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India is striving to achieve its climate mitigation goal of reducing the greenhouse gas (GHG) emission intensity of the economy by 33-35% by 2030 from 2005 levels. The energy-related carbon dioxide (CO2) emissions are more than three-fourth of the total GHG emissions in the country. The drivers of energy-related CO2 emissions are often analysed to help countries track their climate change mitigation goals. There is limited evidence on the factors driving changes in India's emissions in the past two decades. In this study, the drivers of change in India's energy-related CO2 emissions during 1990-2017 are examined using index decomposition technique under the Kaya identity framework. The trends in the Kaya factors show decarbonisation of India's economic output during 1990-2017, mainly driven by decoupling between economic growth and energy consumption. The decarbonisation of the energy supply is not found to be significant during the study period. Decomposition analysis of annual changes shows a positive contribution of population and income in the change in emissions during the entire study period. In some of the years of low economic growth, the energy intensity effect contributed to the increase in emissions. The decomposition analysis of aggregate changes shows that net increase in emissions during 1990-2005 is not significant due to offset by energy intensity effect. The emissions increased sharply during 2005-2010 due to a positive contribution of energy intensity effect. The net increase in emissions during 2010-15 and 2015-17 is low again due to the offset by energy intensity effect.

Keywords: Energy-related CO2 emissions, Kaya identity, Index decomposition analysis, Log Mean Divisia Index

JEL Code: Q40, Q50

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India is striving to achieve its climate mitigation goal of reducing the greenhouse gas (GHG) emission intensity of the economy by 33-35% by 2030 from 2005 levels. The energy-related carbon dioxide (CO_2) emissions are more than three-fourth of the total GHG emissions in the country. The drivers of energy-related CO_2 emissions are often analysed to help countries track their climate change mitigation goals. There is limited evidence on the factors driving changes in India's emissions in the past two decades. In this study, the drivers of change in India's energy-related CO_2 emissions during 1990-2017 are examined using index decomposition technique under the Kaya identity framework. The trends in the Kaya factors show decarbonisation of India's economic output during 1990-2017, mainly driven by decoupling between economic growth and energy consumption. The decarbonisation of the energy supply is not found to be significant during the study period. Decomposition analysis of annual changes shows a positive contribution of population and income in the change in emissions during the entire study period. In some of the years of low economic growth, the energy intensity effect contributed to the increase in emissions. The decomposition analysis of aggregate changes shows that net increase in emissions during 1990-2005 is not significant due to offset by energy intensity effect. The emissions increased sharply during 2005-2010 due to a positive contribution of energy intensity effect. The net increase in emissions during 2010-15 and 2015-17 is low again due to the offset by energy intensity effect.

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1 Introduction

The Nationally Determined Contributions (NDCs) are driving the actions on climate change mitigation and adaptation globally. India's NDC highlights the ongoing efforts in the country to protect the environment and reduce reliance on fossil fuels. The overall target on emission intensity states that India will reduce the emissions intensity of its GDP by 33 to 35 per cent by 2030 from 2005 level (UNFCCC, 2015). India submitted its Second Biennial Update Report (BUR-2) to the United Nations Framework Convention on Climate Change (UNFCCC) in December 2018 containing the GHG emission inventory for the year 2014. The GHG emission inventory provided in this report indicates that the share of CO_2 emissions from the energy sector in the total GHG emissions in 2014 were 80%. India has a strong policy focus on energy efficiency and renewable energy. India's energy intensity has been declining and is one of the driving factors for the decline in emission intensity. The share of renewable energy in the total installed capacity and the electricity generation has also increased over the last decade. According to BUR-2 report, the emission intensity declined by 21% in 2014 from the 2005 level (GoI, 2018). Despite encouraging results on India's progress towards achieving the emission intensity target, the research on the factors driving India's emissions and emission intensity is limited in the country (WRI, 2018; CSTEP, 2018).

The energy-related CO_2 emissions in an economic region change due to a shift in scale, intensity and structure of activities in the region. Changes in per capita income and population changes the level of economic activities and hence are classified as scale effects. The energy use per unit of economic output and carbon content of fossil fuels, also known as energy intensity and carbon intensity of energy, respectively are the two intensity effects. The intensity effect is caused due to structural changes, technological changes and behavioural changes. The structural changes can include changes in the structure of economic activities, structure of the primary energy supply and fossil energy supply. The factors driving the emissions, i.e. population, per capita income, the structure of the economy, the energy intensity of economic output and the structure of the energy supply are commonly analysed using the Kaya Identity framework. The changes in aggregate emissions in a period are often decomposed into the Kaya factors using index decomposition analysis (IDA) (Metz et al., 2007).

Several studies have examined the drivers of changes in energy-related CO_2 emissions to guide efforts to attain climate goals (Raupach et al., 2007; Tunç et al., 2009; Oh et al., 2010;

Goh and Ang, 2018). These studies aim to study the extent to which economic activity, energy policies, and market forces are driving carbon emissions in a given region. While some studies have analysed overall emissions trends, others have also examined emissions in specific sectors such as electricity generation, industry and transport. The effects of different macroeconomic policies on carbon dioxide emissions through changes in shares of industrial sectors and the use of various energy sources have been studied using decomposition methods. Few studies have quantified the contributions from renewables (Mohlin et al., 2018) in emission reduction using decomposition analysis. The analysis of drivers of emissions using decomposition methods is also being used to track climate policy implementation and inform future policy development (Goh and Ang, 2018; Kuriyama et al., 2019; Le Quéré et al., 2019). The technique is popular as it offers a simple approach to analyse a country's progress towards its climate goals using publicly available data.

In this study, the drivers of India's energy-related CO_2 emissions are examined, and the contributions of the driving factors in the change in emissions are identified. India's energy-CO_2 emissions have been scarcely investigated to determine the contributions of different driving factors in the overall changes in the emissions. There are two country-specific studies (Nag and Parikh, 2000; Paul and Bhattacharya, 2004) and two cross-country studies (Raupach et al., 2007; Peters et al., 2017) examining drivers of change in India's energy-CO_2 emissions. Three of the four studies study the drivers of emissions in the pre-2005 period (Nag and Parikh, 2000; Paul and Bhattacharya, 2004; Raupach et al., 2007). The most recent research examines the changes in emissions during 1990-2015 (Peters et al., 2017) in a cross-country context.

The drivers of emissions in India have not been analysed since the past two decades in a country-specific context. This paper analyses the most recent data using improved techniques of IDA for estimating the effects of underlying drivers of the increase in emissions in the country. There is a growing number of studies analysing the decline in emissions in developed economies since the last decade (Le Quéré et al., 2019; Mastrandrea et al., 2020). These studies quantify the effects of several factors such as energy efficiency, substitution to natural gas and renewable energy sources and changes in the economic cycles on the decline in emissions. In this paper, the annual changes in India's emissions are studied, and the role of different factors such as per capita income, energy intensity, the share of fossil fuels and substitution of fossil fuels are examined. There have been several improvements in energy efficiency, and the adoption of renewable energy sources in the country and the role of these factors in driving the emissions are not known. This study estimates the contribution of changes in energy intensity and substitution to renewable energy sources in offsetting the increases in emissions.

This paper is divided into six sections. In section 2, the past studies on factors driving India's energy-related CO_2 emissions are reviewed. In section 3, the methodology, including the model and data, is discussed. The results are discussed in section 5. The conclusions drawn from the study are presented in section 6.

2 Past studies

In this section, four studies that have examined India's energy-related CO_2 emissions are reviewed. Two of these studies are country-specific studies, and the other two are cross-country studies. In the first country-specific study in the country, Nag and Parikh (2000) decomposed per capita emissions from primary energy consumption into fuel mix, energy intensity and per capita GDP. The authors also decomposed final energy consumption (into emission coefficient, fuel mix, energy intensity and structural effect) and transformation and conversion sector (into fuel intensity effect, generation mix effect and fuel quality effect). The authors applied the Divisia decomposition technique of IDA on annual time series data for consumption of various commercial energy sources and the value-added data from various Government ministries. The analysis of the energy-related CO_2 emissions is carried out from 1970 to 1995, both annually and aggregate of five years.

The study by Nag and Parikh (2000) gave useful insights into the changes in India's CO_2 emissions for 25 years since 1970. The authors found that the main driver of per capita emissions until 1980 was energy intensity, and since then, the income effect took the lead. During 1970-1980, the per capita emissions had increased by 29.4%, and during 1980-1990, the increase was 52%. Energy intensity contributed nearly 21% of the per capita emissions increase in the 1970s; the contribution declined to 6.8% in 1980s. The authors attribute this trend to higher income growth and improved energy efficiency. The per capita emissions during 1990-1995 increased by 22%, driven primarily by income effect (16%) and energy intensity effect (4.3%). The contribution of fuel mix effect was negative and small during 1970-1990 (-1.3%) and positive but much lower during 1990-1995 (0.2%). The authors found that in the entire period, all the effects contributed to the increase in emissions.

In the second country-specific study, Paul and Bhattacharya (2004) decomposed the energy-CO_2 emissions into carbon emission coefficient, energy intensity, economic structure and GDP, similar to the final energy decomposition in study by Nag and Parikh (2000). Using sector-wise commercial energy consumption from third party data source and GDP at factor cost by economic activity at constant prices from National Accounts Statistics of India, the authors decomposed the emissions from 1980 to 1996 using a complete decomposition approach. In contrast to the findings of Nag and Parikh (2000), the authors found that the energy intensity effect reduced the aggregate increase in CO_2 emissions during 1980-85 and 1985-90. Their results for the period 1990-96 that energy intensity effect contributed to increasing the emissions during 1990-96 is consistent with the findings of Nag and Parikh (2000). The authors also found that while the activity effect was two-thirds of the total increase in 1980-85, it was more than 95% during 1985-90 and 1990-96.

The first cross-country study analysing India's CO_2 emissions was reported by Raupach et al. (2007). The authors analysed CO_2 emissions from fossil-fuel burning and industrial processes of selected countries and regions, including India, during 1980-2005. In this study, the emissions were decomposed into four driving factors - population, GDP, energy intensity and carbon intensity of energy. The primary energy consumption and CO_2 emission data are taken from EIA and population, and GDP data is taken from UNSD and World Economic Outlook. The authors estimated the proportional growth rate of CO_2 emissions as the summation of the proportional growth rates of the driving factors on year to year basis with all quantities normalised to 1 in 1990. The authors find that population and GDP contribute to an increase in emissions in the entire period. The same is valid for energy intensity until 1996, after which the energy intensity contributes to reducing the increase in emissions. The role of the carbon intensity of energy is neither visibly significant nor indicate a trend in the entire period (a very flat inverted U, changing the sign in the mid-1990s). These findings are similar to Nag and Parikh (2000) and contrary to Paul and Bhattacharya (2004).

In a recent cross-country study, Peters et al. (2017) examine the CO_2 emissions from fossil fuels for key countries and the world during 1990-2015. The authors study the historical (1990-2015) and future (2015-2100) trends in emissions for the world and key countries, including India by decomposing the emissions into measurable indicators that are directly impacted by energy and climate policy. In this study, the CO_2 emissions are decomposed into GDP, energy intensity and carbon intensity of energy. The carbon intensity of energy is further decomposed into fossil share and fossil intensity. The data source for CO_2 emissions is Global Carbon Budget 2016 v1.0, and that of primary energy sources in this study is the 2016 edition of BP'

Statistical Review of World Energy'. The source for GDP data is the same as that of Raupach et al. (2007). The authors report that in India, the emission increased predominately due to GDP during the entire period. Contribution of energy intensity in decreasing the emissions begin in the mid-1990s and continues until 2015. The authors do not find any clear trend in the carbon intensity of energy, which is driven primarily by fossil intensity as compared to fossil share.

To summarise, all the four studies find that population and income contribute to increasing emissions in each year from 1970 until 2015. However, there are changes in the direction of the contribution of the third most important driver, energy intensity. Energy intensity was the most important driver of change in India's per capita energy-CO_2 emissions during 1970-80 (Nag and Parikh, 2000). During 1980-1995 the contribution of energy intensity declined but remained positive (Nag and Parikh, 2000; Raupach et al., 2007). Contribution of energy intensity in decreasing the emissions began in mid-1990s (Raupach et al., 2007; Peters et al., 2017) and continued until 2015 (Peters et al., 2017). The role of the carbon intensity of energy was found to be minute and does not follow a trend in these studies.

3 Methods

The role of changes in the scale, structure and intensity of activities in the changes in CO_2 emissions are commonly studied using Kaya identity. Its significance in examining the drivers of CO_2 emissions increased since IPCC used it for developing emission scenarios in the early 1990s. A special case of the IPAT identity (Impact(I) = population (P) $\times$ affluence (A) $\times$ technology (T)), it is a tautology that equates CO_2 emissions to the product of population, per capita income, energy per unit of income and CO_2 emissions per unit of energy, as shown in Eq. 1.

$$CO2 = P \times \frac{GDP}{P} \times \frac{E}{GDP} \times \frac{CO2}{E} \tag{1}$$

Where, $CO2$ is the total CO_2 emissions, P are the population, GDP is the gross domestic product, and E is the primary energy supply. The ratio of $\frac{GDP}{P}$ is the per capita income, $\frac{E}{GDP}$ is the energy intensity of the economy and $\frac{CO2}{E}$ is the carbon intensity of energy.

The Kaya identity is written in growth rates by taking logarithms and differentiating with respect to time to study the contribution of each of the factors in the total changes with time. The proportional growth rate of a quantity X(t) is given by $r(X) = \frac{1}{X}\frac{dX}{dt}$ and the Kaya Identity for proportional growth rates is arrived. The changes in the CO_2 emissions are often analysed either annually or over a longer duration, say 5-10 years or even more. Decomposition using proportional growth rates is valid for short-term changes (dt). For long-term analysis between two years, other techniques to estimate the decomposing factors are used, such as the ones proposed under index number theory.

The use of decomposition of aggregate using index number theory in energy economics was driven by the need to account for changes in industrial output to project future electricity demand. From a simple arithmetic procedure proposed by Hankinson and Rhys (1983) and a revised method suggested by Reitler et al. (1987), several techniques have evolved under the index number framework. A similarity between disaggregating changes in energy intensity into structural and intensity factors and other economic index number problems was first recognised by Boyd et al. (1988). For example, in disaggregating an increase in the value of some product group into changes in price and physical quantity, a change in value to two periods of time is decomposed into price index and quantity index. The commonly used price indices derived from index number theory are Laspeyres index, Paasche index, Fisher index (an average of the Paasche and Laspeyres indices) and Divisia index.

The commonly used methods in industrial energy efficiency in the 1990s were the Laspeyres index method and the Divisia index method. In the Laspeyres index method, each factor is estimated by measuring a change in energy consumption associated with a change in the corresponding variable, say from year 0 to year T, while holding all the other variables constant at their respective values in year 0. In the Divisia index method, the factors are formulated in terms of the weighted average of logarithmic changes in the relevant variables. The use of the Divisia index approach in separating structural and energy efficiency components in U.S. manufacturing production was first demonstrated by Boyd et al. (1987). The problem of residuals in these techniques and their inability to deal with zero values in the dataset was found by several researchers (Park, 1992; Ang and Choi, 1997; Sun, 1998). Since then, several decomposition techniques have been developed that do not give rise to residuals. These techniques are also known as perfect decomposition methods.

The most commonly used perfect decomposition method in the current literature on energy consumption and energy-related CO_2 emissions is the Log mean Divisia index (LMDI) method. This method was proposed as refined divisia index method by Ang and Choi (1997). It gives complete decomposition and can deal with zero values in the dataset. The method refines the Divisia index method by using a logarithmic weight function instead of the arithmetic mean weight scheme.

3.1 Model

This paper uses the extended Kaya identity where the carbon intensity of the energy is further decomposed into fossil share, fossil mix and fossil intensity as shown in Eq. 2

$$CO_2 = \sum_i CO2_i = \sum_i P \times \frac{GDP}{P} \times \frac{E}{GDP} \times \frac{FF}{E} \times \frac{FF_i}{FF} \times \frac{CO2_i}{FF_i} \tag{2}$$

Where, $CO2_i$ is $CO2$ emissions and FF_i is the energy from fossil fuel of type i and FF is the total energy from all fossil fuels. The ratio $\frac{FF}{E}$ is the share of fossil fuels in the total primary energy supply, $\frac{FF_i}{FF}$ is the share of fossil fuel type i in total fossil fuel energy supply and $\frac{CO2_i}{FF_i}$ is the carbon dioxide emission intensity of fossil fuel type i. For simplicity each of the factors are abbreviated as follows $\frac{GDP}{P}$ as g (per capita income), $\frac{E}{GDP}$ as ei (energy intensity), $\frac{FF}{E}$ as fs (fossil share), $\frac{FF_i}{FF}$ as fm (fossil mix), and $\frac{CO2i}{FF_i}$ as fi (fossil carbon intensity).

Hence, the total CO_2 emissions is decomposed into six factors - population effect, income effect, energy intensity effect, fossil share, fossil structure and fossil carbon intensity, as shown in Eq. 3.

$$CO2 = \sum_i CO2_i = \sum_i \underbrace{P}_{\text{population}} \times \underbrace{g}_{\text{per capita income}} \times \underbrace{ei}_{\text{energy intensity}} \times \underbrace{fs}_{\text{fossil share}} \times \underbrace{fm_i}_{\text{fossil mix}} \times \underbrace{fi_i}_{\text{fossil carbon intensity}} \tag{3}$$

The change in the emissions from year 0 to T can be calculated as ratio change ($CO2_T/CO2_0$) or difference change ($CO2_T - CO2_0$). The decomposition using ratio change is known as multiplicative, and that of difference change is known as additive. In multiplicative decomposition, the ratio change is a product of ratio changes of all the factors. In additive decomposition, the difference change is the summation of difference change of all the factors. The additive decomposition technique is used to estimate the value change in CO_2 emissions as the sum of value changes in all the six factors, as shown in Eq 4.

$$\Delta C_{tot} = CO2_T - CO2_0 = \Delta C_P + \Delta C_g + \Delta C_{ei} + \Delta C_{fs} + \Delta C_{fm} + \Delta C_{fci} \tag{4}$$

where the effect of each factor is the weighted average of logarithmic changes of the relevant variables and the weights are logarithmic mean of change in emissions.

3.2 Data

This study covers the period from 1990 to 2017 for which annual time-series data for both energy consumption and CO_2 emissions by fuel type is taken from the IEA Data & Statistics. Annual time-series data for population and GDP are taken from the World Bank. All the data series are reported for the calendar year. The GDP is taken in USD, calculated at constant 2010 market prices. In the case of the population, the published estimates are considered.

The energy data is extracted from the annual energy balance sheets from the IEA Data & Statistics (IEA, 2019b). The data include the primary energy supply by fuel type and CO_2 emission by fuel type. Energy supply coal, crude oil, petroleum products, natural gas, hydro, nuclear, renewable, electricity and bio-energy are included. The $CO_{,2}$ emissions by fuel type extracted from the database, are calculated using IPCC methodology (IEA, 2019a). Most studies in the literature consider commercial energy supply in estimating the energy intensity and share of fossil fuels in the total primary energy supply. In India, the percentage of commercial energy supply has increased from 54% in 1990 to 75% in 2017. The non-commercial sources of energy include fuelwood, crop residue, and animal waste. These energy sources are used in rural households to meet their energy needs. Following the practice in the literature, the commercial energy sources are considered for decomposition analysis.

4 Results

Before moving to the decomposition results, the trends in India's energy and energy-related CO_2 emissions are analysed. The demand for energy and related CO_2 emissions in India have been growing steadily. As per the estimates by International Energy Agency (IEA), India's primary commercial energy supply had quadrupled in the past 27 years from 172 Mtoe in 1990 to 695 Mtoe in 2017. The compounded annual average growth rate during the entire period was 5.3%. The share of fossil fuels in the supply had remained at around 96% in the whole period. However, if the energy from biofuels is included, the percentage of fossil fuels in India's primary energy supply was 54% in 1990, and it increased to 75% in 2017. As mentioned in the previous section, the analysis in this paper is limited to the primary energy supply of commercial energy sources and related CO_2 emissions.

The share of different fuels in the primary commercial energy supply is shown in Figure 1. Coal and oil continue to be the dominant sources of the primary commercial energy supply accounting for 88-89% of the supply, followed by natural gas (7-8%). The share of hydro has declined from more than 3% in 1990 to less than 2% in 2017. The share of other renewable energy sources has increased from less than 0.01% in 1990 to 1% in 2017. The percentage of nuclear has increased from 1% to 1.5% during this period. In the absence of any significant changes in the fuel share, the energy-related CO_2 emissions has followed a growth rate similar to energy supply. The four-fold increase from 528 Mt in 1990 to 2161 Mt in 2017 and the annual growth rates are shown in Figure 2.

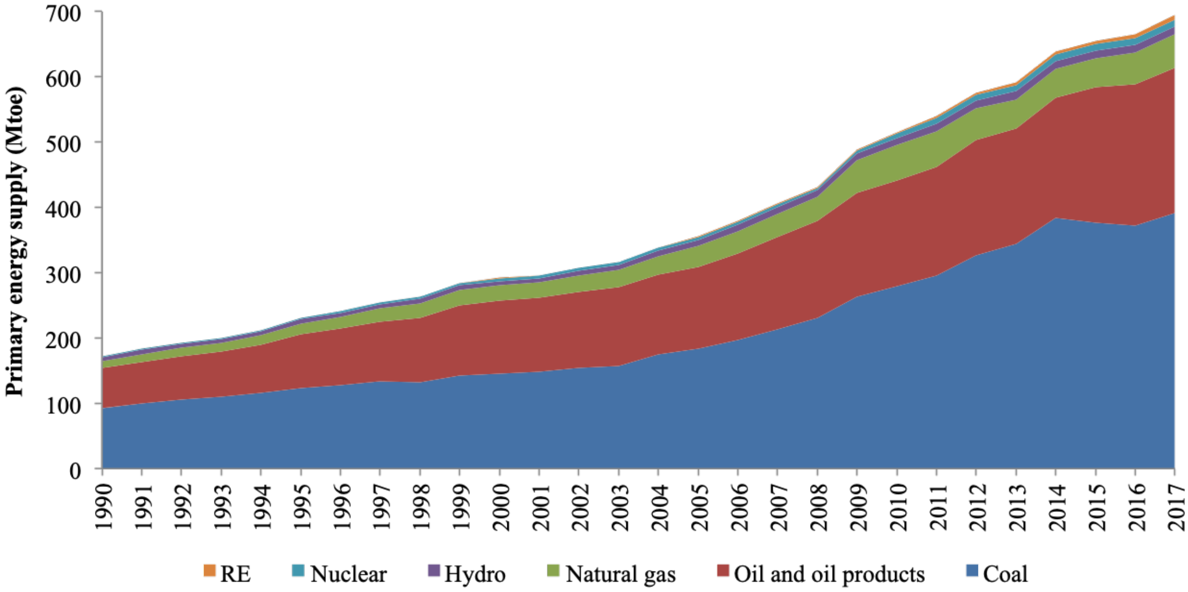

Figure 1: India's primary commercial energy supply by fuel (Source: IEA Data & Statistics (IEA, 2019b))

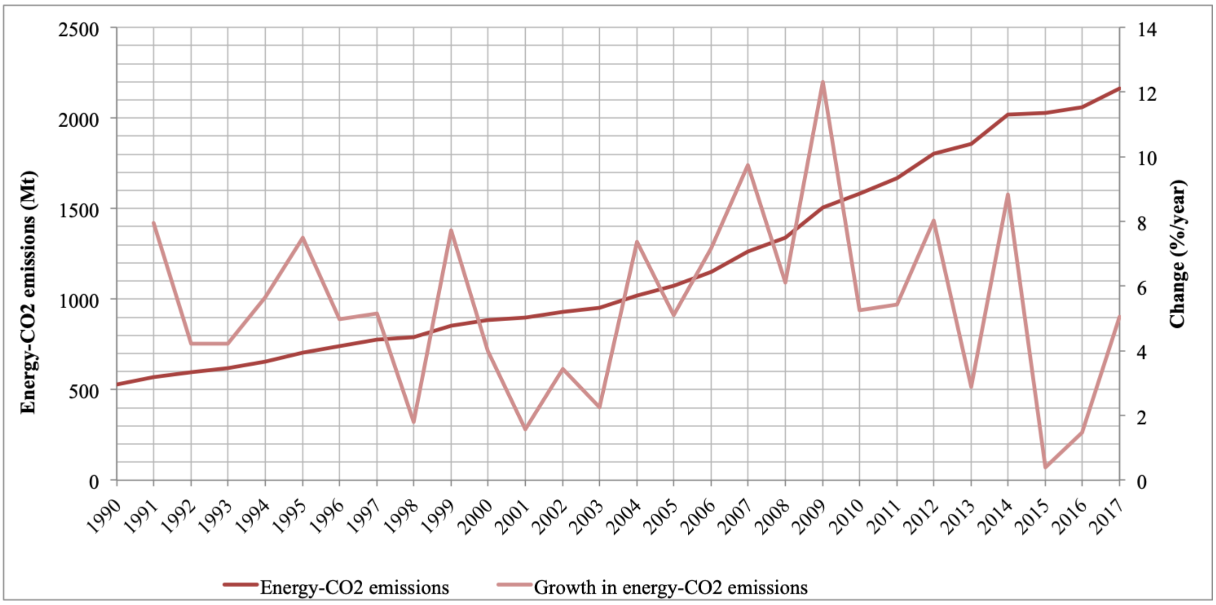

Figure 2: India's energy-related CO_2 emissions (Source: IEA Data & Statistics (IEA, 2019a)

India's primary commercial energy supply and GDP in constant 2010 US$is shown in Figure 3. The relationship between the two variables has been extensively explored by researchers to understand the direction of causality. A statistic of importance for policymakers is the ratio of the two, i.e. primary energy supply per unit of economic output, also known as the energy intensity of GDP. Another element of interest is the CO_2 emissions per unit of GDP, which includes both energy intensity of GDP and carbon intensity of energy. India's energy intensity of GDP and carbon intensity of GDP during 1990-2017 is shown in Figure 4.

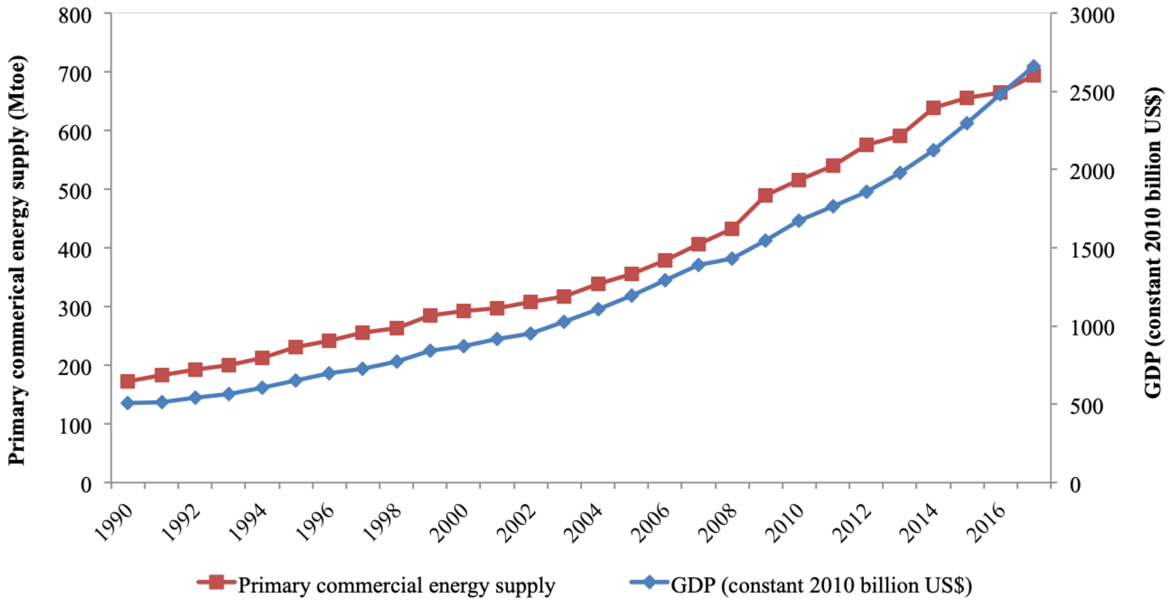

Figure 3: India's primary commercial energy supply and GDP at constant 2010 USD (Source: IEA Data& Statistics (IEA, 2019b) and (WB, 2019))

India's energy intensity increased in 1991 and continued to decline at a varying rate until 2007. The energy intensity increased in 2008 and 2009. It declined in 2010, did not change until 2012 and remained at a higher level until 2014. The energy intensity is declining at a faster rate since 2015 (Figure. 4). A change in energy intensity is mainly due to structural factors such as structural changes in the economy and intensity factors such as energy efficiency improvements and changes. The role of these factors to the shift in CO_2 emissions quantified using KAYA Identity and index decomposition analysis are discussed in subsequent sections.

4.1 Trends in Kaya factors

The time-series of the five Kaya factors - population (P), per capita income (g), energy intensity (ei), fossil share (fs) and fossil carbon intensity (fci) for 1990-2017 are shown in Figure. 5.

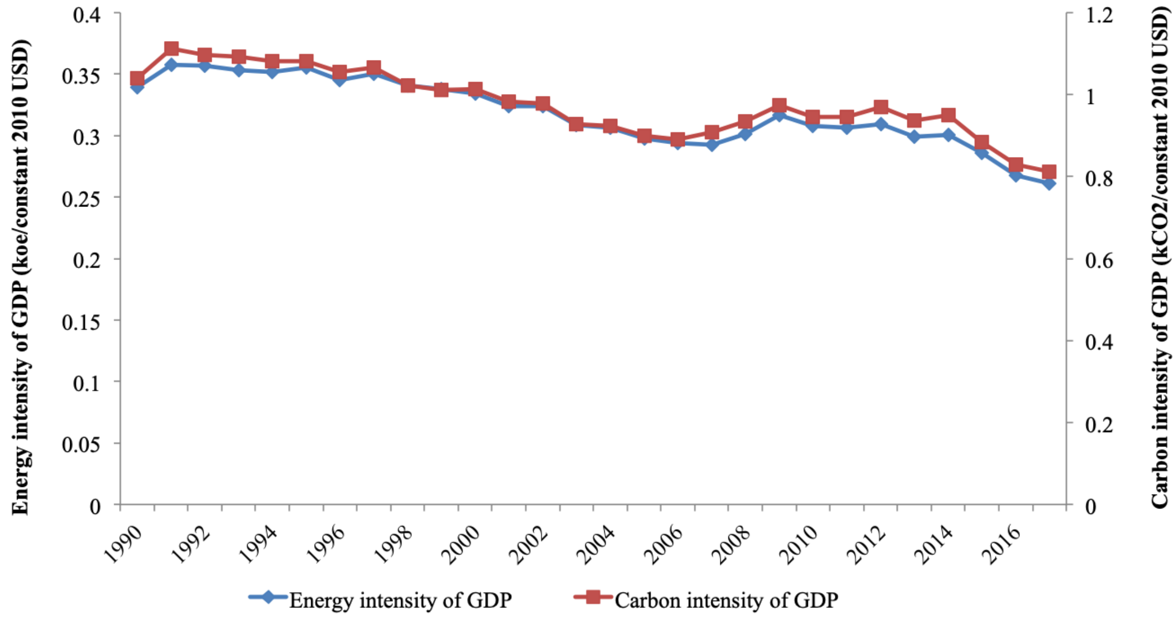

Figure 4: India's energy intensity and carbon intensity of energy (Source: Author estimates)

All quantities are normalised to 1 in the year 1990 to show the relative contributions of changes in Kaya factors. Before 1998, $CO2$ increased as a result of increases in both P and g, while ei, fs and fci remained at 1990 levels. After 1998, both P and g continued to increase, and fs and fci remained nearly steady, but ei started to decline. The increase in $CO2$ as a result of an increase in P and g was offset by a decrease in ei such that $CO2$ and g followed a similar trajectory during 1998-2007. However, since 2007 $CO2$ increased at a faster pace than g as ei increased in 2008 and 2009 and did not change much up to 2014. The trend is changing since 2014, and ei is declining at a fast pace. The decline is contributing to offset the increase in $CO2$ as a result of an increase due to P and g. Any significant change in fs and fci cannot be seen during the study period. A decline in ei indicates decoupling between energy use and GDP growth and a decline in fs indicate an increase in adoption of non-fossil energy sources. Hence, while we observe decoupling between energy use and GDP growth, the decarbonisation of the energy supply is not yet noticed.

4.2 Index decomposition analysis results

Moving to the results of the decomposition analysis, the changes in $CO2$ are decomposed into contributions from the population, per capita income, energy intensity, fossil share, fossil mix and fossil carbon intensity. The change in $CO2$ during 1990-2017 are analysed in two ways -

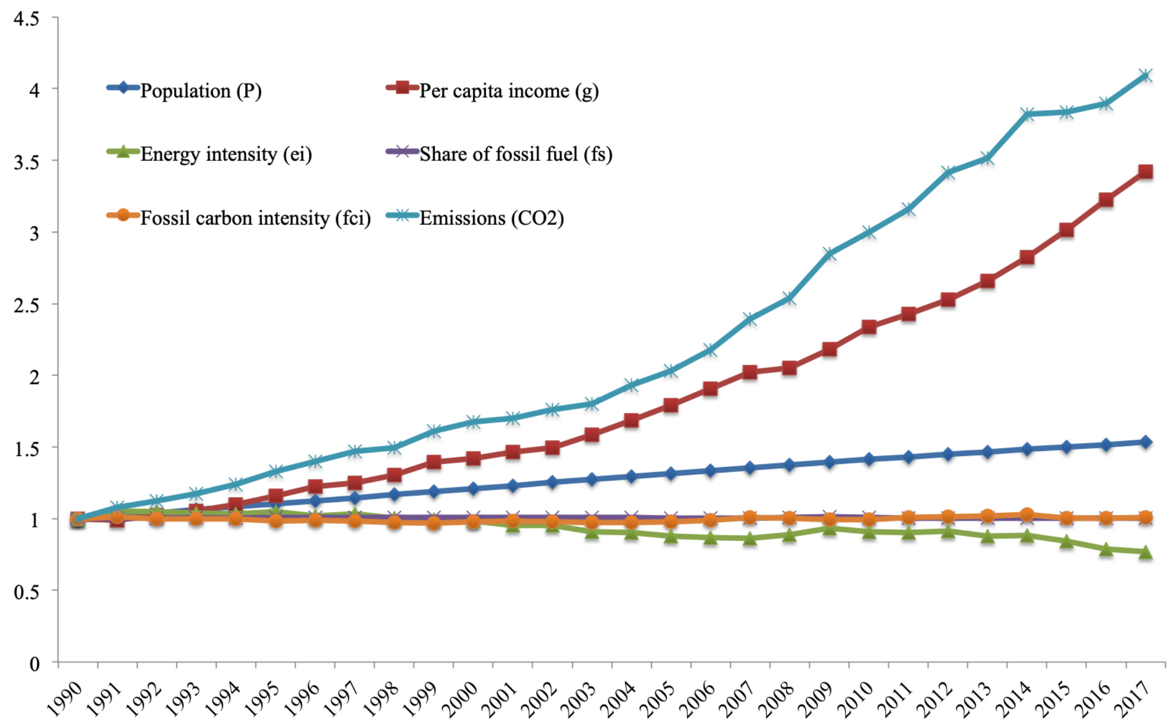

Figure 5: Factors in the Kaya identity normalised to 1 at 1990; Fossil carbon intensity includes both fossil mix and carbon intensity of each fossil fuel ($fci = \sum_i (fm_i \times fci_i)$)

annual changes during 1990-2017 and aggregate changes in five periods of five years (1990-2015) and the sixth period of three years (2015-17). The decomposition results for annual changes in $CO2$ from 1990 to 2017 is shown in Table 1 and plotted in Figure 6. Similar results of the decomposition of aggregate changes in $CO2$ is shown in Table 1 and the same is plotted in Figure 7.

Decomposition analysis results of the annual changes in emissions show that the change in emissions is always positive, i.e. the emissions in each successive year have been higher than the previous years. This is in contrast to many other countries where a decline in emissions is observed during the years of low economic growth. Population and per capita income growth has put upward pressure on emissions in all the years of the chosen period. Among the other four factors, energy intensity is the most significant factor driving emissions. A decline in the growth rate of emissions in most years is a result of offsetting by energy intensity effect. There are a few years in which energy intensity contributed substantially to an increase in emissions such as 1991, 1997, 2008 and 2009. Some of these years are also the years of low economic growth in India. The contributions of fossil share, fossil mix and fossil carbon intensity do not show any trends in the decomposition of annual changes.

Table 1: Decomposition of annual changes in India's CO_2 emissions

	ΔC_p	ΔC_g	ΔC_{ei}	ΔC_{fs}	ΔC_{fm}	ΔC_{fi}	ΔC_{tot}
1990-91	11	-5	28	2	1	4	41
1991-92	12	19	-1	1	-2	-7	23
1992-93	12	16	-6	2	2	0	26
1993-94	12	29	-3	-2	-1	-1	34
1994-95	13	36	8	3	-7	-3	50
1995-96	14	39	-22	1	0	2	33
1996-97	14	16	12	-1	-4	2	39
1997-98	14	33	-22	-3	-8	2	15
1998-99	15	55	-7	2	-1	-3	61
1999-00	15	17	-9	0	0	10	34
2000-01	15	27	-29	-2	2	1	14
2001-02	15	19	0	2	-2	-4	31
2002-03	16	56	-45	-1	-1	-4	20
2003-04	16	59	-8	0	8	-3	73
2004-05	17	63	-29	-3	0	3	50
2005-06	17	69	-14	-3	1	5	75
2006-07	18	71	-4	2	4	23	113
2007-08	19	20	38	7	5	-12	78
2008-09	20	87	70	4	-4	-13	163
2009-10	21	105	-45	-7	2	5	81
2010-11	21	62	-8	-8	7	10	84
2011-12	21	71	18	7	23	-4	137
2012-13	22	92	-63	-6	21	-14	50
2013-14	22	116	10	5	18	-9	163
2014-15	23	133	-102	0	-22	-23	8
2015-16	22	138	-131	-3	-16	20	31
2016-17	22	124	-53	-1	2	11	104
1990-2017	460	1565	-418	-2	28	-2	1631

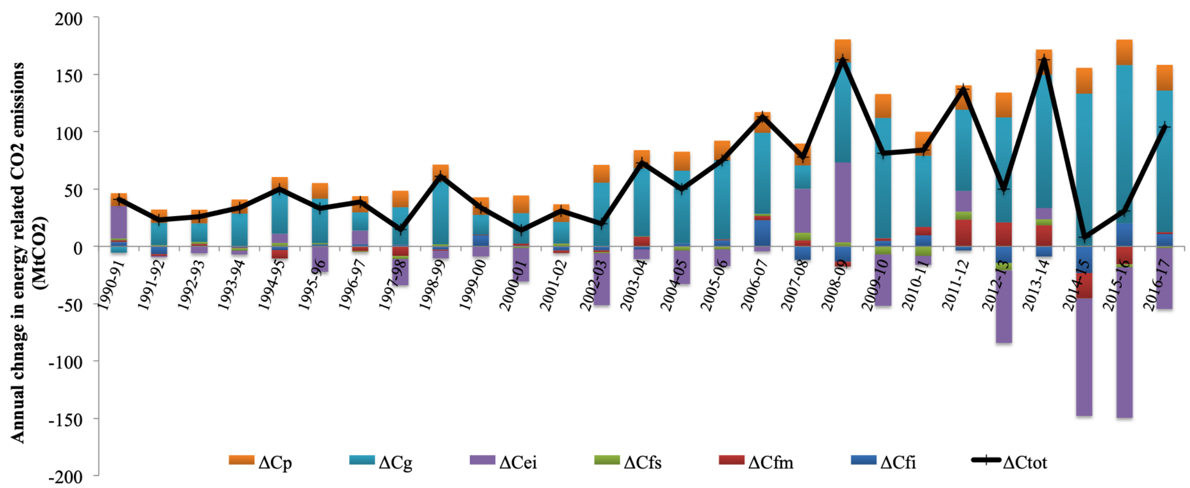

Figure 6: Decomposition of annual changes in India's CO_2 emissions into contributions from population, GDP per capita, energy intensity, fossil share and fossil intensity

The aggregation of effects shown in Figure 7 magnifies the effects obtained from the decomposition of annual changes. In this figure, it can be seen that in the first three periods of five years the increase in emissions due to population effect and income effect is offset by energy intensity effect such that the net increase in emissions is not significant. The net increase in CO_2 emissions during 1990-95, 1995-00 and 2000-05 is 174, 182 and 188 $MtCO_2$ respectively. The change in emissions in 2005-10 is 510 $MtCO_2$, and in this period, all the effects contribute to the increase in emissions. The increase in emissions due to the income effect in 2010-15 is greater than the corresponding increase in 2005-10. Still, the net increase in emission in 2010-15 is lower than 2005-10 due to the offset by energy intensity effect. The energy intensity effect has significantly offset the increase in emissions during 2015-17.

Table 2: Decomposition of aggregate changes in India's CO_2 emissions

	ΔC_p	ΔC_g	ΔC_{ei}	ΔC_{fs}	ΔC_{fm}	ΔC_{fi}	ΔC_{tot}
1990-95	60	95	26	6	-6	-7	174
1995-00	72	159	-48	-1	-13	12	182
2000-05	79	223	-111	-3	6	-6	188
2005-10	95	352	44	2	8	8	510
2010-15	109	473	-145	-2	48	-40	442
2015-17	45	261	-184	-4	-14	31	135
1990-2017	460	1565	-418	-2	28	-2	1631

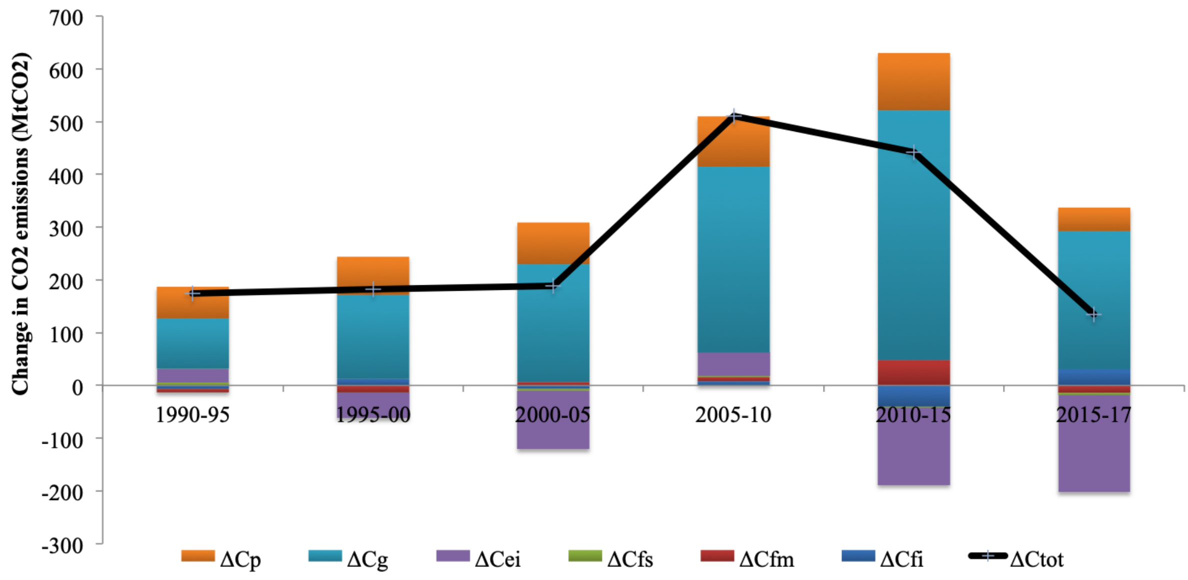

Figure 7: Decomposition of aggregate changes in India's CO_2 emissions into contributions from population, GDP per capita, energy intensity, fossil share and fossil intensity

4.3 Key findings

The results from growth in factors of Kaya identity and decomposition of the change in emissions into Kaya factors both annual and aggregate from 1990 to 2017 are summarised below:

- The analysis of Kaya factors show that while there is decoupling between energy use and GDP growth since late 1990s, the decarbonisation of the energy supply is not yet significant.

- The decomposition results of annual changes show that population and per capita income are the main drivers of emissions in India. The results show that emissions in India increased even in the years of low economic growth, mainly driven by a positive energy intensity effect.

- The decomposition of the aggregate changes shows that during 1990-2005, the increase in emissions due to population effect and income effect is offset by energy intensity effect such that the net increase in emissions is not significant. The increase in emissions in 2005-10 is significanty high since all the effects contribute to the increase in emissions in this period. The offset by energy intensity is observed during 2010-15 which is pronounced during 2015-17.

5 Conclusions

Research on drivers of energy-related CO_2 emissions can help countries track their climate goals amid changing economic cycles, market forces and policy outcomes. India's energy-CO_2 emissions have not been investigated to identify the contributions of different driving factors since the past two decades in a country-specific context. There are two India specific (Nag and Parikh, 2000; Paul and Bhattacharya, 2004) and two cross-country studies (Raupach et al., 2007; Peters et al., 2017) in the published literature that examine the drivers of changes in India's energy-related CO_2 emissions. All the four studies found that population and income contribute to increasing emissions in each year from 1970 until 2015. Energy intensity was the most important driver of change in India's per capita energy-CO_2 emissions during 1970-80 (Nag and Parikh, 2000). During 1980-1995 the contribution of energy intensity declined but remained positive (Nag and Parikh, 2000; Raupach et al., 2007). Contribution of energy intensity in decreasing the emissions began in mid-1990s (Raupach et al., 2007; Peters et al., 2017) and continued until 2015 (Peters et al., 2017). (Peters et al., 2017) did not find any clear trends in India's carbon intensity of energy.

In this study, the drivers of India's energy-related CO_2 emissions during 1990-2017 are examined using index decomposition analysis (IDA) under an extended Kaya Identity framework. The CO_2 emissions are decomposed into six Kaya factors - population, per capita income, energy intensity, fossil share, fossil mix and fossil carbon intensity. The change in emissions in a given period is calculated as the difference change of all the factors. The difference change is computed as the weighted average of logarithmic changes of the factors, and the weights are the logarithmic mean of changes in the emissions. Using the annual time series data from IEA Energy balance the trends in energy consumption and related CO_2 emissions are analysed. The Kaya factors derived from available data on population and GDP in constant 2010 USD are then computed. The changes in Kaya factors are examined by normalising all value to 1 in 1990. The decomposition into Kaya factors is carried out for annual changes and aggregate changes in emissions.

The trends in the Kaya factors shows decarbonisation of India's economic output during 1990-2017, starting in the late-1990s. The decarbonisation is driven by decoupling between economic growth and energy consumption. Decomposition analysis of the annual changes in emissions shows that the change in emissions is always positive, even in the years of low economic growth mainly due to a positive contribution of the energy intensity effect. Finally, the analysis of aggregate changes in emissions shows that the net increase in emissions during 1990-2005 is not significant due to offset by energy intensity effect. The emissions increased sharply during 2005-2010 due to a positive contribution of energy intensity effect. Again, the net increase in emissions during 2010-15 and 2015-17 is low due to the offset by energy intensity effect.

This study confirms decoupling of India's economic output and energy consumption since the late 1990s reported in past studies and provides evidence that the decoupling has continued until 2017. The study also confirms that the changes in the carbon intensity of energy do not show a clear trend of decarbonisation of the energy supply even until 2017. The finding on the positive contribution of energy intensity in the years of low economic growth requires additional research to identify the underlying cause. Also, further decomposition of energy intensity into structural factors is needed to isolate the effects of structural changes and technological improvements.

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