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**Abstract**

*Energy efficiency plays a central role in climate change mitigation policies, but their impact on economy-wide energy consumption is uncertain. Improved methods to measure energy efficiency savings are adopted mainly in countries with mandatory energy efficiency targets. These countries combine bottom-up and top-down methods to enhance reliability. India has implemented various energy efficiency measures, and their impact is estimated using the simplified deemed savings bottom-up approach. Index Decomposition Analysis is a simple top-down approach, but its use in India is limited due to data gaps. Using India's energy balances from International Energy Agency, I estimate the energy efficiency savings in India during 2011-19. I find that the IDA estimates are lower than the government's deemed savings estimates. The underlying assumption in the simplified deemed savings approach and data gaps in index decomposition analysis limits the usability of the estimates. National level targets on energy efficiency can push improvements in energy savings measurement techniques used in India. The targets can also address a few barriers in the energy efficiency markets.*

**Keywords: energy efficiency savings, energy efficiency targets, energy intensity, decomposition analysis, manufacturing energy intensity, energy balances**

**JEL Code: Q4, K3, O13**

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Energy efficiency plays a central role in climate change mitigation policies, but their impact on economy-wide energy consumption is uncertain. Improved methods to measure energy efficiency savings are adopted mainly in countries with mandatory energy efficiency targets. These countries combine bottom-up and top-down methods to enhance reliability. India has implemented various energy efficiency measures, and their impact is estimated using the simplified deemed savings bottom-up approach. Index Decomposition Analysis is a simple top-down approach, but its use in India is limited due to data gaps. Using India's energy balances from International Energy Agency, I estimate the energy efficiency savings in India during 2011-19. I find that the IDA estimates are lower than the government's deemed savings estimates. The underlying assumption in the simplified deemed savings approach and data gaps in index decomposition analysis limits the usability of the estimates. National level targets on energy efficiency can push improvements in energy savings measurement techniques used in India. The targets can also address a few barriers in the energy efficiency markets.

Keywords: energy efficiency savings, energy efficiency targets, energy intensity, decomposition analysis, manufacturing energy intensity, energy balances

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# 1 Introduction

Defining goals, setting targets, and tracking indicators are central to meeting desired objectives of a policy. The UN Sustainable Development Goals aim to meet the targets of energy efficiency, renewable energy, and sustainable industrialisation. Countries are tracking sustainable energy goals using indicators such as energy intensity and the share of renewable energy to meet the targets (United Nations, 2015). Similarly, the target of limiting the global temperature rise to 1.5 degrees is central to climate mitigation policy. At the country level, the Nationally Determined Contributions (NDC) and the net-zero emission targets are directing national actions on climate mitigation. Globally, indicators such as absolute emissions and emissions intensity of GDP are used for setting emission reduction targets.

Energy efficiency continues to top the list of least-cost options for meeting energy and emissions intensity targets (Gillingham and Stock, 2018). Despite a central role in climate mitigation, significant uncertainty remains regarding how energy-efficient technologies, strategies, and policies affect economy-wide energy consumption. As countries make goals toward net zero emissions, it is critical to understand energy efficiency's contribution to such goals (Saunders et al., 2021). There are several challenges in estimating the impacts of energy efficiency both at the measure level and at the national level. These challenges deter countries from undertaking a comprehensive assessment of the energy savings from energy efficiency.

National targets encourage countries to adopt frameworks for estimating energy efficiency savings. For example, European Union has developed methodologies to measure the progress of member countries in meeting their energy efficiency targets (Labanca and Bertoldi, 2016). The research on estimating the impact of energy efficiency programs is growing (Boonekamp, 2006; Gillingham et al., 2018; Saunders et al., 2021). However, these approaches are not adopted in countries that do not have national targets and regulations. Few countries have adopted national targets on energy intensity, productivity, and total energy consumption indicators. For example, China and Thailand have economy-wide energy intensity targets, and Australia and the United States have economy-wide energy productivity targets. European Union (EU) has put energy efficiency targets on total energy consumption (International Energy Agency, 2017).

Energy intensity has become a preferred indicator to track a country's progress in energy efficiency. However, it is not an accurate indicator of energy efficiency as it includes the effects of changes in the structure of energy use activities. For example, a shift in activity from agriculture to services results in a decline in energy intensity. Structural changes can be separated from the effect of the decrease in energy intensity in the change in energy consumption using the decomposition technique (Ang, 2004). Energy saved measured using IDA includes savings due to autonomous technological improvements and energy efficiency policies (Boonekamp, 2006). IDA is a top-down approach that analyses the energy flows and activity indicators at the sub-sectoral, sectoral or national level.

Developed countries such as the EU, the US, Canada, and Australia routinely use index decomposition analysis (IDA) to track their energy efficiency trends (Goh and Ang, 2019). International Energy Agency (IEA) also reports global energy efficiency trends using IDA (Goh and Ang, 2019). In its recent energy efficiency report, IEA said that the final energy consumption of IEA members and other major economies would have increased by 65% instead of one-third in 2017 compared to 2000 if no efficiency improvements had occurred (International Energy Agency, 2018). Few recent studies have used IDA to estimate energy saved from energy efficiency improvements (Su et al., 2022) and compared it with the energy saved calculated from deemed savings approach in government reports (Trotta, 2020; Reuter et al., 2019). IDA is also used to estimate the energy efficiency index, and the index is then regressed on other economic and price variables to determine the drivers of energy efficiency improvements (Metcalf, 2008). Recent literature attempts to estimate the effect of energy efficiency policies using the energy efficiency index calculated from IDA (Gorus and Karagol, 2022; Jain and Goswami, 2021).

In many countries, the energy savings from energy efficiency policies are estimated using bottom-up approaches by aggregating the effect of individual energy efficiency measures. The most straightforward bottom-up approach is the deemed savings approach. Early literature on energy efficiency potential found that the deemed savings estimates are more than the actual energy savings (Gillingham et al., 2018). In its simplest form, the deemed savings approach does not consider the changes in behavioural factors due to energy efficiency programs. The savings are estimated using assumptions about the power ratings of the products and operating hours. Several methods under the top-down and bottom-up approaches have evolved over the past few decades. Acknowledging the limitations of the two methods, many studies now use both to estimate energy savings. Even the framework adopted by EU countries to track their energy savings target includes both bottom-up and top-down approaches (Thomas et al., 2012).

Following global practices, India has implemented various policies and programs to improve the efficient use of energy in industries, appliances, buildings, and agriculture. India's energy intensity is declining, and energy efficiency plays a vital role. Most energy efficiency policies in India are not driven by absolute targets of reduction in energy consumption. The target of policies that promote the adoption of energy-efficient products or practices is to increase the coverage of the programs and increase the share of energy-efficient products in total sales. The savings from the energy efficiency programs are estimated using a simplified deemed savings approach. The energy saved from energy efficiency policies in the country has been reported annually for the last few years (BEE, 2021). The energy saved during 2011-12 and 2019-20 is shown in Fig. 1. These estimates have not been compared with any other bottom-up or top-down approaches.

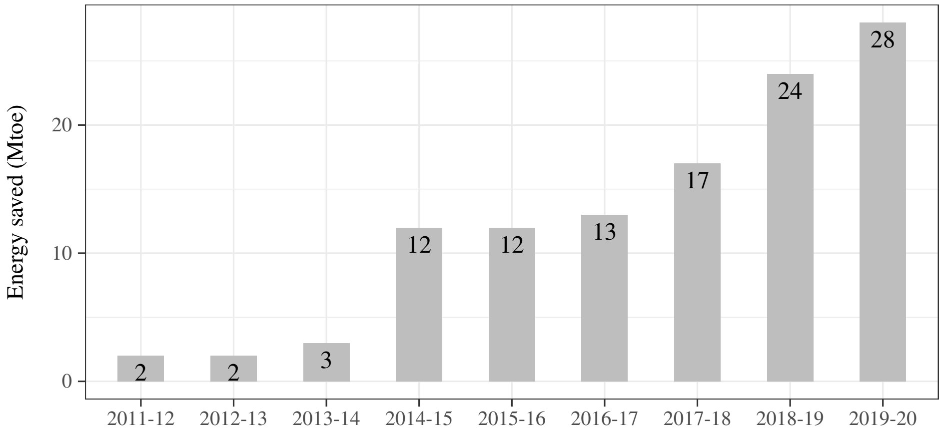


Figure 1: Estimates of energy saved from energy efficiency policies in India (2011-12 to 2019-20)
Source: BEE 2021

In decomposition analysis, the accuracy with which the energy efficiency effect can be estimated depends on the availability of energy use disaggregated by end-use and activity levels data. While most developed economies have detailed disaggregate data available, it is not the case for developing countries. Data limitations have restricted the use of top-down approaches for estimating energy savings from energy efficiency improvements in India. Few studies in India have used decomposition analysis to evaluate the contribution of energy efficiency and structural changes in energy consumption and intensities (International Energy Agency, 2018; Shrestha et al., 2021). However, these studies do not estimate energy savings from efficiency. The research on evaluating the role of energy efficiency in Indian manufacturing using top-down approaches is also limited (Reddy and Ray, 2010; Dasgupta and Roy, 2017). Further, most existing studies do not cover India's energy intensity decline in the past decade. A recent study examines India's energy efficiency index in a cross-country analysis (**?**).

In this paper, I use IDA to estimate energy savings due to energy efficiency improvements in India. I estimate energy savings due to improvements in primary energy intensity, the energy intensity of electricity supply, final energy intensity and manufacturing energy intensity. I estimate the effect of structural changes on the overall economy and manufacturing. The energy saved due to changes in energy intensity minus the energy saved due to structural changes is a close estimate of energy saved from energy efficiency improvements. I compare the decomposition analysis results to the government's reported savings from energy efficiency. I also discuss the data gaps and highlight the limitations of the findings. This paper is divided into five sections. Section 2 discusses the decomposition analysis approach used in the paper to estimate energy saved from efficiency improvements. Section 3 explains the data and issues in India, Section 4 discusses the results, and Section 5 concludes. Additional details are included in the appendix section. Appendix A reviews practices for estimating energy savings from energy efficiency. Appendix B presents details of India's energy efficiency policies and how the savings are calculated.

## 2 Methodology

In this study, I apply IDA to changes in India's energy consumption and estimate energy savings from efficiency improvements. I analyse the changes in four energy flows - primary energy consumption, energy consumed in electricity supply, final energy consumption and manufacturing energy consumption. The difference in these energy flows in a given period is decomposed into its drivers, and the effects of the drivers in the total change are estimated using the Logarithmic Mean Divisia Index (LMDI) approach (Ang, 2015). I decompose the changes in primary energy consumption into intensity and activity effects. The intensity effect is the energy saved in primary energy consumption due to the overall decline in energy intensity. The energy saved due to the overall decrease in energy intensity is due to the reduction in the energy intensity of electricity supply and final energy consumption. I estimate the energy saved due to changes in the energy intensity of the electricity supply and the final energy consumption and manufacturing energy consumption.

### 2.1 Decomposition of primary energy supply

Energy savings from improvement in energy intensity in a given period could be calculated by separating the effect of increased economic output. Assuming that the energy consumed between two periods 0 and T are $E^0$ and $E^T$ and the economic output are $Q^0$ and $Q^T$, the energy intensities are given by $I^0$ = $E^0/Q^0$ and $I^T$ = $E^T/Q^T$. The change in energy consumption is due to increased economic output and decreased energy intensity. The effect of change in economic output can be called activity effect (act) and energy intensity as the intensity effect (int). This can be written as the difference between the product of two quantities changing from period 0 to T.

$$E^T - E^0 = \Delta E^T = Q^T I^T - Q^0 I^0 = \Delta E^{0,T}_{int} + \Delta E^{0,T}_{act} \quad (1)$$

In Eq. 1 the problem of quantifying the activity and intensity effect was addressed in the earlier work on manufacturing energy intensities in mid-1980 using the concepts from index number theory (Boyd et al., 1987). The issue of quantifying the price and quantity effect on the total change in economic output is similar. The price and quantity effects are commonly estimated as indexes and not in absolute quantities.

In the current literature, the change in energy consumption due to energy intensity is estimated by multiplying the logarithmic means of energy consumption in two periods and the difference in the log of the energy intensity. The change in energy consumption due to energy intensity improvement is calculated as per Eq. 2.

$$\Delta E_{int}^{0,T} = L(E^T, E^0)[ln(\frac{I^T}{I^0})] \tag{2}$$

Similarly, the change in energy consumption due to a change in economic activity is estimated as per Eq. 3

$$\Delta E_{act}^{0,T} = L(E^T, E^0)[ln(\frac{Q^T}{Q^0})] \tag{3}$$

where $L(E^T, E^0)$ is the logarithmic mean of $E^T and E^0$.

## 2.2 Decomposing energy consumed in electricity supply

Energy savings in electricity supply is due to energy-efficiency improvements in electricity generation, transmission, and distribution. The change in energy consumption in the electricity supply is due to an increase in energy consumption due to an overall increase in electricity demand and a decrease in the energy intensity of electricity generation and transmission and distribution. Assume that input energy for electricity generation in periods 0 and T are $E_{in}^0$ and $E_{in}^T$ and electricity generated are $E_g^0$ and $E_g^T$. Electricity plants consume energy, and some are lost in transmission and distribution. Let the final energy consumed in two periods are $E_c^0$ and $E_c^T$. The energy intensity of electricity generation (say, $I_g$) is given as the ratio of input energy and electricity generated (i.e. $I_g$ = $E_{in}$/$E_g$). Similarly, the intensity of electricity transmission and distribution (say, $I_{td}$) is given as the ratio of electricity generated and electricity consumed (i.e. $I_{td}$ = $E_g$/$E_c$). The energy used for electricity generation can be written as shown in Eq. 4

$$E_{in} = E_c \times \frac{E_g}{E_c} \times \frac{E_{in}}{E_g} = E_c \times I_{td} \times I_g \tag{4}$$

The change in energy consumption for electricity generation between periods 0 and T can be written as shown in Eq 5. The change is decomposed into consumption effect (con), transmission and distribution effect (tand) and generation effect (gen).

$$E_{in}^T - E_{in}^0 = \Delta E_{in}^T = E_c^T I_{td}^T I_g^T - E_c^0 I_{td}^0 I_g^0 = \Delta E_{con}^{0,T} + \Delta E_{tand}^{0,T} + \Delta E_{gen}^{0,T} \tag{5}$$

The two-factor decomposition of the change in energy consumption discussed above can be extended to the three-factor decomposition. Under the LMDI framework, the effects are estimated as the difference in the log of the factors in two periods weighted by the logarithmic mean of $E_{in}^T$ and $E_{in}^0$. The formula for the three effects is given in Eqs 6-8.

$$\Delta E_{con}^{0,T} = L(E_{in}^T, E_{in}^0)[ln(\frac{E_c^T}{E_c^0})] \tag{6}$$

$$\Delta E_{tand}^{0,T} = L(E_{in}^{T}, E_{in}^{0})[ln(\frac{I_{td}^{T}}{I_{td}^{0}})] \quad (7)$$

$$\Delta E_{gen}^{0,T} = L(E_{in}^{T}, E_{in}^{0})[ln(\frac{I_{g}^{T}}{I_{g}^{0}})] \quad (8)$$

where $L(E_{in}^{T}, E_{in}^{0})$ is the logarithmic mean of $E_{in}^{T} and E_{in}^{0}$.

### 2.3 Decomposition of final energy consumption

The change in final energy consumption is due to an increase in overall energy consumption, structural changes in the sectors that change their activity levels, and a decline in energy consumed per unit of activity in the sectors. The changes in the economy's structure can either favour energy savings (shift from agriculture and industry to services) or increase energy consumption (e.g., change from private to public modes of transport). Reliable estimation of the structural effect requires reliable estimates of energy and activity data at the disaggregate level.

Assume the final energy consumed in periods 0 and T are $FE_T$ and $FE_0$. The overall economic activity, gross domestic product (GDP), is $Q_T$ and $Q_0$. Assume that an economy is divided into m energy-consuming sectors indexed by i. The activity level and energy consumption in each sector are given by $FE_i$ and $Q_i$. The sectoral activity share in total activity (say, $S_i$) is given as the ratio of the activity level of the sector and the overall activity (i.e., $S_i$ = $Q_i$/$Q$). The energy intensity of the sectoral activity (say, $I_i$) is the ratio of the energy consumed and the sectoral activity (i.e., $I_i$ = $FE_i$/$Q_i$). The final energy consumption can be written as shown in Eq 9

$$FE = \sum_{i=1}^{m} FE_i = \sum_{i=1}^{m} Q \frac{Q_i}{Q} \frac{FE_i}{Q_i} = \sum_{i=1}^{m} QS_i I_i \quad (9)$$

The change in energy intensity estimated using Eq 1 is due to both - changes in the share of sectors in the total output and changes in energy intensity of sectoral activity. In a three-factor decomposition, the shift in energy consumption is decomposed into activity, structure, and real intensity effect. Based on additive decomposition, a sector's energy consumption change between 0 and T is estimated as a sum of these three effects ( 10). To differentiate the activity and intensity effects from Eq 1, the activity effect is called as final activity (fact), and the sectoral energy intensity effect is the real energy intensity effect (rint).

$$\Delta FE^{0,T} = FE^{T} - FE^{0} = \Delta FE_{fact}^{0,T} + \Delta FE_{str}^{0,T} + \Delta FE_{rint}^{0,T} \quad (10)$$

Similar to the formulae discussed in previous sections, the activity ($\Delta E_{act}^{0,T}$), structure ($\Delta E_{str}^{0,T}$) and real intensity ($\Delta E_{int}^{0,T}$) effects are calculated using the following formulae

$$\Delta FE_{fact}^{0,T} = \sum_{i=1}^{m} L(FE_i^{T}, FE_i^{0}) ln \frac{Q^{T}}{Q^{0}} \quad (11)$$

$$\Delta FE_{str}^{0,T} = \sum_{i=1}^{m} L(FE_i^T, FE_i^0) ln \frac{S_i^T}{S_i^0} \tag{12}$$

$$\Delta FE_{rint}^{0,T} = \sum_{i=1}^{m} L(FE_i^T, FE_i^0) ln \frac{I_i^T}{I_i^0} \tag{13}$$

#### 2.3.1 Decomposition of manufacturing energy consumption

As shown in Eq. 13, the real energy intensity effect includes energy saved due to energy efficiency improvements and structural changes within the sectors. The impact of structural changes in the sectors can be separated by decomposing sectoral energy consumption into the activity, structure, and intensity effects. The activity effect, structure effect, and energy intensity effect in sector i with sub-sectors are estimated using an approach and formulae similar to Eq 11-13 considering the overall activity of the sector, the share of sub-sectors in overall sectoral activity, and energy intensity of the sub-sectors.

The three effects for all sectors can be estimated if their disaggregate energy consumption and activity data are available. If the three effects of all sectors are calculated, then the real energy intensity effect (Eq. 7) of the sector will be the sum of the structure and real intensity effect of all subsectors ( 12).

$$\Delta FE_{rint}^{0,T} = \sum_{i} \Delta FE_{str-i}^{0,T} + \sum_{i} \Delta FE_{rint-i}^{0,T} \tag{14}$$

Assuming that the sector real energy intensity effect is mainly due to energy efficiency improvements in sub-sectors, the energy saved in final energy consumption due to energy efficiency improvements from 0 to T is given as

$$ES^{0,T} = \sum_{i=1}^{m} -\Delta FE_{rint-i}^{0,T} \tag{15}$$

In this study, since disaggregated data is available only for the manufacturing sector, I calculate the real intensity effect on final energy consumption and the real intensity and structure effect on manufacturing energy consumption. I subtract the structure effect of the manufacturing sectors from the real intensity effect estimated from final energy consumption to arrive at the energy saved due to energy efficiency improvements in final energy consumption. The sum of energy saved in the electricity sector and the final energy consumption is the total energy saved due to energy efficiency improvements (Eq 16)

$$ES^{0,T} = -(\Delta E_{td}^{0,T} + \Delta E_{gen}^{0,T} + \Delta FE_{rint}^{0,T} - \Delta FE_{str-manf}^{0,T}) \tag{16}$$

## 3 Data

In IDA, disaggregated energy use and activity data are required. Accuracy in estimating energy savings from energy efficiency improvements depends on the availability of disaggregated energy data. The disaggregated energy use data is taken from energy balances. The activity data is sourced from national accounts for production sectors (i.e., industry, agriculture, and services) and other sources for consumption sectors (transport and households). In this study, I use India's energy balance from IEA's world energy balances and India's National Account Statistics (NAS) published by the Government of India.

## 3.1 Energy balances

The source of energy use disaggregate by sectors and fuels of a country are its energy balance tables. The energy used by various industries is aggregated in standard energy units and reported in energy balance tables. Most countries follow the International Recommendations on Energy Statistics (IRES) adopted by United Nations Statistical Commission in 2011 to develop national energy balances (UN 2017). An energy balance is an accounting framework for the compilation and reconciliation of data on all energy products entering, exiting, and used within the national territory of a given country during a reference period.

India's official energy balance tables are reported in Energy Statistics, an annual publication by the Ministry of Statistics and Programme Implementation (MOSPI), Government of India. MOSPI follows IRES recommendations to prepare India's energy balance. Another government source of India's national energy balance is India Energy Dashboard (IED), launched by Niti Aayog. The IED energy balances follow IRES recommendations partially and give energy use by sectors but not by sub-sectors. IED provides single-window access to the country's energy data with state-wise production and consumption of all energy sources. IEA and United Nations Statistics Division (UNSD) publish India's energy balances among international sources. A notable difference between the national energy balances (MOSPI and IED) and international energy balances (IEA and UNSD) is that the international energy balances include biofuels and waste. Excluding the biofuels and waste from IEA and UNSD, the four sources' estimates of India's key energy indicators are shown in Table 1.

It is evident from the Table that the four data sources differ in many ways. MOSPI's primary energy supply, total final energy consumption, and industry energy consumption data differ by magnitude from all three data sources. UNSD industry energy consumption data is higher than IEA and IED. UNSD, MOSPI, and IED data on energy use in transport, residential, commercial, agriculture, and allied areas are similar. Still, the final consumption not specified elsewhere is around 20-25% of the total final energy consumption. In IEA, the energy not specified is 4%, and the energy consumption by sectors is higher than in other datasets. In all four datasets, the energy use by manufacturing industries is not entirely disaggregated as a large share is under 'industry not specified elsewhere'. The energy consumption not specified elsewhere likely represents the energy consumed by unorganised manufacturing. The

Table 1: India's energy flow from four datasets

| Energy flow (all values in mtoe) | IEA | UNSD | MOSPI | IED |
|---|---|---|---|---|
| TPES | 747 | 751 | 906 | 734 |
| TFEC | 412 | 472 | 551 | 410 |
| Industry | 179 | 249 | 318 | 173 |
| Mining and quarrying | 4 | 2 | 2 | na |
| Construction | 1 | 5 | 8 | na |
| Manufacturing | 107 | 68 | 73 | na |
| Iron and steel | 65 | 52 | 56 | na |
| Chemical and petrochemical | 8 | 13 | 14 | na |
| Non-ferrous metals | 2 | 0 | 0 | na |
| Non-metallic minerals | 21 | 0 | na | na |
| Transport equipment | 1 | 0 | na | na |
| Machinery | 1 | 0 | 0 | na |
| Food and tobacco | 6 | 0 | na | na |
| Paper, pulp and printing | 2 | 1 | 1 | na |
| Wood and wood products | 0 | 0 | na | na |
| Textile and leather | 1 | 1 | 1 | na |
| Industry not elsewhere specified | 67 | 174 | 236 | na |
| Transport | 104 | 59 | 57 | 49 |
| Residential | 61 | 52 | 52 | 51 |
| Commercial and public services | 20 | 8 | 8 | 11 |
| Agriculture/forestry/fishing | 31 | 19 | 19 | 20 |
| Final consumption not elsewhere specified | 18 | 85 | 96 | 106 |

Source: IEA (2022), UNSD (2022), MOSPI (2022), NITI (2022)

percentage of manufacturing energy under non-specified in UNSD and MOSPI is 70% as compared to around 40% in IEA. IEA data is close to IED data with the advantage of the availability of energy data by manufacturing industries. Hence, this paper uses IEA data for primary energy, electricity supply, and final energy consumption by sectors (industry, transport, residential, commercial, agriculture & allied) and by ten manufacturing industries.

### 3.2 Activity data

The choice of activity data in a decomposition analysis depends on the data availability. The most commonly used activity indicators for national level analysis are value added by production sectors. Value added from manufacturing industries is also a popular indicator for decomposing manufacturing energy consumption. Few studies have used value added by the transport sector as the activity data in the transport sector. However, since the value added by the transport sector does not include private

Table 2: Activity data used for decomposition analysis in the study

| Energy flow | Activity data | Source |
|---|---|---|
| Total primary energy supply | GDP in constant 2011-12 Rs | MoSPI (2022) |
| Energy in electricity generation | Electricity consumed by end-users | IEA (2022) |
| Final energy consumption | | |
| Industry | Value added in industrial sector (2011-12 Rs) | MoSPI (2022) |
| Commercial | Value added in commercial sector (2011-12 Rs) | MoSPI (2022) |
| Agriculture | Value added in agriculture sector (2011-12 Rs) | MoSPI (2022) |
| Transport | Gross Domestic Product (2011-12 Rs) | MoSPI (2022) |
| Residential | Private personal consumption expenditure (2011-12 Rs) | MoSPI (2022) |
| Manufacturing | Value added by manufacturing industries (2011-12 Rs) | MoSPI (2022) |

transport, it may not be a complete indicator of transport activity. The most commonly used transport activity indicator is vehicle distance travelled. Studies have used GDP as the activity indicator when this data is unavailable. The household activity indicator includes private consumption expenditure, population, etc. Some studies also use the physical output from manufacturing industries depending on data availability. Table 2 shows the activity data used in this study.

The value added by production sectors is reported in India's National Account Statistics (NAS). Since the energy intensity of a production sector is estimated as the ratio of energy use and activity, the consumer categories in the activity data and energy data are mapped. India's economic activity in national accounts has been reported under ten categories since 2011-12. These categories are agriculture and allied, mining, manufacturing, public utilities, construction and services including trade, hotels, transport, storage, communication, transport, financial services, real estate, public administration and defence. The activity data of agriculture and allied is taken as given in the NAS. The activity data for the industry is estimated as the sum of mining, manufacturing and construction activity. The service activity data is calculated as the sum of the output from all services, including utility services, transport, trade, storage, communication, financial, real estate, public administration and defence.

The value added by manufacturing industries is also reported in the NAS. The industries in India are classified as per the Indian National Industrial Code (NIC). The energy data for manufacturing industries in IEA is as per the UN Statistical Commission's International Standard Industrial Classification (ISIC-Rev4). India's NIC was last revised in 2008 following the revision of ISIC-Rev4. NAS does not report the statistics as per NIC-2008 but maps its reporting categories to NIC. In NAS, the manufacturing sector is divided into six categories - food, textiles, metals, machinery, chemical and petrochemicals and others. Each category is further disaggregated into specific industries. The NAS maps each industry with the NIC code up to two- and three-digit codes. This study uses the mapping of NAS categories to NIC codes to estimate the value added by manufacturing industries.

The IEA's World Energy Data and Statistics categorises the industry into twelve categories and maps each category to the ISIC divisions and groups. The ferrous and non-ferrous metals are two separate categories in IEA data. Other categories include paper, food, minerals, machinery, transport equipment, wood, textile, mining, construction and non-specified industry. The mapping of the industries in NAS, NIC-2008 and IEA industry classification is shown in Table 3. The table excludes mining, construction and industries not specified elsewhere.

Table 3: Manufacturing industry codes in IEA, ISIC Rev 4 and NIC 2008

| S.No | IEA Industry Name | Short name | ISIC Rev.4 Classification and NIC-2008 code | NIC 2008 code description |
|---|---|---|---|---|
| 1 | Iron and Steel | IRNSTL | Group 241 and Class 2431 | Manufacture of basic iron and steel + casting of iron and steel |
| 2 | Non-ferrous metals | NONFERR | Group 242 and 2432 | Non-ferrous metals + casting of non-ferrous metals |
| 3 | Chemicals | CHEMICAL | Divisions 20 and 21 Excluding petrochemical feedstocks. | Manufacture of chemical and chemical products, pharmaceuticals, medicinal and botanical products |
| 4 | Pulp, Paper and Print | PAPERPRO | Divisions 17 and 18 | Manufacture of paper and paper products + Printing and reproduction of recorded media except publishing |
| 5 | Food Processing, Beverages and Tobacco | FOODPRO | Divisions 10 to 12 | Manufacture of food products, beverages & tobacco |
| 6 | Non-Metallic Minerals | NONMET | ISIC Rev. 4 Division 23 | Manufacture of other non-metallic mineral products |
| 7 | Transport Equipment | TRANSEQ | Divisions 29 and 30 | Manufacture of transport equipment |
| 8 | Machinery | MACHINE | Divisions 25 to 28 | Manufacture of fabricated metal products, machinery and equipment except transport equipment |
| 9 | Wood and Wood Products | WOODPRO | Division 16 | Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting material |
| 10 | Textile and Leather | TEXTILE | Divisions 13 to 15 | Manufacture of textiles, apparel & leather products |

Source: IEA (2021), MoSPI (2022)

# 4 Results

The issues in the availability of disaggregated energy and activity data from national sources have limited the use of top-down approaches for estimating energy saved from energy efficiency improvements in India. In this study, I use disaggregate energy data from IEA's World energy balances and activity data from national accounts statistics to estimate the energy saved from improved energy efficiency in India during 2011-19. First, I decompose the primary energy supply using GDP as an activity indicator and estimate the contributions of activity and energy intensity in the change in primary energy consumption. Second, I decompose the energy consumed in the electricity supply into activity, generation intensity and transmission and distribution intensity effects. Third, I decompose the final energy consumption in activity, structure and real intensity. The savings due to the real energy intensity of the final energy consumption is due to a reduction in energy intensities and structure of the sub-sectors. The sub-sector energy and activity data are available for the manufacturing sector. So, similar to final energy consumption, I decompose the manufacturing energy consumption in activity, structure and real intensity. The sub-sectoral energy and activity data is unavailable for other sectors. Hence, I do not estimate the effect of structural changes in these sectors. The decomposition analysis results are presented in the sub-sections below, followed by a discussion.

## 4.1 Primary energy consumption

Fossil fuels dominate the energy products in India's energy supply. Traditional biomass is also consumed in rural households in India. The primary energy from various energy products consumed in India during 2011-19 is shown in Fig 2. In IEA data, energy supplied from biofuels is estimated using sample surveys and modelling techniques. Due to the uncertainties in the reliability of estimates and lower energy conversion efficiencies, the energy from traditional biofuels is not included in estimating indicators such as per capita income and energy intensity. In this study, I consider the commercial energy supplied and consumed for analysing changes in energy intensity using decomposition analysis.

India's primary energy consumption from commercial energy sources increased from 540 mtoe in 2011 to 737 mtoe in 2019. The share of fossil fuels in primary energy consumption has declined by 1 per cent from 96% in 2011 to 95% in 2019. The energy from renewable sources such as wind and solar has increased at a CAGR of 18%, but the impact on the total share is insignificant. The energy supply from fossil fuels increased at a CAGR of 3.4% and that from non-fossil energy sources at 5.8%. The energy intensity of the primary energy consumption declined from 0.26 MJ/Rs(constant 2011-12) in 2011 to 0.21 MJ/Rs(constant 2011-12) in 2019 at a CAGR of around 2% annually. India's primary energy supply change during 2011-19 was 196 mtoe. If the energy intensity had not declined, an additional 127 mtoe was required to meet the primary energy demand. The decomposition of the change in primary

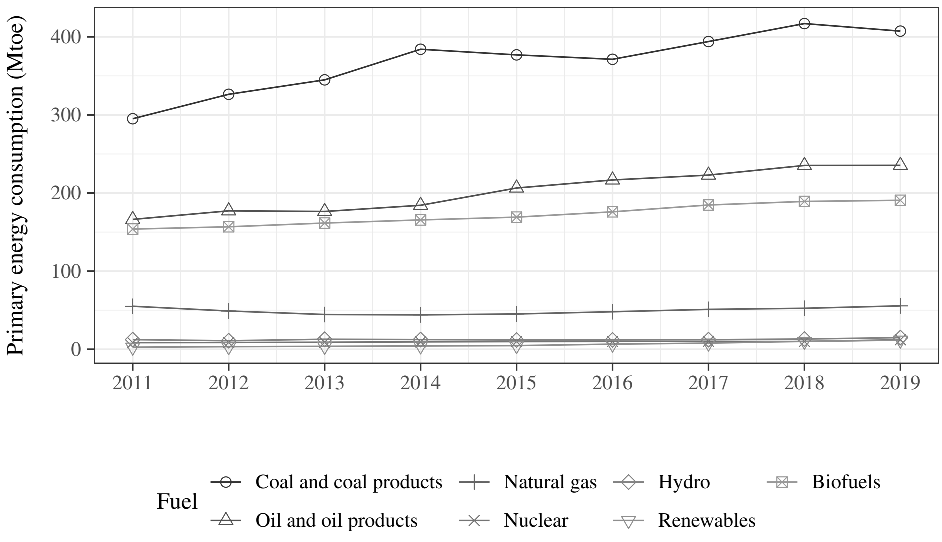


Figure 2: India's primary energy consumption during 2011-19
Source: IEA2022. Note: IEA World Energy Balances reports data for all energy products, including biofuels.

energy consumption in activity and structure effects are shown in Fig. 3.

The decline in energy intensity of the economic output is due to several factors. The improvements in the efficiency of electricity generation and distribution, efficient use of electricity and other fuels and structural changes in the economy. The electricity plants transform the primary energy supply to generate electricity and refineries produce petroleum products. End-users consume the remaining primary energy, electricity and petroleum products. The change in primary energy consumption for electricity generation is due to increased electricity generation, a change in the fuel consumed per unit of electricity generated and electricity generated per unit of electricity consumed. These effects are discussed in the following sections.

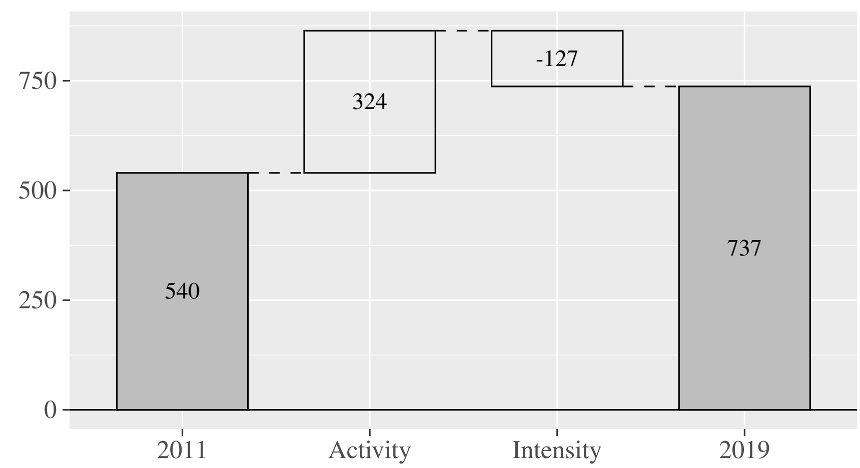


Figure 3: Decomposition of primary energy consumption during 2011-19

## 4.2 Energy consumed in electricity supply

The primary energy supplied to the electricity plants increased from 239 mtoe in 2011 to 337 mtoe in 2019. The share of fossil fuels in electricity generation declined from 89% in 2011 to 87% in 2019. The percentage of nuclear and hydro remained the same, and the share of RE increased from 1% in 2011 to 3% in 2019. Since the increase in RE share is insignificant, I do not estimate the structural effect of electricity generation. The decline in the intensity of electricity generation is assumed to be due to improvements in the efficiency of electricity generation and a reduction in transmission and distribution losses. The inverse of efficiency of electricity generation is the energy intensity of electricity generation, i.e., energy consumed per unit of electricity generated. The energy intensity of transmission and distribution is the ratio of energy generated per unit of energy consumed. The energy intensity of electricity generation, transmission, and distribution declined at a CAGR of 1% during 2011-19. Without the decline in energy intensity of electricity generation, transmission, and distribution, an additional 57 mtoe of primary energy would have been required to meet the demand. Hence, 57 mtoe of energy is saved due to improvements in energy intensity in the electricity sector. The decomposition results of energy consumed by the electricity sector are shown in Fig 4

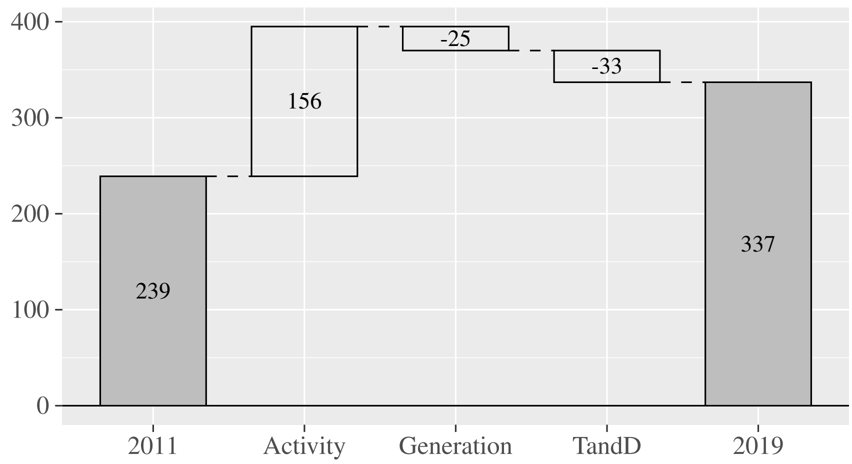


Figure 4: Decomposition of energy consumption for electricity supply during 2011-19

## 4.3 Final energy consumption

India's final energy consumption increased from 283 mtoe in 2011 to 388 mtoe in 2019. During 2011-19 industrial energy consumption grew at a CAGR of 3.6%. Industry accounts for more than 40% of final energy consumption in India, followed by transport and residential. The energy consumption growth rate was 4.6% for transport and 4% for residential during 2011-19. The growth rates of energy consumption in agriculture, industry and commercial and services were 3.5%, 2.6% and 6.5%, respectively.

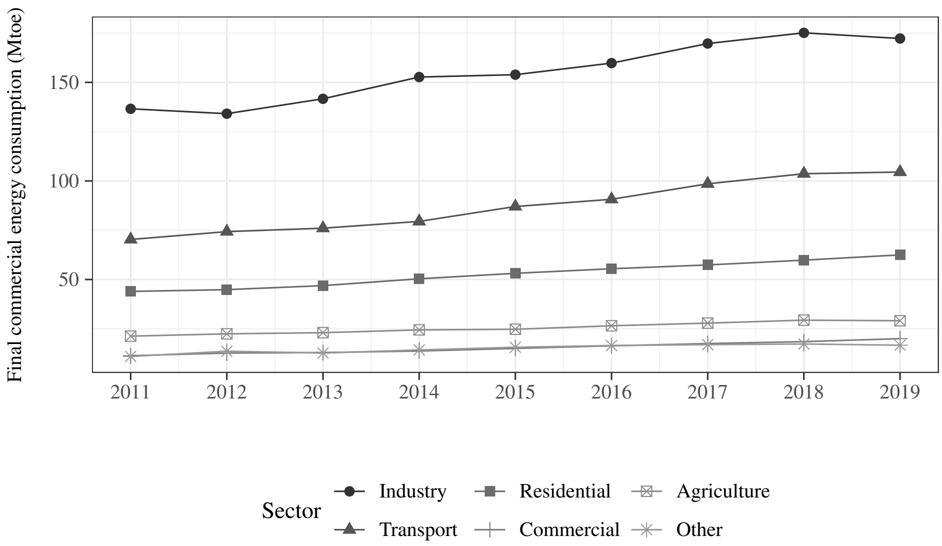


Figure 5: India's final energy consumption during 2011-2019

Source: IEA2022. Note:'Other' include energy used in the sector not specified elsewhere. This figure does not include the fuels used for non-energy use and energy from biofuels.

Final energy consumption intensity declined from 2011 to 2019 at a CAGR of 2.2%. The energy intensity of the industrial, commercial, and service sectors declined at a CAGR of 1.8% and 0.5%, respectively. The energy intensity of the agriculture sector increased at a CAGR of 0.5%. Decomposition results show that the final consumption would have been 66 mtoe higher without improvements in energy intensity. The improvements in the energy intensity of final energy consumption are due to structural change and real energy intensity improvements. Around two-thirds of energy saved due to the decline in energy intensity of final consumption is due to real energy intensity improvements (44 mtoe), and the remaining one-third is due to structural changes (22 mtoe) in the economy. Hence, energy saved due to real energy intensity improvements is 44 mtoe during 2011-19 (Fig. 6).

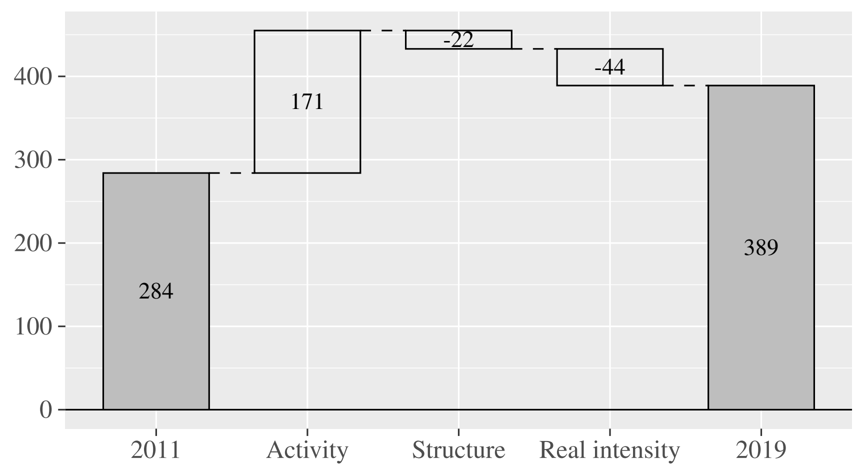


Figure 6: Decomposition of final energy consumption during 2011-19

## 4.4 Manufacturing energy consumption

The total energy consumed by all manufacturing units in India increased from 152 Mtoe in 2011 to 215 in 2019 Mtoe. Around half of the total energy used in manufacturing is not specified in any manufacturing industry. India's energy consumption by manufacturing units includes energy used by organised and unorganised manufacturing units. The unorganised manufacturing units are not registered, so industry disaggregated energy data is unavailable. The disaggregated data of the remaining energy used by manufacturing is used in this study for decomposition analysis. Metals, minerals and chemicals consume around 90% of the total energy. The increase in energy consumption during 2011-19 is driven by increased energy consumption by iron and steel and industries not specified. The energy consumed by minerals and chemicals has not changed much during this period.

The manufacturing energy consumption, excluding the consumption not specified elsewhere, increased from 84 mtoe in 2011 to 104 mtoe in 2019. Correspondingly the energy intensity declined from 0.31 MJ/Rs (constant 2011-12) to 0.24 MJ/Rs (constant 2011-12). The energy intensity of most manufacturing industries has declined except for food and food products and wood and wood products. The decline in the energy intensity of iron and steel is also not as significant as in other sectors. Decomposition results show that the increase of 20 Mtoe in manufacturing energy consumption during 2011-19 would have been 43 Mtoe without energy intensity improvements. The structural changes and real energy intensity improvement saved 3 and 21 Mtoe, respectively (Fig. 8).

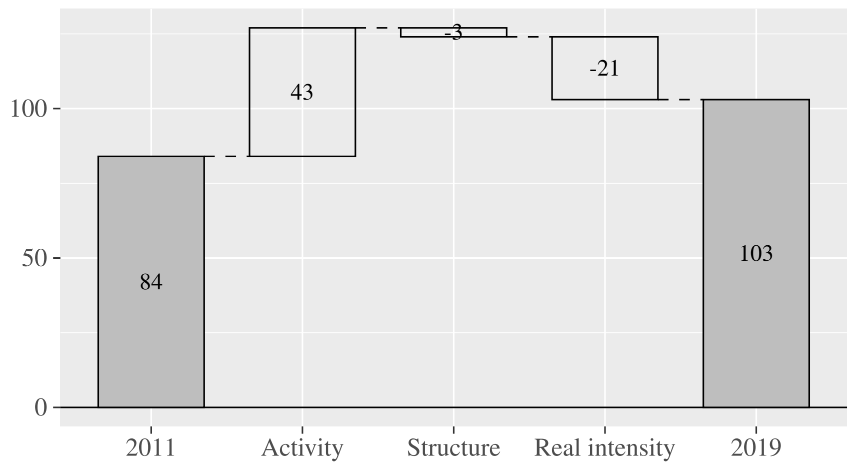


Figure 8: Decomposition of manufacturing energy consumption during 2011-19

## 4.5 Discussion

The decomposition analysis results on India's primary energy, energy for electricity supply, final energy consumption and manufacturing energy consumption during 2011-19 explain the drivers of the decline in India's energy intensity during this period. The primary energy consumption increased due to activity

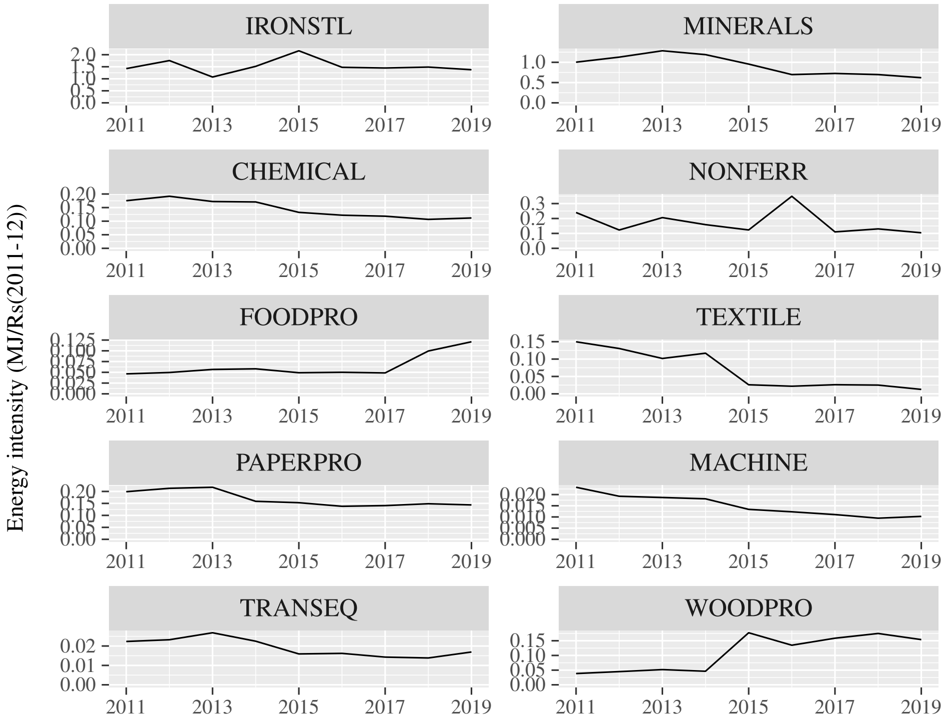


Figure 7: Energy intensity of Indian manufacturing industries during 2011-2019

Source: Estimated from IEA2022 MOSPI2021. Note: Energy intensity is the ratio of energy consumed and the value added in constant 2011-12 Rs

(324 Mtoe) and decreased due to the energy intensity of GDP (127 Mtoe), causing a net change of 196 Mtoe during 2011-19. The energy consumed for electricity supply increased due to activity (156 Mtoe) and decreased use to generation efficiency (25 Mtoe) and transmission and distribution efficiency (33 Mtoe), resulting in a net change of 98 Mtoe and savings of 58 Mtoe. The final energy consumption increased due to activity (171 Mtoe) and decreased due to structure (22 Mtoe) and real energy intensity (44 Mtoe), resulting in a net change of 105 Mtoe. The real energy intensity contributes to around two-thirds of the decline in final energy intensity. The savings of 44 Mtoe due to the real energy intensity is due to a reduction in energy intensities and structure of the sub-sectors.

Aggregating the estimated values, the energy saved due to energy efficiency improvements is 56 Mtoe in power supply and 41 Mtoe in real energy intensity of final energy consumption. The decomposition analysis shows that the total energy saved due to energy efficiency improvements in India during 2011-19 is 99 Mtoe (Figure 9). Assuming the structural changes in these sectors are non-negative, the estimated savings from decomposing final energy consumption is a lower bound for the energy saved. For example, if the change in the modal share of the transport has caused an increase in energy consumption, the energy savings estimate will be higher by that value. Similarly, if there is an increase in electricity consumption due to weather effects, the energy saved from energy efficiency improvements will be higher than the estimated value.

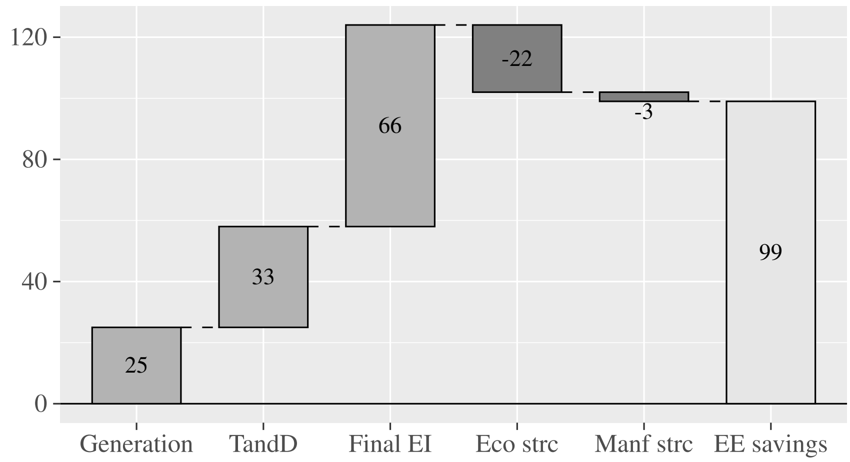


Figure 9: Energy saved due to energy efficiency improvements during 2011-19

To summarise, there are four key findings from the study. First, the energy efficiency improvements in power generation and supply and declines in energy intensity of final energy consumption contribute equally to the energy saved due to the overall decrease in primary energy intensity. Second, two-thirds of the energy intensity improvements in final energy consumption are due to the real energy intensity decline, and the remaining one-third is due to structural changes. Third, around 50% of the energy saved in the final energy consumption is due to declining manufacturing energy intensity. Fourth, in the manufacturing sector, around 86% of energy intensity improvements are due to the decline in real-energy intensity, and the remaining 14% is due to structural changes.

The energy efficiency savings estimated from IDA includes policy effects and autonomous technology improvements. IEA estimates that autonomous efficiency improvements result in around a 1% annual decline in energy intensity. As discussed earlier in this paper, India's energy intensity declined at a CAGR of 2% annually. Hence, around half of the energy savings estimated from IDA, i.e. about 50 Mtoe, could be due to energy efficiency policies. However, as noted in Fig 1, the government estimates of energy saved from energy efficiency policies during 2011-19 are around 113 Mtoe. The two estimates differ by order of magnitude. This difference exemplifies the shortcomings in the methods employed to estimate the savings. The underlying assumption in the simplified deemed savings approach and data gaps in index decomposition analysis limits the usability of the estimates.

# 5 Conclusions and Policy implications

Measuring energy savings from energy efficiency is essential to track progress in a country's development and climate change mitigation goals. Few countries have mandated energy savings in their national targets. These countries use various methods to estimate savings from individual energy efficiency measures and the economy-wide impact of energy efficiency to meet the regulatory requirements. Each method has a few drawbacks, and researchers and policymakers are now combining different approaches to provide robust estimates. Using multiple approaches to estimate energy savings from energy efficiency improvements provides better estimates of the impact of energy efficiency improvements in a country.

India has put forward quantitative targets for reducing its emissions intensity and increasing the share of renewable energy in the energy supply. Energy efficiency is identified as one of the essential means of reducing emission intensity. However, there are no energy savings targets through energy efficiency improvements. India has implemented several energy efficiency policies, and the impact of these policies is estimated using a simplified deemed savings approach. The government estimates the economy-wide effect of energy efficiency policies by aggregating the impact of individual energy efficiency measures. Due to data gaps in India, the research to examine energy savings and energy efficiency contributions to actual energy consumption is limited. The recent improvements in India's energy intensity have not yet been discussed from an energy savings perspective.

In this study, the energy savings from energy efficiency improvements are estimated using actual energy consumption data for the past decade, examining the recent improvements in energy intensity. I apply index decomposition analysis to India's energy consumption and calculate the energy saved attributed to energy efficiency improvements during 2011-19. Using India's energy balances from IEA and activity levels from the NAS, I estimate the real energy intensity effect that closely approximates energy efficiency savings. IDS estimates of energy efficiency savings include the effect of autonomous energy efficiency improvements and policy effects. Excluding the effect of the autonomous improvements, the energy efficiency savings from IDA differs significantly from the government's deemed savings estimates. Similar differences have been reported in recent studies (Trotta, 2020).

The study shows that India can use top-down approaches to compare its bottom-up energy efficiency savings estimates. Energy and activity data at the disaggregated level are essential for reliable estimates. The energy savings estimates from bottom-up approaches combined with estimates from top-down approaches can be used to set energy efficiency targets at the national level. National level targets will push framework development and adoption for measuring energy savings. The targets will also address a few barriers in the energy efficiency markets. India can begin with a voluntary target on energy savings and make them mandatory as the methods for data collection and savings calculations improve.

# A Savings from energy efficiency and policies

Energy savings occur over time mainly due to energy efficiency improvements, whether autonomous or induced by the policy. Energy savings cannot be measured directly but can be estimated as the difference between pre and post-energy efficiency measures. Few countries have developed frameworks and guidelines to measure, monitor and verify energy savings to meet the regulatory requirements. EU was the first to place mandatory energy savings targets on its Member States. Under the Energy End-use Efficiency and Energy Services Directive (ESD), the EU set an overall target of at least 9% annual energy savings between 2008 and 2016. Harmonised calculation methods were developed for member states for reporting savings. These reports discuss the methods and issues relating to measuring energy savings at the consumer and national levels.

The methods of estimating energy savings are categorised under bottom-up and top-down approaches. Under bottom-up methods, the energy savings is calculated for each participant and multiplied by the number of participants in the energy efficiency program. There are three main approaches: deemed savings, engineering, and energy monitoring. In the deemed savings approach, the savings for each participant is estimated using certain assumptions and does not involve on-field data collection. The savings are calculated using an engineering formula in the engineering estimation, and few parameters can be measured in the field. In the case of the energy monitoring method, the energy consumption is metered, and the actual savings are recorded. The top-down methods rely on energy efficiency indicators calculated from national statistics.

The most commonly used method for estimating savings at the national level in most countries is the deemed savings approach. There are usually issues in calculating savings from any energy savings program, even for a program participant. The estimates are sensitive to assumptions on baseline energy consumption and the lifetime of the intervention. Further, the estimates will be different for a retrofit, and new purchases and any changes in the usage patterns due to improvement in energy efficiency are also unaccounted for. These issues increase when the energy saving from one participant is scaled up to include all participants. A common issue is a free-rider effect where few participants would have undertaken the intervention even in the absence of the program. The issues increase further if there is an overlapping between programs. For example, consider the case where a country estimates energy savings from appliance standards and labels using sales of higher efficiency products. Assume that the country also promotes energy-efficient appliances using a financing scheme and estimates savings using sales of efficient appliances under that scheme. Note that the savings generated from the financing scheme are already accounted for under the appliance labelling scheme. If double counting is not considered, it will inflate the total savings from the two programs.

Index decomposition analysis is one of the commonly used methods to estimate a country's energy savings or energy efficiency trends. IDA provides estimates of total energy saved due to energy efficiency improvements subject to the availability of disaggregated data on energy use and economic activities. However, the effect of energy efficiency policies on energy savings cannot be isolated using IDA.

# B India's energy efficiency policy targets and achievements

India's energy efficiency policies are implemented under the aegis of The Energy Conservation Act (ECAct) enacted in 2001 and the National Mission for Enhanced Energy Efficiency (NMEEE) adopted in 2009. The ECAct established the Bureau of Energy Efficiency (BEE) under the Ministry of Power, Government of India, in 2002. Additionally, Energy Efficiency Services Limited (EESL) was founded in 2009 to provide solution-driven innovation for promoting energy efficiency. BEE, EESL, and other organizations have been designing and implementing energy efficiency policies and programs for various sectors in the country. The policies are sector-specific and use various policy instruments such as information, regulation, financial incentives, bulk procurement, etc. In the following subsections, I discuss a few of these policies, the method used to estimate savings, and the estimated savings.

## B.1 Perform Achieve and Trade (PAT) Scheme

PAT scheme focuses on improving the specific energy consumption (energy used per unit of output) of energy-intensive industries. It combines regulatory and market-based instruments to achieve cost-effective energy efficiency savings. BEE initiated the PAT scheme in 2010 and is implementing it in cycles. The first cycle (PAT-1) began in 2012 and was completed in 2015. The sixth cycle of the scheme started in 2020-21 and will end in 2023. The plan covers 13 sectors and more than 1000 industrial consumers.

Under the scheme, industries are required to reduce their specific energy consumption by a given target. Each ton of oil equivalent of energy saved is certified as one energy-saving certificate (EScert). The industries overachieving the targets can sell the excess Escerts to underachieving industries. Under each cycle, industrial consumers are identified, and a baseline energy consumption is set. Assuming an energy saving potential, an energy saving target is set in absolute terms, and the target is distributed to individual industries in terms of specific energy consumption. The targets for industries are calculated through a detailed and systematic calculation. The measurement, verification, and reporting of savings is through energy audits, self-reporting, verification, and cross-checking.

BEE estimates the energy saved from the program using each industry's change in specific energy consumption and its production data at the starting year of assessment. The industries measure and report their specific energy consumption as per the regulatory requirements of the scheme. Since the estimated savings are actual measured savings, they are expected to be reliable estimates.

### B.2 Appliance labelling and performance standards

Appliance labels and standards aim to promote the adoption of energy-efficient appliances in all sectors of the economy. Appliance labelling is an information program, and minimum performance standards are a regulatory instrument. BEE initiated it in 2006 as a voluntary program for a few appliances. As on March 2022, a total of 26 appliances are covered under the scheme, of which ten are in the mandatory regime. The mandatory regime not only implies that all manufacturers are mandated to place the labels, but only products of minimum efficiency standards are permitted to be sold in the market. The products are labelled using star labels, where more stars imply higher energy efficiency. The labels get updated as efficiency standards are strengthened periodically. The targets under this policy are to increase the program's coverage, include more products under performance standards, and continually enhance the performance standards for products under the mandatory regime.

BEE estimates the program's effect using data on the share of different star-rating appliances in total sales. The total manufactured volume of each appliance is assumed to be the sales. The energy consumed by the least energy efficiency appliance is considered to be the baseline energy consumption of the appliance. The difference in the baseline energy consumption and energy consumption of the star-rated appliance is multiplied by the number of star-rated appliances manufactured and the assumed hours of operation to arrive at energy saved. There are two fundamental assumptions in this estimation - baseline energy consumption and average hours of operation. This method of estimating savings is known as the engineering method. The literature documents the possibility of overestimating savings due to the assumptions involved and the presence of an 'energy-efficiency gap.'

### B.3 UJALA

UJALA scheme supports the adoption of energy-efficient appliances in the residential sector by providing financial support for higher capital costs. Under the scheme, efficient appliances are procured in bulk at affordable rates. EESL aggregated the demand for LEDs and energy-efficient tube lights and ceiling fans. The program is implemented with the electricity distribution companies through a benefit-sharing approach. The approach to estimating savings is the same as appliance labels and standard programs. The sale of LEDs, energy-efficient tube lights, and ceiling fans under the UJALA program is considered to estimate the savings. A baseline power rating of appliance replaced and operating hours is assumed. The number of appliances sold is multiplied by the wattage difference and working hours to arrive at the energy saved. This method also suffers from the possibility of over or underestimation due to the assumptions involved.

### B.4 Other energy-efficiency programs

In addition to the policies mentioned above for appliances and industries, there are several other energy efficiency programs in India. Several building energy efficiency codes and certifications are developed for residential and commercial buildings. These building codes and certificates aim to promote efficient practices in designing and constructing buildings in the residential and commercial sectors. BEE and EESL are implementing demand-side management programs to improve energy efficiency in water pumping and street lighting in municipal services. The Government of India initiated the Corporate Average Fuel Economy (CAFE) standards in the transport sector. The savings from the program is estimated using the deemed savings approach. The savings from all the programs are calculated using engineering analysis that is based adoption of energy-efficient alternatives and assumptions on usage and energy saved.

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