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Drivers of Energy Related CO_2 Emissions in India: A Decomposition Analysis

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Abstract The trade-off between economic growth and levels of greenhouse gas emission is one of the most debated issues in the context of climate change mitigation. For countries like India, while a faster growing Gross Domestic Product (GDP) is recognized to be a positive sign for the economy, the same leads to the emission of greenhouse gases to a greater extent due to increasing economic activities. Thus the question remains whether it is possible to decouple the activity growth from emission. This requires an understanding of the drivers of emission and identification of potential mitigation options with respect to them. The present study analyses the drivers of Carbon Dioxide (CO_2) emission in India based on Log Mean Divisia Index (LMDI) during the period 1990-2014. Growth in GDP, structural change of the economy, change in energy intensity of activities and change in fuel mix are identified to be the drivers of the change in emission over time. Results suggest that the growth in GDP, i.e. the activity growth remained the main factor that led to an increase in emission for the country. However, enhanced energy efficiency has remained one of the major drivers to neutralize a part of the activity effect. So far the fuel mix has not played an important role in the mitigation effort in India. Therefore, recent emphasis on greater energy efficiency and increase in the share of renewable in the energy mix may play a critical role in the country's emission reduction efforts.

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INTRODUCTION

The tradeoff between economic growth and levels of greenhouse gas (GHG) emission is one of the major challenges that transitioning countries like India face. While the growth rate of Gross Domestic Product (GDP) is one of the major factors that drive the transition, the consequent increase in GHG emission is also inevitable. During the period 2010-15, while GDP increased by 59% at a constant price in India (from 82 Trillion INR to 113.86 Trillion INR), the emission of CO_2 per year also increased by 29% (from 1.72 Million tonne to 2.22 Million tonne). Out of this 2.22 Million tonne, 2.06 Million tonne is from fuel combustion. In fact, India was one of the top three countries in CO_2 emissions in 2015 though per capita emission of the country remained considerably low (World Bank 2017). Since the growth in GDP is not something to be compromised for the

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economic health of a developing country, the question remains how to decouple economic growth from emission? One possible way is to reduce the energy and emission intensity of GDP i.e. reduction in energy consumption or emission per unit of GDP. In 2015, India government signed an agreement under the United Nations Framework Convention for Climate Change (UNFCCC) to reduce the emissions intensity of its GDP by 33-35%. India also pledged that 40% of the country's electricity would come from non-fossil fuel-based sources, such as wind and solar power, by 2030 (UNFCCC 2015). In order to achieve this target, it's essential to make policies that are favorable to high economic growth along with reduced CO_2 emissions. For that, one needs to understand and analyze the drivers of CO_2 emission in the country. In a simple framework, where the economy can be considered to have three sectors- agriculture, industry and services, total emission depends on the level of activity of each of the sector – both absolute and relative. If the absolute level of activity goes up, this is expected to increase both GDP and emission, other factors remaining constant. If the relative share of a sector that is inherently less energy and emission intensive (service sector, for example) goes up, the emission is likely to decrease due to this structural shift of the economy in favor of emission non-intensive sector. Besides, enhanced energy efficiency is always a source of mitigation. Finally, the type of fuel matters. For example, while natural gas is generally far less emitting than coal, direct emission from the renewable energy sources are nil. Therefore, an increased share of cleaner fuel in the energy mix also acts as a mitigation tool. Understating these drivers of emission helps to figure out the performance of the country with respect to these drivers and to identify potential drivers to explore further. In the present study, a decomposition of energy related CO_2 emission in India has been carried out for the period 1990 – 2015. It considers three sectors of the economy: Agriculture and & Allied Services (A), Industry (I), Services (S) and four fuel types - coal, oil, natural gas and other (this includes cleaner energy sources). Note that this analysis takes into consideration the energy consumption (both primary and secondary) by the end-use sectors and therefore, the power generation sector is not considered.

The chapter is further divided into four sections. Section 2 elaborates the methodology, Section 3 describes the construction and sources of data, Section 4 presents results and discussion and section 5 states the conclusions.

METHODOLOGY

Log Mean Divisia Index (LMDI) based decomposition of CO_2 emission is carried out for India to understand the drivers of the emission. LMDI has gained interest among researchers and was first used in 1998 to study the factor decomposition for the CO_2 emissions from China's industrial sectors (Ang and Choi 1997, Ang 2012). This method aims to break down the changes in emission into different indicators and thereby providing a detailed view of the effects of defined factors. It gives perfect decomposition, satisfies the factor reversal test and is consistent in aggregation.

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Under this framework, total energy related CO_2 emission at period t is expressed as Eq. (1).

$$\sum_i \sum_j C_{ij}^t = \sum_i \sum_j Q^t \frac{Q_i^t}{Q^t} \frac{E_i^t}{Q_i^t} \frac{E_{ij}^t}{E_i^t} \frac{C_{ij}^t}{E_{ij}^t} = \sum_i \sum_j Q^t S_i^t I_i^t M_{ij}^t U_{ij}^t \qquad \textbf{\textit{(1)}}$$

Where,

i = 1,2,3 denotes the three major sectors- Agriculture, Industry and Services

j= 1,2,3,4 denotes the types of fuel i.e. Coal, Oil, Natural Gas and Cleaner Energy Sources (CES).

t denotes the time period

Q_t = GDP of India at constant price at period *t*

Q_i^t = GDP of sector *i* at constant price at period *t*

E_i^t = Total energy consumption of sector *i* at period *t*

E_{ij}^t = Consumption of fuel *j* by sector *i* at period *t*

C_{ij}^t = Emission from fuel *j* in sector *i* at period *t*

$S_i^t = Q_i^t / Q^t =$ share of sector i in total output at period t.

$I_i^t = E_i^t / Q_i^t =$ energy intensity of sector i at period t

$M_{ij}^t = E_{ij}^t / E_i^t =$ share of fuel j used in sector i at period t

$U_{ij}^t = C_{ij}^t / E_{IJ}^t =$ emission factor of fuel j in sector i at period t

The changes in CO_2 emissions from *t=0* (base year) to *t=T* (target year) can be expressed either in additive or in multiplicative form. Since one form can be obtained from the other, in this study we have used only the additive form where the change in emission can be decomposed as Eqn. (2):

$$\Delta C_{total} = C^T - C^0 = \Delta C_{act} + \Delta C_{str} + \Delta C_{int} + \Delta C_{mix} + \Delta C_{emf} \qquad \textbf{\textit{(2)}}$$

Where,

ΔC_{total} is the change in CO_2 emission during the study period and given $\boldsymbol{W_{ij}} = \frac{\boldsymbol{C_{ij}^T - C_{ij}^0}}{\boldsymbol{\ln C_{ij}^T - \ln C_{ij}^0}}$,

$\Delta C_{act} = \boldsymbol{\sum_{ij} W_{ij} \ln \left(\frac{Q^T}{Q^0}\right)}$ is the *Activity Effect* i.e. the change in aggregate CO_2 emission associated with a change in the overall level of activity (represented by GDP in constant price).

$\Delta C_{str} = \sum_{ij} W_{ij} \ln \left(\frac{S_i^T}{S_i^0}\right)$ is the *Structural Effect* and refers to changes in emission due to changes in the economic structure($S_i^t = \frac{Q_i^t}{Q^t}$).

$\Delta C_{int} = \sum_{ij} W_{ij} \ln \left(\frac{I_i^T}{I_i^0}\right)$ is the *Energy Intensity Effect* and is defined as the change in emission associated with the changes in sectoral energy intensities.

$\Delta C_{mix} = \sum_{ij} W_{ij} \ln \left(\frac{M_{ij}^T}{M_{ij}^0}\right)$ is the *Fuel Mix Effect* that accounts for the change in emission due to the change in share of different fuels in sectors' total energy consumption.

$\Delta C_{emf} = \sum_{ij} W_{ij} \ln \left(\frac{U_{ij}^T}{U_{ij}^0}\right)$ is *Emission Factor Effect* i.e. the change in emission due to change in the emission factor of a particular fuel with respect to a particular sector. Note that in this study, the emission factor has

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taken to be constant over the study period and hence this factor is not accounted for in the final analysis.

Data

The analysis requires activity data, fuel wise energy consumption and CO_2 emission data for each of the sectors during 1990-2015. The analysis requires sector-wise activity data (which can be aggregated to total activity) deflated by price index, fuel wise energy consumption and CO_2 emission data for each of the sectors.

Sectoral output data: For the activity, GDP of India at 2004-05 prices has been considered. The real GDP data (at 2004-05 prices) for various years are collected from Niti Ayog / Planning Commission, Government of India[1]. Also, the shares of GDP in various sectors (agriculture and allied services, industry and services) were collected. This has been used to calculate GDP of each sector at a given period, so as to compute the structural effect.

Fuel-wise energy consumption data for each sector: Fuel-wise energy consumption data was obtained from the Energy Statistics published by the Ministry of Statistics and Programme Implementation (MoSPI), Government of India for the required years. The energy balance, available within the Energy Statistics, for each of the fuel type, consists of the total primary energy supply-divided among various input sources and also the final consumption of the energy-divided among various use cases. The energy balance also accounts for the transfers from one source of fuel to another and various losses during the transfer and production. Energy consumption is reported in thousand tonnes of oil equivalent (ktoe) on a net calorific value basis. The source reports consumption of ten types of fuels: coal; crude oil; oil products; natural gas; nuclear; hydro; geothermal, solar, etc.; biofuels and waste; electricity[2] for various sectors including industry, transport, residential, commercial and public services, agriculture/forestry, fishing, and a non-specified sector. They also report the non-energy use of different types of fuels. However, as the objective is to understand the energy use and emission profile, non-energy uses are not considered. All economic sectors reported in Energy Balance are aggregated into three economic sectors so as to match the sectors for which activity data are available. Transport, residential and commercial and public services are included in the service sector. Energy use of non-specified sectors is divided among the three specific sectors based on their share in GDP. Fuel use reported in Energy Balance is aggregated to four fuel categories coal (C), oil (O; crude oil and oil products), natural gas, clean energy sources (CES; nuclear, hydro, geothermal, solar, biofuel etc.). Since the study considers only the end-use sectors, how to distribute the primary energy consumption related to power generation among them is a crucial question. Some studies have computed total emissions from power generation and then distributed it

[1] https://data.gov.in/catalog/gdp-india-and-major-sectors-economy-share-each-sector-gdp-and-growth-rate-gdp-and-other

[2] Although heat is one of the categories, there is no data under this category in India

Table 1: Mapping of economic sectors and energy sources to categories used in the paper

Economic sector in the Energy Balance	Economic sector in the study	Fuel category from energy balance	Fuel category in the study
Industry	Industry (I)	Coal	Coal (C)
Transport	Services (S)	Crude Oil	Oil (O)
Residential	Services (S)	Oil Products	Oil (O)
Commercial and public services	Services (S)	Natural Gas	Natural Gas (NG)
Agriculture / forestry	Agriculture and Allied Services (A)	Nuclear	Clean Energy Sources (CES)
Fishery	Agriculture and Allied Services (A)	Hydro	Clean Energy Sources (CES)
Non-specified and non-energy use of fuel	Non included in the analysis	Geothermal, solar, etc.	Clean Energy Sources (CES)
		Biofuels and waste	Biofuels (BF) – CES
		Electricity	Distributed in different categories based on the source of production

to each economic sector according to the share of electricity used by each sector. We use an improved method in the present study. The only assumption that we make is that the fuel mix, i.e. the share of primary fuels in power generation does not vary across sectors. That is to say, if x_1, x_2, x_3 and x_4 are the proportions of coal, oil, natural gas and clean energy sources used to produce each unit of electricity consumed by the industry sector, then the same proportions will hold for each unit of electricity consumed by agriculture and service sector as well. Energy Statistics also publishes data on sources on primary fuel for electricity and heat generation. Based on this, we have tracked down the consumption of primary fuel for each sector through consumption of electricity. Table 1 provides the mappings of fuels and sectors from sources to the classifications that are considered here.

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Therefore, the total consumption of jth fuel by ith sector is calculated as

$E_{ij}^{t} = E_{ij}^{t\prime} + E_{ij}^{t\prime\prime}$

where, $E_{ij}^{t\prime}$ represents the direct consumption of fuel j by sector i and $E_{ij}^{t\prime\prime}$ represents the utilization of j^{th} fuel in producing electricity consumed by sector *i.*

Table 2: Emission factors of different fuel category

Fuel category	Revised IPCC 1996	Parikh 2009 (India specific for coal, follows IPCC 2006 for oil and natural gas)	INCCA 2010 (for 2007)	
Unit of measurement	Tonnes of carbon/TJ	Tonnes of carbon/tonne of fuel (per cubic meter for natural gas)	Tonnes of carbon/TJ (converted from tonnes of carbon dioxide using the factor 0.2727	Tonnes of carbon/ktoe
Coal	~ 26.1 tc/TJ	1.614 tc/t	~ 25.86 tc/TJ	~ 1083tc/ktoe
Oil	~19.6 tc/TJ	3.1024 tc/t	~19.44 tc/TJ	~ 814tc/ktoe
Natural Gas	15.3 tc/TJ	0.0021 tc/m^3	15.2 tc/TJ	~636tc/ktoe

** Values are approximated due to aggregation of various categories of each fuel*

Emission factor: Change in fuel-wise emission factor in each sector is considered to be one of the drivers of the change in total emission. While this factor is important to be included in the model for accounting purpose, the practical implications are limited. This is because there is no significant change in the emission factor reported for various fuels over time since the 1990s (see Table 2). This emission factor, however, relates to emission due to fuel combustion activities, and so does the present study. Industrial process emission, which takes place due to the transformation of raw material, is not considered here. Another important point to note, following hypothesis of Intergovernmental Panel on Climate Change (IPCC) energy module, this study assumes that biomass consumption is equal to re-growth and hence does not contribute to emission (IPCC 1996)[3]. In this study, India specific emission factors published in Indian Network for Climate Change Assessment (INCAA, 2010) are used for all the years. For comparison, emission factors reported in Parikh (2009) is also mentioned in Table 2. Therefore, while the accounting framework

[3] Any departure from this assumption is counted in Land Use Change and Forestry model in IPCC

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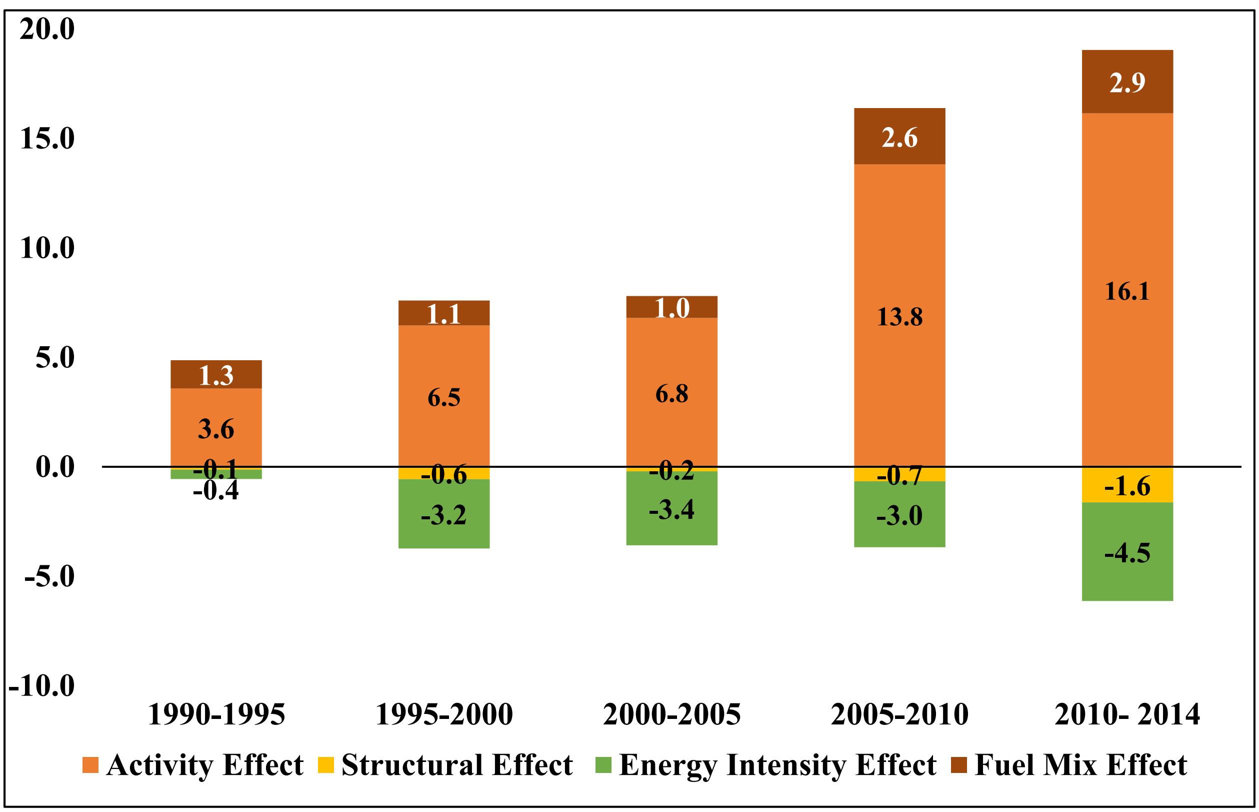
will hold, no change in emission due to a change in emission factor will be accounted for. However, we keep this factor for future reference.

RESULT AND DISCUSSION

The decomposition analysis shows the contribution of each of the drivers in total energy related CO_2 emission in India. The results are presented by dividing the study period into 5 sub-periods (Figure 1). Figure 1 suggests that during 1990-1995, the index for the total increase in energy related CO_2 emission in the country increased by 4.4 Out of this, 3.6 is due to Activity Effect. Both Structural Effect and Energy Intensity Effect contributed to the reduction in emission, but the impacts are negligible. Important to note that Fuel Mix effect actually led to an increase in emission, not only during this period but across the study period. For the other sub-periods, one may observe that the similar trend continues. With increase in GDP, the Activity Effect continues to dominate the trend of increase in emission. However, the role of Energy Intensity Effect has become much significant in the recent year that has pulled the emission down to a greater extent. In-fact during 2010-14, more than 25% of emission increase due to Activity Effect has been neutralized by Energy Intensity Effect. While the Activity Effect resulted in an index value of 16.1, the index value of Energy Intensity Effect is -4.5.

Figure 1: Decomposition of energy related CO_2 emission in India.



Upon seeing the decomposition analysis, multiple aspects were brought to notice. GDP of India is growing by a fast pace and with the increase in GDP more and more energy requirement is at various sectors and thus, the rise in CO_2 emissions. As the industry sector was growing faster than other sectors in the early 1990s, and the industrial sector being an energy intensive consumer, the Structural Effect had limited contribution to emission mitigation. The Structural Effect is changing towards a more significant magnitude to neutralize a part of emission because of the rise of the share of service sector in the recent past. This is obvious as the service sector is less energy intensive as compared to the industrial sector. The changes by the energy mix effect resonates with the notion that energy mix is highly effected through the major development in electricity plants and such developments are conducted at national and state level in multiple stages spanning across many years and in turn affecting the energy mix consumed in different sectors. It should be noted that the energy mix effect is majorly positive and is contributing an increase in CO_2 emissions.

This lays emphasis on the lagging use of cleaner fuels in India and the fact that rising energy demand in India is fulfilled more on fossil fuels.

Finding suggests that India requires a two way policy mix – on the energy supply side, the fuel mix needs to be improved with a greater contribution of renewable and other cleaner fuel. The efficiency of electricity plants and other energy consuming industries should be hugely increased. This is true for the end-use sectors as well. Infact, in possible cases, substitution of coal by natural gas in the short run will lead to desired results. On the other hand, key work is needed to manage the demand side of the picture. Energy efficient solutions could be a leading answer to the same. There are stated efforts to promote greater use of renewable in the energy mix mainly through solar and wind and at the same time shifting towards supercritical technologies for coal based power plants. On the other side, efforts are being made to efficiently use the energy in the demand side through various innovative policy measures under the overall ambit of Energy Conservation Act 2001 including policies such as Perform Achieve and Trade, Energy Conservation Building Codes etc. (GoI 2017).

CONCLUSION

This paper has deployed an Index Decomposition Analysis method to decompose the energy related CO_2 emission in India. Results suggest that while Activity Effect remains the main driving force behind the increase in emission, with some contribution from the fuel mix effect, the Energy Intensity Effect has become stronger to neutralize parts of growing emission. This will definitely have a positive contribution towards achieving the target reduction of emission intensity under the Paris Agreement, but in order to reduce total emission more rigorous efforts are to be made to explore the channel of fuel mix. Finally, this paper only has scratched the surface of the question. To truly identify the cause of the emission of carbon dioxide from energy use, more factors should be taken into account. The policies should also take into account the huge disparity of energy access and energy poverty in India, and it is important that the

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new policies should not inhibit the economic growth of India.

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