ENERGY INTENSITY AND CO_2 EMISSIONS: INDIA'S PROGRESS TOWARDS ENERGY AND CLIMATE CHANGE MITIGATION GOALS

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1 Overview

Improvements in energy efficiency and renewable energy sources are the key to addressing the energy and climate change challenge globally. The energy consumption and related CO_2 emissions have been growing due to the overall economic growth. India's primary commercial energy supply increased four folds in 2017 since 1990. As per the estimates by International Energy Agency (IEA), the energy-related CO_2 emissions had grown from 528 Mt in 1990 to 2161 Mt in 2017. The CO_2 emissions per unit of economic output declined steadily from 1991 to the mid-2000s, remained at a higher level until 2014, and is declining (Fig. 1).

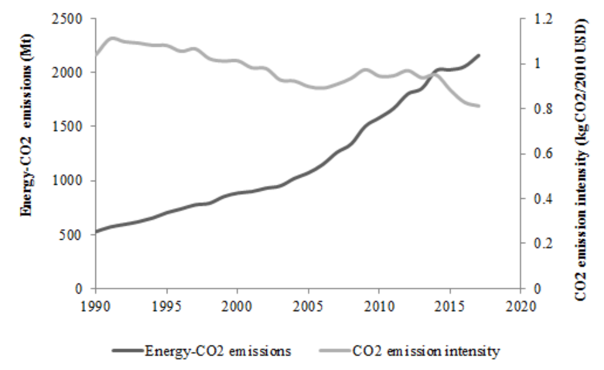

Figure 1: India's CO2 emissions and emission intensity (Source: IEA Database)

India's per-capita energy consumption is one-third of the global average. Despite national programs to increase clean energy access, 21% of the primary energy demand is still met from biomass-based energy sources. The economy is mainly dependent on fossil energy sources. Around 95% of the commercial energy supply is completed from coal, oil, and natural gas. More than half of the fossil fuel energy is from coal (56%) followed by oil (35%) and natural gas (7%). While struggling to provide clean energy access to its population, India faces the challenge of meeting its climate change mitigation goals.

Energy efficiency is key to meeting India's energy and climate goals. Several policies in the country aim to address the known barriers to energy efficiency, such as insufficient information, high capital cost, and low energy costs. In a sectoral approach to energy efficiency, both regulatory and market-based instruments have been adopted. The government of India introduced mandatory appliance labels in 2010 and minimum efficiency standards in 2012. The program was introduced for few appliances, to begin with, and was expanded gradually. The government of India introduced mandatory energy audits for industries in the early 2000s and mandatory targets for reduction in specific energy consumption in 2012. The energy efficiency in agriculture and municipal lighting and water pumping is implemented under electricity distribution utilities' demand-side management programs. Besides, there are building codes to set minimum performance standards for buildings. There are limited efforts so far to improve the energy efficiency of vehicles. However, there is a thrust on a shift toward hybrid/electric vehicles.

One of the challenges in implementing energy efficiency policies is estimating energy savings and emission reduction. Several approaches measure energy savings, such as metering, engineering estimates or deemed savings approach, and model-based estimates. There are both merits and demerits of each method. The use of a technique depends on the nature and size of the energy efficiency investment. The impact of energy efficiency on aggregate energy consumption and emission reduction is increasingly being evaluated using index decomposition analysis. In a recent study, Trotta (2020) used IDA on the final energy consumption of Finland to estimate the energy savings from energy efficiency in different end-use sectors. The authors found that the estimates of energy saved from energy efficiency improvements using IDA are lower than the official estimates using deemed savings approach.

India uses different methodologies to estimate energy savings and emissions reduction from energy efficiency programs. The savings are calculated either in terms of energy saved or avoided capacity addition. The most commonly used approach is the deemed savings approach. The official estimates of savings using deemed savings approach from energy efficiency policies in agriculture during 2012-17 are 2.3 mtoe. The savings in the industrial sector from actual metering are 8.67 mtoe during 2012-15. The corresponding reduction in CO2 emissions is 31 MtCO2.

In this paper, I study the drivers of India's energy-related CO_2 emissions during 2000-2018 using index decomposition analysis (IDA)(Ang, 2004). Few studies have examined India's CO_2 emissions using IDA (Paul and Bhattacharya, 2004; Nag and Parikh, 2000). This paper analyses the most recent data using improved techniques for estimating the effects of underlying drivers under IDA. I estimate the emission reduction due to energy efficiency improvements in industries, commercial and services, and the agriculture sector. I then compare the estimates with the official estimates of savings.

2 Methods

The energy-CO_2 emissions of a region are driven by changes in economic activity and intensity of emissions from the economic activity. The intensity effect is determined both by technological factors and structural factors. The structural factors could change the economy's structure, such as a change in the services sector's share. It could also be due to sector-specific structural changes, such as shifting towards less energy-intensive industries or fuel mix changes. On the other hand, technological factors include the adoption of energy-efficient technologies in production sectors. The effect of energy-efficient technologies can be estimated with data on energy consumption by sub-sectors. This paper only separates the impact of economic structure changes and the sector energy intensity from the aggregate intensity effect in the absence of such data. Hence, sector energy intensity effect includes energy-efficient technology effect and sector-specific structure effect.

I apply the four-factor decomposition on sector-wise energy and emissions data using the extended Kaya identity given in Eq. 1.

$$CO2_t = \sum_i CO2_{it} = \sum_i \underbrace{GVA_t}_{\text{activity effect}} \times \underbrace{\frac{GVA_{it}}{GVA_t}}_{\text{economy structure}} \times \underbrace{\frac{E_{it}}{GVA_{it}}}_{\text{sector-energy intensity}} \times \underbrace{\frac{CO2_{it}}{E_{it}}}_{\text{carbon intensity}} \tag{1}$$

Where,
$CO2_t$ is the total CO_2 emissions from all value adding sectors
$CO2_{it}$ is the CO_2 emissions from value adding sector i in year t
GVA_{it} is the value added by sector i in year t
GVA_t is the total value added by all the sectors
E_{it} is the energy consumption of value adding sector i in year t

Simplifying the notation, $\frac{GVA_t}{P_t} = G_t$; $\frac{GVA_{it}}{GVA_t} = S_{it}$; $\frac{E_{it}}{GVA_{it}} = EI_{it}$ $\frac{CO2_{it}}{E_{it}} = C_{it}$

The contribution of each factor in the total change is calculated using Eq 2.

$$\Delta CO2_{tot} = CO2_t - CO2_0 = \Delta CO2_P + \Delta CO2_{GV} + \Delta CO2_S + \Delta CO2_{EI} + \Delta CO2_C \tag{2}$$

The effect of the contributing factors are calculated using log-mean divisia index technique (LMDI). The effect of a factor, say EI is calculated using Eq. 3

$$\Delta CO2_{ei} = \sum_i \frac{CO2_{iT} - CO2_{i0}}{lnCO2_{iT} - lnCV_{i0}} \times ln(\frac{EI_{it}}{EI_{i0}}) \tag{3}$$

3 Results

India's total energy-CO2 emissions by end-use sectors are plotted in Fig 2. The industry has the largest share in total emissions, followed by residential and transport. The emissions have increased throughout the years, with the largest and lowest increase in 2014 and 2015, respectively. The annual average growth in emissions during 2000-18 is 80 MtCO2. Industries, transport, and households contribute most to the increase in emissions. Industries contributed to a decline in emissions in only one year, i.e., 2015. The analysis of drivers of emissions and decomposition of the change in emissions in the production sectors are discussed below.

3.1 Kaya factors

The drivers of India's energy-CO2 emissions for 2000-18 are plotted in Figs. 3-5. There has been a significant shift in India's economic structure in the last two decades. The share of the primary sector has continuously

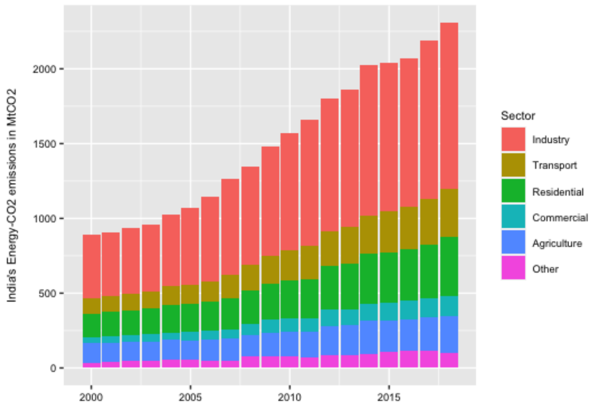

Figure 2: Change in India's CO2 emissions by end-use sector (Source: Author estimates)

declined, and that of the tertiary sector has increased. The percentage of industries in the total GVA increased until 2010 and has not changed significantly in the last few years. Industries are much more energy-intensive as compared to agriculture and the allied sector. The shift away from agriculture to industries causes an increase in the energy intensity of the economy. However, the service sector is much less energy-intensive than agriculture and industries. Hence, the recent shift away from both agriculture and industries towards the primary sector leads to a decline in India's energy intensity.

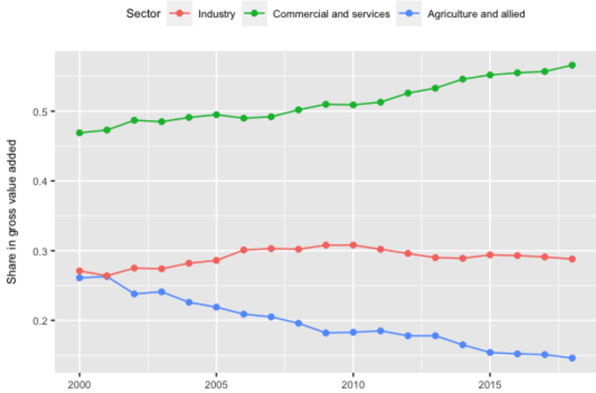

Figure 3: Share of production sectors in the total gross value added (Source: MOSPI, Govt.of India)

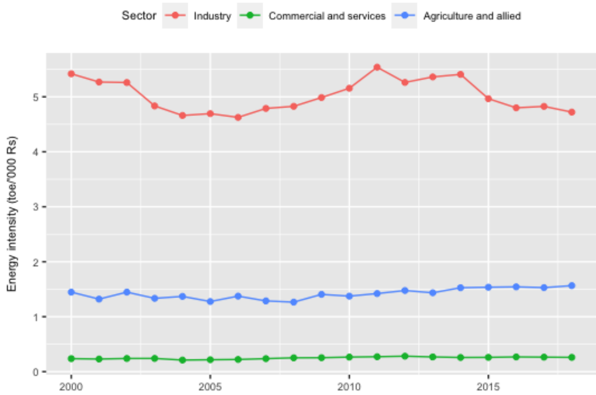

Figure 4: Energy intensity of production sectors in India (Source: Author estimates)

The energy intensity of industries in India declined by 8% in 2009 compared to 2000 levels. It increased sharply in 2010 and began dropping only in 2015. As compared to the 2014 level, the energy intensity of industries

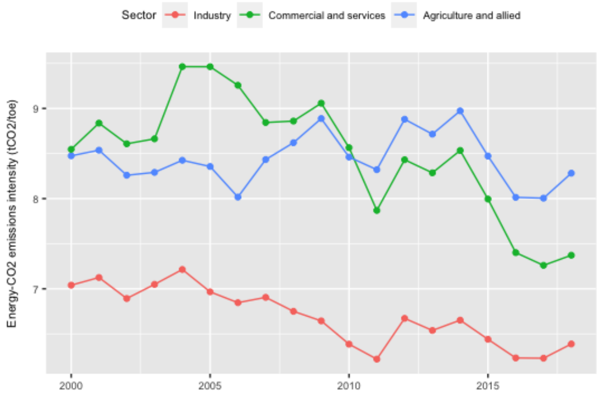

Figure 5: Carbon intensity of energy use by production sectors in India (Source: Author estimates)

declined by 13% in 2018. On the other hand, the energy intensity of the agriculture and industry sectors has been increasing. The carbon intensity of energy in the country was declining until 2011. After that, it increased sharply in 2012 and began dropping only in 2015. At the sector level, the carbon intensity of industries and the commercial and services sector is declining, but that of the agriculture sector has not changed significantly.

3.2 Decomposition results

The results of decomposition analysis can be presented annually or at specific intervals. The effects in each year for the three production sectors are shown in Fig 6. In the annual estimates, the trend in activity effect is clear but not in others. The trends in the four effects in specific periods are shown in Fig. 7.

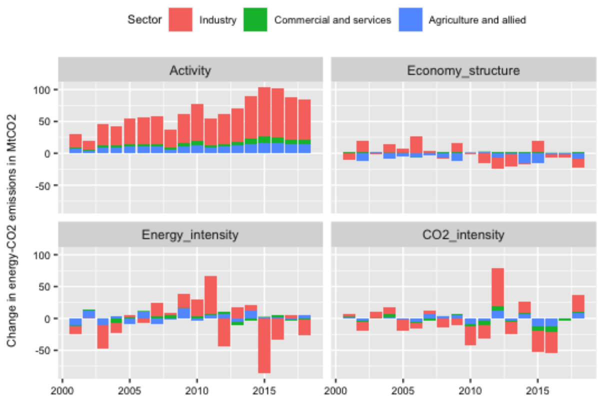

Figure 6: Annual estimates of the effects using index decomposition analysis (Source: Author estimates)

3.2.1 Activity effect

The activity effect shows the effect of population and per-capita income growth on CO_2 emissions. The activity effect has contributed to an increase in emissions from all the sectors in all years during 2000-18. Even in the global financial crisis, the activity effect contributed 24 $MtCO_2$ to the total CO_2 emissions. The average annual contribution of activity effect to the total CO_2 emissions has increased from 38 $MtCO_2$/year during 2000-05 to 91 $MtCO_2$/year in 2015-18. The contribution of the industrial sector in the activity effect has increased from 71% to 75% during 2000-18. However, the share of agriculture sectors in the activity effect has declined from 22% to 16%. The percentage of the services sector has increased marginally from 7% to 9%.

3.2.2 Economy structure effect

The economic structure effect shows the effect of changes in the structure of the economy on CO_2 emissions. The decomposition results that during 2000-10 the shift towards industry sector pushes the emissions upwards and

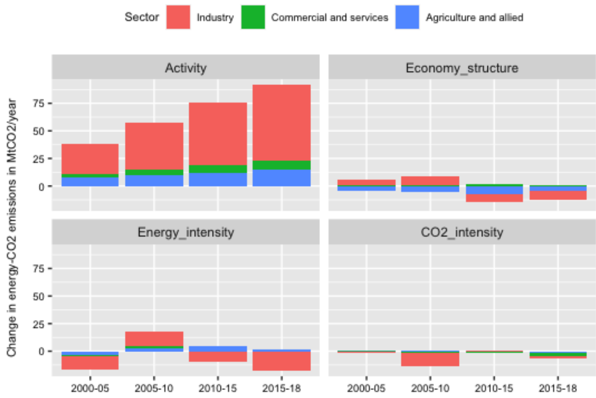

Figure 7: Estimates of the effects using index decomposition analysis aggregated in five period (Source: Author estimates)

the shift away from agriculture sectors pushes the emissions downwards. The net effect of this structural shift is negligible. However, during 2010-18, the shift towards the commercial and services sector pushed the emissions downwards. In this period, the net increase in CO2 emissions is reduced by 12 Mt annually due to the economic structure effect. Most of this effect is due to the shift to less emission-intensive commercial and service sectors.

3.2.3 Sector energy intensity effect

The energy intensity effect shows changes in the intensity of energy use in three production sectors. The energy intensity of the production sectors changes either due to the adoption of energy-efficient technologies or changes in the sectors' structure. This can be termed the sector structure effect to distinguish the structural modifications in sectors from the structural changes in the economy. The changes due to energy-efficient technologies are termed as technology effect.

The sector energy intensity effect that includes both sector structure effect and technology effect changed its net impact on the CO2 emissions twice during 2000-18. During 2000-05 the energy intensity effect pushed the emissions downwards by 17 MtCO2/year. However, during 2005-10, the energy intensity caused an increase in the CO2 emissions at an approximately similar rate. After that, energy intensity again began pushing the emissions downwards. This effect magnified sharply during 2015-18. The industries drive the decline in emissions due to the energy intensity effect during 2010-18. During this period, the increase in the energy intensity of the agriculture and allied sectors caused a rise in emissions.

3.2.4 Carbon intensity effect

The carbon intensity effect in this study shows the impact of changes in the fuel mix of the energy used in the production sectors. This effect has not had any significant impact until 2015. A sizeable negative effect during 2005-10 was due to the increase in the share of natural gas in the energy supply. However, there is a net negative effect of around 7 MtCO2/year in the last three years that could be due to an increase in the electricity generation from renewable energy sources.

4 Discussion and future work

The decomposition results show that during 2012-15, energy efficiency in industries resulted in emission reduction of 60 MtCO2. The corresponding value from the official estimates is 31 MtCO2. This study finds that in the agriculture sector, the emissions increased by 8 MtCO2 during 2012-17 due to increased energy intensity. This contrasts with the official estimates of emission reduction due to energy savings from energy-efficient pumping systems.

It is important to recall that the official estimates of energy savings in industries are from direct measurements and that from the agriculture sector are from deemed savings approach. This study confirms that the deemed savings approach overestimates the actual savings from energy efficiency investments. The study also confirms that the national estimates of savings from energy efficiency in industries are lower than the real savings from a reduction in energy intensity of industries in the country.

As discussed above, the emissions reductions from improvements in energy intensity of industries are due to both efficiency improvements and structural changes within the sectors. This study does not separate the effect of structural changes within the industry to isolate the impact of technologies in emission reduction. Another limitation of the study is that the comparison of findings is limited to official estimates of energy savings and emission reduction from energy efficiency policies. An additional review of the literature is required for the comparison of the results. Finally, it is also essential to compare the findings using official energy data for a robustness check. Further research in these directions can help better estimate the effect of energy-efficient technologies on India's energy-CO2 emissions.

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