapidly developing economies in the world. International Monetary Fund (IMF) accounts India is the 11th largest in terms of nominal GDP in the world and 3rd largest by purchasing parity (PPP). India's industrial and agriculture sector accounts for 28.6% and 14.6% of the country's GDP while the service sector contributes 57.2% respectively. Nevertheless, "there is widespread inequality as 42% of the Indian population survives under $1.25 a day (Planning Commission of India). To provide an acceptable standard of living and economic wellbeing India needs to grow more than 8% for the next couple of decades. (Integrated Energy Policy, IEP document, Planning Commission, GOI".

Inadequate energy supply affects India's economic growth badly. However, India is considered the 5th largest consumer of energy in the international rankings. In the year 2009 India's per capita energy consumption is 650 koe which is far below the world average. International Energy policy estimated that India is expected to raise its major energy supply 3 o 4 times by 2031 to keep GDP growth 8 per cent. Because of the huge availability of coal reserves, India's 55 per cent energy supply rest on coal energy. However, coal is considered an unclean fuel, consumption of coal emits a huge amount of carbon dioxide. At the international level, India is considered the 4th largest carbon emitter after the USA, China, and Russia. Whereas, in terms of per capita CO2 emission India is significantly below the world average. Therefore, the Indian economy facing the challenges between economic progress and environmental security like other developing nations.

At the early stage of economic growth, the EKC hypothesis indicates a direct linkage between environmental pollution and economic growth but the level of pollution declines after reaching a certain level of economic growth. Therefore, the Environmental Kuznets Curve hypothesis shows an inverted U-shaped linkage between pollution and economic growth. The shape of the EKC curve is based on three effects such as composition effect, technical effect and scale effect. At the beginning phase of industrialization, the level of pollution will be high due to heavy economic activity. This effect is considered a scale effect. When the level of economic activity rises, organizations adopted the use of cleaner technology as a consequence the pollution levels declines. This effect is known as a technological effect. When the organizations produce intensive goods in the production method the composition effects take place.

EKC studies specific to India

Literature by Khanna and Zilbermen (2001) and Bhattacharya and Ghoshal (2009) obtained the EKC hypothesis in their study; though Dietzenbacher and Mukhopadhyay (2007) Mukhopadhyay and Chakrobarty (2005) have denied the presence of EKC hypothesis. Managi and Jena (2007) empirically establish the presence EKC in the case of India Jayanthakumaran et al. (2012) empirically found that there is no linkage between CO2 emission and economic growth.

Theoretical background

Most EKC studies suggested that in the early stage of economic growth the environmental quality declines and successively improves in the well along. The analysis also found that environmental pollution surges quicker than the increase in income in the initial stage of economic growth and reduces with the rise in income level.

Possible explanations for the EKC are seen in the following ways.

I. The transformation of economic activity from agrarian structure to polluting industrial stage than to a progressive clean service economic structure.
II. Higher the income of the inhabitants will increase the performance for environmental quality.

The presence of EKC in the literature has been questioned on various grounds. Some of them are quality parameters namely local pollutants, which indicates the presence of the Environmental Kuznets Curve. Nevertheless, past literature could not predict the level of income in which the level of environmental pollution declining.

The key motivation of this study is based on whether economic growth is a solution or problem of environmental pollution.

The initial study found an inverted U shaped hypothesis in the NBER working paper by Grossman and Kruegar (1991). This hypothesis defined the 'U' curve as the Intensity Use Hypothesis. This states that the intensity of material use diminishes beyond a certain level of income.

Kuznets (1955) investigated the linkage between per capita income and income inequality. The study shows that in the initial stage both the variables shows a positive direction but when it reaches the turning point then it started declining. This linkage between the two variables characterized in the form of a bell-shaped curve. This bell-shaped curve is known as the Kuznets curve. After the 1990's this Kuznets curve gets a new insight into the EKC literature. This EKC defined the per capita income and environmental pollution follow the inverted U shaped. Later this u shaped relationship between environmental pollution and per capita income known as Environmental Kuznets Curve. A set of studies like Grossman and Kruger (1991); Shafik and Bandyppadhyay (1992) Panayotou (1993) initially examined an inverted U shaped relationship between per capita income and pollution. Neverthless, Panayotou (1993) created this relationship as the Environmental Kuznets Curve or EKC Hypothesis.

In the initial phase of economic growth, environmental problems, and awareness is low and insignificant. The development of environmental-friendly technologies is not available. As a consequence pollution level rises with increasing per capita income for a certain level beyond which the quality of the environment increases so as income. As economic progress takes place with the strength of sectoral development the waste generation limit increases. When the economy achieved a higher level of development environmental awareness, better technology, environmental regulation and the level of environmental expenditure rises. As a result of which the level of environmental pollution gradually diminishes and the quality of the environment boosted.

This EKC hypothesis deals with a process of dynamic change. The analysis of EKC hypothesis is unambiguous about the time factor. The EKC studies have been examined empirically and various econometric tools have been employed for single and multi countries as well. In this study, the EKC hypothesis studied with yearly data from 1970-2016.

The EKC studies have been examined empirically and various econometric tools have been employed both for single and multiple nations. In this study, the EKC hypothesis examined the relationship between carbon emission, energy consumption, economic growth, population density, and trade liberalization with yearly data from 1971 to 2016.

The reminder of this paper is prepared as follows: Review of literature described in the second section. Data and variables are given in the third section. Model selection is presented in the fourth section. Empirical results explained in the fifth section and concluding remarks are discussed in the sixth section.

2. Review of literature

Kanjilal and Ghosh (2013) examined the presence of EKC hypothesis in the context of India from 1971-2008. The variable of the study includes per capita energy use, carbon emission, GDP and Trade openness. All the variables collected from World Development Indicators. By employing the threshold cointegration approach the empirical result found that carbon emission is highly elastic concerning real per capita income and energy consumption in India. The study also suggests that there is a long-run relationship between the variables.

Jalil and Mahmud (2009) investigated the environmental Kuznets curve hypothesis between carbon emission and GDP growth in the context of China from 1975- 2005. The variables include energy consumption, carbon emission, foreign trade, and income for the analysis. By employing the Granger causality and autoregressive distributed lag model the empirical result shows the existence of the EKC hypothesis in the study period in the context of China. The findings also reveal that unidirectional causality runs from economic growth to carbon emission.

Ahmed and Long (2012) studied the presence of EKC hypothesis in the case of Pakistan throughout 1971-2008. The study used economic growth, CO_2 emission, energy consumption, and trade liberalization, and population density for the analysis. All the variables sourced from WDI. The study used the ARDL and error correction econometric model. The empirical result suggests that the U-shaped relationship found both in the short-run and long-run between carbon emission and economic growth. The findings reveal that energy consumption and economic growth causes environmental pollution in Pakistan. Furthermore, the result also indicates population density harms the environment whereas, the openness of trade supports improving the environment.

He and Richard (2010) investigated the Environmental Kuznets Curve hypothesis in the context of Pakistan for 1971-2009. The variable includes in this study are per capita carbon emission, real GDP per capita, and squared of real GDP, energy use and trade openness. Carbon emission and energy consumption data are obtained from World Development Indicators (WDI). The real GDP and trade openness data are cumulated from The Economic Survey of Pakistan (2008-09). By using the ARDL cointegration and Granger causality test, the result shows that the long-run linkage among the variables and the study supports the presence of the EKC hypothesis in the context of Pakistan. The result also shows unidirectional causality from economic growth to carbon emissions. Rising energy consumption raises carbon emission in the short-run as well as in the long run. However, the openness of trade helps to decline carbon emission in the long run.

Bekhet (2014) examined the existence of EKC and the causal linkage between energy consumption, carbon emission, and population in UAE and Saudi Arabia countries for the period 1975-2011. The variable includes CO_2 emission per capita is in metric tons, real GDP per capita is in constant 2005 US dollars, energy consumption per capita is in kt of oil equivalent, and the total population. The study employed the ARDL economtric model. All variables are sourced from WDI. The empirical result found that EKC is not applied in both countries UAE and Saudi Arabia. The cointegration result confirms that there is a long-run linkage among the variables. The result also reveals unidirectional causality from GDP to CO_2 emission. Energy consumption increases CO_2 emission both in the short-run and long-run in Saudi Arabia but the UAE case only in the long run.

Aslanidis and Iranzo (2009) re-addressed the linkage between per capita income and pollution in 77 Non-OECD developing nations spanning from 1971-1997. The analysis includes per capita carbon dioxide emission and national income. The methodology used by the study is Non-linear Least Square (NLS) and Panel Smooth Transition Regression (PSTR) model for the analysis. The empirical result shows the absence of EKC in the context of all these nations.

Table 1. *Summary of review of literature*

Authors	Country	Time Period	Methodology	EKC Hypothesis
Ang (2008)	Malaysia	1971-1999	VECM, GC	NO
Halicioglu (2009)	Turkey	1960-2005	ARDL, GC	YES
Iwata et al. (2010)	France	1960-2003	ARDL	YES
Fodha, and Zaghdcod (2010)	Tunisia	1961-2004	VECM, GC	YES
Saboori et al. (2011)	Malaysia	1980-2009	ARDL, VECM, GC	YES
Tiwari (2011)	India	1971-2007	VAR, GC	YES
Shahbaz et al. (2012)	Pakistan	1971-2009	ARDL, GC	YES
Kareem et al. (2012)	China	1971-2008	VECM, GC	NO
Shahbaz et al. (2013)	Romania	1980-2010	ARDL	YES
Tiwari et al. (2013)	India	1966-2011	ARDL, VECM, GC	YES
Jali and Mahmud (2009)	China	1975-2005	ARDL, GC	YES
Ahmed and Long (2012)	Pakistan	1971-2008	ARDL	YES
He and Richard (2010)	Canada	1948-2004	Semiparametric	YES
			flexible	
			parametric	
Ang (2007)	France	1960-2000	ARDL, VECM	YES
Soytas et al. (2007)	USA	1960-2004	Toda-Yamamoto GC	NO
Ang (2008)	Malaysia	1971-1999	VECM, Granger Causality	No
Chebbi (2010)	Tunisia	1971-2004	VECM, Impulse Response (IRF)	No
Halicioglu (2009)	Turkey	1960-2005	ARDL, Granger causality	YES
Ghosh(2010)	India	1971-2008	ARDL, Johansen Juselius	YES
Ahmed and Long (2012)	Pakistan	1971-2008	ARDL	YES
Alam et al. (2012)	Bangladesh	1972-2006	ARDL	YES
Esteve and Tamarit (2012)	Spain	1857-2007	Threshold Cointegration Test	YES
Fosten et al. (2012)	UK	1850-2002	Non-linear threshold	YES
			cointegration and Error Correction Test	
Fosten et al. (2012)	United States	1900-2000	Ordinary Least Square (OLS)	YES
Saboori et al. (2012)	Malaysia	1980-2009	ARDL	YES
Giovanis (2013)	UK	1991-2009	Dynamic Panel Dta	No

Authors	Country	Time Period	Methodology	EKC Hypothesis
Saboori and Sulaiman (2013)	Malaysia	1980-2009	ARDL, Johansen Juselius	YES
Shabbaz et al. (2013)	South Africa	1965-2008	ARDL	YES
shabbza et al. (2013)	1980-2009	Malaysia	VECM, GC Test	YES
Farhani et al. (2014)	1971-2008	Tunisia	ARDL	YES
Lau et al. (2014)	Malaysia	1970-2008	ARDL, GC	YES
Yong and Zhao (2014)	India	1970-2008	GC & Directed Acyclic Graphs (DAG)	YES
Multi-Country Analysis				
Pao and Tsai (2010)	BRIC COUNTRIES	1971-2005	VAR &ECM	YES
Jounky (2010)	36 High inocme countries	1980-2005	VECM	YES
Orubu and Omotor (2011)	47 African countries	1990-2002	Longitudial Panels data	YES
Arouri et al. (2012)	12 MENA countries	1981-2005	Bootstrap Panel and cointegration techniques	YES
Wang (2013)	150 nations	2005-2011	Oradinary Leaste Square (OLS)	No
Apergis and Payne (2014)	7 Central American countries	1980-2010	Panel cointegration Test	YES
Apergis and Payne (2014)	189 countries	1990-2011	Panel Fully Modified Least Square (OLS)	Yes
Farhani et al. (2014)	10 MENA countries	1990-2010	Panel data Method	YES'
Cowan et al. (2014)	The BRICS countries	1990-2010	Panel Causality Test	YES
Menash (2014)	6 African countries	1980-2000		
Onafowora and Owoye (2014)	8 countries	1970-2010	ARDL	only for 2 countries

3. Description of variables, data and period of study

In this study, we have used annual data spanning the period from 1971 to 2016 in the context of India. The variables used in this study are GDP per capita in constant 2010 US $ as a proxy for economic growth, square of per capita GDP, per capita energy consumption (kg of oil equivalent). Trade openness, per capita CO2 emission metric tons, and Foreign Direct Investment (FDI). All the variables are sourced from World Development Indicators (WDI) website. All the variables used after logarithm transformation.

4. Model specification

To examine the long-run relationship among the variables the analysis used the linear logarithmic quadratic functional form.

$$CO_2 = \alpha_0 + \beta_{01}Y_t + \beta_{02}Y_t^2 + \beta_{03}E_t + \beta_{04}\,T_t + \beta_{05}FDI_t + \epsilon_t \qquad (1)$$

t = defined time period = 1, 2,…, n.

Where ϵ_t is the error term, T defined as foreign trade.

“If the EKC hypothesis is true, the expected sign of β_{01} is positive and β_{02} is negative. The statistical significance of β_{02} implies a monotonically increasing relationship between per capita carbon emission and income. The coefficient of per capita energy use β_{03} is expected to be positive as higher energy consumption leads to higher carbon emission. The expected sign of β_{04} is mixed depending mainly on the development stage and environmental aspects of the production process of an economy. In the case of the developed economy the sign of expected to be negative because a developed economy prefers to import pollution-intensive products from developing economies where environmental protection law is less stringent. Due to this reason, the expected sign for a developing economy is positive (Grossman and Krueger, 1991)". "The expected sign of T_t is also dependent on if the economy is export and import oriented. The coefficient of T_t can be negative in a developing economy if majority of its manufacturing products are imported from a developed country."

ARDL bound testing cointegration approach

The ARDL model estimates the unrestricted error correction model. The model representation is shown in equation 2.

$$\Delta CO_2 = \alpha_0 + \sum_{i=1}^{n} b_{1i}\Delta CO_{2t-i} + \sum_{i=1}^{n} b_{2i}\Delta Y_{t-i} + \sum_{i=1}^{n} b_{3i}\Delta Y_{t-i}^2 + \sum_{i=1}^{n} b_{4i}\Delta E_{t-i} + \sum_{i=1}^{n} b_{5i}\Delta T_{t-i} + \sum_{i=1}^{n} b_{6i}\Delta FDI_{t-i} + \delta_1 CO_{2t-1} + \delta_2 Y_{t-1} + \delta_3 Y_{t-1}^2 + \delta_4 E_{t-1} + \delta_5 T_{t-1} + \delta_6 FDI_{t-1} + \epsilon_{1t} \tag{2}$$

F-test is employed to test whether a cointegration linkage exists between the variables the null hypothesis of no cointegration among the variables in Eq- (2) is H_0; $\delta_1 = \delta_2 = \delta_3 = \delta_4 = \delta_5 = \delta_6 = 0$, against H_1; $\delta_1 \neq \delta_2 \neq \delta_3 \neq \delta_4 \neq \delta_5 \neq \delta_6 \neq 0$, which signified as FCO_2 (CO_2/Y, Y^2, E, T, FDI).

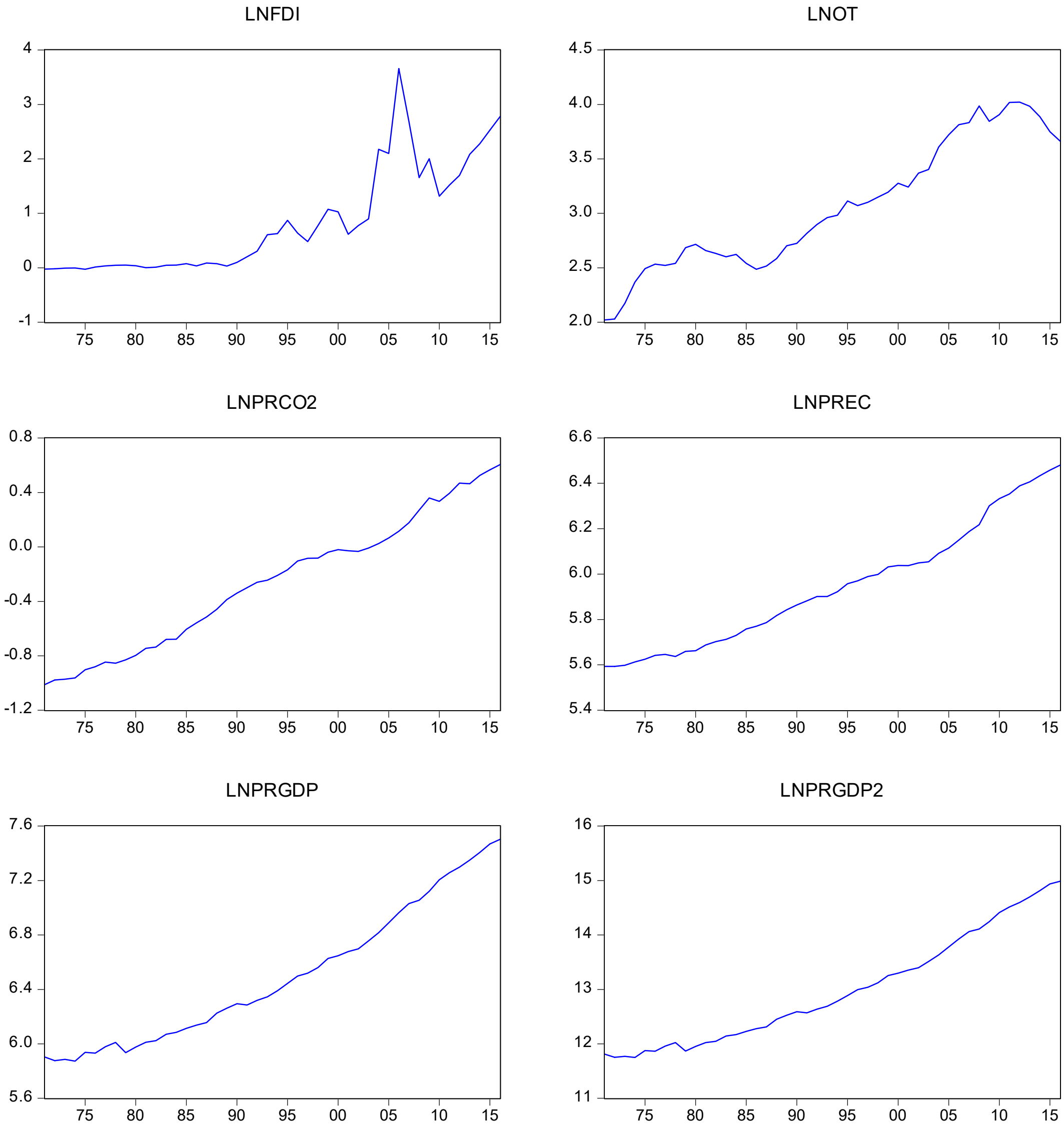
Unrestricted error correction test

To know the short-run dynamics we have estimated the error correction model (ECM), the equation as follows

$$\Delta CO_2 = \alpha_0 + \sum_{i=1}^{n} b_{1i}\Delta CO_{2t-i} + \sum_{i=1}^{n} b_{2i}\Delta Y_{t-i} + \sum_{i=1}^{n} b_{3i}\Delta Y_{t-i}^2 + \sum_{i=1}^{n} b_{4i}\Delta E_{t-i} + \sum_{i=1}^{n} b_{5i}\Delta T_{t-i} + \sum_{i=1}^{n} b_{6i}\Delta FDI_{t-i} + \delta_1 CO_{2t-1} + \delta_2 Y_{t-1} + \delta_3 Y_{t-1}^2 + \delta_4 E_{t-1} + \delta_5 T_{t-1} + \delta_6 FDI_{t-1} + \theta\, ECT_{t-i} + \epsilon_{1t} \tag{3}$$

Here, the ECT_{-I} is the error correction term, and in the end, we estimate the stability of coefficients sum (CUSUM) and cumulative sum square (CUSUMSQ).

Figure 1. *Variable plots*



5. Empirical results and interpretation

The summary statistics are reported in Table 2. The table shows the coefficient of skewness is greater than zero for all variables. The coefficient of kurtosis is relatively high in the case of foreign direct investment. The result also indicates jb test rejects the null hypothesis of normal distribution for all the variables.

Table 2. *Descriptive statistics*

	LNFDI	LNOT	LNPRCO2	LNPREC	LNPRGDP	LNPRGDP2
Mean	0.82	3.05	-0.26	5.94	6.49	12.99
Median	0.54	2.97	-0.22	5.91	6.36	12.73
Maximum	3.65	4.02	0.60	6.48	7.50	14.98
Minimum	-0.03	2.01	-1.01	5.59	5.87	11.74
Std. Dev.	0.97	0.59	0.48	0.27	0.50	1.01
Skewness	1.06	0.21	0.07	0.44	0.52	0.51
Kurtosis	3.13	1.85	1.82	2.07	2.00	2.00
Jarque-Bera	8.79	2.89	2.66	3.15	3.97	3.97
Probability	0.01	0.23	0.26	0.20	0.13	0.13

The co-movement analysis is presented in the following Table 3. The result of correlation statistics indicates that there is a high correlation exist between the variables.

Table 3. *Co-movement analysis*

Variables	LNFDI	LNOT	LNPRCO2	LNPREC	LNPRGDP	LNPRGDP2
LNFDI	1					
LNOT	0.87* [12.10] (0.00)	1				
LNPRCO2	0.84* [10.34] (0.00)	0.94* [19.52] (0.00)	1			
LNPREC	0.86* [11.31] (0.00)	0.94* [19.98] (0.00)	0.98* [46.51] (0.00)	1		
LNPRGDP	0.88* [12.86] (0.00)	0.95* [21.42] (0.00)	0.97* [32.55] (0.00)	0.99* [71.25] (0.00)	1	
LNPRGDP2	0.88* [12.86] (0.00)	0.95* [21.50] (0.00)	0.97* [32.60] (0.00)	0.99* [71.24] (0.00)	0.99* [2931.12] (0.00)	1

Note: [ ] shows' statistics and ( ) indicates 'P' values and * indicates 1% level of significance.

The unit root test is shown in Table 4. The result of the unit root test indicates that all the variables are integrated of order 1 i.e., I (1). This result provides strong evidence to investigate the long-run linkage between the variables by using the ARDL bound testing method which is independent of the order of integration.

Table 4. *Unit root test*

Variables	ADF Test		PP Test	
	Level	First Difference	Level	First Difference
lnprgdp	3.68 (1.00)	-6.01* (0.00)	4.93 (1.00)	-6.04* (0.00)
lnprgdp2	3.55 (1.00)	-6.03* (0.00)	4.30 (1.00)	-6.06* (0.00)
lnprco2	0.88 (0.99)	-6.31* (0.00)	0.83 (0.99)	-6.33* (0.00)
lnprec	3.20 (1.00)	-5.04* (0.00)	2.80 (1.00)	-5.18* (0.00)
lnot	-1.62 (0.46)	-2.84* (0.06)	-1.50 (0.52)	-4.64* (0.00)
lnfdi	-0.84 (0.79)	-7.54* (0.00)	-0.72 (0.82)	-7.51* (0.00)

Note: * shows 1% level of significances. ( ) denoted the probability value.

Table 5. *Unit root test with unknown structural break*

Variables	ADF Test at Level		ADF Test at First Difference	
	Statistics	Break Date	Statistics	Break Date
lnprgdp	0.87 (0.99)	1993	-7.59** (0.01)	1993
Lnprgdp2	0.76 (0.99)	1993	-7.59** (0.01)	1993
Lnprco2	-0.84 (0.99)	2005	-6.84** (0.01)	2008
lnprec	-0.20 (0.99)	2004	-6.99** (0.01)	2009
lnot	-2.86 (0.75)	1988	-5.85** (0.01)	2013
Lnfdi	-3.69 (0.28)	2003	-8.33** (0.01)	2004
Significance				
CV 1%	-4.94			
CV 5%	-4.44			
CV 10%	-4.19			

Note: ** show the significance at 5% and ( ) parenthesis indicates the probability values.

Table 5 shows the unknown structural break unit root test result while employing the Augmented Dickey-Fuller (ADF) structural break. The result shows in the presence of structural break the variables are found to be non-stationary. The structural break found in 1993, 2005, 2004, 1988 and 2003.

Table 6. *Long-run and short-run analysis*

Dependent Variables: lnCO2			
Long-run Results			
Variables	Coefficients	T-statistics	P-vale
Lnprec	2.56	14.57	0.00*
Lnprgdp	3.25	8.79	0.00*
Lnprgdp2	-0.27	-11.78	0.00*
Lnot	-0.00	-0.09	0.92
Lnfdi	0.02	1.16	0.12
C	-24.88	-30.43	0.00*
Short-run Results			
Variables	Coefficients	T-statistics	P-vale
D (lnprec)	1.86	7.86	0.00*
D (lnprgdp)	8.41	4.75	0.00*
D (lnprgdp2)	-0.70	-4.81	0.00*
D (lnot)	-0.09	-1.75	0.09
D (lnfdi)	0.00	0.30	0.76
$ECT_{(T-1)}$	-1.02	-3.75	0.00*

Note: * shows the 1% level of significance.

The long-run results are reported in Table 6. The result reveals that energy consumption has a positive impact on carbon emission. An increase in energy consumption will increase CO_2 emission. Furthermore, economic growth has a positive impact on carbon emission. High economic growth leads to high emissions. The negative coefficient of square GDP suggests that the existence of the EKC hypothesis. The result shows that a 1 per cent rise in economic growth will decrease carbon emission by 2.56% in the long run. While the negative sign of the square term seems to corroborate the decline of CO_2 emission and a higher level of economic growth. The long-run result also reveals that openness of trade and foreign direct investment does not have any impact on CO_2 emission.

The ECM_{T-1} short-run results are presented in Table 6. The short-run elasticity of CO_2 emission, concerning energy consumption, is positive and significant. The positive sign of per capita energy consumption is indicating that in India for each one per cent increase in energy consumption per capita CO_2 emission also increases by 1.86 per cent. Economic growth is another positive significant factor in the short-run which shows that increase in economic growth leads to more carbon emission. However, the square of economic growth is a negative and significant variable. The negative sign of the square of economic growth supports the existence of an environmental Kuznets curve in India. The openness of trade is negative and insignificant in the short-run and the foreign direct investment is positive and insignificant in the short run. The statistical significance of the error correction term ECT_{t-1} with an appropriate sign (-) is an indication of the speed of adjustment towards the long-run equilibrium after dis-equilibrium in the short run. This indicates that any deviation from the long-run equilibrium between CO_2 emission and other variables is corrected in each period and restored to the long-run equilibrium level after disequilibrium in the short run.

Table 7. *Diagnostics test of error correction model*

Tests	F-statistics	Prob.
Breusch Godfrey Serial Correlation LM Test	3.16	0.06
Breusch Pagon Godfrey- Heteroskedasticity Test	0.79	0.70
Heteroskedasticity Test: ARCH	1.82	0.18
Heteroskedasticity Test: Glejser	0.99	0.50

Table 7 reported the diagnostics test result which shows that the error correction model is free from serial correlation, autoregressive conditional heteroskedasticity, and functional from. And the model is well specified.

The empirical results of the ARDL bound testing result are shown in Table 8. The ARDL result shows that the estimated F-statistics is greater than the critical values of both upper bound and lower bound. This ARDL result confirms that there is a long-run equilibrium relationship between the variables.

Table 8. *ARDL result for cointegration*

F-Statistics	Optimal Lag Order	Lower Bound I (0)	Upper Bound I (1)
		Critical Values	Critical Values
5.688*	4, 4, 2, 2, 3, 1	3.74 (1%)	5.06 (1%)
		2.86 (5%)	4.49 (5%)
		2.45 (10%)	3.52 (10%)

Note: * Indicates 1% level of significance.

Table 9. *ARDL diagnostic test*

Tests	F-statistics	Prob.
Breusch Godfrey Serial Correlation LM Test	2.09	0.14
Breusch Pagon Godfrey- Heteroskedasticity Test	0.88	0.59
Heteroskedasticity Test: ARCH	0.27	0.60
Heteroskedasticity Test: Glejser	0.72	0.74

The ARDL diagnostic test result is reported in Table 9. Table 9 reveals that the ARDL bound testing approach is free from serial correlation, autoregressive conditional heteroskedasticity, and functional form and the model is well specified.

6. Concluding remarks and policy suggestions

The major objective of this study is to investigate the existence of an environmental Kuznets curve hypothesis in the context of India. The study employed the autoregressive distributed lag model over the period 1971 to 2016. The empirical result of the co-movement analysis found that there is a high correlation between the variables. The ordinary least square result confirms that economic growth has a positive and significant impact on carbon emission. The OLS result initially confirms that there is an existence of an environmental Kuznets curve for India. The ARDL bounds testing result suggests that there is a long-run equilibrium relationship among the variables when carbon emission is the dependent variable. The long-run cointegration result reveals that energy consumption has a positive impact on carbon emission. The negative square of GDP indicates that the existence of the EKC hypothesis in India. This confirms that the negative sign of the square GDP coefficient suggests that the presence of the EKC hypothesis in India. The error correction result shows that the positive sign of per capita energy consumption is indicating that in India for each 1 per cent increase in energy consumption per capita CO_2 emission also increases by 1.86 per cent. The statistical significance of the error correction term ECT_{t-1} with an appropriate sign (-) is an indication of the speed of adjustment towards the long-run equilibrium after disequilibrium in the short run.

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