Indicators of carbon emission intensity from commercial energy use in India

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Abstract

This study tries to analyze the commercial energy consumption evolution patterns in India in terms of primary energy requirements and final energy consumption and their implications for overall carbon intensity of the economy. The relative contribution and impact of different factors such as activity levels, structural changes, energy intensity, fuel mix and fuel quality on the changes in aggregate carbon intensity of the economy have been studied, taking into account coal quality which has declined drastically in the last two decades. The major findings of the study are: firstly, from the 1980s onwards, income effect has been the major determinant of India’s per capita emission increase, although prior to that, energy intensity used to be the most important factor. Secondly, there has been a major shift towards electricity from primary energy carriers in the major energy consuming sectors, and the higher end use-efficiency of electricity has been able to compensate for the high emission coefficient of electricity consumption. Thirdly, emission intensity of thermal power generation shows a substantial decline when the data is controlled for the declining quality of coal used in power generation. © 2000 Elsevier Science B.V. All rights reserved.

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1. Introduction

The third session of the Conference of Parties (COP 3) to the UNFCCC (United Nations Framework Convention of Climate Change) held in Kyoto had highlighted the role of developing countries in helping to solve the problem of climate change...
even though there is consensus on 'common but differentiated responsibilities' as specified during the 1992 Earth Summit at Rio. These concerns rest on the premise that developing countries would become a dominant force in the demand side of the world coal and oil markets\(^1\) during the next two decades.

In the present analysis, we study emissions due to energy use in India at different levels of energy use and activity. India is one of the developing world's largest consumers of energy, primarily because of its huge population, rapidly rising income, urbanization and industrialization. Coal, which is the most polluting of all fossil fuels, is the most abundant source of commercial energy in India. India is the third largest producer of coal in the World after China and the USA with total coal reserves of approximately 200 billion tonnes. India's coal industry is growing at 7%, well above the world average of 3% (IEA, 1993) and most of the coal produced is used for indigenous use. On the other hand, India has been unable to raise its oil production substantially in the 1990s. Rising oil demand of almost 10% per year has led to sizeable oil import bills. In 1995 India's installed generation capacity was 81,000 MW, of which 75% was thermal and 67% of the electricity generated in India is from coal. Keeping in view all these factors, the approach paper to the Ninth Plan has emphasized the satisfaction of energy demand from indigenous resources so as to reduce the vulnerability of the economy to uncertainties of external markets as well as outflow of scarce foreign exchange resources (Murthy et al., 1997). Even though a number of steps have been taken to orient energy sector towards market based economy and penetration of alternative sources such as gas and renewable forms resource endowments patterns (Parikh, 1997; Reid and Goldenberg, 1998; Srivastava, 1997), some constraints, such as energy supply security issues, inadequate gas distribution infrastructure, stagnation of oil production in the last decade (Rao and Parikh, 1996) and lack of investible funds and weak institutions imply that India's economy would continue to be dependent on carbon-intensive fuels at least in the medium term.

In absolute terms, India is the world's sixth largest emitter of energy related CO\(_2\), according to estimates of IEA reports (1993), contributing to 3.3% of world CO\(_2\) emissions. Although measured on per capita basis, India's energy related CO\(_2\) emissions are very low (it was approx. 0.78 t of CO\(_2\) per person in 1993, five times below the world average of 3.90) energy related emissions have been growing rapidly, almost doubling between 1980 and 1990.

In the present study, we try to identify the major factors, which have influenced carbon emissions at different levels of energy use in India by using the Divisia decomposition technique. While rising incomes and increase in population contribute more to demand for primary energy sources, rapid urbanization and industrialization result in a shift from primary energy forms to transformed energy, namely electricity and from non-commercial to commercial energy. To this extent it becomes important to analyze the carbon intensity changes resulting from substitution of coal, oil and non-commercial fuels by electricity on the one hand

\(^1\)Consumption of petroleum and coal accounts for 41.2% and 38.5% of world's total CO\(_2\) emissions from consumption and flaring of fossil fuels.
and from changes in economic activity, sectoral and sub-sectoral shifts, and changes in energy efficiency on the other.

Our study seeks to answer the following questions:

1. What is the relationship between economic growth, energy intensity and carbon intensity? What has been the role of past national economic and energy policies on the trajectory, of these components?
2. How has the commercial energy consumption pattern evolved in India in terms of final energy consumption and primary energy consumption? What have been their implications for overall carbon intensity of the economy?
3. What is the relative contribution of different factors such as activity levels, structural changes, energy intensity and fuel mix on the changes in aggregate carbon intensity of the economy?
4. What can we infer from the past patterns of energy demand? How has the substitution of primary energy carriers namely coal, petroleum products by electricity contributed to overall carbon intensity changes in the wake of large generation and transmission and distribution losses in India?
5. Is there any evidence of environmental Kuznets curve behavior between economic growth and per capita income?

There exists a number of studies involving decomposition of energy consumption, energy intensity and emissions, which have attempted to distinguish the relative contribution of the different factors affecting changes in energy consumption (Boyd et al., 1987, 1988; Li et al., 1990; Shrestha and Timilsina, 1996, 1997, 1998). The studies can be broadly categorized into cross-country studies (Torvanger, 1991; Shrestha and Timilsina, 1996; Ang and Pandiyan, 1997) and country-specific studies (Boyd et al., 1987, 1988; Li et al., 1990; Lin and Chang, 1996; Huang, 1993) and most of the studies have preferred to concentrate on a specific sector of the economy, the most frequently studied sector being the manufacturing sector (Li et al., 1990, for Taiwan; Torvanger, 1991, for OECD countries). Shrestha and Timilsina (1996, 1997) have studied CO₂, SO₂ and NOₓ emissions in the power sector for selected Asian economies.

So far, not much detailed study has been done on India. Srivastava (1997) has studied the past trends in energy consumption and economic growth in India, which primarily was a statistical analysis of the energy scenario and failed to capture the various factors which influenced such energy and emission trends. Shrestha and Timilsina (1996) studied emission from power generation in India as part of a cross-country analysis of 12 countries.

All the previous studies have provided useful information regarding energy and emission indicators. However, one needs to be aware of the limitations of the analyses. The inter-country comparison of indicators of emission tends to be biased due to a number of reasons. Firstly, cross-country comparisons involve strong assumptions since the data used are not homogeneous in definition and measurement across countries. Indicators calculated to assess energy efficiency vary from country to country and the interpretations of similar ratios diverge considerably (Bosseboeuf et al., 1997). The data used by Shrestha and Timilsina (1996) for
instance, has been derived from ADB (1992, 1993), AEEMTRC (1994) and IEA (1993), for analyzing the emission intensity of power generation in 12 countries. India has been studied along with other countries using this data source. These data assume calorific value as constant across countries whereas in India the calorific value of power grade coal has declined from 4822 kcal/kg in 1974 to 3736 kcal/kg in 1994, a decrease of approximately 22.5%. Our paper shows that conclusions differ significantly when indigenous data source that gives gross calorific value of each fuel, is used instead of data that add these fuels in weight regardless of varying quality across time. Secondly, detailed and richer data from such sources facilitate detailed decomposition and study of other important factors, which influence emissions considerably. Important indicators might be neglected due to data limitations and inferences could be misleading.

In this paper, we carry out three separate analyses for India. First, we look at growth in per capita emissions through primary energy requirements for India, which is more indicative of efficiency of generation and distribution as it includes losses. Next, we study final energy consumption from two broad perspectives: carbon emission arising due to final consumption of only commercial primary energy carriers such as coal and carbon emission arising due to final energy consumption including both primary energy carriers as well as electricity. The difference between the results in the two cases reflects the effect of substitution of primary energy carriers by electricity in final energy consumption. This kind of substitution has two implications as far as carbon emissions are concerned. Electricity has high end use efficiency but its generation and distribution involves huge losses especially so since major generation in India is from primarily coal based thermal plants. Increase in demand for electricity for end use consumption could therefore lead to increased carbon emissions. For further insights we also analyze the effects of fuel quality, fuel mix, and energy intensity on emissions from electricity generation separately. Changes in emission intensity in the power sector is a major indicator of change in efficiency because emission in the thermal power sector results from fossil fuel consumption to generate power, and emissions would be directly proportional to the ratio between total primary energy (TPE) consumed and total final energy generated (TFE).  

2. Methodology

We carried out a study of emission intensity at three different levels of energy use and activity, using the Divisia decomposition technique. Although various decomposition techniques have been used for similar analyses, like Laspeyres index method (Howarth et al., 1991; Schipper et al. 1997) and the more recent, factor analysis (Landwehr and Jochem, 1997), we have chosen to use Divisia decomposition technique due to its various advantages over other indices including its

\[ \frac{TPE}{TFE} \]

which can be interpreted as the inverse of generational and distributional efficiency.

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2 Transmission and distribution losses account for approximately 21% of total generation in India.

3 TPE/TFE can be interpreted as the inverse of generational and distributional efficiency.
simplicity of implementation and size of residual (Ang and Lee, 1994; Greening et al., 1997).

The decomposition equations for per capita emission and emission intensity and the components for each of the analyses are explained below. Carbon emission intensity has been defined as the ratio between total carbon emitted by a sector and activity level of that sector. In different studies, activity is taken as physical output or a measure of output such as PKm. in transport or value added. We have chosen value added as the determinant of activity level for study of emission due to final energy consumption by sectors and total thermal power generation as a measure of activity level for emission intensity of power generation.

2.1. TPER (total primary energy requirements)

For studying movements in per capita emissions and its indicators, we have done the analysis for the period between 1970 and 1995 and have considered emissions from primary energy consumption, namely coal, oil and hydro and nuclear power. We decompose per capita emission into fuel mix, energy intensity and per capita GDP.

The identity for the per capita emission can be written as,

\[ c_t = \frac{C_i}{N_t} = \sum_i k_{it} \cdot \frac{F_{it}}{\sum_i F_{it}} \cdot \frac{\sum_i F_{it} \cdot GDP_t}{N_t} \]

(1a)

\[ = \sum_i k_{it} \cdot \frac{F_{it} \cdot GDP_t}{F_i \cdot GDP_t} \cdot \frac{\sum_i F_{it}}{N_t} \]

(1b)

Where,

\[ C_i = \sum_i k_{it} \cdot F_{it} \]

(2)

\[ k_{it} \] = carbon emission coefficient of energy source \( i \), which is constant over time;

\[ N_t \] = population in year \( t \);

\[ F_{it} \] = consumption of primary energy carrier \( i \) (coal, crude oil, natural gas, hydro and nuclear power);

\[ F_i \] = total energy consumed (expressed in gigajoules); and

\[ GDP_t \] = gross domestic product in year \( t \).

\(^4\)The concept of value added as proxy of activity level for the sector in question is not error free especially for sectors like transport where private trips do not contribute to value addition in the sector. However, studies where changes in carbon intensity are considered at sector level, it becomes the most suitable indicator for measuring aggregate output if not the best.

\(^5\)Emission coefficient is 0.026 TC/GJ for coal and 0.021 TC/GJ for all petroleum products. For natural gas it is 0.0136 TC/GJ.
For ease of notation, we write the decomposition Eq. (1b) as

\[ c_t = \sum_i k_{it} m_{it} I_t PC_t. \]  

(3)

The above relation between the variables is the decomposition we use to base our analysis on Divisia approach. This relationship can also be written as a decomposition of the growth rates of emission intensity of the four component indices, i.e.

\[ g_e = g_m + g_I + g_{PC} \]  

(4)

where growth rates can be expressed as

\[ \frac{dY/dt}{Y} = \frac{\ln Y}{dt} \]  

(5)

where, \( Y = c, m, I, PC \)

Integrating both sides of Eq. (4) expressed as in Eq. (5) and taking antilog, yields a constant time Divisia index decomposition of the change in emission intensity. A Divisia index is the exponential of the weighted sum of growth rates where weights are each component’s share in aggregate. Thus, the weights change over time and can be written as \( W_{i,t} \) where,

\[ W_{i,t} = \frac{k_{i,t} \times m_{i,t} \times I_t \times PC_t}{\sum_j k_{j,t} \times m_{j,t} \times I_t \times PC_t} \]  

(6)

Therefore,

\[ \frac{c_t}{c_{t-1}} = \exp \left( \int_{t-1}^{t} \sum_i W_i d\ln m_i dt \right) \times \exp \left( \int_{t-1}^{t} \sum_i W_i d\ln I dt \right) \times \exp \left( \int_{t-1}^{t} \sum_i W_i d\ln PC dt \right) \]  

(7)

However, our observations being discrete, time approximation has to be made and since for short-time periods, integrals can be approximated by means of the start-point and end-point, we use the weights as:

\[ \tilde{W}_{i,t} = \frac{W_{i,t} + W_{i,(t-1)}}{2} \]  

(8)

so that,

\[ Dm = \exp \left( \sum i \tilde{W}_{i,t} \ln \frac{m_{i,t}}{m_{i,(t-1)}} \right) \]  

(9)
\[ DI = \exp \left\{ \sum_i \bar{W}_i, \ln \frac{I_i}{I_{(i-1)}} \right\} \]  
(10)

\[ DPC = \exp \left\{ \sum_i \bar{W}_i, \ln \frac{PC_i}{PC_{(i-1)}} \right\} \]  
(11)

and,
\[ \frac{c_i}{c_{(i-1)}} = Dm \cdot DI \cdot DPC + R \]  
(12)

\( Dm \) = index for changing energy mix in the economy;
\( DI \) = index for changing energy intensity in the economy;
\( DPC \) = index for per capita income in the economy; and
\( R \) = residual term due to approximation.

\( R \) is very small in the case of Divisia index compared to other techniques of decomposition like the Laspeyres index with either fixed or rolling base year (Greening et al., 1997). Other features of this technique which prompted us to choose it for analysis are that the discrete form index approaches the continuous form index when length of the time period goes to zero. \( DI \) is also flexible since it employs moving weights rather than fixed weights.

2.2. Total final energy consumption, TFEC: inter sectoral analysis

Overall emission intensity of the sectors is decomposed into emission coefficient, fuel mix, energy intensity and structural effect. The residential sector has been excluded from this analysis as personal income of this sector and value added of other sectors are not comparable.\(^6\) The following variables have been used for the decomposition:

\( k_{is} \) = carbon emission coefficient of fuel \( i \) in sector \( s \), this coefficient does not vary across sectors. In the case of electricity, total carbon emissions were first calculated by summing over the products of individual fossil fuels used in power generation and their respective emission coefficients. This was divided by the total electricity used by final consumers to get the emission coefficient for electricity.\(^7\) This weighted coefficient is dependent on the fuel quality and fuel mix in power generation, generation efficiency, transmission, and distribution losses. Calculation of emission for power sector is discussed in detail in the following section.

\(^6\)In National Income Accounting they appear in separate accounts.
\(^7\)Emission is divided by consumption instead of production because of the transmission and generation losses involved which make actual power consumption less than generation.
\[ E_{is} = \text{energy used from } i \text{ in sector } s. \text{ This is measured in gigajoules (GJ).} \]
\[ VA_s = \text{the volume of output measured as value added in sector } s. \]
\[ VA = \text{the sum of value added over all sectors.} \]
\[ C_{is} = \text{carbon emission from use of fuel } i \text{ in sector } s. \]

\[ C_{is} = k_{is} \times E_{is} \quad (13) \]

\[ C_s = \text{total emission from sector } s, \text{ i.e.} \]
\[ C_s = \sum_i C_{is} \quad (14) \]

\[ C_s = \text{total emission of carbon from all fuels and all sectors.} \]
\[ C = \sum_{i,s} C_{is} \quad (15) \]

\[ c = \text{Aggregate emission intensity over all sectors defined as total carbon emission divided by total value added.} \]

For our analysis emission intensity \( c \) is written as the following identity:
\[ c = \frac{C}{VA} = \sum_{i,s} k_{is} \times E_{is} \times E_s \times \frac{VA_s}{VA} \quad (16) \]

To facilitate notation let us write
\[ e_{is} = \frac{E_{is}}{E_s} \quad (17a) \]
\[ I_s = \frac{E_s}{VA_s} \quad (17b) \]
\[ S_s = \frac{VA_s}{VA} \quad (17c) \]
so that,
\[ C = \sum_{i,s} k_{is} e_{is} I_s S_s \quad (18) \]

The Divisia indices of the above components are found using the methodology described in the previous section. The final decomposition into indices of major components can be written as:
\[ \frac{c_i}{c_{i-1}} = Dk \cdot De \cdot DI \cdot DS + R \quad (19) \]
where $R$ is a residual term due to approximation, and $Dk$, $De$, $DI$, and $DS$ are the Divisia indices for effects due to changes in emission coefficient, energy mix, energy intensity and structural shift.

Since final energy intensities refer to the final end uses of energy, they are more suitable for comparing the energy required for final consumption against value added than primary energy intensities. All sectoral activities do not respond equally to population changes and therefore specific energy intensity changes in each sector provide greater insight than energy per GDP or energy per capita. The analysis has been done twice, once including power in the group of energy sources used by the sectors and again by excluding it and using only petroleum products, gas and coal.

2.3. Transformation and conversion sector

The components of the emission intensity studied are ‘fuel intensity effect’, i.e. effect due to change in fuel intensities (e.g. improvements in generation efficiency of power plants), generation mix effect and fuel quality effect (due to changing heat value of the fuels). An earlier study by Shreshtha et al. (1996) assumed constant calorific value of coal for all the countries thus neglecting the following two effects of declining calorific value of coal. Firstly, for the same amount of electricity generated (GWH), a bigger quantity of coal may have to be consumed and secondly, since the carbon content of fuel is directly linked with the fuel’s energy content, the carbon per kilogram of fuel also reduces.

We call these two effects intensity effect and quality effect, respectively. Since these two effects are in opposite directions the net effect on carbon emissions would depend on the relative strengths of these two effects. The decomposition equation can be written as

\[
c_i = k_{it} \cdot q_{it} \cdot f_{it} \cdot g_{it},
\]

where,

- $c_i$ = carbon emission intensity of thermal power generation;
- $k_{it}$ = emission coefficient of fuel $i$;
- $q_{it}$ = fuel quality of $i$ (in GJ/unit weight of fuel $i$); and
- $f_{it}$ = fuel intensity, defined as

\[
f_{it} = \frac{F_{it}}{Q_{it}}
\]

where,

- $F_{it}$ = amount of fuel $i$ used for power generation in year $t$.
- $Q_{it}$ = power generation based on fuel type $i$ in year $t$.
- $g_{it}$ = share of power generated from fuel $i$ in total generation in year $t$. 
The final decomposition into indices of major components can be written as

$$\frac{c_t}{c_{t-1}} = Dq \cdot Df \cdot Dg + R$$

where,

- $Dq$ = Divisia index for changing fuel quality;
- $Df$ = Divisia index for fuel intensity; and
- $Dg$ = Divisia index for generation mix.

To show the extent to which data limitations or assumptions in analyses affect results we have done the decomposition exercise for the power sector, once using constant calorific value of coal and once using varying calorific value of coal. We have fixed the calorific value of only coal for the former analysis because coal is used in large quantities by the power sectors and its quality has declined the most for coal compared to the other fuels used.

We have used annual time series data for consumption and quality (gross calorific value) of coal, lignite, high-speed diesel oil, light diesel oil, furnace oil, LSHS and natural gas by thermal power plants. The period of analysis is 1974–1994.

3. Data sources

Independent data sources were used for the three analyses. The details and source data are given below.

3.1. TPER (total primary energy requirements)

We use annual time series data for consumption of coal, crude oil, natural gas and hydro and nuclear power by the economy for the period between 1970 and 1995. Data sources for the analysis are Petroleum and Natural Gas Statistics, (MoPNG), Coal directory of India, (CCO)$^8$, Central Electricity Authority, (CEA)$^9$ and National Accounts Statistics (CSO)$^{10}$.

3.2. TFEC (total final energy consumption)

Four sectors have been studied, namely industry, agriculture, commercial and

$^8$Coal directory of India, Coal Controller’s Organisation, Ministry of Coal, Government of India (several issues).

$^9$Public electricity supply: All India Statistics: General Review, Central Electricity Authority, Government of India (several issues).

$^{10}$National Accounts Statistics, Central Statistics Organization, Ministry of Planning and Programme Implementation, Government of India (several issues).
transport. Data for energy use in agriculture includes consumption of petroleum products and natural gas by plantations (like tea), but does not include petroleum products used by the agriculture sector for transportation of agricultural commodities. Annual time series data for consumption and fuel quality (in kcal/kg) for each of these six fuels, namely coal, high speed diesel oil, light diesel oil, furnace oil, LSHS and natural gas and electricity by each of the sectors has been used for the period 1984–1994. Same data for aviation turbine fuel has been additionally used by the transport sector. Fuel consumption and fuel quality data are from energy statistics Ministry of Petroleum and Natural Gas, MoPNG and Central Electricity Supply Authority, Government of India (CEA). Data for sectoral value added have been acquired from National Accounts Statistics of India (CSO).

3.3. Transformation and conversion sector

Study has been done for the period between 1974 and 1994 using annual time series data for fuel quality of each of the six fuels, i.e. coal, high speed diesel oil, light diesel oil, furnace oil, LSHS and natural gas and their consumption by power sector. Source of this data is Central Electricity Supply Authority (CEA).

4. Discussion of results

4.1. Per capita emissions

Increase in per capita emission in itself is not so much of a concern to India as the current level of emissions have reached a mere 0.23 Tc per capita. However, it is important to identify contribution of the various factors, namely mix of energy sources, efficiency of energy use and rising income which boosts greater energy use, and also the change in trend of these factors for suitable policy analysis.

The results as shown in Fig. 1 indicate that until 1980, energy intensity was the major determining factor behind per capita emissions and from 1980 onwards income effect became the major contributor to per capita emissions. In the first decade of study, growth rate of per capita emissions was lower than in the 1980s when per capita emissions grew by 51.7% from 1980 to 1990 (Table 1). In the period 1970–1980, it was 29.4%. From 1980 to 1990, income effect showed a sharp rise by 44% and approximately 89% of the growth in per capita emissions were contributed by this factor. From 1990 to 1995, per capita emission rose by approximately 22% and all the three effects contributed to the rise, although fuel mix effect was almost nil (the index being very close to 1). Approximately 21% of the per capita emission rise was influenced by intensity component, that is, during this period economic activity became more energy intensive. Fuel mix effect has been almost constant, slightly moving in favor of reduced emission.

The above analysis clearly shows that although rising energy intensity was the major factor behind per capita emission during the 1970s, from the 1980s onwards, income became the most important factor. Such a trend could be indicative of
higher energy efficiency in the 1980s and can be attributed to the reason that after the first oil crisis in 1973, India undertook the policy of energy independence, which on the demand side implied energy efficiency. This along with the fact that India saw a high annual rate of growth in the 1980s led to a shift in the trend. Annual growth rate increased to approximately 6% in the 1980s from a low of approximately 3% in the 1970s. So although energy intensity used to contribute

Table 1
Divisia index decomposition of per capita emission intensity*

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<tbody>
<tr>
<td>Per capita emission</td>
<td>1.294</td>
<td>1.517</td>
<td>1.216</td>
</tr>
<tr>
<td>Energy mix effect</td>
<td>0.987</td>
<td>0.986</td>
<td>1.002</td>
</tr>
<tr>
<td>(– 6.0)</td>
<td>(– 2.7)</td>
<td>(1.2)</td>
<td></td>
</tr>
<tr>
<td>Energy intensity effect</td>
<td>1.210</td>
<td>1.068</td>
<td>1.043</td>
</tr>
<tr>
<td>(75.0)</td>
<td>(13.8)</td>
<td>(20.61)</td>
<td></td>
</tr>
<tr>
<td>Income effect</td>
<td>1.083</td>
<td>1.440</td>
<td>1.163</td>
</tr>
<tr>
<td>(29.6)</td>
<td>(88.9)</td>
<td>(78.1)</td>
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*Note. Figures in parentheses indicate percentage contribution of the various effects to change in per capita emission.
nearly 75% of the per capita emission in the 1970s, the contribution declined to only approximately 13.8% in the 1980s.

If the existence of an environmental Kuznet’s curve (EKC) is assumed for India, the rapidly rising per capita emissions following the trend of rising per capita income indicates that India is still in the rising slope of the inverted U-shaped EKC. CO₂ being a global pollutant does not inflict local damage and its abatement cost being very high, the peak of EKC for CO₂ is usually expected to be very high, if at all it exists (Cole et al., 1997). The presence of Kuznets curve for CO₂ emission is debatable since CO₂ being a global pollutant does not give rise to local disutility in the short run (Arrow et al., 1995; Moomaw and Unruh, 1997). However, in India, potential for improved efficiency in energy use, transmission and distribution of electricity, completion of the shift towards commercial fuels from traditional fuels and full electrification of all villages indicate towards the possibility of reaching a peak of the Kuznets curve. The downward movement might have to be a conscious effort towards removal of market distortions, structural change towards less polluting sectors (growth of the service sector) and international transfer of energy efficient and emission abating technologies.

4.2. TFE: cross-sectoral analysis

Changes in emission intensity of the four sectors have been shown in Fig. 2 as estimated from their energy use and composition including electricity. Comparing the different sectors, we find that transport sector had the strongest reduction in intensity of 18%, between 1984 and 1994 followed by the industrial sector where the reduction was approximately 8%. Emission intensity in the agricultural sector, however, has risen sharply by approximately 2.5 times. This could be explained by the fact that highly subsidized price of power in the agricultural sector, has led to indiscriminate use of electricity in this sector. Emission pertaining to fossil fuel use in power generation is considered as emission from electricity. Electricity being a transformed energy has a high emission coefficient due to generation and transmission losses; thus, emission resulting from electricity consumption is very high for the agricultural sector. Approximately 95% of emission in agriculture comes from electricity consumption.

In the transport sector, coal use in railways has been gradually substituted for electricity, so emission due to coal use shows a drop from 26% in 1984 to 1% in 1994. Although emission coefficient of electricity is higher than coal, emission from power consumption shows an increase of only 1% because end use efficiency of electricity is very high. Diesel consumption and hence emission from it has increased, and it is the major contributor to emission from the transport sector. Its share of emission increased to 75.5% in 1989 and 86% in 1994 from 62% in 1984. In the commercial sector, the major fuels consumed have been natural gas and electricity and the share of natural gas in total emission has been increasing over time. It increased by 5% between 1984 and 1989 and by 1.5% between 1989 and 1994. Share of emission from electricity consumption has declined from 84% in 1984 to 76% in 1994. In the industrial sector emission due to coal consumption
increased from 38% in 1984 to 42% in 1994. Emission from power consumption has decreased by approximately 4% in this period.\textsuperscript{11}

Results of the Divisia decomposition on emission intensity due to consumption of major primary energy carriers and electricity are presented in Fig. 3, which shows the evolution of carbon emission intensity, emission coefficient, fuel mix, energy intensity and structural effects. Fig. 4 presents the results of the analysis without considering power consumption by the sectors. Hence it does not include the emission coefficient change effect which results solely from the changing coefficient of power.

Fig. 3 shows that in the period between 1984 and 1987, all the three factors of energy intensity, emission coefficient and structural effect contributed to the rising emission intensity. In the period between 1984 and 1987, emission intensity increased by 15%, of which approximately 64.5% was contributed by the rise in emission coefficient. The effect of this factor, however, declined gradually. From 1991 onwards energy intensity effect was the most dominating factor in the rise in emission intensity. Results indicate that the contribution of the different factors have varied considerably over the years without showing any clear trend. So study of sub-periods might be misleading depending on the choice of end-points.

When the above analysis is carried out without including power consumption by

\textsuperscript{11} We consider power bought from utilities. Some of the coal consumed by the industries is used for generating power within industries.
Fig. 3. Decomposition of emission intensity of final energy consumption (including electricity).

The different sectors, results show (Fig. 4) that emission intensity from direct consumption of fossil fuels is falling and declining energy intensity is the major causal factor behind this change emission intensity. Fuel mix effect and structural shift show similar movements as in the previous analysis including electricity, the former contributing to reduction in emission intensity while the latter showing movement towards energy intensive sectors. In the period from 1984 to 1994, emission intensity shows a fall of 28% caused primarily by energy intensity effect, which contributes 121% of the decline and by fuel mix effect, which contributes 14% of the decline. Structural shift has an effect of approximately 35% to an increase in emission intensity.

The two analyses, with and without power sector, captures implicitly the effect of fuel substitution. The sharply declining fuel energy intensity in the second analysis and a rising energy intensity in the first analysis, shows that in Indian economic sectors, direct fossil fuel consumption has been substituted by power consumption. This substitution has been distinct for the transport sector. However, the fact that the fuel mix effect is less than 1 (0.973), indicates that the reduction in fossil fuel use and improved efficiency of end use of electricity dominates over the rise in electricity use.
4.3. Transformation and conversion sector

Coal is the major fuel used in thermal power generation in India. However, the quality of coal going to thermal power generation has been declining in India as shown in Fig. 5. Energy used in power generation, measured as gigajoules per gigawatt hour (GWH) of thermal power generation shows a sharp decline when the calorific value of coal used is taken into account. From 1974 to 1984, the ratio of primary energy input in GJ to final electricity output in GWH declined by 12.4% and from 1984 to 1994, it further declined by 14%.

We have carried out our analysis using both constant calorific value (5000 kcal/kg) and varying calorific value of coal to study the impact of coal quality decline on measurement of emission intensity growth. Results show (Figs. 6 and 7) that the impact of coal quality on emission is substantial and the analysis fails to project the true picture if this aspect is ignored.

Emission intensity with constant calorific value of coal (Fig. 6) follows the path of fuel intensity while fuel quality effect (resulting from quality variations in other fuels used in power generation like various petroleum products and natural gas) and generation mix effects have remained almost constant. Emission intensity shows a decline by approximately 5.5% in the period of analysis. However, when changing quality of fuels is included in the analysis, the decline in emission intensity turns out to be much higher, approximately 25%. The decomposition for sub-periods are shown in Table 2a,b and the major contributor to fall in emission intensity is...
intensity in all the sub-periods in Table 2a, is the fuel quality effect. In the overall period of analysis, fuel quality effect contributed almost 74% of the decline in emission and the rest of the decline was contributed by intensity (24%) and
generation mix effect (2%). In the analysis without coal quality (Table 2b), intensity effect is the major determinant of emission intensity.

5. Policy implications and conclusion

Need for GHG abatement on the one hand and urgency for improvement in energy efficiency, especially of non-renewable fossil fuel sources on the other, and the uncompromisable objective of development have diverted attention of energy policy of developing countries, more towards energy intensity changes of economic activity or GDP. The three different levels of analyses in this paper help us to face the questions posed at the beginning of the paper. Study of per capita emission from primary energy use shows that although rising energy intensity was the most important factor in the 1970s, from the 1980s onwards, rising per capita income became the major determinant of per capita emissions. The change in the trend can be attributed to the energy policy of the government emphasizing self-sufficiency through increased efficiency on the demand side and also the increased rate of economic growth in the 1980s.

Emissions from end-use of commercial energy by the four major sectors namely industry, transport, agriculture and commercial sector were studied through decomposition of emission intensity into fuel mix effect, energy intensity effect, and structural shift. Differences in the analyses, with and without inclusion of power
Study of the major transformation sector of thermal power generation shows that the declining quality of fuels used in power sector has played a major role in reducing emission intensity in this sector and neglecting fuel quality effect overestimates emissions and underestimates efficiency improvement. The fact that fuel intensity has not varied much in spite of a declining fuel quality indicates an

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**Table 2**

(a) Divisia indices of emission intensity from power generation (with coal quality effect)

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<tbody>
<tr>
<td>Emission intensity</td>
<td>0.891</td>
<td>0.951</td>
<td>0.907</td>
<td>0.9747</td>
</tr>
<tr>
<td>Fuel quality</td>
<td>0.927</td>
<td>0.943</td>
<td>0.953</td>
<td>0.9653</td>
</tr>
<tr>
<td>Intensity effect</td>
<td>(67.52)</td>
<td>(116.3)</td>
<td>(50.55)</td>
<td>(38.9)</td>
</tr>
<tr>
<td>(35.1)</td>
<td>(−7.3)</td>
<td>(41.97)</td>
<td>(−35.98)</td>
<td></td>
</tr>
<tr>
<td>Fuel mix effect</td>
<td>1.000</td>
<td>1.004</td>
<td>0.990</td>
<td>1.001</td>
</tr>
<tr>
<td>(−0.01)</td>
<td>(−8.8)</td>
<td>(10.73)</td>
<td>(−3.0)</td>
<td></td>
</tr>
</tbody>
</table>

(b) Divisia index decomposition of emission intensity from power generation (without coal quality effect)

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<tr>
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</thead>
<tbody>
<tr>
<td>Emission intensity</td>
<td>0.962</td>
<td>1.015</td>
<td>0.955</td>
<td>1.013</td>
</tr>
<tr>
<td>Fuel quality</td>
<td>1.005</td>
<td>0.996</td>
<td>1.002</td>
<td>1.001</td>
</tr>
<tr>
<td>Intensity effect</td>
<td>(−1.3)</td>
<td>(−22.7)</td>
<td>(−4.4)</td>
<td>(12.1)</td>
</tr>
<tr>
<td>(108.3)</td>
<td>(85.1)</td>
<td>(89.7)</td>
<td>(73.28)</td>
<td></td>
</tr>
<tr>
<td>Generation mix</td>
<td>1.003</td>
<td>1.005</td>
<td>0.993</td>
<td>1.002</td>
</tr>
<tr>
<td>(7.1)</td>
<td>(37.5)</td>
<td>(14.6)</td>
<td>(14.6)</td>
<td></td>
</tr>
</tbody>
</table>

*Note: Figures in parentheses indicate percentage contribution of the components to change in emission intensity.*

*Quality effect implies the effect of changes in calorific value of fuels used other than coal in power generation.*

consumption indicated that there has been significant substitution of primary energy carriers by electricity in energy consumption by the sectors. Furthermore, the analysis, including electricity, showed that overall growth in emission intensity has been contributed mainly by rise in energy intensity, although structural composition of production seemed to have been in favor of reduced emissions. Although emission coefficient of electricity consumption is much higher than primary fossil fuel consumption, our analysis showed that the effect of change in energy consumption mix, i.e. substitution of primary fuels by electricity has contributed towards reduction in emission intensity, the fuel mix effect being less than unity. The higher end-use efficiency of electricity consumption more than compensates for the high emission coefficient of electricity consumption. Thus, fuel shift towards electricity in India is favorable for emission reduction. The magnitude of this effect can be further enhanced through improvement in transmission and distributional efficiency, which would help in reducing the emission coefficient of electricity use.
improvement in efficiency. This improvement in efficiency could be due to the reason that although coal quality declined drastically, the reduction in price of inferior quality coal was much less than proportionate. This brought about ‘forced efficiency’ of coal use in power plants to avoid increased expenses of acquiring larger quantities of coal and also increased transportation cost of coal.

From the study of emission at different levels and the trend of the components, it can be expected that emissions will continue to be influenced by increased energy use by middle and upper income groups as more and more consumer products, especially electrical gadgets, penetrate into the market. Given that per capita energy consumption is very low and only a small percentage of households own consumer durables in India, it is expected that demand for energy will rise and so will emissions. The analysis indicates that energy consumption and hence emission in India are still in the rising slope of the EKC and peak might be reached when the organic level of energy use is reached, i.e., when full electrification and motorization of the economy is complete (Sengupta, 1997) and the economy shifts from traditional to commercial fuels and from primary energy forms to transformed energy. Efficiency improvements through technological and managerial solutions could help India to ‘tunnel through’ the EKC. So far, most of the improvement in efficiency has come through autonomous technological improvement and not conscious technical shift towards newer and more efficient technologies. India is expected to become more and more important as global energy consumer and therefore autonomous technological change will not be enough to attain the desired level of efficiency and emission reduction. It is important to recognize the features of the energy market in India which affect efficiency improvements. These include several price and non-price factors like improvement of energy infrastructure and removal of imperfections in the energy market.

References


