Carbon Emissions from Energy Use in India: Decomposition Analysis

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Abstract

For becoming fastest-growing large economy in the world, India has set a target growth rate of 9%, reaching an economy of $5 trillion by 2024-25. It is an immense challenge to meet both the growth target and keeping the CO_2 emissions under control. The present paper aims at discovering the determinants for explaining CO_2 emissions in India by carrying out a complete decomposition analysis, where the residuals are fully distributed to the determinants, for the country during the period 1990–2018.

The analysis reveals that the biggest contributor to the rise in CO_2 emissions in India is the expansion of the economy (scale effect). The intensity of CO_2 and the change in composition of the economy, which nearly move in tandem, also contribute to the rise in CO_2 emissions, although more slowly. A declining energy intensity of Indian economy is responsible for a considerable reduction in CO_2 emissions. As a typical result for an upcoming economy, this paper did not find evidence for an environmental Kuznets curve. This implies that continued economic growth will lead to a continued increases in CO_2 emissions.

JEL: Q4; Q54

Keywords: Decomposition analysis; India; Energy; CO_2 emissions; Economic growth; Environmental Kuznets curve

I. INTRODUCTION

With a population of 1.4 billion and a real GDP growth of 6.2% over the period 1990-2018, India has set a target growth rate of 9% for becoming the fastest-growing large economy in the world, reaching a $5 trillion economy by 2024-25 (IEA, 2020). India's sustained economic growth, large population and rapid urbanization are placing an enormous demand on its energy resources, energy systems and infrastructure. Moreover, population density is high throughout most of the country.

The Government of India (GoI) aims to achieve 100 smart cities, LPG connections to all housing, and universal electricity access. Moreover, India's 2008 National Action Plan on

Climate Change (NAPCC) set out eight national missions to promote India's sustainable development objectives including National Solar Mission and National Mission for Enhanced Energy Efficiency and National Mission on Strategic Knowledge for Climate Change. At the Conference of the Parties (COP) 15 in Copenhagen in 2008, India announced voluntary targets to reduce the emissions intensity of its GDP by 20-25% against 2005 levels by 2020. In 2015 the Government of India submitted their Intended Nationally Determined Contributions (INDC), after the GoI ratified the Paris Agreement in 2016. India's Nationally Determined Contribution (NDC) focuses strongly on actions related to the energy sector and some of the targets are:

- Reducing the emissions intensity of GDP by 33-35% from 2005 levels by 2030;
- Achieving 40% cumulative installed capacity of electric power from non-fossil fuel-based energy resources by 2030 with low-cost international finance; and
- Creating an additional carbon sink of 2.5-3 billion tons of CO_2 equivalent through creation of additional forest and tree cover by 2030.

At the Climate Summit of United Nations in September 2019, Prime Minister Modi announced an increased ambition to promote renewable energy towards a target of 450 GW overall installed capacity.

The world is progressing towards UN Goal 7, with an encouraging note that the energy sector is becoming more sustainable and also widely accessible. Lack of access to energy may hamper the efforts to contain the current pandemic effects across many countries in the globe (UN, 2021a). In India, about 300 million people lack access to electricity. Successfully addressing the challenge of India's energy poverty and achieving the sustainable development goals would require poverty reduction and removal of social and economic inequality.

The power system of India is presently going through a major shift to higher shares of renewable energy. India's coal supply has increased rapidly since the early 2000s, and coal continues to be the largest domestic source of energy supply for electricity generation, which leads to a higher CO_2 intensity. The government aims to increase the share of natural gas in the country's energy mix to 15% by 2030, from 6% today (IEA, 2020). The consumption of natural gas is 50% imported and 50% locally produced as of 2018.

Taking into account all these challenges India faces, the present paper aims at discovering the determinants for explaining CO_2 emissions in India by carrying out a complete decomposition analysis for the country during the period 1990–2018. Here, the role of four factors, namely scale, composition, energy and carbon intensity are used to explain changes in CO_2 emissions. In a complete decomposition analysis, the residuals are fully distributed to these four determinants. In addition, changes in the sectoral composition of the economy, technologies in the energy mix, the energy and carbon intensity, link between national income and carbon emissions in India are also examined.

The outline of this paper is as follows. A literature survey is presented in Section 2. Section 3 presents the methodology used. Section 4 presents the results and discusses the changes in the energy situation in India and undertakes a complete decomposition analysis and tests whether an environmental Kuznets curve (EKC) can be found in India. The final section concludes.

II. LITERATURE SURVEY

There is a good number of publications on decomposition analysis of emissions worldwide. However, work is lacking on the situation in India considering the current context of CO_2 emission reductions. A broad review of the literature is provided in this section.

Xu and Ang (2013) undertook a comprehensive survey of literature which focuses specifically on emissions by various countries through reviewing eighty papers that have appeared in peer-reviewed journals during 1991–2012. Review of studies that have been conducted in developed and developing countries at national scales (and for various sectors including national total emissions).

According to Ang (2004), practitioners need to have a common understanding and consistency on the method used in decomposition analyses in empirical studies.

Ang and Choi (1997) proposed a refined Divisia index decomposition using logarithmic function by replacing the arithmetic mean weight-function which had no residual.

Su and Ang (2012) highlighted novel new methods in structural decomposition analysis (SDA), namely structural decomposition analysis (SDA) and index decomposition analysis (IDA). They compared SDA and IDA using the latest available information.

According to Hoekstra *et al* (2003), decomposition analysis is often used to understand changes in various indicators, among them are energy use, CO_2 emissions, but also labor demand and the value added to the economy. They considered SDA using an input–output model and IDA which uses more aggregated sector data and provided a hypothetical numerical example.

Tiwari (2011) examined causality by considering energy consumption, CO_2 emissions and economic growth for India. This study covered the period 1971-2007 using the Granger approach (VECM framework) and the Dolado and Lütkepohl's approach. The study concluded that India's Energy consumption has positive impact on CO_2 emissions and GDP, but its impact is negative on capital and population.

Wolde-Rufael, and Idowu (2017) examined whether income inequality has a role in environmental degradation in India and China, where both countries are much concerned about their unsustainable energy consumption. In both India and China, a long run, but a statistically insignificant link between income inequality and CO_2 emissions have been observed.

Kojima and Bacon (2009) using a decoupling method found decoupling of economic growth and emissions in India find that an increasing share of the service sector in GDP and falling energy intensity of industry as a major contributor in achieving decoupling of economic growth and emissions.

Table 1 summarizes main methods used in some important studies on Decomposition Analyses. The countries covered in these studies vary from single country, such as Brazil, China , Ethiopia, India and Turkey to various studies with multi-country coverage.

Table1: Methods used on decomposition analyses in various studies

Method	Authors
Index Decomposition Analysis (IDA)	Andreoni and Galmarini (2016), Wang and Zhou (2018), Su *et al* (2020)
Structural Decomposition Analysis (SDA)	Pal *et al* (2015), Tandon and Ahmed (2016), Karstensen *et al* (2020), Wang *et al* (2020)
Logarithmic Mean Divisia Index (LMDI)	Pachauri and Muller (2008), De Freitas and Kaneko (2011), Xu *et al* (2014), Chen and Yang (2015), Zhang and Da (2015), Dasgupta and Roy (2017), Kanitkar (2020), Taka *et al* (2020)
Refined Laspeyres decomposition model (LASP)	Lise (2006), Ebohon and Ikeme (2006), Wang *et al* (2005)
Other decomposition methods:	Sun (1998), Nag and Parikh (2000), Paul and Bhattacharya (2004), Zhang *et al* (2009), Reddy and Roy (2010), Attari and Attaria (2011)

The studies presented all try to untangle factors that cause CO_2 emissions and to recommend ways to reduce these emissions. The so-called "scale effect" is often prominent in developing countries, where population growth and growth of the economy are often found as the key contributing factors to rising CO_2 emissions. The present paper has as the main purpose to employ a recent data set (1990-2018) for India with a sectoral breakdown to numerically calculate the impact of four different components of growth, namely scale, composition, intensity of energy use and carbon emissions and their contributions to increases in CO_2 emissions.

III. MATERIALS AND METHODS

Decomposition analysis

In studies at the country level, it is of particular interest to decompose the elements that drive changes in CO_2 emissions (or energy consumption). This paper decomposes CO_2 emission amounts into four effects. Setting up the Kaya identity as shown in Eq. (1) can do this:

$$\begin{aligned} \mathrm{CO_2\ emissions} &= \underbrace{\mathrm{GDP}}_{\substack{\text{scale}\\ \text{effect}}} \times \sum_i \left(\underbrace{\frac{\text{Added value}_i}{\text{GDP}}}_{\substack{\text{composition}\\ \text{effect}}} \times \underbrace{\frac{\text{Energy use}_i}{\text{Added value}_i}}_{\substack{\text{energy intensity}\\ \text{effect}}} \times \underbrace{\frac{\mathrm{CO_2}\ emissions_i}{\text{Energy use}_i}}_{\substack{\text{carbon intensity}\\ \text{effect}}} \right) \\ &= P \times \sum_i (G_i \times I_i \times E_i) \end{aligned} \quad (1)$$

Where

CO_2 emissions are the total for India, measured in million tons (Mtons)

GDP is the total for India, measured in trillion Indian Rupees in 2015 prices.

Added value$_i$ is the share of GDP for sector *i*.

Energy use$_i$ is the share of energy use for sector *i*, measured in billion tons of oil equivalent (btoe)

CO_2 emissions$_i$ is the share of CO_2 emissions for sector *i*, measured in Mtons.

Sectors *i* are: Agriculture, Industry, Transport and Other.

P is GDP (scale effect).

G_i is Added value$_i$ divided by GDP (composition effect).

I_i is Energy use$_i$ divided by Added value$_i$ (energy intensity effect).

E_i is CO_2 emissions$_i$ divided by Energy use$_i$ (carbon intensity effect).

The total CO_2 emissions are fully equal to the product of total GDP (P), and the sum of the sectoral products of the added value per GDP (G_i), energy consumption per added value (I_i) and the CO_2 emissions per energy consumption (E_i).

To explain the changes in CO_2 emissions, let us define the differences (ΔP, ΔG_i, ΔI_i, ΔE_i) with respect to the base-year 1990, for instance $\Delta P_{\text{current}} = P_{\text{current}} - P_{1990}$, and so on. Then using the four factors from the Kaya identity as given in Eq. (1), it is possible to decompose the CO_2 emissions into four effects. First, the scale or activity effect represents additional emissions of CO_2 which is caused by economic growth. If the scale effect is found the dominating effect, then emissions of CO_2 increase linearly with the level of GDP. Second, the composition effect shows the increase of emissions due to changes in the composition of the economy. If the economy specializes in cleaner sectors, then there will be fewer additions to CO_2 emissions. Third, the energy intensity effect shows that when the energy intensity goes down the level of CO_2 emissions goes down too. For example, the energy intensity may be improved by the introduction of energy saving technologies. Fourth, the carbon intensity effect shows that when the carbon intensity reduces the level of CO_2 emissions reduces too. For instance, switching to a cleaner fuel mix in energy consumption can lower the carbon intensity. The last two effects represent two types of technological change.

Eq. (2) presents the required formulas for undertaking the complete decomposition analysis with LASP (Zhang and Ang, 2001). This is implemented in EXCEL to do the calculations.

$$
\begin{aligned}
Peff_t = \;& \Delta P_t \sum_i \Big[G_{i,1} \Big\{ I_{i,1}E_{i,1} + \frac{1}{2}\big(\Delta I_{i,t}E_{i,1} + I_{i,1}\Delta E_{i,t}\big) + \frac{1}{3}\Delta I_{i,t}\Delta E_{i,t} \Big\} \\
& + \Delta G_{i,t} \Big\{ \frac{1}{2} I_{i,1}E_{i,1} + \frac{1}{3}\big(\Delta I_{i,t}E_{i,1} + I_{i,1}\Delta E_{i,t}\big) + \frac{1}{4}\Delta I_{i,t}\Delta E_{i,t} \Big\} \Big] \\
Geff_t = \;& P_1 \sum_i \Delta G_{i,t} \Big\{ I_{i,1}E_{i,1} + \frac{1}{2}\big(\Delta I_{i,t}E_{i,1} + I_{i,1}\Delta E_{i,t}\big) + \frac{1}{3}\Delta I_{i,t}\Delta E_{i,t} \Big\} \\
& + \Delta P_t \sum_i \Delta G_{i,t} \Big\{ \frac{1}{2} I_{i,1}E_{i,1} + \frac{1}{3}\big(\Delta I_{i,t}E_{i,1} + I_{i,1}\Delta E_{i,t}\big) + \frac{1}{4}\Delta I_{i,t}\Delta E_{i,t} \Big\} \\
Ieff_t = \;& P_1 \sum_i \Delta I_{i,t} \Big\{ G_{i,1}E_{i,1} + \frac{1}{2}\big(\Delta G_{i,t}E_{i,1} + G_{i,1}\Delta E_{i,t}\big) + \frac{1}{3}\Delta G_{i,t}\Delta E_{i,t} \Big\} \\
& + \Delta P_t \sum_i \Delta I_{i,t} \Big\{ \frac{1}{2} G_{i,1}E_{i,1} + \frac{1}{3}\big(\Delta G_{i,t}E_{i,1} + G_{i,1}\Delta E_{i,t}\big) + \frac{1}{4}\Delta G_{i,t}\Delta E_{i,t} \Big\} \\
Eeff_t = \;& P_1 \sum_i \Delta E_{i,t} \Big\{ G_{i,1}I_{i,1} + \frac{1}{2}\big(\Delta G_{i,t}I_{i,1} + G_{i,1}\Delta I_{i,t}\big) + \frac{1}{3}\Delta G_{i,t}\Delta I_{i,t} \Big\} \\
& + \Delta P_t \sum_i \Delta E_{i,t} \Big\{ \frac{1}{2} G_{i,1}I_{i,1} + \frac{1}{3}\big(\Delta G_{i,t}I_{i,1} + G_{i,1}\Delta I_{i,t}\big) + \frac{1}{4}\Delta G_{i,t}\Delta I_{i,t} \Big\}
\end{aligned}
\tag{2}
$$

From Eq. (2) it is seen that in order for calculating, say, the scale effect (*Peff*$_t$) we have to consider the difference in P weighed by the other three factors as presented in Kaya identity. However, this first term leaves a residual. The residual is then distributed by applying the principle of 'jointly created and equally distributed' (Zhang and Ang, 2001). By fully distributing the residuals in the decomposition analysis it become a complete decomposition analysis with LASP. This helps us in explaining the halves, thirds and quarters appearing in the formula, which has terms with respectively two, three and four deltas. The scale effect is obtained by adding all these terms. The other effects like *Geff*$_t$ (Composition effect), *Ieff*$_t$ (Energy intensity effect), *Eeff*$_t$ (Carbon intensity effect) have been derived in a similar way. By summing up the scale, composition, energy intensity and carbon intensity effects, it is possible to derive the changes in CO_2 emissions with respect to base-year 1990. In this process, there is no residual. This methodology has been used for decomposition of the changes in the emission level of CO_2 over the period 1990–2018 in India.

EKC test

In addition, a test will be performed to verify whether an environmental Kuznets curve (EKC) can be found for India. To establish this, the following equation needs to be estimated with OLS:

$$ln(\text{CO2}) = \alpha + \beta_1\, ln(\text{GDP}) + \beta_2 (ln(\text{GDP}))^2 \qquad (3)$$

The coefficient of the quadratic term (β_2) needs to be both negative and statistically significant. In this case there will be a so-called inverted U relationship between GDP and CO_2 emissions, implying that as GDP grows, the rate of CO_2 emissions will slow down and ultimately even decrease; there will be a decoupling of CO_2 emissions from a growing economy. This is the EKC relationship (Stern, 2004).

Data

Data for the present work on India have been collected from various sources. These data comprise annual observations over the years 1990–2018, namely:

- total population measured in millions,
- gross domestic product (GDP) measured in trillion INR (Indian Rupees) in 2015 prices,
- total supply of primary energy per technology measured in billion tons of oil equivalents (btoe),

- total consumption of primary energy per sector per technology in btoe and
- total emissions of CO_2 per sector measured in Mtons derived with the sectoral approach.

Energy data are collected from IEA (2021). The added value per sector have been collected from UN (2021b). Economic liberalization process stared in India in the early 1990s. We have started our analysis from the year 1990 and have taken the period of 1990 to 2018 which has been divided into three sub-periods, namely: 1990-2000, 2000-2010 and 2010-2018. The reference year is 1990.

For preparing the data for analysis of complete decomposition, the Indian economy has been divided into four different sectors, namely the primary agricultural sector, the secondary industrial sector, tertiary transport sector and services sector. The value added for the sectors of agriculture and industry are separately specified in the data and has been used straightaway. However, the value added for transport is only available in combination with communication. In this paper for lack of sufficient information, the value added of transport and communication has been used as a proxy for the transport sector. The remaining value added has been assigned to the services sector in the economy.

IV. RESULTS AND DISCUSSION

The level of CO_2 emissions in India are subjected to a decomposition analysis over the period 1990–2018. Energy use changes with technologies and sectors. Energy technologies have been divided broadly into two categories namely fossil fuel (coal, lignite, oil and gas) and renewable (wind, solar, hydro and bioenergy) (Jana & Singh 2022, Jana 2022). Energy-using sectors that have been considered in the present analysis are agriculture, industry, transport, and services.

Sectoral division for energy consumption has been done as for value added. This has been done simply by taking the numbers in btoe as published in IEA (2021a). It is also possible to derive the composition of different fuel types in supply of primary energy from these energy balances as presented in Figure 4. Emissions from energy consumption has been calculated using emission factors given in IPCC guidelines II (Chapter I.6) (given in Table 2). Table 2 presents the emission factors (in tons carbon per TJ) per ton of used fuel type. The carbon content of coal is the highest with 26.8 tons carbon per TJ, while the carbon content is lowest for natural gas with 15.3 tons carbon per TJ. Emissions from energy sources like animal waste, wood, wind power, geothermal, hydro, nuclear and traded electricity have not been taken into consideration.

Table 2: Emission factors of fuels (in tons carbon per TJ)

Coal	Crude Oil	Oil Products	Natural gas
26.8	20.0	19.5	15.3

Source: IPCC (2000).

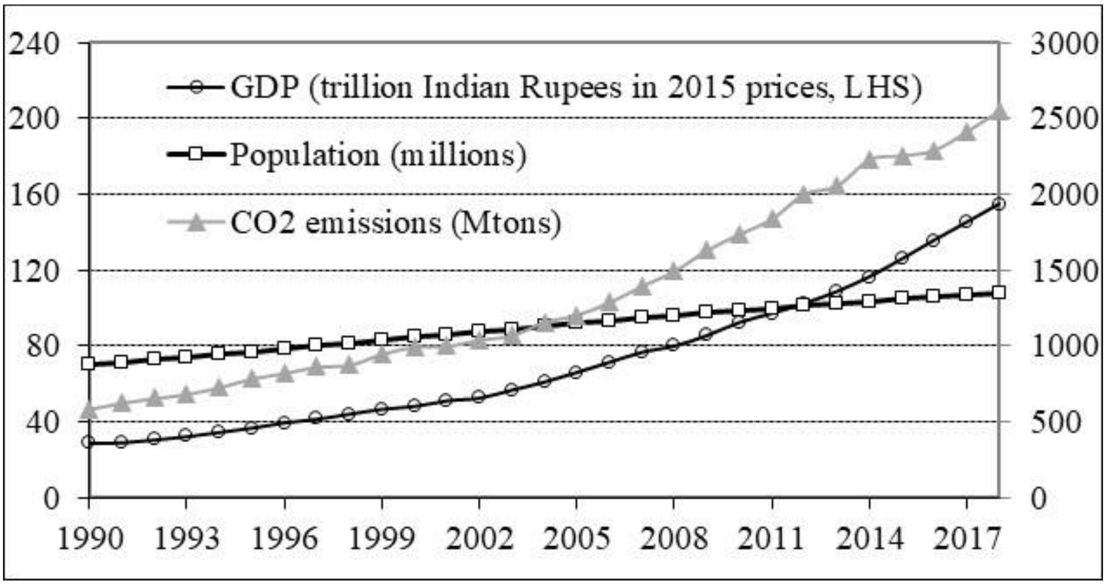
There are two ways to estimate CO_2 emissions from energy consumption, namely the reference and sectoral method (IPCC, 2006). The reference method uses a carbon flow account (inputs and outputs of carbon fuels) and correcting for non-emitted carbon in fuels. The sectoral method uses consumption figures for different sectors. The outcomes of these two methods are generally different, for various reasons like different sources of statistics. The difference of these two methods is on average about 2% in the data set used in this study. In the present paper, the level of emissions is based on the second method i.e., sectoral method. This method is preferred as it gives the required breakdown of CO_2 emissions per sector so that it can be used in the complete decomposition analysis with LASP.

In addition to the four sectors namely agricultural, industrial, transport and services, there is a fifth sector, namely power generation. This conversion sector has a relatively low value added in the national accounts; a separate consideration may probably yield a distorted image of the economy. Following Paul and Bhattacharya (2004), the emissions of CO_2 from power generation are assigned to four sectors in the economy proportional to their electricity consumption as has been given in the energy balances.

GDP, CO_2 emissions and population growth in 1990– 2018

To show structural changes in the Indian economy, Figure 1 plots the development of GDP and population in India during the period 1990–2018. The economy has been growing at an average per capita annual growth rate of 4.6%, which is higher than average world long-term growth.

Figure 1: GDP in real terms, CO_2 emissions and population in India



Source: Authors' estimation based on IEA(2021)

In order to assess the performance of Indian economy, Table 3 compares the situation of economic development in India in 1990 and 2018 with countries in 2018, similar in terms of GDP. This shows that based on GDP, in 1990 India was at a comparable level as where Ethiopia and Mozambique are in 2018. Thanks to economic growth, India is comparable to Vietnam and Honduras in 2018, which is a considerable improvement in a 28-year period.

Table 3: The stages of development in India in years 1990 and 2018 linked to a comparable stage of development of other selected countries in 2018

	GDPPC in 2010 prices	Agricultural sector	Industrial sector	Services sector	Population (millions)
Ethiopia in 2018	571	31.1	27.3	41.6	109.2
India in 1990	**581**	**40.3**	**27.9**	**31.8**	**873.3**
Mozambique in 2018	593	24.6	25.3	50.0	29.5
Vietnam in 2018	1,964	14.7	34.2	51.1	95.5
India in 2018	**2,086**	**16.5**	**29.7**	**53.8**	**1352.6**
Honduras in 2018	2,219	11.6	26.8	61.6	9.6

* Source: WDI (2021), whereas sectoral shares and population for India are derived as explained in the text.

Energy consumption in India by sector and by fuel

Before presentation of the analysis of results of the complete decomposition, the nature of the data is here presented. The real GDP in India has increased with an annual rate of 6.2% and the population has increased with an annual rate of 1.6%. The development of the sectoral share of GDP during 1990-2018 of the four sectors is presented in Figure 2.

Figure 2: Share in the Indian economy of four considered sectors

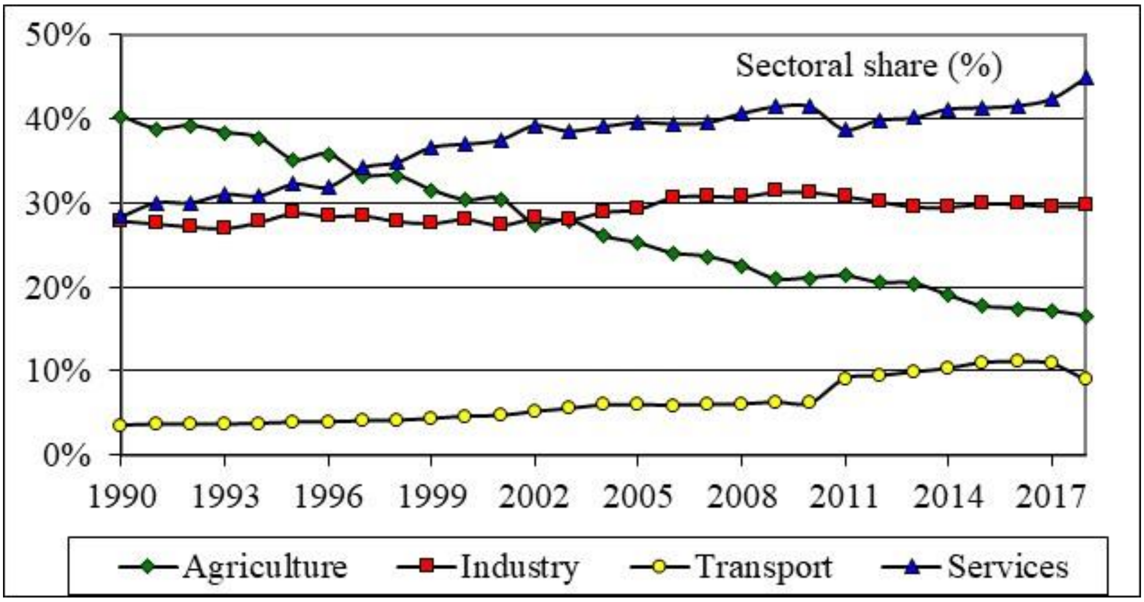


Figure 2 shows that the industrial sector (from 27.9% in 1990 to 29.7% in 2018) and transport sector (from 3.5% in 1990 to 8.9% in 2018) increase to some extent during the period 1990–2018. There is a substitution between an increasing share of the service sector (from 28.4% in 1990 to 44.9% in 2018) and a decreasing share of the agricultural sector (from 44.3% in 1990 to 16.5% in 2018). From a traditional viewpoint, one would expect that an economy moves from a farm-based economy to an industrial economy and finally enters into an economy dominated by services sector. Contrary to this traditional view, India's sectoral composition leapfrogged the industrial phase, where the agricultural sector has been substituted by the services sector.

The development over time of the sectoral energy consumption per value added (energy intensity) is presented in Figure 3. The graph depicts the changes of energy intensity. Table 4 reveals that the overall energy intensity of Indian economy decreased steadily by 53.7%, namely with decreases of 22.8% in 1990–2000, 20.7% in 2000–2010 and 24.3% in 2000–2018. Figure 3 shows that the agricultural sector has become much more energy intensive, with an increase of 53.6%. Moreover, there has been a substantial decrease in the energy intensity in services by 78.6%. The decrease in the services sector over the subperiods were stable. Furthermore, the energy intensity in the transport sector decreases substantially with a rate of 63.9% over the period 1990–2018. The energy intensity in the industrial sector also decreased during the mentioned period by 46.5% with the highest decrease of 24.9% in the first decade.

Figure 3: Sector-wise growth of energy intensity (per value added) in India

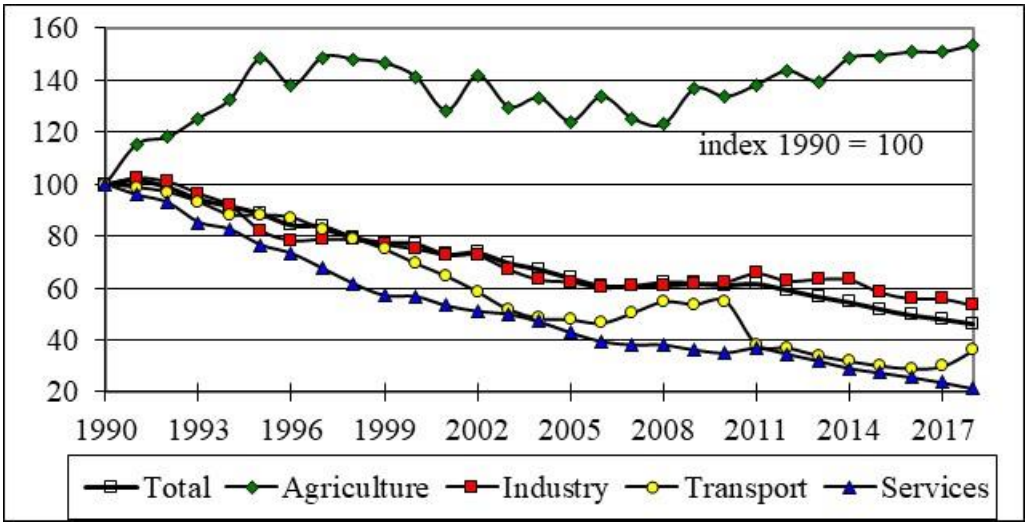


Table 4: Changes (%) in energy intensity during 1990 to 2018 in India

	Agriculture	Industry	Transport	Services	Total
1990-2000	41.2%	-24.9%	-30.5%	-43.2%	-22.8%
2000-2010	-5.4%	-16.8%	-21.0%	-38.0%	-20.7%
2010-2018	15.0%	-14.4%	-34.3%	-39.2%	-24.3%
1990-2018	53.6%	-46.5%	-63.9%	-78.6%	-53.7%

Source: Authors' estimation

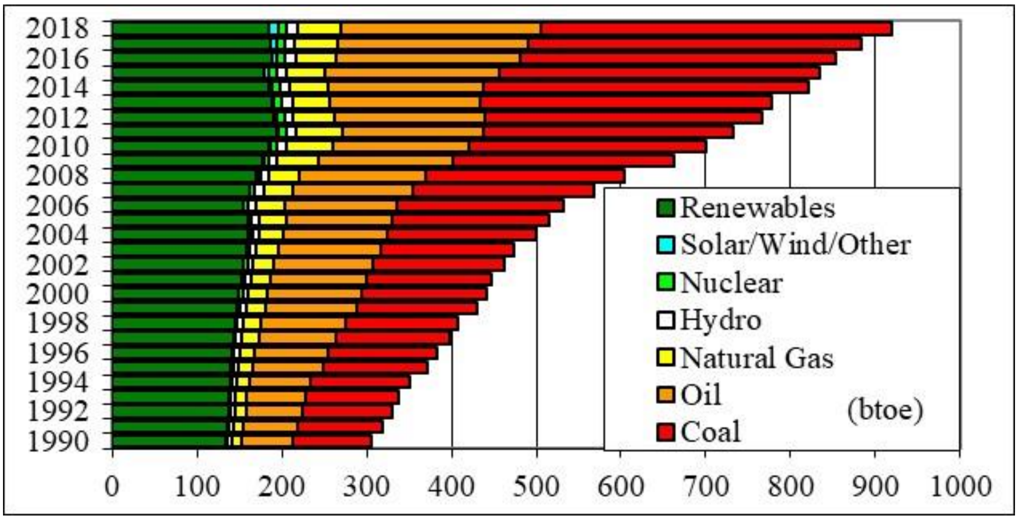
In interpreting the results of the changes in energy intensity (per value added), energy intensity has decreased except in the agricultural sector. This can be explained by focusing on the sectoral level. Due to mechanization, energy intensity mainly increased in the first decade when it shifted from animal to tractor power. The energy intensity is found to decrease over all subperiods in all other sectors. Historically, following various sector specifications and policy measures, especially after the Energy Conservation Act of 2001, Integrated Energy Policy in 2005 and National Action Plan on Climate Change (NAPCC) in 2008, emissions per unit of output have been reduced considerably, especially in the industry sector leading to substantial relative decoupling (Das and Roy, 2020).

India has been able to reduce CO_2 emissions by various policies, such as phasing out inefficient older thermal power units; deregulation of diesel price by reducing subsidies and increasing taxes on fossil fuels like petrol and diesel; setting up a corpus, National Clean Environment

Fund (NCEF); implementation of Renewable Purchase Obligation (RPO) where power distribution companies are obligated to buy at least 15% of electricity from renewable energy producers; and providing incentives to the producers of renewable energy and importing hydro-power from neighboring countries Bhutan (Das and Roy, 2020).

Figure 4 presents the composition of fuel types in primary energy supply in India during the 1990–2018 period. Figure 4 shows that fast growing demand for energy in India is primarily met with an increase in the share of oil (factor 1.28) and coal (factor 1.48) in the energy supply. In 1990, coal contributed 30.3%, oil 20.0% and renewables 43.7% to the primary energy supply in India (Table 5). In 2018, coal contributed 45.0%, oil 25.6%, natural gas 5.7% and renewables 20.1% to the primary energy supply in India. The share of traditional renewables, e.g., fuelwood, has been found to decrease at the expense of an increase in the share of coal in the energy supply.

Figure 4: Shares (%) of different fuels in primary energy supply in India



Source: Authors’ estimation

Table 5: Shares (%) of different fuels in primary energy supply in India in 1990 and 2018

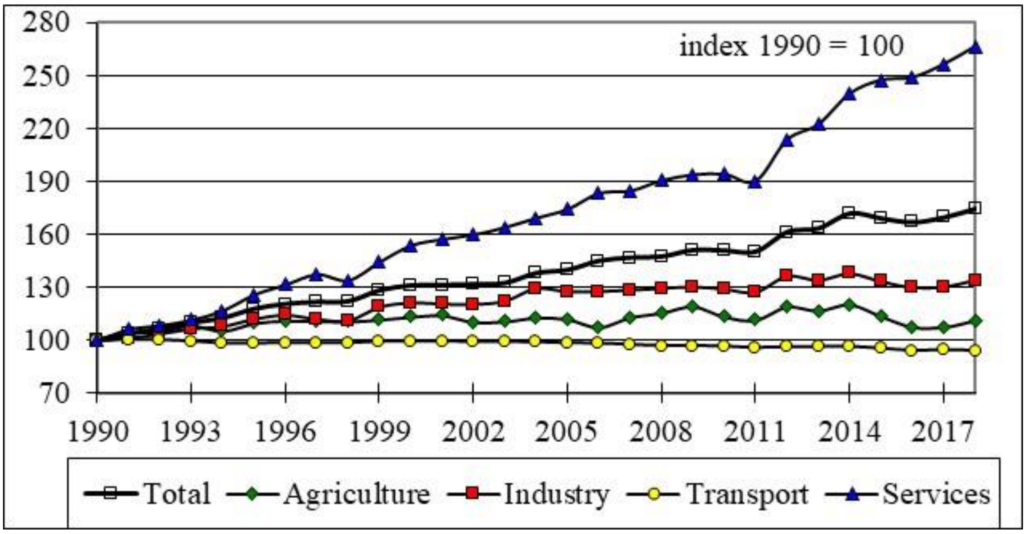
	Coal	Oil	Natural Gas	Hydro	Nuclear	Solar/Wind/ Other	Renewables (fuelwood)	Total btoe
1990	30.3%	20.0%	3.5%	2.0%	0.5%	0.0%	43.7%	306
2018	45.0%	25.6%	5.7%	1.4%	1.1%	1.1%	20.1%	919
Share Growth Factor	1.48	1.28	1.65	0.70	2.05	N.A.	0.46	3.01

Source: Authors' estimation based on IEA(2021)

The growth of CO_2 emissions per unit of energy consumed (carbon intensity) for different sectors are presented in Figure 5. In parity with Figure 3, the carbon intensity for all sectors is presented with respect to base level of 100 in 1990. Table 6 shows the percent changes of carbon over three periods, showing that the carbon intensity has increased over time in all the sectors, except the transport sector. Over the period 1990–2018, the carbon intensity increased by 74.5%. The increase in carbon intensity has been found to be the highest in the services sector, which shows an increase of +166% over the 1990–2018 period. The carbon intensity increased in the agricultural and industrial sectors by +11.4 and +34.1% respectively.

Interpretation of the result in Figure 5 indicates that the services sector and the industrial sector to a lesser extent, have both become more carbon intensive. The 'gain' of a reduction in energy intensity in India is slightly more than offset by the 'loss' in an increased carbon intensity in the services sector. The main reason for an increase in carbon intensity in the services sector is electrification, which has seen the share of coal increase in the electricity generation mix, leading to a higher CO_2 emission factor of the Indian power grid. The aggregate effect of energy efficiency and carbon intensity gain is a gradual rise in CO_2 emissions. Hence, there was no significant reduction in carbon intensity in the various sectors of Indian economy, except for transport.

Figure 5: Sector-wise growth of carbon intensity (per energy consumption) in India



Source: Authors' estimation

Table 6: Change (%) in carbon intensity (per energy consumption) in India

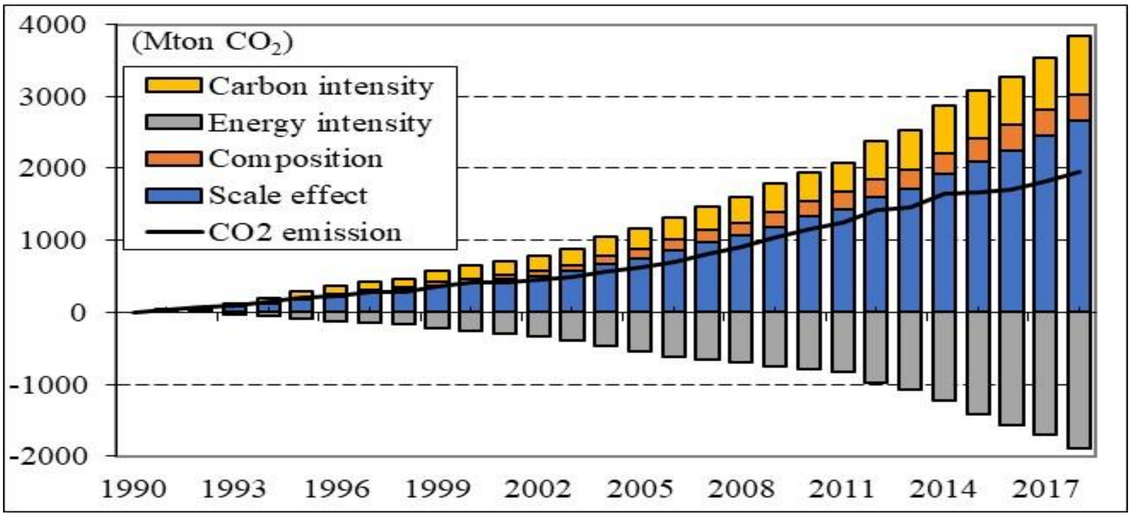
	Total	Agriculture	Industry	Transport	Services
1990-2000	31.0%	13.4%	21.4%	-0.6%	53.7%
2000-2010	15.1%	0.1%	6.3%	-2.9%	26.3%
2010-2018	15.7%	-1.9%	3.9%	-2.4%	37.2%
1990-2018	74.5%	11.4%	34.1%	-5.7%	166.1%

Source: Authors' estimation

Decomposition analysis

A complete decomposition analysis, as proposed by Sun (1998) has been presented in this section. Given the availability of data, changes in CO_2 emissions over time with respect to the base-year 1990 can be decomposed into a number of factors. Figure 6 presents the results of the (non-binding Kyoto) decomposition analysis for India. Figure 6 presents decomposition of the total national CO_2 emissions. The difference between the current amount of CO_2 emissions and the amount of CO_2 emissions in base year 1990 is given in Figure 6. For instance, the increase of 409.5 Mtons CO_2 emissions in 2000 with respect to 1990 is the sum of the scale (409.6 Mtons), composition (63 Mtons), energy intensity (–250.3 Mtons) and carbon intensity (187.3 Mtons) effects.

Figure 6. Decomposition of the difference in the level of emissions CO_2 (in Mtons CO_2) with respect to the level of emissions in 1990



Source: Authors' estimation

Table 7 shows the level and percent changes over three periods. Figure 6 shows that the scale effect is the main driver for increasing CO_2 emissions. More specifically, Table 7 reveals that the scale effect already accounts for +135.5% of rising emissions of CO_2 over the whole period. The carbon intensity (+41.8%) and composition effect (+18.6%) move in tandem. However, the carbon intensity effect varies more than the composition effect. Therefore, the composition of the Indian economy has become somewhat dirtier, where the CO_2 emissions have increased over time because of carbon intensity effect. The opposite is true for the energy intensity effect where carbon emissions decreased. Over the period 1990–2018 the energy intensity effect accounts for a decrease of 95.9% in CO_2 emissions (Table 7).

Table 7: Decomposition of the change in the levels of CO_2 emissions (Mton) in India

	Scale effect	**Composition effect**	**Energy Intensity effect**	**Carbon Intensity effect**	**CO_2 emissions**
1990-2000	409.6	63.0	-250.3	187.3	409.5
2000-2010	918.9	144.3	-540.9	218.6	740.8
2010-2018	1327.4	157.7	-1089.3	414.6	810.3
1990-2018	2655.8	365.0	-1880.5	820.4	1960.6
% share of effect					
1990-2000	100.0	15.4	-61.1	45.7	100.0
2000-2010	124.0	19.5	-73.0	29.5	100.0
2010-2018	163.8	19.5	-134.4	51.2	100.0
1990-2018	135.5	18.6	-95.9	41.8	100.0

Source: Authors' estimation

Link CO_2 emissions and GDP

To verify the link between CO_2 emissions (CO2) and GDP in India, it is also possible to test whether there is an EKC for India with respect to the greenhouse gas emission as measured by CO_2 emissions. The OLS regression results are as follows, where the standard errors are presented in the parenthesis.

$$ln(\mathrm{CO2}) = \underset{(0.05)}{3.48} + \underset{(0.013)}{0.873}\, ln(\mathrm{GDP})\,; R^2_{\mathrm{adj}} = 0.994 \quad (4)$$

$$ln(\mathrm{CO2}) = \underset{(0.50)}{3.32} + \underset{(0.243)}{0.954}\, ln(\mathrm{GDP}) - \underset{(0.0291)}{0.0097}(ln(\mathrm{GDP}))^2; R^2_{\mathrm{adj}} = 0.994 \quad (5)$$

The variables are also tested for normality with the Jarque-Bera test, which did not give sufficient evidence to conclude that the dataset is not normally distributed. Two equations are estimated, namely a linear relationship between CO_2 emissions and GDP (4) and the quadratic equation to test whether there is an EKC. While the goodness of fit (R^2_{adj}) of the estimated quadratic regression equation (5) is high, the estimation results reveal that EKC does not hold for India, as the regression coefficient of the quadratic term in the estimated regression equation is insignificant, though it possesses the right sign.

Therefore, the yearly data covering the period 1990–2018 show that the CO_2 emissions have been linearly increasing in the level of GDP and no EKC can be observed in CO_2 emissions for India. Hence, in India, economic growth is not (yet) decoupled from carbon emissions during the studied period. This result is in parity with the conclusion derived from the decomposition analysis that GDP growth (scale effect) is the major determinant of increase in CO_2 emissions in India.

V. CONCLUSION AND POLICY IMPLICATIONS

The present paper has decomposed the factors that drive CO_2 emissions in India, through changes in four components, namely scale, composition, energy intensity and carbon intensity. Changes in sectoral composition of the economy over time were also considered. The study has also addressed the changes in energy mix and addressed the following questions: How has the energy and carbon intensity changed over time and across sectors in India? What is the link between national income and carbon emissions in India?

The study shows that the overall energy intensity dropped over the period 1990–2018 in India with a decline in all the sectors except agriculture. The considerable increase of energy use in the agricultural sector in India, may be explained by agricultural mechanization process. In spite of declining overall energy intensity, the level of CO_2 emissions per energy unit consumption (carbon intensity) has increased between 1990-2018 in India. This increase in emission is found highest in the services sector, more than offsetting the gains achieved through an improved energy intensity.

The research derives that carbon emissions are increasing considerably in the Indian economy. The decomposition analysis demonstrates that, out of four effects, the scale effect is most dominant, with the implication that CO_2 emissions in India are increasing due the expansion of the economy (scale effect). The actual sectoral composition of the economy and the level of carbon intensity are also found to have considerable contribution to increasing CO_2 emissions. The energy intensity of the Indian economy is found to be decreasing and is responsible for decreasing CO_2 emissions. Hence, without proper carbon policies, it is unlikely that emissions of CO_2 can be reduced in India. Although various policies adopted by the Government of India have helped in achieving relative decoupling in these sectors, the current dominance of coal in the mix of primary energy remains as a big hindrance in reducing pollution.

This paper has analyzed the causes of CO_2 emissions in a country with a high potential for growth. Looking at the sectoral composition, the share of the agricultural sector is 16.5% and that of the service sector is 53.8% in 2018. This shows that India is still in the middle of her transition towards a modern developed economy. Moreover, India has skipped the industrialization phase, leapfrogging from agricultural dominated society to a services sector dominate society. For transition of India into a modern society, a path with high level of carbon emissions is foreseen. Future policy research is very much necessary in finding ways for further reduction of these emissions in India.

India is playing active role at international level in the global fight against climate change. India's NDC under the Paris Agreement sets out targets to reduce emissions intensity and to increase the share of non-fossil fuels i.e., renewables in its power generation capacity among others. Although the emissions intensity of GDP of India is found to decrease in line with targeted levels, progress towards supply of a low-carbon electricity remains very challenging. The services sector in India is the fastest growing sector India is currently facing shortages of coal. In order to achieve above average high level of growth, efficient use of energy and low carbon path are very much needed.

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