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Carbon Emissions from Energy Use in India: Decomposition Analysis

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ABSTRACT

To become the 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 the growth target and keep the CO_2 emissions under control. The present paper aims to discover the determinants for explaining CO_2 emissions in India by conducting a complete decomposition analysis, where the residuals are fully distributed to the determinants for the country from 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 the 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 the 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 increased CO_2 emissions.

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, 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 the National Solar Mission, the National Mission for Enhanced Energy Efficiency, and the 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 its 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 the creation of additional forest and tree cover by 2030.

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

The world is progressing towards UN Goal 7, with an encouraging note that the energy sector is becoming more sustainable and widely accessible. Lack of access to energy may hamper the efforts to contain the current pandemic effects across many countries (UN 2021a). In India, about 300 million people lack access to electricity. Successfully addressing India's energy poverty and achieving sustainable development goals would require the reduction of poverty and 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). Natural gas consumption is 50% imported and 50% locally produced as of 2018.

Considering all these challenges India faces, the present paper aims to discover the determinants for explaining CO_2 emissions in India by carrying out a complete decomposition analysis for the country from 1990-2018. Here, the role of four factors, scale, composition, energy, and carbon intensity, explain changes in CO_2 emissions. The residuals are fully distributed to these four determinants in a complete decomposition analysis. In addition, changes in the economy's sectoral composition, technologies in the energy mix, energy and carbon intensity, and the 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, undertakes a complete decomposition analysis, and tests whether an environmental Kuznets curve (EKC) can be found in India. The final section concludes.

PAST STUDIES

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 & Ang (2013) undertook a comprehensive survey of literature focusing specifically on emissions by various countries by reviewing eighty papers that appeared in peer-reviewed journals from reviews of studies conducted in developed and developing countries at national scales (and for various sectors, including national total emissions).

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

Ang & Choi (1997) proposed a refined Divisia index decomposition using a logarithmic function by replacing the arithmetic mean weight function with no residual.

Su & 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: energy use, CO_2 emissions, 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 in India. This study covered 1971-2007 using the Granger approach (VECM framework) and Dolado and Lütkepohl's approach. The study concluded that India's Energy consumption positively impacts CO_2 emissions and GDP, but its impact negatively impacts capital and population.

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

Using a decoupling method, Kojima & Bacon (2009) found the decoupling of economic growth and emissions in India, an increasing share of the service sector in GDP, and falling energy intensity of industry as major contributors to achieving decoupling of economic growth and emissions.

Table 1 summarizes key characteristics of some important studies on applied studies using Decomposition Analyses. The main methods used are as follows:

- Index Decomposition Analysis (IDA),
- Structural Decomposition Analysis (SDA),
- Refined Laspeyres decomposition model (LASP),
- Logarithmic Mean Divisia Index (LMDI) and
- Other decomposition methods.

The countries covered vary from single countries, such as Brazil, China, Ethiopia, India, and Turkey, to various studies with multi-country coverage.

In summary, the studies presented try to untangle factors that cause CO_2 emissions and 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 to be 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.

Table 1: Summary of the past studies.

Author(s)	Years of Analysis	Method	Countries covered	Key results
Andreoni and Galmarini (2016)	1995-2007	Index Decomposition Analysis (IDA)	33 world countries	They found economic growth as the main driving factor of energy-related increase in CO_2 emissions.
Wang and Zhou (2018)	1995-2009	Theil index and IDA	China and India	They examined global per capita consumption-based emission inequality in 1995–2009.
Su et al. (2020)	1990-2015	IDA	G7 and BRICS	They developed a framework for some countries' index decomposition of carbon dioxide.
Das and Paul (2014)	1993-94 to 2006-07	Structural Decomposition Analysis (SDA)	India	They used input-output analysis to estimate direct and indirect CO_2 emissions by households in India.
Pal et al. (2015)	1994-1995 and 2006-2007	SDA	India	They found that change in emission intensity negatively impacts India's greenhouse gas (GHG) emissions.
Tandon and Ahmed (2016)	1993-94 to 2007-08	SDA	India	They analyzed the sector-wise changes in production technology and its effect on the demand for direct and embodied energy.
Karstensen et al (2020)	1996-2009	SDA between years, which expands on the Kaya identity	India	They found that India's GHG emissions until 2009 economic growth and technological intervention have helped reduce emission growth.
Wang et al. (2020)	2000 to 2014	SDA	Group of Twenty (G20) countries	They concluded that reducing energy intensity in Russia, India, China, and South Korea has great potential to reduce global energy consumption and improve global energy efficiency.
Lise (2006)	1980-2003	Complete decomposition analysis and LASP	Turkey	They found that the major cause of the rise in CO_2 emissions in Turkey is the expansion of the economy (scale effect).
Ebohon and Ikeme (2006)	–1971 1998	Refined Laspeyres decomposition model (LASP)	Sub-Saharan African countries	They found that CO_2 emission intensity has been attributable to energy consumption intensity.
Wang et al. (2005)	1957 to 2000	Logarithmic Mean Divisia Index (LMDI)	China	They analyzed the change in aggregated CO_2 in China.
Pachauri and Muller (2008)	1980-2005	LMDI	India	They analyzed the importance of different drivers by conducting a decomposition analysis of household electricity consumption in India.
De Freitas and Kaneko (2011)	1970-2009	LMDI	Brazil	They evaluated the changes in CO_2 emissions from energy consumption in Brazil.
Xu et al. (2014)	1995-2011	LMDI	China	They found that production is the major driver for reducing carbon emissions.
Chen and Yang (2015)	1995-2011	LMDI	China	They presented a coupled decomposition analysis of emissions in China.
Zhang and Da (2015)	1996 to 2010	LMDI	China	The authors found that the scale effect was the main driver of China's carbon emissions increase.
Dasgupta and Roy (2017)	1990-91 to 2012-13	Decoupling elasticity and LMDI	India	They found that the change in emission intensity of GDP is highest in agriculture (24%) and lowest in Industry (-23%), and India has achieved relative decoupling during the study period.
Kanitkar (2020)	1971 and 2008	LMDI and arithmetic mean Divisia index (AMDI)	India	They found that the improvements in energy efficiency are the main contributing factor to the reduction in the overall emission intensity of GDP.

Table Cont....

Author(s)	Years of Analysis	Method	Countries covered	Key results
Taka et al. (2020)	1990 and 2017	Kaya identity combined with the LMDI decomposition approach	Ethiopia	They found that the main drivers of energy-based CO_2 emissions are the economic effect (52%), population effect (43%), and fossil fuel mix effect (40%), while the emission intensity effect (14%) was not strongly pronounced.
Sun (1998)	1973–1990	complete decomposition model	World Energy	They applied a complete decomposition model for the decomposition of world energy consumption.
Nag and Parikh (2000)	1970-1995	Divisia decomposition technique	India	They found the increase in per capita emission after 1980 was due to a rise in per capita income.
Paul and Bhattacharya (2004)	1980 and 1996	decomposition method	India	Activity growth is a major cause of a rise in emissions, while energy intensity change contributes to the reduction of CO_2 emission, especially in industry and transport sectors.
Zhang et al. (2009)	1991–2006	decomposition analysis	China	They showed that economic activity has a major positive effect on changes in CO_2 emission in all the major economic sectors.
Reddy and Roy (2010)	1992-2002	Total decomposition analysis model	India	They showed that most intensity reductions are driven purely by structural effect rather than energy intensity.
Attari and Attaria (2011)	1971-2008	Decomposition Analysis	Pakistan, India, and China	The population contribution to CO_2 emission is high in Pakistan, and the contribution of energy intensity in reducing emissions is high in China.

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 to be the dominating effect, then emissions of CO_2 increase linearly with the level of GDP. Second, the composition effect shows increased emissions due to economic changes. If the economy specializes in cleaner sectors, 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 introducing 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 complete decomposition analysis with LASP (Zhang & Ang 2001). This is implemented in EXCEL to do the calculations.

$$Peff_t =$$

$$\Delta P_t \sum_i \left[G_{i,1} \left\{ I_{i,1} E_{i,1} + \frac{1}{2}\left(\Delta I_{i,t} E_{i,1} + I_{i,1} \Delta E_{i,t}\right) + \frac{1}{3} \Delta I_{i,t} \Delta E_{i,t} \right\} + \Delta G_{i,t} \left\{ \frac{1}{2} I_{i,1} E_{i,1} + \frac{1}{3}\left(\Delta I_{i,t} E_{i,1} + I_{i,1} \Delta E_{i,t}\right) + \frac{1}{4} \Delta I_{i,t} \Delta E_{i,t} \right\} \right]$$

$$Geff_t =$$

$$P_1 \sum_i \Delta G_{i,t} \left\{ I_{i,1} E_{i,1} + \frac{1}{2}\left(\Delta I_{i,t} E_{i,1} + I_{i,1} \Delta E_{i,t}\right) + \frac{1}{3} \Delta I_{i,t} \Delta E_{i,t} \right\} + \Delta P_t \sum_i \Delta G_{i,t} \left\{ \frac{1}{2} I_{i,1} E_{i,1} + \frac{1}{3}\left(\Delta I_{i,t} E_{i,1} + I_{i,1} \Delta E_{i,t}\right) + \frac{1}{4} \Delta I_{i,t} \Delta E_{i,t} \right\}$$

$$Ieff_t =$$

$$P_1 \sum_i \Delta I_{i,t} \left\{ G_{i,1} E_{i,1} + \frac{1}{2}\left(\Delta G_{i,t} E_{i,1} + G_{i,1} \Delta E_{i,t}\right) + \frac{1}{3} \Delta G_{i,t} \Delta E_{i,t} \right\} + \Delta P_t \sum_i \Delta I_{i,t} \left\{ \frac{1}{2} G_{i,1} E_{i,1} + \frac{1}{3}\left(\Delta G_{i,t} E_{i,1} + G_{i,1} \Delta E_{i,t}\right) + \frac{1}{4} \Delta G_{i,t} \Delta E_{i,t} \right\}$$

$$Eeff_t =$$

$$P_1 \sum_i \Delta E_{i,t} \left\{ G_{i,1} I_{i,1} + \frac{1}{2}\left(\Delta G_{i,t} I_{i,1} + G_{i,1} \Delta I_{i,t}\right) + \frac{1}{3} \Delta G_{i,t} \Delta I_{i,t} \right\} + \Delta P_t \sum_i \Delta E_{i,t} \left\{ \frac{1}{2} G_{i,1} I_{i,1} + \frac{1}{3}\left(\Delta G_{i,t} I_{i,1} + G_{i,1} \Delta I_{i,t}\right) + \frac{1}{4} \Delta G_{i,t} \Delta I_{i,t} \right\} \quad ...(2)$$

Eq. (2) shows that to calculate the scale effect ($Peff_t$), we must consider the difference in P weighed by the other three factors 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 & Ang 2001). By fully distributing the residuals in the decomposition analysis, it becomes a complete decomposition analysis with LASP. This helps us explain the halves, thirds, and quarters in the formula, which has terms with 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), and $Eeff_t$ (Carbon intensity effect) have been derived similarly. 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 the base year 1990. In this process, there is no residual. This methodology has been used to decompose the changes in the emission levels 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:

$$ln(\mathrm{CO2}) = \alpha + \beta_1 \, ln(\mathrm{GDP}) + \beta_2 (ln(\mathrm{GDP}))^2 \quad ...(3)$$

The coefficient of the quadratic term (β_2) must be 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 is collected from IEA (2021). The added value per sector has been collected from the UN (2021b). The economic liberalization process started 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: 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: the primary agricultural sector, the secondary industrial sector, the tertiary transport sector, and the services sector. The value added for agriculture and industry sectors are separately specified in the data and have been used immediately. However, the value added for transport is only available in combination with communication. In this paper, the value added of transport

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).

and communication has been used as a proxy for the transport sector for lack of sufficient information. The remaining value added has been assigned to the services sector in the economy.

RESULTS AND DISCUSSION

The level of CO_2 emissions in India is subjected to a decomposition analysis from 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). The energy-using sectors considered in the present analysis are agriculture, industry, transport, and services.

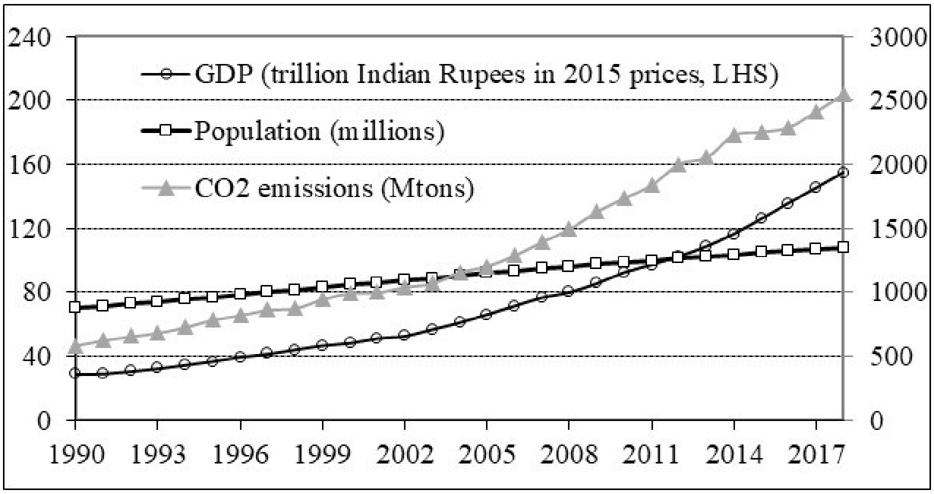
Sectoral division for energy consumption has been done as for value-added. This has been done simply by taking the numbers published in IEA (2021a). It is also possible to derive the composition of different fuel types in the primary energy supply from these energy balances. Emissions from energy consumption have 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 of carbon per TJ, while the carbon content is lowest for natural gas, with 15.3 tons of carbon per TJ. Emissions from energy sources like animal waste, wood, wind power, geothermal, hydro, nuclear, and traded electricity have not been considered.

Two ways to estimate CO_2 emissions from energy consumption exist, the reference and sectoral method (IPCC 2006). The reference method uses a carbon flow account (inputs and outputs of carbon fuels) and corrects 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 statistics sources. The difference between these two methods is, on average, about 2% of the data set used in this study. In the present paper, the level of emissions is based on the second method, i.e., the sectoral method. This method is preferred as it gives the required breakdown of CO_2 emissions per sector for the complete decomposition analysis with LASP.

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

GDP, CO_2 Emissions, and Population Growth in 1990-2018

To show structural changes in the Indian economy, Fig. 1 plots the development of GDP and population in India during the period 1990-2018. The economy has been growing at an



Source: Authors' estimation based on IEA(2021).

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

Table 3: The stages of development in India in the 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.

average per capita annual growth rate of 4.6%, higher than average world long-term growth.

To assess the performance of the Indian economy, Table 3 compares the economic development situation 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 to Ethiopia and Mozambique in 2018. Thanks to economic growth, India is comparable to Vietnam and Honduras in 2018, a considerable improvement in 28 years.

Energy Consumption in India by Sector and by Fuel

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

Fig. 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) increased to some extent during 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 an economy to move from a farm-based economy to an industrial economy and finally enter into an economy dominated by the services sector. Contrary to this traditional view, India's sectoral composition leapfrogged the industrial phase, where the services sector has substituted the agricultural sector.

The development over time of the sectoral energy consumption per value added (energy intensity) is presented in Fig. 3. The graph depicts the changes in energy intensity. Table 4 reveals that the overall energy intensity of the Indian economy decreased steadily by 53.7%, with decreases of 22.8% in 1990-2000, 20.7% in 2000-2010, and 24.3% in 2000-2018. Fig. 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 was stable. Furthermore, the energy intensity in the transport sector decreases substantially, with a rate of 63.9% from 1990–2018. The

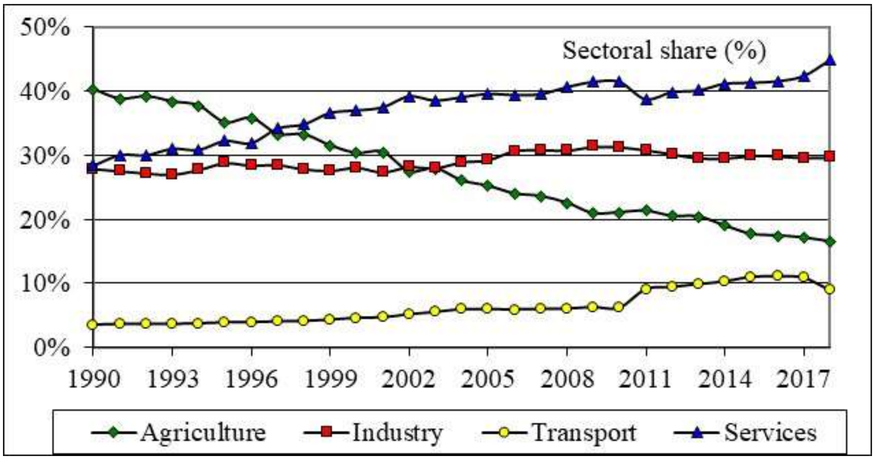


Fig. 2: Share in the Indian economy of four considered sectors.

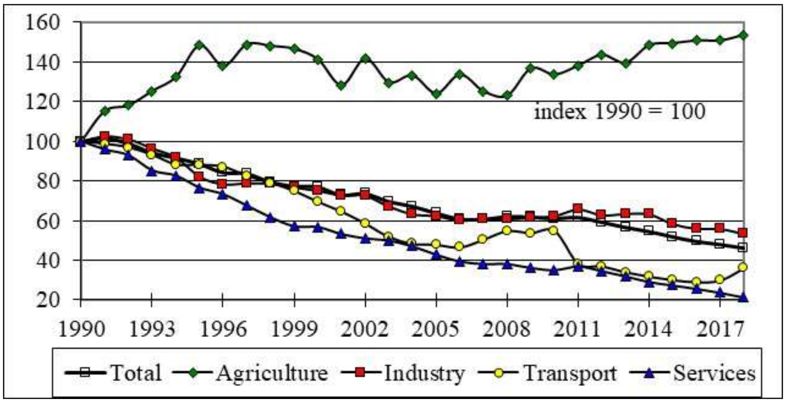


Fig. 3: Sector-wise growth of energy intensity (per value added) in India.

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

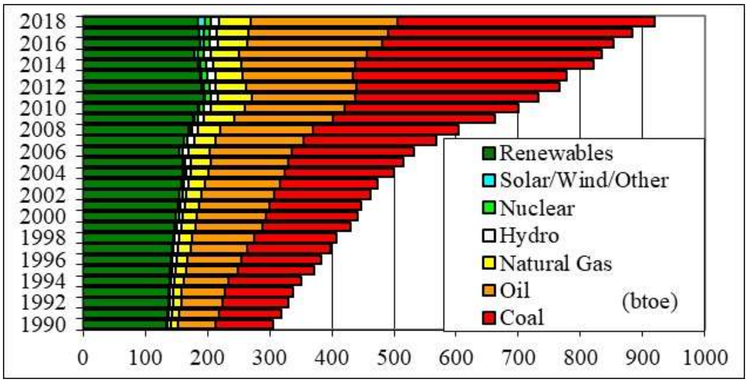
	Agriculture	Industry	Transport	Services	Total
1990-2000	41.2%	-24.9%	-30.5%	-43.2%	-22.8%
2000-2010	-5.4%	-16.8%	-21.0%	-38.0%	-20.7%
2010-2018	15.0%	-14.4%	-34.3%	-39.2%	-24.3%
1990-2018	53.6%	-46.5%	-63.9%	-78.6%	-53.7%

Source: Authors' estimation

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.

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 overall 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 & Roy 2020).

India has been able to reduce CO_2 emissions through various policies, such as phasing out inefficient older thermal power units, deregulation of diesel prices 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



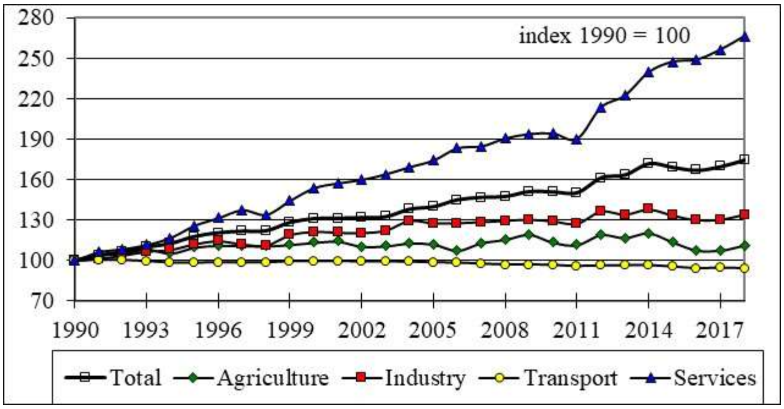
Source: Authors' estimation.

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

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).



Source: Authors' estimation

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

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%

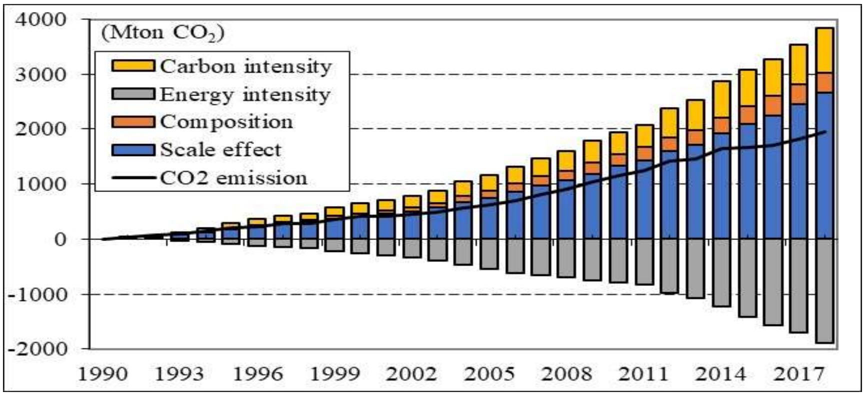
Source: Authors' estimation.

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).

Fig. 4 presents the composition of fuel types in primary energy supply in India during the 1990–2018 period. Fig. 4 shows that the 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 decreased at the expense of an increase in the share of coal in the energy supply.

The growth of CO_2 emissions per unit of energy consumed (carbon intensity) for different sectors is presented in Fig. 5. In parity with Fig. 3, the carbon intensity for all sectors is presented with respect to the base level of 100 in 1990. Table 6 shows the percent changes in 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 is 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 Fig. 5 indicates that the services and industrial sectors have become more carbon-intensive to a lesser extent. 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 increased carbon intensity in the services sector is electrification, which has seen the share



Source: Authors' estimation

Fig. 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.

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 the Indian economy, except for transport.

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 several factors. Fig. 6 presents the results of the (non-binding Kyoto) decomposition analysis for India. Fig. 6 presents a 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 the base year 1990 is given in Fig. 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.

Table 7 shows the level and percent changes over three periods. Fig. 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 the carbon intensity effect. The opposite is true for the energy intensity effect, where carbon emissions decreased. From 1990–2018, the energy intensity effect accounts for a decrease of 95.9% in CO_2 emissions (Table 7).

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

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

India with respect to greenhouse gas emissions as measured by CO_2 emissions. The OLS regression results are as follows: the standard errors are presented in the parenthesis.

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

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

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: 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 has 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 the increase in CO_2 emissions in India.

CONCLUSION

The present paper has decomposed the factors that drive CO_2 emissions in India through changes in four components: scale, composition, energy intensity, and carbon intensity. Changes in the sectoral composition of the economy over time were also considered. The study has also addressed the energy mix changes and 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 India's overall energy intensity dropped from 1990–2018, with a decline in all sectors except agriculture. The agricultural mechanization process may explain the considerable increase in energy use in the agricultural sector in India. Despite declining overall energy intensity, the level of CO_2 emissions per energy unit consumption (carbon intensity) increased in India between 1990-2018. This increase in emission is found to be highest in the services sector, more than offsetting the gains achieved through an improved energy intensity.

The research shows that carbon emissions are increasing considerably in the Indian economy. The decomposition analysis demonstrates that, out of four effects, the scale effect is dominant, implying that CO_2 emissions in India are increasing due to 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 a 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 achieve relative decoupling in these sectors, the current dominance of coal in the mix of primary energy remains a big hindrance in reducing pollution.

This paper has analyzed the causes of CO_2 emissions in a country with a high growth potential. 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 its transition toward a modern, developed economy. Moreover, India has skipped the industrialization phase, leapfrogging from an agricultural-dominated society to a services sector-dominated society. For the transition of India into a modern society, a path with a high level of carbon emissions is foreseen. Future policy research is necessary to further reduce these emissions in India.

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

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