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CO_2 emissions structure of Indian economy

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ABSTRACT

This paper analyses carbon dioxide (CO_2) emissions of the Indian economy by producing sectors and due to household final consumption. The analysis is based on an Input–Output (IO) table and Social Accounting Matrix (SAM) for the year 2003–04 that distinguishes 25 sectors and 10 household classes. Total emissions of the Indian economy in 2003–04 are estimated to be 1217 million tons (MT) of CO_2, of which 57% is due to the use of coal and lignite. The per capita emissions turn out to be about 1.14 tons. The highest direct emissions are due to electricity sector followed by manufacturing, steel and road transportation. Final demands for construction and manufacturing sectors account for the highest emissions considering both direct and indirect emissions as the outputs from almost all the energy-intensive sectors go into the production process of these two sectors. In terms of life style differences across income classes, the urban top 10% accounts for emissions of 3416 kg per year while rural bottom 10% class accounts for only 141 kg per year. The CO_2 emission embodied in the consumption basket of top 10% of the population in urban India is one-sixth of the per capita emission generated in the US.

1. Introduction

Energy sector in India is poised for transformation due to the high economic growth as well as great concern for climate change induced by greenhouse gases (GHGs), especially carbon dioxide (CO_2) emissions due to use of fossil fuels. According to the United Nations Framework Convention on Climate Change (UNFCCC) adopted at Rio Summit in 1992 India does not have the responsibility to reduce emissions below the current values, however it is committed to slow down the emissions growth as a signatory of the UNFCCC and due to concerns regarding impact of climate change. Therefore the CO_2 emissions by various sectors need to be estimated so that measures can be undertaken to reduce the emissions as far as possible without compromising economic growth. This calls for estimates of CO_2 emissions at national levels by major sources and sectors. Indeed the UNFCCC adopted at the Rio Summit in 1992 requires all nations to report national inventories of greenhouse gas emissions. Since CO_2 emissions growth is largely influenced by anthropogenic factors, especially by production activities that require fossil fuels, the relationships of energy use with economic growth and its structure need to be analyzed before undertaking an exercise in projections for the future.

There have been several studies on the emissions of GHGs in India, and some of them deal with sectoral emissions in the country [1–7]. Parikh and Gokarn is one of the earliest attempts at estimating emission levels in various sectors of the economy for the year 1983–84 [1]. Murthy et al. made a detailed study of interactions among economic growth, energy demand and carbon emissions for the Indian economy using Input–Output (IO) table for 1989–90 and projected emissions for 2004–05 [2,3]. Mukhopadhyay and Forsell estimated the trends of CO_2, SO_2 and NO_x between the periods 1973–74, 1983–84, 1991–92 and 1996–97 using the IO approach [4]. Nag and Parikh provide time series estimates of indirect carbon emissions per unit of power consumption [7]. Garg et al. analyzed sectoral trends of multi gas emission inventory of India [6]. Sharma et al. analyzed the total greenhouse gas emissions from India for broad sectors such as energy, industrial processes, agriculture activities, land use, land use change and forestry and waste management practices for 1990, 1994 and 2000 [8].

This paper attempts to provide a more recent and detailed perspective on CO_2 emissions for India by major sectors for the year 2003–04 based on the latest available Social Accounting Matrix (SAM), which incorporates the IO flows at 25-sector level and 10 household classes for that year. Specifically, this paper analyzes the following questions:

- What is the total emission of the Indian economy by fuel type and by demand categories?

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Table 1
Computation of emission coefficients by fuel type.

	Output weight (1)	Emission factor (tons/GJ) (2)	Indian Calorific value (GJ/ton) (3)	Emission Coefficient (tons of CO_2 per ton of fuel) $(4)=(2)\times(3)\times 44/12$
Coking coal	0.0728	0.0255	16.7472	1.5677
Non-coking coal	0.8574	0.0261	16.7472	1.6045
Lignite	0.0699	0.0290	16.7472	1.7777
Total coal				1.6140
Petroleum products		0.0202	41.868	3.1024
Natural gas		0.0153	0.038	0.0021

Note: 1) for natural gas, the calorific value and emission coefficient are per cubic metre; 2) emission factors for types of coal are from GOI [5], and for petroleum products and natural gas from IPCC.

- What are the direct emissions by sectors?
- Which are the major emitting sectors by fuel type?
- What are the direct and indirect emissions by final demand?
- What are the emissions by different expenditure classes in rural and urban areas?

The rest of the paper is organised as follows: Section 2 describes the data and methodology used to estimate the CO_2 emissions. Section 3 discusses the results to answer the above questions. The last section concludes the paper.

2. Database and methodology for estimating CO_2 emissions

An SAM is a matrix representation of all transactions and transfers taking place in an economy in particular year between different production activities, factors of production and institutions such as households, corporate sector, government and rest of the world. Embedded in the SAM is the IO table, which reports the use of goods as intermediate inputs in the production process of various commodities as well as the final demands. The final uses are typically distinguished into six categories (i) Private Final Consumption Expenditure (PFCE), (ii) Government Final Consumption Expenditure (GFCE), (iii) Gross Fixed Capital Formation (GFCF), (iv) Change in Stocks (CIS), (v) Exports of goods and services (EXP) and (vi) Imports of goods and services (IMP).

The IO system is a well accepted method for analysis of direct and indirect input demand for producing output in various sectors of the economy. Leontief developed the formal analytical structure of the IO system during the course of his study on structure of the economy of the United States [9]. Typically, an IO table provides us with a snapshot of the structure of the inter-sectoral linkages in an economy for a given year. The main virtue of the IO framework is that it tracks the supply (domestic production plus imports) and demand (intermediate use plus various types of final demands) for goods and services in a consistent manner. Given that the database refers to one year, the IO coefficients might reflect some abnormalities, especially if the year happens to be an abnormal one. Internationally, some studies have attempted to assess the errors in IO coefficients [Simonovites [10], Roland-Holst [11], Kop Jansen [12], Dietzenbacher [13], ten Raa [14]]. These studies have made use of other micro (firm or plant) level data to estimate the various multipliers and compare them with those implied by IO tables.

Following the seminal ideas in Leontief [15], the IO method has been found to be useful in examining energy–environment–economy interactions, for example by Ayres and Kneese [16], Bullard et al. [17], Casler and Wilbur [18], Miller and Blair[19], Lange [20]. This method helps to trace the direct and indirect emissions caused by consumption and other elements of final demand. This way the ultimate source of demand of emission in an economy could be identified. In the Indian context, several authors have examined energy–environment issues using the IO analysis [Parikh and Gokarn [1], Singh [21], Mukhopadhyay and Chakraborty [22], Roy and Mukhopadhyay [23], Murthy et al. [2,3].

The analysis in this paper makes use of the SAM/IO table for the year 2003–04 prepared by Saluja and Yadav [24]. This SAM consists of 73 production sectors and 10 expenditure classes. For the purpose of this paper, the 73 sectors are aggregated into 25 broad sectors retaining the major energy producing and energy using sectors separately.

We might note that the estimates used in this paper are based on one year's data that is consistent with the National Accounts Statistics for India which in turn is based on the methods suggested by the United Nations Systems of National Accounts. We are not aware of any error analysis for Indian IO table. The main difficulty to carry out such an analysis seems to be the lack of relevant micro level data. While it would be interesting to assess the errors in the Indian IO tables, it would require a separate study and we have refrained from it in this paper.

Table 2
Decomposition of emissions of CO_2 in India, 2003–04 (MT of CO_2).

	Coal & lignite	Crude petroleum	Petroleum products	Natural gas	Cement industry	Total
Emissions in the production process to support						
i) Household consumption	358.3	27.8	178.8	56.1	4.4	625.5
ii) Government consumption	66.2	2.9	19.7	10.6	3.4	102.9
iii) Investment	282.4	8.4	64.9	24.8	46.4	426.9
iv) Exports	193.3	9.8	55.8	18.8	3.3	281.0
v) Less imports	217.5	8.8	56.3	23.5	1.8	307.9
vi) Total (*A*)	682.7	40.2	263.0	86.8	55.7	1128.4
Emissions due to direct demand						
i) Household consumption	13.7	0.0	67.9	0.0	0.0	81.5
ii) Government consumption	0.4	0.0	6.2	0.4	0.0	6.9
iii) Total (*B*)	14.0	0.0	74.0	0.4	0.0	88.5
Total emissions $(A)+(B)$	696.7	40.2	337.0	87.2	55.7	1216.9

Source: computed by authors.
Note: emission in the production of clinker is 0.537 tons of CO_2 per ton of clinker, which amounts to 0.451 tons of CO_2 per ton of cement.

Table 3
Key indicators for major CO_2 emitting countries (2005).

Country	CO_2 emissions (Mt of CO_2)	Population (million)	Per capita CO_2 (tons of CO_2/population)	CO_2/GDP (kg CO_2/2000$)	CO_2/GDP (PPP) (kg CO_2/2000$ PPP)
USA	5817	297	19.61	0.53	0.53
China	5060	1305	3.88	2.68	0.65
Russia	1544	143	10.79	4.41	1.12
Japan	1214	128	9.50	0.24	0.35
India	1147	1095	1.05	1.78	0.34
World	27,136	6432	4.22	0.75	0.50

Source: IEA [25].

2.1. Estimating direct emissions

The above IO framework has been extended to incorporate CO_2 emissions by calculating the amount of CO_2 emissions that take place in the production of the various economic activities. If $X = (X_i)$ is a vector of output of various sectors and $E = (E_i)$ is a vector of emission coefficients representing the volume of CO_2 emissions per unit of output in different sectors, the quantity E_iX_i indicates the emission generated by the sector i. This is called the direct emissions of sector i. The direct emission coefficients are estimated for 2003–04 by examining the fossil fuel used as inputs in the production process in each of the 25 sectors [1–3]. The emission coefficients by fuel type used in this study are 1.614 and 3.102 tons of CO_2 per ton of coal and petroleum products, respectively, and 0.0021 tons of CO_2 per cubic metre of natural gas. These coefficients are arrived by considering emissions by fuel type in tons per Giga Joule (tons/GJ) after adjusting for the calorific values of the fuel types used in India (see Table 1).

2.2. Estimating direct and indirect emissions

Productions of various commodities are ultimately geared towards meeting final demands, and they generate emissions due to the direct and indirect use of fossil fuels. As an example, in the production of cars direct emissions occur due to the use of fossil fuels in the car-producing sector itself. Indirect emissions in car manufacturing occur due to the use of inputs such as steel, whose production itself would have generated emissions. The steel sector in turn uses iron-ore and coal, the production of which involves use of fossil fuel, and so on. The sum total of all such direct and indirect emissions in the production of one unit of final demand of a commodity j can be estimated as,

$$\sum_i E_i b_{ij} \quad (1)$$

where b_{ij} is the (i,j)th element of the matrix $(I - A)^{-1}$ and A is the IO flow matrix (see Annexure for details). Multiplying the direct and indirect emission coefficients of a sector by the corresponding level of final demand will give the amount of total direct and indirect carbon emissions by final demand of that sector. The total carbon emissions in the economy are just the sum over all sectoral direct and indirect emissions due to final demand.

Table 4
Direct CO_2 emissions and output by sectors, 2003–04.

S. No	Sectors	Total emissions		Output	
		MT	Share (%)	Rs. lakhs	Share (%)
1	Electricity	310.3	27.50	12,950,450	2.69
2	Manufacturing, nec	202.5	17.95	69,255,585	14.37
3	Steel	127.1	11.26	13,343,149	2.77
4	Other transport	121.9	10.81	33,581,833	6.97
5	Cement industry	102.2	9.05	1,921,936	0.40
6	Other services	86.2	7.64	160,786,411	33.36
7	Petroleum products	43.8	3.88	16,735,471	3.47
8	Fertilizers	35.3	3.12	3,261,853	0.68
9	Non-metallic minerals	27.1	2.40	3,369,917	0.70
10	Agro-processing	25.5	2.26	26,089,772	5.41
11	Construction	12.8	1.14	38,832,573	8.06
12	Textiles	10.7	0.95	15,372,951	3.19
13	Food grains	7.9	0.70	18,875,752	3.92
14	Other crops	4.1	0.36	22,367,855	4.64
15	Railway transport services	3.4	0.30	4,256,108	0.88
16	Coal & lignite	2.6	0.23	3,341,353	0.69
17	Fishing	1.6	0.14	3,096,709	0.64
18	Mining & quarrying	0.8	0.07	1,470,046	0.30
19	Crude petroleum	0.7	0.06	1,626,127	0.34
20	Oilseeds	0.7	0.06	5,093,778	1.06
21	Forestry	0.6	0.06	2,968,721	0.62
22	Natural gas	0.5	0.04	1,536,919	0.32
23	Sugarcane	0.2	0.02	2,328,186	0.48
24	Animal husbandry	0.1	0.01	18,017,519	3.74
25	Water supply & gas	0.1	0.01	1,510,532	0.31
	Total emissions	1128.4	100.0	481,991,507	100.0

Source: authors' estimates.
Note: 1) for cement industry, emissions in the clinker production process are included here; 2) 'nec' denotes 'not elsewhere classified'.

3. Results

Discussion of the results proceeds as follows: we start with estimates of total emissions in the Indian economy as a whole by fuel types and by demand categories for the year 2003–04. This is followed by a discussion of the estimates at the sectoral level. In Section 3.2 we provide the break-up of the sectoral emission estimates by fuel type. Section 3.3 provides the estimates of the direct and indirect emissions due to the household consumption pattern, while Section 3.4 discusses the emissions by different expenditure classes in rural and urban areas.

3.1. Total emissions in the Indian economy

Table 2 shows the CO_2 emission levels in India by various fuel types and demand categories.[1] The total carbon dioxide CO_2 emission due to economic activities for the year 2003–04 has been estimated at 1217 million tons (MT) in India. The per capita emissions turn out to be about 1.14 tons. Of the total emissions, coal and lignite accounts for 697 MT, i.e. 57.3%. Petroleum products and natural gas account for another 27.7% and 7.2% of emissions, respectively. Crude oil accounts for 3.3% and clinker for residual 4.6% in the cement production process. Turning to demand categories, as much as 1128 MT or 93% of total emissions takes place in the production process of various goods and services, by way of use of fossil fuels and clinker production in cement industry. Thus, carbon dioxide emission in India predominantly originates in the production system, which goes towards meeting both intermediate input use as well as final demands for various goods and services

[1] The total domestic production of coal, petroleum products and natural gas in the year 2003–04 was 408 MT, 122 MT and 31,962 million cubic metres, respectively.

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Table 5
Direct CO_2 emissions from coal and lignite, 2003–04.

S. No	Sectors	CO_2 emission (MT)	Share (%)
1	Electricity	274.5	40.2
2	Manufacturing, nec	148.6	21.8
3	Steel	120.7	17.7
4	Cement industry	46.0	6.7
5	Other services	31.5	4.6
6	Non-metallic minerals	22.9	3.4
7	Agro-processing	18.0	2.6
8	Textiles	8.1	1.2
9	Fertilizers	7.7	1.1
10	Coal & lignite	1.8	0.3
11	All other sectors	2.9	0.4

Source: authors' estimates.

except the direct use of fossil fuels by households and government. Emissions due to direct fuel use by households and governments account for only 6.7% and 0.6% of the total emissions.

To provide a comparative perspective of our estimates of India's emissions, Table 3 provides the estimates for 2005 of the top 5 emitting countries in the world [25]. It is seen that our estimates obtained from detailed sectoral analysis are somewhat higher (about 6%) than the economy-level estimates of International Energy Agency (IEA). In fact, our estimates of 1217 MT place India slightly ahead of Japan. Nevertheless, in per capita terms India's emissions are way below that of the other countries. Carbon intensity of GDP in purchasing power parity (PPP) terms is also low in India.

3.2. Direct emission by production sectors

Table 4 shows the direct emissions by the 25 sectors in descending order of emissions. At the top is the electricity sector with a share of 28% of total emissions in 2003–04 in India, though its share in output is less than 3%. Manufacturing (not elsewhere classified, nec), steel, other transport and cement appear next in that order. Other services, which accounts for about 33% of output, comes sixth in terms of CO_2 emission with a share of 8%. These six sectors together account for 84% of total emissions. It may be noted that some of the sectors such as agro-processing, construction, textiles, food grains, other crops, and animal husbandry, that are large in terms of output, are not major direct emitters of CO_2.

3.2.1. Emissions due to coal & lignite

A total emission of CO_2 due to coal is 683 MT in India. Table 6 reports the top ten CO_2 emitting sectors due to use of coal & lignite as inputs in the production process. A thermal power plant emits the maximum amount of CO_2 using coal & lignite as fuel for generation of electricity. As Table 5 shows 275 MT of CO_2 are emitted in generation of electricity by thermal power plants accounting for 40% of the total CO_2 emissions due to coal. This is followed by manufacturing (nec), steel and cement industries having 149, 121 and 46 MT of CO_2 emission respectively. The top ten sectors contribute 99.6% of the CO_2 emissions due to coal.

Table 6
CO_2 emissions from petroleum products, 2003–04.

S. No	Sectors	CO_2 emission (MT)	Share (%)
1	Other transport	121.9	46.4
2	Manufacturing, nec	28.2	10.7
3	Other services	24.7	9.4
4	Electricity	21.1	8.0
5	Fertilizers	14.3	5.4
6	Construction	11.3	4.3
7	Food grains	7.8	3.0
8	Agro-processing	5.9	2.3
9	Steel	5.5	2.1
10	Non-metallic minerals	4.2	1.6
11	All other sectors	18.0	6.8

Source: authors' estimates.

3.2.2. Emissions due to petroleum products

Total emissions of CO_2 due to petroleum products are 263 MT in India. Table 6 reports the top ten CO_2 emitting sectors due to use of petroleum products as inputs in the production process. Not surprisingly, other transport, which includes motorcars, buses, aviation, and shipping, accounts for nearly half (122 MT) of the CO_2 emission due to petroleum products. Manufacturing (nec) sector emits 28 MT of CO_2 followed by other services and electricity at third and fourth places with 25 and 21 MT of CO_2 respectively. The top ten sectors together account for 93% of the total CO_2 emissions due to petroleum products.

3.2.3. Emissions due to natural gas

A total emission of CO_2 due to natural gas is 87 MT. Just five sectors (Table 7) account for 98% of these emissions. These are other services, manufacturing (nec), electricity, fertilizers and agro-processing. Starting from a low base, the use of natural gas has increased rapidly in recent years, especially in electricity generation.

3.3. Direct and indirect carbon emissions by final demand

Production of any good or service involves the use of several goods and services as raw materials. Thus, when demand for a good changes, its effect is felt not only in the sector that produces that particular good, but also in rest of the economy due to production chain linkage. Direct and indirect emissions' analysis helps us to understand how much of emission takes place in the entire production chain of a good or service. Table 8 reports the direct and indirect emission coefficients defined as the emissions caused by the production vector needed to support final demand in that sector at unit level and expressed as tons of carbon dioxide per lakh Rupees of final demand at 2003–04 prices. Cement and electricity occupy the first and second highest positions in terms of direct and indirect emissions per unit of final demand followed by steel, fertilizer and non-metallic minerals, respectively.

The total direct and indirect emissions of a sector would depend on not only the direct and indirect emission coefficients of that sector, but also on the level of sectoral final demand. Taking both these factors into consideration, Table 9 ranks the sectors according to the level of direct and indirect emissions taking place in meeting the final demand in each sector. When both direct and indirect effects are considered, the construction sector has the highest contribution to CO_2 emission with a share of about 24% of the total (Table 9). As Table 4 revealed earlier, the direct emission coefficient of construction activity is not high. This is because it does not take much of fossil fuel based energy to construct a building or a road. But, construction sector uses a lot of energy-intensive materials such as bricks, cement, iron and steel, aluminium, glass, asbestos and so on.

Table 7
CO_2 emissions from natural gas, 2003–04.

S. No	Sectors	CO_2 emission (MT)	Share (%)
1	Other services	30.0	34.5
2	Manufacturing, nec	25.8	29.7
3	Electricity	14.7	16.9
4	Fertilizers	13.3	15.4
5	Agro-processing	1.6	1.8
6	All other sectors	1.5	1.8

Source: authors' estimates.

Table 8
Direct and indirect emission coefficients by fuel type per unit of final demand (tons per Rs. lakh).

S. No	Sectors	Coal & lignite	Crude petroleum	Petroleum products	Natural gas	Cement industry	Total
1	Cement industry	27.7	0.1	1.1	0.3	29.0	58.2
2	Electricity	26.7	0.3	2.5	1.5	0.0	31.0
3	Steel	15.6	0.1	1.3	0.4	0.0	17.4
4	Fertilizers	5.5	0.6	5.6	4.8	0.0	16.5
5	Non-metallic minerals	9.8	0.2	2.0	0.2	0.5	12.7
6	Manufacturing	7.0	0.1	1.2	0.7	0.0	9.1
7	Construction	4.6	0.1	1.0	0.2	1.6	7.6
8	Other transport	2.3	0.5	4.2	0.2	0.0	7.1
9	Railway transport services	4.9	0.1	1.2	0.3	0.1	6.6
10	Textiles	3.9	0.1	1.0	0.3	0.0	5.4
11	Petroleum products	0.9	2.5	0.6	0.1	0.0	4.1
12	Agro-processing	2.3	0.1	0.9	0.3	0.0	3.7
13	Coal & lignite	2.6	0.1	0.7	0.2	0.0	3.5
14	Food grains	1.3	0.1	1.2	0.5	0.0	3.1
15	Mining & quarrying	1.3	0.1	0.8	0.1	0.0	2.3
16	Water supply & gas	1.5	0.0	0.3	0.1	0.2	2.3
17	Other services	1.2	0.0	0.4	0.3	0.0	2.0
18	Oilseeds	0.7	0.1	0.7	0.4	0.0	1.9
19	Sugarcane	0.7	0.1	0.5	0.3	0.0	1.6
20	Other crops	0.6	0.1	0.6	0.3	0.0	1.5
21	Crude petroleum	0.6	0.1	0.5	0.1	0.0	1.3
22	Natural gas	0.6	0.1	0.5	0.1	0.0	1.2
23	Fishing	0.4	0.1	0.7	0.0	0.0	1.2
24	Forestry	0.3	0.0	0.3	0.0	0.0	0.8
25	Animal husbandry	0.3	0.0	0.2	0.1	0.0	0.6

Source: authors' estimates.

The importance of indirect effects can be noted from the fact that the top five sectors, namely construction, agro-processing, textiles, food grains and non-metallic minerals, account for nearly 85% of the total direct and indirect emissions of CO_2. However, the direct emission of these five sectors together was only 7% (Table 4). On the other hand, electricity, which ranked first position by direct emission with a share of 28%, occupies only seventh position with a share of 4% when indirect effects are included. Similarly, steel and cement sectors, which held third and fifth positions by direct emission appear at the bottom of the table by direct and indirect emissions. Steel and cement are primarily intermediate goods and direct final demand component is not large. In fact, net final demand for them and a few other sectors in 2003–04 is negative due to stock drawdown and/or imports. Thus, the negative numbers in Table 9 imply that emission in the country in 2003–04 have been avoided due to emissions generated either in previous years or in rest of the world.

Table 9
Direct and indirect emissions of top ten sectors of the Indian economy.

S. No	Sectors	CO_2 emission (MT)	Share (%)
1	Construction	266.3	23.6
2	Manufacturing	238.9	21.2
3	Other services	220.5	19.5
4	Other transport	145.9	12.9
5	Agro-processing	81.8	7.3
6	Textiles	55.6	4.9
7	Electricity	47.4	4.2
8	Food grains	43.5	3.9
9	Non-metallic minerals	19.4	1.7
10	Petroleum products	18.2	1.6
11	Other crops	17.1	1.5
12	Railway transport services	9.0	0.8
13	Animal husbandry	8.0	0.7
14	Oilseeds	3.4	0.3
15	Fishing	3.4	0.3
16	Water supply & gas	2.4	0.2
17	Forestry	1.5	0.1
18	Sugarcane	1.0	0.1
19	Natural gas	−0.5	0.0
20	Coal & lignite	−0.8	−0.1
21	Fertilizers	−4.6	−0.4
22	Mining & quarrying	−4.7	−0.4
23	Crude petroleum	−12.1	−1.1
24	Steel	−15.5	−1.4
25	Cement industry	−16.8	−1.5

Source: authors' estimates.

3.4. Emissions by expenditure class

We now turn to the question possible differential emission effects of consumption pattern of different income classes in India. In particular, we enquire the question of quantum of emission generated, directly and indirectly, in producing the consumption basket of 10 income classes, 5 rural and 5 urban. Fig. 1 gives the population distribution by various monthly expenditure classes in the SAM prepared by Saluja and Yadav arranged in ascending order of household per capita expenditure [24]. In both rural and urban areas, EC1, EC2, EC3, EC4 and EC5 account for 10%, 20%, 40%, 20% and 10% of the population arranged in increasing order of mean per capita expenditure. Thus, one might view EC1 as abject poor, EC2 as poor (below poverty line), EC3 as average, EC4 as above average and EC5 as the relatively rich in expenditure distribution.

Fig. 2 gives the distribution across households of direct CO_2 emissions due to direct use of fossil fuels in running private cars, cooking and use of kerosene in lighting, etc. As reported in Table 3, total CO_2 emissions on this count by all households are 82 MT and accounts for about 7% of total emissions in the economy. Emissions due to direct use of fossil fuels by rural households are low and vary between 9 and 129 kg per person. In urban areas, the figures vary between 63 and 683 kg per capita. The substantial difference in the emissions of urban top class EC5 from the rest of the population is primarily due to use of private motor transport vehicles by this class. Since production process accounts for most of the emissions, it is more important to examine direct and indirect emissions taking place in producing the consumption baskets of the various expenditure classes. We turn to this below.

Fig. 3 gives the per capita direct and indirect emissions CO_2 arising out of the consumption basket across different expenditure classes in rural and urban areas. This includes the emissions due to

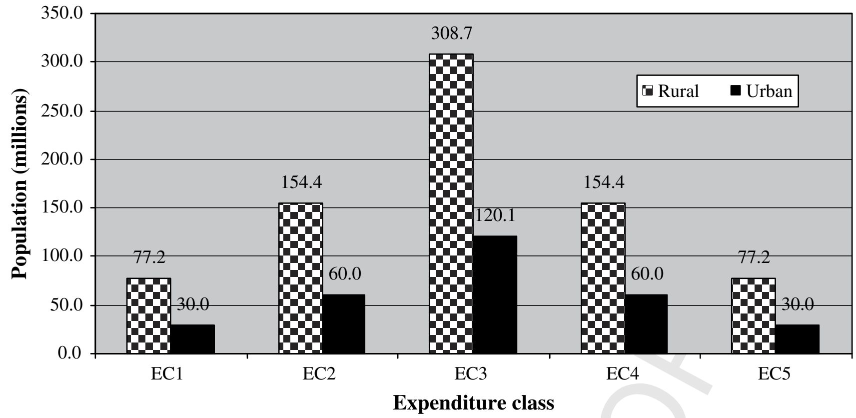

Fig. 1. Distribution of population with expenditure level 2003–04. Note: EC1, EC2, EC3, EC4 and EC5 represent 10%, 20%, 40%, 20% and 10% of the rural/urban population arranged in ascending order of per capita monthly expenditure, respectively. Source: SAM 2003–04, Saluja and Yadav [24].

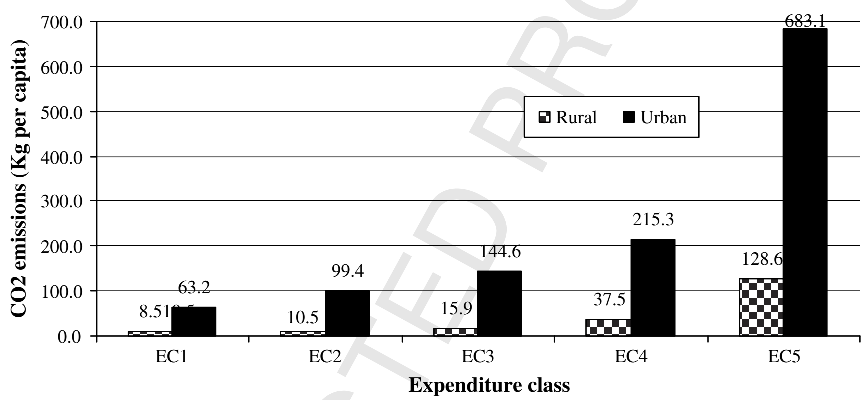

Fig. 2. Emissions of CO_2 due to direct use of fossil fuels by households, 2003–04. Source: authors' estimates.

the direct use of fossil fuels by households, as well as the embodied emissions in the different items of their consumption basket. As seen earlier in Table 3, the total emission on account of household consumption (direct use of fossil fuels, as well as the embodied emissions in the consumption basket), is 707 MT. There is wide disparity in total carbon emission generated to produce the consumption basket between rural and urban households, and between various classes within rural and urban areas.

The average consumption pattern of a representative Indian belonging to the urban top 10% accounts for emission of 4099 kg per year while that of rural bottom 10% class accounts for only 150 kg per year. The urban/rural difference in the emission ranges between 1.8 times for EC1 and 3 times for EC5. The average per capita direct and indirect emissions for rural and urban areas as a whole is 465 kg and 1160 kg, respectively. Considering population of 1072 million, per capita emission turns out to 660 kg for 2003–04. Of this, 359 MT (51%) of emissions are by the 72% of Indians living in rural areas and the balance 348 MT (49%) of emissions are by the 28% of Indians living in urban areas. The disparity within urban areas is also more than that within the rural areas. If we use the ratio of per capita emission of top 10% to bottom 10%, it is 15:1 in urban areas while it is about 9:1 in rural areas. Lastly, it may be of interest to note

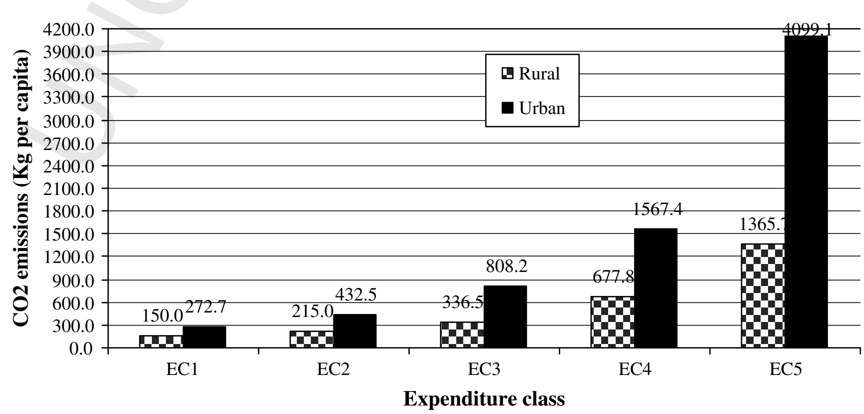

Fig. 3. Direct and embodied emissions of CO_2 by expenditure classes. Source: authors' estimates.

that consumption basket of top 10% of the population in urban India (2.7% of the total population in India) embodies CO_2 emission of 4.1 tons per capita per annum. This is about a fifth of the per capita CO_2 emissions generated in the USA and just falls short of the world average of 4.2 tons per capita (Table 3).

4. Conclusion

This paper provides estimates of CO_2 emissions for the Indian economy by fuel type, sector, final demand and expenditure classes. It uses the latest available SAM for India for the year 2003–04, and the IO table embedded in the SAM. The SAM has been aggregated to 25 sectors covering the entire economy, while keeping the major energy producing/energy using sectors separately.

A total emission of the Indian economy in 2003–04 is estimated to be 1217 MT of CO_2. Most of these emissions (57%) arise due to the use of coal and lignite. Direct emissions by households account for about 7% only. At a sectoral level, highest direct emissions are in electricity sector.

Estimates of the direct and indirect emissions of CO_2 to meet the final demand bring out the importance of indirect emissions in the production chain of the economy. While the top five sectors in terms of direct (on-site) emissions are electricity, manufacturing (nec), steel, other transport, and cement industry, the top five by direct and indirect emissions turn out to be construction, manufacturing (nec), other services, other transport and agro-processing.

In terms of life style differences across household expenditure classes, the urban top 10% accounts for emissions of 4099 kg per capita per year while rural bottom 10% accounts for only 150 kg per capita per year. The CO_2 emission embodied in the consumption basket of top 10% of the population in urban India is one-fifth of the per capita emission generated in the US.

Uncited reference

[26].

Annexure

The IO matrix captures inter-industry flows of intermediate inputs among the various sectors of the economy. By convention, a column shows all the inputs required from the various sectors in the production process of a particular activity, while a row shows the material flows from a particular sector to different sectors. A technology coefficient matrix is generated from the input absorption matrix by dividing all elements in the input column by the output level of the activity represented by the column. Thus, if $A=(a_{ij})$ is the coefficient matrix, then a typical element a_{ij} represents the amount of input i required to produce one unit of output j. In the IO framework, the commodity balance is given by the equation:

$$X_i = \sum_j a_{ij} X_j + F_i \quad \text{(a)}$$

where

$$F_i = C_i + G_i + I_i + EX_i - M_i$$

and X_i is the output level of sector i, F_i is the final demand level of sector i being composed of private consumption (C_i), government consumption (G_i), investment (I_i) and net exports ($EX_i - M_i$) i.e. exports less imports, and a_{ij} is the technology coefficient as defined above. For analyzing sectoral carbon emission, we have used a 25 sector SAM table for the Indian economy prepared for the year 2003–04. Using the matrix notation, we may rewrite equation (a) as:

$$X = AX + F \quad \text{(b)}$$

or

$$X = (I - A)^{-1} F \quad \text{(c)}$$

which gives the solution for the output vector X of dimension (25×1), given the final demand vector F (25×1) and the technology matrix A (25×25). Extensions of this system to estimate CO_2 emissions are explained in the text.

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Q3

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