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The Relationship Between Economic Growth and Carbon Emissions in India

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THE RELATIONSHIP BETWEEN ECONOMIC GROWTH AND CARBON EMISSIONS IN INDIA

Kaumudi Misra∗

Abstract

This paper attempts to analyse the relationship between economic growth and carbon emissions in India. The parameters selected for understanding this relationship are GDP (as a proxy of economic growth) and CO_2 emissions for the period 1970-2012. The study includes other important parameters such as energy consumption (oil) and urbanisation. Granger causality is used to check the existence of unidirectional and bi-directional causalities between the variables. The results reveal that there exists a unidirectional causality from energy consumption and GDP to carbon emissions. The ARDL model is used to understand the long run and short run relationship between the variables. The study finds that there exists a long run relationship between the variables whereas in the short run, there is no relationship between the variables. The findings imply that any attempt at reducing carbon emissions without bringing in energy efficiency will adversely affect the economic growth of the country.
Keywords: Carbon emissions, GDP, ARDL model

Introduction

Energy plays a vital role for the development of any economy. The growth of an economy is very important as it helps in reducing poverty and unemployment. The demand for energy from various sectors of the economy has witnessed tremendous growth. The increased usage of energy (fossil fuels) has caused environmental degradation throughout the world. Therefore, the issue at hand is to reduce carbon emissions without compromising on economic growth.

This goal can be achieved in two ways: One is by bringing in energy efficiency and two by adopting clean technology. Adoption of clean technology requires huge investments and is achievable in the long run. Energy efficiency can be achieved in the short run and therefore must be the focus of the economy.

India is one of the fastest developing countries after China with its GDP growth rate of 7.5 percent in 2015. Table 1 compares the economic growth and sector-wise contribution to the GDP made by USA, EU, China and India to their respective economies.

Table 1: GDP growth and sector-wise contribution to GDP in 2015 (percent)

Country	GDP growth rate	Service sector	Manufacturing sector	Agricultural sector
USA	2.9	78.92	20.5	1.05
EU	2.2	73.4	25.1	1.6
China	6.9	50.2	40.9	8.8
India	7.5	52.93	29.61	17.46

Source: Eurostat (2018)

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In 2015, India's GDP growth is the highest in comparison to the other nations with 7.5 percent. That of USA and EU are 2.9 and 2.2 respectively as the developing nations – India and China –have more potential to grow. This happens as the developing nations adopt new technologies that were invented in the developed nations whereas the developed nations are already functioning with advanced technology. This phenomenon of economic growth is called catch-up-growth (Popov and Jomo, 2017). The sector-wise contribution to GDP shows that it is the service sector which is dominant in the USA and EU followed by manufacturing and agricultural sectors. In the case of India and China, the service sector contributes half to the GDP. In China,40 percent of the GDP comes from the manufacturing sector which justifies it being the highest CO_2 emitter in the world. In the case of India, the manufacturing sector contributes about 30 per cent of the GDP with the agricultural sector contributing 17 percent. It is important to note that the agricultural sector contributes only 1 and 1.6 per cent to the GDP in the USA and EU respectively. When looking at CO_2 emissions, India is the fourth largest CO_2 emitter (in terms of absolute and per capita carbon emissions) after China, USA and European Union (Edgar.jrc.ec.europa.eu. (2018).

Table 2: Carbon emissions (2015)

Country	Absolute emissions (KT)	Per capita emissions (T)	% of total emissions
China	1,06,41,789	7.7	29.51
USA	51,72,336	16.1	14.37
EU	34,69,671	6.9	9.62
India	24,54,968	1.9	6.81

Source: EDGAR Database, 2017

Table 2 depicts carbon emissions from the top four emitting countries in the world which together account for 60.31 per cent of the total carbon emissions. It is evident from the table that China leads in terms of absolute emissions and in contribution to the total emissions. USA is the highest carbon emitter in terms of per capita emissions. India is the fourth largest carbon emitter contributing 6.81 per cent to the world carbon emissions. Though India's per capita emissions is much lesser when compared to the top three emitters it is important for India to reduce its emissions for the following reasons: its per capita emissions is rising since 1990, its dependence on the conventional sources of energy (coal and oil). Also India's energy intensity is twice that of the matured countries, India uses twice as much of energy to produce an output when compared to the developed nations.

Currently India faces a twin challenge of striving towards economic development for the reduction of poverty and unemployment, but at the same time it needs to mitigate its carbon emissions in order to safeguard itself from the adverse effects of climate change. It is important to identify the major causes of emissions as this will help India to mitigate emissions by having minimal effect on the economic growth of the country. The current work aims at analysing the relationship between economic growth and emissions in India.

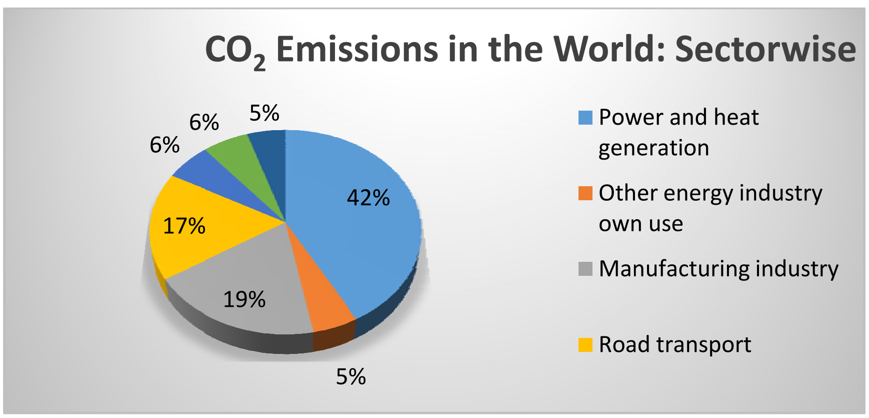
The structure of the paper is as follows: Comparison of carbon emissions among the top emitters, review of literature on the relationship between economic growth and carbon emissions, data and methodology for the current analysis – relationship between carbon emissions, GDP, energy intensity and electricity generation, results and discussion (aggregate and disaggregate analysis) and conclusion.

Comparison of Carbon Emissions among the Top Emitters

Carbon emissions are a result of burning of fossil fuels. The following section attempts to compare the carbon emissions across different sectors, modes and countries. The countries and entities that are selected for the comparison are China, USA, European Union and India. This is because these four are the top carbon emitters. The sectors that are considered are: Power and heat generation, manufacturing industry and road transport. The modes (resource) include coal, oil, gas and others.

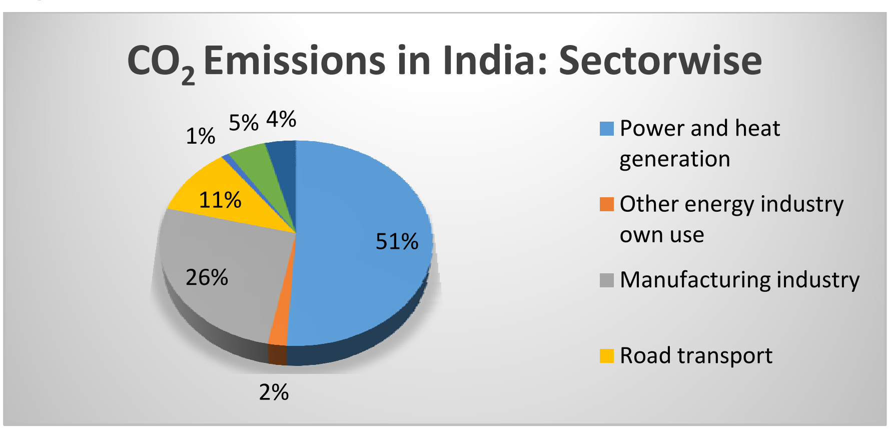
1. We begin with comparing sector-wise emissions in the world and then in India.

Graph 1: CO_2emissions in the world: Sector-wise



Source: Trends in CO_2 emissions – 2016 report, PBL Netherlands Environmental Assessment Agency

Graph 2: CO_2 emissions in India: Sector-wise



Source: Trends in CO_2 emissions – 2016 report, PBL Netherlands Environmental Assessment Agency

Note: In both the graphs, the upper section blue represents the category of other transport, the green is residential area and the dark blue represents other buildings.

World over, it is the generation of electricity and heat that causes 42 per cent of the total carbon emissions, followed by the manufacturing sector and road transportation contributing 19 and 17 per cent respectively. In the case of India, the same trends are witnessed, where power and heat generation cause 51 per cent of the total emissions, followed by the industrial sector and the transport sector emitting 26 per cent and 11 per cent respectively. This is because India is majorly dependent on conventional sources for its energy needs.

2. The burning of fossil fuels isthe root cause of carbon emissions. The following table compares emissions coming from the burning of fuels mode-wise.

Table 3: CO_2 emissions from fossil fuel combustion (MT)

Country/Group	Coal	Oil	Gas	Others	Total
China	7,433	1,145	299	32	8,909 (27.68%)
USA	1,702	1,990	1,399	26	5,120 (15.91%)
European Union	1,128	1,290	867	54	3,340 (10.38%)
India	1,348	447	72	1	1,868 (5.81%)
World	14,796	10,825	6,381	175	32,190

Source: Trends in CO_2 emissions – 2016 report, PBL Netherlands Environmental Assessment Agency

India emits 5.81 per cent of the total CO_2 emissions in the world. China stands ahead of the other nations by emitting 28 per cent of the total CO_2 emissions, followed by the USA and the European Union. India is far behind the top three emitting countries, and it emits 6 per cent of the total emissions by the combustion of fossil fuels. But it is important to note that India's dependence on coal is more than that of the European Union. It is also important to note that 60 per cent of the total emissions from the combustion of fossil fuel comes from the above four listed countries. Also, the energy mix of the developed nations is very different from that of the developing ones – India and China. Both the USA and EU have tapped the gas and oil resources, thereby reducing their dependence on coal.

Further comparison of India with the top emitting countries in terms of emissions from different sectors and sources has been done to better understand the position of India in terms of emissions. The comparison has been for the following sectors – electricity and heat generation, industries and the transport sectors, as these are the major emitting sectors in both the world and India.

3. Carbon emissions from heat and power generation

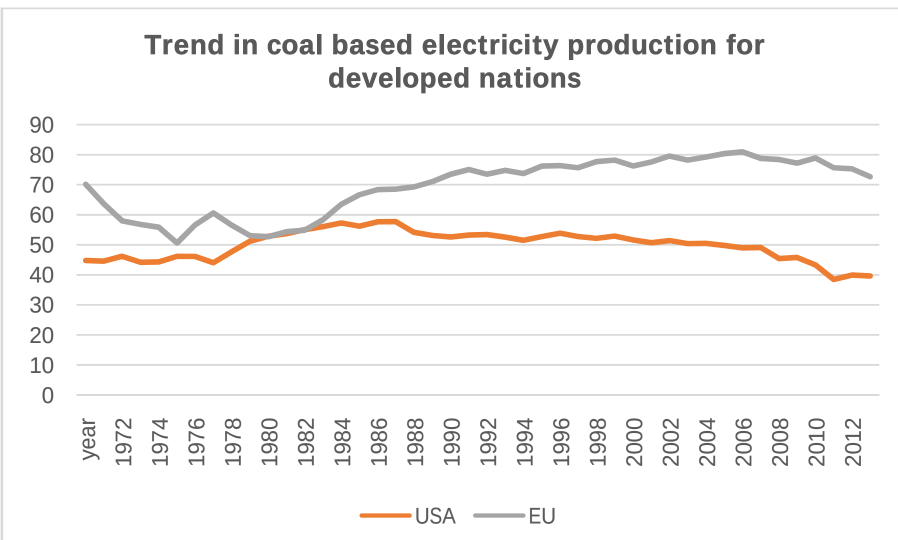
Table 4: CO_2 emissions from power and heat generation (MT)

Country/Group	Coal	Oil	Gas	Others	Total
China	4,251	15	56	32	4,353 (31.88%)
USA	1,596	29	486	18	2,128 (15.58%)
European Union	927	50	239	38	1,254 (9.18%)
India	886	25	32	1	945 (6.92%)
World	9,887	887	2,753	128	13,656

Source: Trends in CO_2 emissions – 2016 report, PBL Netherlands Environmental Assessment Agency

Heat and electricity generation being the major cause of emissions both for the world economy and in India, the comparison of India with the leading emitting countries is vital. It is important to note that both India and China are heavily dependent on coal for the generation of electricity. One-third of the emissions in both the USA and the European Union come from gas usage; this resource remains largely untapped in the case of China and India. India remains fourth in terms of emissions produced by the generation of power and heat.

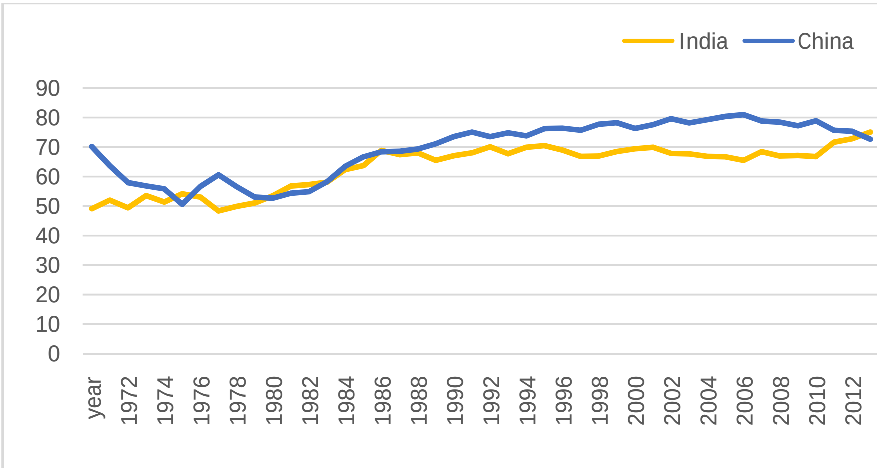
Graph 3: Dependence on coal for electricity generation by USA and EU



Source: Author's creation based on data from World Bank, 2015

Electricity is the backbone of any country when economic development is taken into consideration. It is used by all the sectors from the industries to the transportation and household sectors. As per the EKC theory, initially when an economy is moving towards economic development, it causes environmental degradation, but after reaching a certain point of development, the environment starts to renew itself. This is so because along with high economic growth, the desire for better environment increases. In the case of both the USA and European Union, both of which are developed nations, the dependence on coal in terms of electricity generation seems to be moving down after a point. This is so because of the energy mix of the countries. The natural resources are tapped and the dependence on conventional sources of energy has been reduced.

Graph 4: Dependence on coal for electricity generation by India and China



Source: Author's creation based on data from the World Bank, 2015

In the case of India and China, the dependence on coal for power generation has been increasing since 1970. In India in 2013, three-fourth of the total electricity generation came from coal, which is higher than China where 72.63 per cent of the electricity was generated using coal. Both India and China are major emitters of CO_2, China being the first and India the fourth largest emitter in the world. It is very important for both the nations to reduce their dependence on coal in order to mitigate emissions. This can be done by modifying the energy mix – tapping the renewable resources and increasing the dependence on natural gas as done by both USA and EU.

4. The following is a comparison of the top four CO_2 emitting countries from the manufacturing sector. The analysis is done on the basis of carbon emissions coming from the following sources: Coal, oil gas and others.

Table 5: CO_2 Emissions from the manufacturing industry (MT)

Country/Group	Coal	Oil	Gas	Others	Total
China	2,484	175	85	-	2,743 (44.86%)
USA	96	66	252	8	422 (6.9%)
European Union	118	85	195	15	414 (6.77%)
India	410	66	17	-	493 (8.06%)
World	3,867	983	1,223	42	6,115

Source: Trends in CO2 emissions – 2016 report, PBL Netherlands Environmental Assessment Agency

It is surprising to note that India stands second in terms of carbon emissions from the manufacturing industry leaving behind the USA and the European Union. The major source of emissions from the manufacturing industry in India is coal followed by oil. India needs to attempt to bring a change in the energy mix by using more oil and gas.

5. Carbon emissions from road transport

Table 6: CO_2emissions from road transport (MT)

Country/Group	Coal	Oil	Gas	Others	Total
China	-	581	29	-	610 (10.97%)
U.S.A	-	1,443	2	-	1,445 (26.05%)
European Union	-	815	3	-	819 (14.76%)
India	-	203	4	-	206 (3.71%)
World	-	5,464	83	-	5,547

Source: Trends in CO2 emissions – 2016 report, PBL Netherlands Environmental Assessment Agency

It is road transport that emits the most CO_2 in comparison to other forms of transport. In terms of emissions from road transport, the USA and the European Union are the front runners, leaving China and India far behind. As per motor vehicles per 1,000 inhabitants, the USA stands first at 795 followed by the European Union with 573 vehicles. India and China have 151 and 154 vehicles respectively (World Bank Indicators, 2017). This statistics justifies the road transport emissions by the above four countries.

The above comparison helps us in identifying the major sectors and sources of carbon emissions in India. It is clear that in India, it is the power and manufacturing industries that cause the maximum CO_2 emissions due to their dependence on conventional sources of energy – coal and oil.

Review of Literature

A plethora of studies have tried to investigate the relationship between energy usage and economic growth. The studies vary in terms of the time period used, the selection of variables, the methodologies adopted and more importantly, their findings.

The review of literature is divided on the following themes:

1. The papers that test the Environmental Kuznets Curve (EKC) hypothesis:

Narayan and Narayan (2010) used the GDP and CO_2 emissions to test the EKC hypothesis for a panel of countries. The study was unique as it employed a new methodology to test the EKC hypothesis - it employs income elasticity to test the hypothesis. The study criticises the age-old methodology of testing the EKC that uses the GDP square as a variable in the model. According to this study, if a country's short run income elasticity is greater than the long run elasticity, then that nation satisfies the EKC hypothesis. Payne (2009), tests the EKC hypothesis for a panel of countries using the CO_2 emissions, energy use, income and income square as the variables. In his analysis, the countries under consideration satisfy the EKC hypothesis.

2. Papers that test the relationship between energy, income and environment:

Ghosh *et al* (2014), in their study for Bangladesh, use GDP, CO_2 emissions and energy consumption to understand the causal relationship between the above mentioned variables. The study uses time series data for the period 1972-2011. The study found that CO_2 emissions affect economic growth negatively whereas energy consumption has a positive effect on economic growth. Another study by Ghosh (2009), uses real GDP, electricity supply and employment to check for causality between electricity supply and real GDP. The study found that the GDP and electricity supply granger causes the employment in the long run whereas in the short run, real GDP granger causes electricity supply in India. Lean and Smyth (2010), found a positive and statistically significant association between electricity consumption and CO_2 emissions and a non-linear relationship between emissions and real output, which satisfies the EKC hypothesis. The study has used GDP, electricity consumption and CO_2 emissions for the analysis. The study by Ghosh (2009), is superior to that of the Lean and Smyth (2010), as the latter uses electricity consumption which doesn't take into consideration the T and D losses. Electricity generation is a better proxy of coal consumption than that of electricity consumption. Ang (2007), finds a unidirectional causality running from the growth of output to the growth of energy to output, and increase in energy causes an increase in CO_2, output growth causes emissions and energy consumption in the long run, CO_2 and output have a quadratic relationship. The study satisfies the EKC hypothesis. The study has used emissions, energy consumption and output as the variables. Further in the case of Bangladesh, Nain *et al* (2015), find that in the short run, electricity consumption causes economic growth and CO_2 emissions, and long run relationship among the variables exist. No feedback causation was found in both the short run and the long run at both aggregated and disaggregated levels. The study stands superior to the earlier mentioned literature as Nain *et al* analyse the causality at both the aggregate and the disaggregate levels. The disaggregate analysis is rare to find in the literature reviewed so far.

3. The papers testing the relationship between carbon emissions and economic growth along with other important variables:

It is important to understand that it is not just the economic growth of a country that causes emissions or environmental degradation for the economy. Emissions are caused due to various reasons and cannot be singularly attributed to the economic growth of a nation. In the line of current thought, the following studies have identified various variables other than GDP that play an important role in determining the emissions of a country. Saidi and Sami (2015) bring in the variables financial development, population, labour and capital along with energy consumption, CO_2 and GDP to understand the relationship between economic growth and emissions for a panel of 58 countries. The study found that financial development happens to have a positive impact on the energy consumption of countries. Also, it was found that economic growth and CO_2 emissions have a positive impact on energy consumption. A study done on India by Zhang and Cheng (2009) uses the urban population as a proxy of urbanisation along with capital for examining the causal relationship between economic growth, energy consumption and carbon emissions. The study found a unidirectional causality from GDP to energy consumption and energy consumption to CO_2 emissions in the long run.

Some studies have included exports as an important variable in their models, whereas others taketrade openness (the ratio of exports + imports to the GDP) as a proxy of trade. See Narayan and Smyth (2008), Halicioglu (2009), Wahid *et al* (2013) and Hossain (2012). Narayan and Smyth found that in the long run, exports and electricity granger cause electricity and exports and income granger cause electricity consumption, whereas in the short run, the income granger causes exports in the Middle Eastern countries. In the case of Turkey, it was found that foreign trade granger causes emission after income and energy consumption (Halicioglu, 2009). There is no significant impact of trade openness on emissions for Malaysia, Indonesia and Singapore; it is the electricity consumption that granger causes emissions in the long run (Wahid *et al*, 2013). The findings of Hussain (2012) state that trade openness granger causes emissions and energy consumption in the short run. It is also found that economic growth causes trade openness.

Fixed capital formation and labour are important parameters for analysing the relationship between economic growth, emissions and energy consumption. See Soytas and Sari (2009), Soytas *et al* (2007), Stern (1993) and Cheng (1999). Yet, the significance of the two parameters differ due to variations in the time periods and the predominant regional factors of the study area.

The papers reviewed so far also differ in terms of panel data analysis and time series analysis. The studies that have done a panel analysis are Saidi and Sami (2015), Narayan and Narayan (2010), Apergis and Payne (2009), Narayan and Smyth (2008) and Lean and Smyth (2010),

Studies that have restricted themselves to analysing one country using the time series analysis: Ghosh *et al* (2014), Ghosh (2009), Zhang and Cheng (2009), Soytas and Sari (2009), Wahid *et al* (2013), Soytas *et al* (2007), Halicioglu (2009), Ang (2007), Stern (1993), Nain *et al* (2015), Sharif (2012), Cheng (1999), Jayanthakumaran *et al* (2012) and Yang and Zhao (2015).

4. Review of the methodology used:

The literature on the causal relationship between economic growth and CO_2 emissions has been varied in terms of the methodology adopted to understand the same. The current section of the handout discusses the methodology adopted by the papers that have done time series analysis. The traditional Vector Auto-Regression (VAR) has been adopted by Wahid *et al* (2013) and Stern (1993). Vector Error Correction Model (VECM) is preferred over VAR when there is existence of co-integration in the variables. Ghosh *et al* (2014) and Cheng (1999) have used the VECM whereas Ang (2007) has used the VECM model but he has adopted the full information maximum likelihood method.

The Auto-Regressive Distributed Lag (ARDL) bounds test is said to be superior to the VAR and VECM methodologies as the latter have to pre-test the variables for co-integration. In the case of ARDL, the variables can be of the order I (1), I (0) or a fraction of these orders. The studies that have adopted the ARDL methodology for testing the causal relationship between economic growth and emissions are Ghosh (2009), Halicioglu (2009), Nain *et al* (2015), Hossain (2014) and Jayantha kumaran *et al* (2012). Further, the Generalised Impulse Model was used by Ghosh *et al* (2014), Zhang and Cheng (2009), Soytas and Sari (2009), Soytas *et al* (2007) and Cheng (1999).

The Toda Yamamoto granger causality test is said to be superior to that of the VAR and VECM models as it does away with the co-integration properties; it is a modified Wald test that tests the restrictions on the parameters of the VAR model. The studies that have adopted the TY methodology are Zhang and Cheng (2009), Soytas and Sari (2009) and Soytas *et al* (2007). The study by Soytas *et al* (2007), for understanding the relationship between energy consumption, income and carbon emissions in the USA stands out as it employs the TY methodology along with the generalised impulse response to capture the causality. It further uses the Generalised Variance Decomposition which points out what proportion of the variation in a variable can be explained by the changes in the other variables in the VAR system.

Data and Methodology

1. Selection of variables:

The following variables have been selected for analysing the relationship between economic growth and carbon emissions in India: CO_2 emissions, GDP, energy consumption and urbanisation. GDP is taken as a proxy for economic growth. All the studies reviewed use energy consumption to understand the relationship between energy and GDP - Sami and Hamami (2015), Ghosh *et al* (2014), Zhang and Cheng (2009), Apergis and Payne (2009), Soytas and Sari (2009), Soytas *et al* (2007), Halicioglu (2009) and Ang (2007). The current study uses energy consumption and urbanisation along with CO_2 and GDP. Energy consumption has been used by a large number of studies - Ghosh *et al* (2014), Ang (2007) and Saidi and Sami (2015). Only one study so far has used urbanisation to understand its impact on CO_2 emissions - Zhang and Cheng (2009). Urbanisation is a very important variable as it increases the energy demands in different ways, like housing and transportation. The urban population has been used as a proxy for urbanisation.

2. Collection of data

The period of the study is 1970-2012.This period is selected based on the availability of the data for all the above-mentioned variables. The data for the above variables are collected from different sources. The data on the country's GDP has been taken from the RBI database, the data is in the constant prices of 2004-05. The data on CO_2 emissions and energy consumption (oil) has been collected from the World Development Indicators. The data for urbanisation has been taken from the World Urbanisation Prospects, United Nations. Urban population is taken as a proxy of urbanisation.

3. Methodology

The Augmented Dicky Fuller test is used to test for stationarity of the variables. The VAR model cannot be adopted as there exists one co-integrating equation in the model. Further, VECM cannot be used due to insufficient data. The ARDL bounds test is said to be superior to the VAR and VECM methodologies as the latter have to pre-test the variables for co-integration. In the case of ARDL, the variables can be of the order I (1), I (0) or a fraction of these orders. The studies that have adopted the ARDL methodology for testing the causal relationship between economic growth and emissions are

Ghosh (2009), Halicioglu (2009), Nain *et al* (2015), Hussain (2014) and Jayanthakumaran *et al* (2012). Further, the Generalised Impulse Model was used by Ghosh *et al* (2014), Zhang and Cheng (2009), Soytas and Sari (2009), Soytas *et al* (2007) and Cheng (1999).The methodology adopted for the current analysis is the ARDL model. The ARDL bounds test is selected for the analysis as both the prerequisites of the ARDL model are satisfied by the data. The requisites for adapting the ARDL model are:

1. All the variables should be I(1) or I(0) or a combination of the two but no variable should be I(2). In the current analysis, all the variables are I(1).
2. There must be only one co-integrating equation in the model. As per the trace statistic and the maximum, there is only one co-integrating equation in the model.

Results and Discussion

1. Data analysis

The relationship between economic growth and carbon emissions in India is tested based on the absolute values and not on the per capita units. This has been done as the Kyoto Protocol has targets to reduce emissions in absolute terms rather than per capita emissions. The analysis is a time series one.

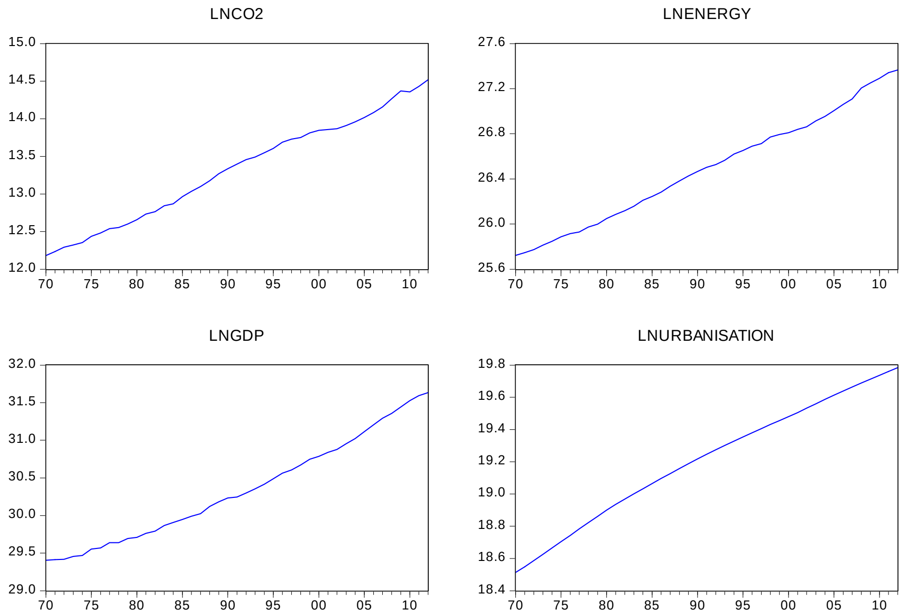
Table 6: Variables and their units of measurement

S.No	Variable	Unit of measurement
1	CO_2 emissions	Kilo tonnes
2	Urbanisation	Absolute numbers
3	Energy consumption (oil)	Energy consumed is in kilograms
4	GDP	Crore rupees

Source: Author's creation

The variables are first converted into their natural logs. This is done to remove the exponential growth factor from the variables. Generally, time series data tend to show a growing trend due to the time factor. The current analysis is done for the period 1970-2012, covering a time span of 42 years. The analysis begins by plotting the raw data.

Graph 5: Plotting of Raw Data



Time series properties of the selected data

It is important to check the stationarity of the variables while using time series data. Following are the results of the unit root test. The Augmented Dickey Fuller test has been used to check for the presence of unit root in the selected variables.

Table 7: Stationarity test

Variable	Level	Ist difference	Intercept	Result
CO_2	13.5692	-5.5640*	With intercept	I (1)
Energy	17.6538	-5.4317*	With intercept	I (1)
GDP	13.4216	-5.7342*	With intercept	I (1)
Urbanisation	0.0158	-2.6036*	Without intercept	I (1)

Source: Author's estimation (significant at one per cent significance level)*

As per the results of the unit root test, all the variables are non-stationary, integrated to the first order.

The granger causality test is used to check for the existence of unidirectional and bi-directional causality among the variables. Following are the results of the same.

Table 8: Granger causality

S.No	Direction of causality	P value	Existence of causality
1	Energy to CO_2	0.0008	Yes
2	CO_2 to energy	0.7762	No
3	GDP to CO_2	0.0630	Yes
4	CO_2 to GDP	0.8441	No
5	Urbanisation to CO_2	0.4568	No
6	CO_2 to urbanisation	0.2486	No
7	GDP to energy	0.3925	No
8	Energy to GDP	0.1336	No
9	Urbanisation to energy	0.8046	No
10	Energy to urbanisation	0.1676	No
11	Urbanisation to GDP	0.1836	No
12	GDP to urbanisation	0.9930	No

Source: Author's estimation

The null hypothesis tested in the granger causality test is that there is no causality between the variables. Based on the analysis of the 'p' values from the causality analysis, causality runs from energy and GDP to CO_2 emissions. Also, it is important to note that there is no endogeneity problem in the above variables. We further attempt to understand the relationship between these variables in the long and short run. For this purpose, the ARDL model has been selected as both the preconditions for the usage of ARDL model have been fulfilled by the variables in the analysis.

According to the results of the co-integration test, both the maximum Eigen value and the Trace statistic suggests that there exists only one co-integrating equation. The model uses six lags of the variables as this gives us the highest R^2 value and the least AIC and SICS values.

Following is the model:

d(lnco2) c d(lnco2(-1)) d(lnco2(-2)) d(lnco2(-3)) d(lnco2(-4)) d(lnco2(-5)) d(lnco2(-6)) d(lnenergy(-1)) d(lnenergy(-2)) d(lnenergy(-3)) d(lnenergy(-4)) d(lnenergy(-5)) d(lnenergy(-6)) d(lngdp(-1)) d(lngdp(-2)) d(lngdp(-3)) d(lngdp(-4)) d(lngdp(-5)) d(lngdp(-6)) d(lnurbanisation(-1)) d(lnurbanisation(-2)) d(lnurbanisation(-3)) d(lnurbanisation(-4)) d(lnurbanisation(-5)) d(lnurbanisation(-6)) lnco2(-1) lnenergy(-1) lngdp(-1) lnurbanisation(-1)

The above model is an ARDL model, where the variables are used in their log form. This is done to remove the exponential effect from the data. CO_2 is the dependent variable, which depends on the lagged variables – CO_2, energy, GDP and urbanisation. The model uses 6 lags of the variables.

Table 9: Results of the equation

Variable	Coefficient	Standard error	t-statistic	Probability value
Constant	-72.2049	37.7463	-1.9129	0.0973
D(lnco2 (-1))	0.3232	1.0838	0.2982	0.7740
D(lnco2(-2))	-0.0243	1.0102	-0.0240	0.9815
D(lnco2(-3))	-3.2391	1.1222	-2.8863	0.0234
D(lnco2(-4)	-3.7868	1.1264	-3.3616	0.0121
D($lnCO_2$(-5))	-1.2170	0.5346	-2.2762	0.0569
D($lnCO_2$(-6))	0.5220	0.2553	2.0440	0.0802
D(lnenergy(-1))	-5.5079	3.7149	-1.4826	0.1817
D(lnenergy(-2))	-4.3306	3.3121	-1.3075	0.2323
D(lnenergy(-3))	-2.7753	3.1133	-0.8914	0.4023
D(lnenergy(-4))	2.0013	2.7264	0.7340	0.4868
D(lnenergy(-5))	7.8006	2.5364	3.0754	0.0179
D(lnenergy(-6))	5.7208	1.9096	2.9956	0.0201
D(lngdp(-1))	3.8772	1.0530	3.6819	0.0078
D(lngdp(-2))	3.7851	1.1558	3.2746	0.0136
D(lngdp(-3))	2.2475	0.9191	2.4452	0.0444
D(lngdp(-4))	2.0385	0.7122	2.8620	0.0243
D(lngdp(-5))	1.0255	0.5805	1.7664	0.1207
D(lngdp(-6))	-4.4521	0.3167	-1.4273	0.1965
D(lnurbanisation(-1))	1.9769	5.8964	0.3352	0.7472
D(lnurbanisation(-2))	0.7190	6.5976	0.1089	0.9163
D(lnurbanisation(-3))	33.0614	9.3038	3.5535	0.0093
D(lnurbanisation(-4))	6.4105	11.0386	0.5807	0.5796
D(lnurbanisation(-5))	-5.2906	8.2002	-0.6451	0.5394
D(lnurbanisation(-6))	-1.8477	3.2211	-0.5736	0.5842
Lnco2(-1)	-1.9231	1.1753	-1.6362	0.1458
Lnenergy(-1)	7.0665	3.6867	1.9167	0.0968
Lngdp(-1)	-2.8780	1.0971	-2.6231	0.0342
Lnurbanisation(-1)	-0.1838	0.6911	-0.2609	0.8016
R^2	0.95			
AIC	-5.8185			
SIC	-4.5429			

Source: Author's estimation

The variables $lnCO_2$ (-3), $lnCO_2$ (-4), $lnCO_2$ (-5) and $lnCO_2$ (-6) are found to be significant in the analysis. Whereas third, fourth and fifth lagged variables of $lnCO_2$have a negative impact on the emissions, the sixth lag has a significant positive impact on the emissions. In the case of energy, the fifth and six lagged variables have a significant positive impact on the emissions, the first four lags being insignificant in the analysis. The first four lags of GDP are found to have a significant positive impact on the carbon emissions. The coefficients of urbanisation are mainly insignificant except for the third lag, which is found to have a significant positive impact on the carbon emissions.

The R^2 implies that 95 per cent of the variation in the CO_2 emissions is caused by the explanatory variables in the model (the lagged variables of CO2emissions, GDP, energy consumption and urbanisation). The remaining 5 per cent of the variation are due to the unaccounted variables which is represented by the error term. The variables lnco2 (-1), lnurbanisation (-1), lnenergy (-1) and lngdp (-1) are used to check for the existence of the long run relationship between the variables. The Wald statistic is used to find out the 'f' statistic which is then compared to the bounds critical value given by Narayan and Narayan (2006).

Table 9: Long run causality

Test statistic	Value	Degree of freedom	Probability
F statistic	7.7082	(4, 7)	0.0105
Chi-square	30.8328	4	0.0000

Author's estimation

The bounds critical value for small samples (30-80) has been given by Narayan (2005). If the estimated F statistic is greater than the upper bound then there exists long run relationship between the variables. If the F statistic falls below the lower bound, there is no relationship between the variables. In cases where the F value falls within the bounds, the relationship is said to be inconclusive. In the current case, our estimated F statistic (7.7082) is greater than the upper bound value i.e. 3.910 at 5% significance level. There exists a long run relationship between the variables. We further go ahead and check for serial correlation and stability of the model.

The model is then tested for the existence of serial correlation and stability. The LM test is used for the testing of serial correlation and the CUSUM test is used for checking the stability of the model. As per the results of the LM test, there is no problem of serial correlation in the model. Further as per the CUSUM test, the model is found to be stable.

Now the error correction term is used as an explanatory variable in the existing model which is free from serial correlation and is stable. The Error Correction Term (ECT) is used as an explanatory in the model to check the speed of adjustment towards the long run equilibrium. The model with ECT(-1) as an explanatory variable is found to be suffering from the problem of serial correlation. To get rid of this problem, we use only one lag of CO_2 as an explanatory variable. Here the model is free from serial correlation. The coefficient of ECT (-1) is found to be -0.51 and it is significant at 5per cent significant level. The speed of adjustment towards long run equilibrium is 51 percent. The whole system can get back to long run equilibrium at the speed of 51 percent. The model is also found to be stable as per the CUSUM test.

The short run causality analysis reveals that there is no causality between the variables in the short run.

Findings and Conclusion

The current study analyses the causal relationship between GDP and CO_2emissions along with energy consumption and urbanisation.

The granger causality test is used to check for the existence of unidirectional and bi-directional causality among the variables. The ARDL model is used along with the LM test and CUSUM test for checking the serial correlation and stability of the model. The variables $lnCO_2$ (-3), $lnCO_2$ (-4), $lnCO_2$ (-5) and $lnCO_2$ (-6) are found to be significant in the analysis. Whereas third, fourth and fifth lagged variables of $lnCO_2$ have a negative impact on the emissions, the sixth lag has a significant positive impact on the emissions. In the case of energy, the fifth and six lagged variables have a significant positive impact on the emissions, the first four lags being insignificant in the analysis. The first four lags of GDP are found to have significant positive impact on the carbon emissions. The coefficients of urbanisation are mainly insignificant except for the third lag, which is found to have a significant positive impact on the carbon emissions. In line with the findings of the current work, Ang (2007), finds a unidirectional causality running from the growth of output to the growth of energy to output, and increase in energy causes an increase in CO_2, output growth causes emissions and energy consumption in the long run.

As per the results of the granger causality test, there exists a unidirectional causality running from energy consumption and GDP to CO_2 emissions. Further, the results of ARDL bounds test reveal that there exists a long run relationship between the variables. The findings are in line with the findings of Zhang and Cheng (2009), which found a unidirectional causality from GDP to energy consumption and energy consumption to CO_2 emissions in the long run. Also, it is found that the whole system gets back to long run equilibrium at the speed of 51 percent. It is also found that none of the variables cause CO_2 emissions in the short run. By this we understand that in India, the consumption of energy, urbanisation and economic growth (GDP), cause CO_2 emissions in the long run, but not in the short run. It is important to take necessary steps in helping the country move towards energy efficiency in order to reduce CO_2 emissions.

A major reason for the carbon emissions caused as a result of economic growth is its dependence on the conventional sources of energy (coal and oil). These sources are easy to acquire and relatively less expensive. As a policy suggestion, the government of India should reduce the usage of conventional energy. They should further provide incentives in the form of subsidies for the adoption of low carbon technologies. Further efforts must be taken to build a market for clean technology, along with a robust financial system that encourages the adoption of low carbon technologies by various sectors in the economy.

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