Estimation of CO$_2$ Emissions using Energy Input - Output (EIO) Tables for India

Megha Shukla

Acknowledgements

Resume

After completing Master degree in Business Economics from University of Delhi in 1996, Megha Shukla joined TERI (The Energy and Resources Institute) in May 1996 as 'Research Associate'. She was promoted to 'Fellow' in April 2004. Since beginning, she has been primarily working in the area of energy. Her assignments include studying of techno-economic feasibility of projects, assessing refinery economics, carrying out sectoral demand supply analysis in the hydrocarbons sector and evaluating government schemes and projects in power sector. She has carried out market surveys of socio-economic & consumers' ability and willingness to pay nature. She was involved with the estimation of elasticities for electricity demand and in the forecasting of demand for various petroleum products and for power sector in various research studies undertaken for various states/regions in India.

She was Area Convenor of Oil and Gas Area of Regulatory and Governance Studies Division during April 2000 till she relocated herself to TERI Bangalore. Since then she has been working in the Area of Energy Reforms. She has vast experience of working with several funding agencies such as World Bank, ADB, Indian Government Departments, Ministry of Power, Ministry of Petroleum and Natural Gas, to name a few. From her research work, she has also published various research papers/ articles in international refereed journals, conference proceedings and magazines.

Her major publications include:

- Cost of unserved power in Karnataka, India: Published in Energy Policy, 34 (2006) pages 1434–1447.
- The present status and future prospects of energy in India- Published in a book "Asian Energy Markets: Dynamics and Trends" by The Emirates Centre for Strategic Studies and Research (ECSSR), 2003.
- Electricity tariffs in India: an assessment of consumers' ability and willingness to pay in Gujarat: Published in Energy Policy 29 (2001) pages 465-478.
- Elasticities of electricity demand in India: Published in Energy Policy 27(1999) pages 137-146.
- Social cost-benefit analysis of Karnataka Watershed Development (KAWAD) project, Karnataka, India, a paper accepted in International Journal of Sustainable Development and World Ecology (IJSD&WE) and likely to be published in early 2008.

Contact details:
Ms Megha Shukla, *Fellow*
The Energy and Resources Institute
4th Main, II Stage, Domlur, Bangalore

Karnataka, India- 560071.
Phone: 080-25356590-95 (Office)
Mobile: 91-9845427023

Contents

Summary of the paper

This paper attempts to construct Energy Input-Output tables expressed in physical and thermal units for India to extend original Indian I-O tables for the years 1993-94 and 1998-99. The advantages it offers is that these tables are able to represent structural relationships of industrial energy use and helps in the analysis of sectoral and national green house gas emissions, such as CO_2. Biomass and limestone are considered part of fuels and sources of CO_2 emissions, respectively, to reflect actual pattern of energy use in India.

In order to adjust the discrepancy between the price– quantity data in I-O, the Energy balance table of IEA are used that contains data on the energy supply and consumption classified by types of energy commodities (thousand tonnes of oil equivalent-ktoe). These two are compared such as EB show the flow of energy commodities, while I-O show the flow of goods and services, in one economy. As they have different origins and purposes, there are several differences in the presentations, concepts and treatment between EB and I-O. I-O is recorded at monetary base in general, while the unit of EB is physical base, ktoe. In the transaction matrix or use matrix of I-O, column wise sectors are demand sectors (or users) of goods and services, while row sectors are suppliers. In EB, users of energies are listed in rows and energy commodities are listed in columns. In a very simplistic explanation, EB is transposed to fit with I-O format. In EB, energy related sectors are more segregated than in I-O, while other sectors are more aggregated than IO. To reformat EB into I-O format, part of energy commodities is aggregated, while several non energy sectors are segregated. General segregation principle is using the nominal input share in I-O.

As next steps, modified I-O tables called Energy I-O tables are used to calculate induced CO_2 emission at national level. EIO here consists of 1) material table which shows detailed sectoral energy inputs in physical unit, 2) calorific table, 3) combustion ratio table, 4) CO_2 emission factor table and 5) CO_2 emission volume table. The derived material table from X matrix is used to estimate induced CO_2 emissions (Y) per activity and total for the economy using the following equation for the years 1993/94 and 1998 (base years), considered in the study:

$$Y = Wi(I - A)^{-1}(f + m) + Wf\, fd = Wi(I - A)^{-1}(f\, d + e) + Wf\, f\, d = \{Wi(I - A)^{-1} + Wf \}\, f\, d + Wi(I - A)^{-1}e,$$

where, $Wi(I - A)^{-1}$:embodied CO_2 emission factor vector for domestic products. Wi: row-vector of CO_2 emission factor for intermediate sectors; Wf: row-vector of CO_2 emission factor for final demand sector; Fd: vector of Domestic final demand, $f = fd + e - m$; Wr : row-vector of CO_2 emission factor for external sectors to produce imported commodity.

It was checked that the induced CO_2 emission estimated from EIO are consistent with other available estimates from say IEA (International energy Agency). As a next step, the forecast on future energy demand, fuel-wise, is estimated based on the per capita consumption

of various energy commodities in rural and urban households in India. The changes in the private final consumption figures for domestic sector is changed in modified I-O tables to estimate induced emissions of carbon for the years 2008 and 2012 and the same is compared with various sources.

In fact, the paper covers analysis of one scenario. The results of this scenario provide the following estimates of induced CO_2 emission for India. It can be clearly seen from the model estimates that carbon emissions are increasing in case of India and without any corrective measures to control existing energy use in Indian economy, there may be serious consequences.

It can be seen from table 1 that carbon emission estimates from this model are comparable for the years 1993-94 and 1998-99. However, it is somewhat different for the future years, which may be because of assumptions used in this paper vis-a-vis assumptions used in other sources. Therefore, it is important to understand the assumptions used by other sources while comparing estimates from I-O framework. It is also important to integrate the developments happening in terms of technology, its' efficiency and other parameters such as price changes etc. to run this model for estimating future CO_2 emissions.

There are few keys recommendations that flow from this paper such as:

- Confirmation of induced CO_2 emission estimates for the base years (1993-94 and 1998-99) using I-O shows that such an exercise or the model as a research tool is worthwhile to be explored further by the researchers.
- Scenarios for the future years and simulation of this model will be more realistic, if detailed data on not just fuel demand (which has been changed in final demand by household sector in I-O and rest of the assumptions such as technology etc. are kept constant) but also on proper technology (efficiency parameters, etc.), investments and share of people using it etc. will be integrated.

Table 1: Estimates on induced CO_2 emissions (in Million Metric Tonnes of Carbon) from I-O model and its comparison with other estimates

Years	IEA	EIA	I-O
1993-94	192	187	200
1998-99	239	235	200
2004-05	296	293	282
2008-09	334	331	420
2011-12	365	362	580

Source: World Energy Outlook, 2005 for IEA; International Energy Outlook by Energy Information Administration, U.S. for EIA and for I-O, it has been estimated in the paper

Note: The estimates of CO_2 emissions from IEA and EIA are interpolated for the years such as 1993-94, 1998-99 and forecasting periods so that it can be compared with the results from I-O model.

Abstract

Energy input-output tables expressed in physical and thermal units are estimated to extend original Indian I-O tables for the years 1993-94 and 1998-99. Advantages of these tables are the ability to represent structural relationships of industrial energy use and to analyze sectoral and national green house gas emissions, such as CO_2. Biomass and limestone are parts of fuels and sources of CO_2 emissions, respectively, to reflect actual pattern of energy use in India. The paper estimates the induced emissions of carbon till 2011-12 based on the simulation of energy consumption data in the domestic sector. Finally, such CO_2 estimates for India are compared with estimates available from other sources such as International Energy Agency (IEA) and Energy Information Administration (EIA).

Keywords: Energy input-output table, CO_2 emissions, domestic sector, scenario

1. Introduction

In 1992, India signed the United Nations Framework Convention on Climate Change (UNFCCC) as a non-Annex I country, which came into force in 1994. Subsequently, the 1997 Kyoto protocol, which came into force in 2005, reasserted the importance of stabilizing greenhouse gas concentrations in the atmosphere. The Protocol laid out guidelines and rules regarding the extent to which a participating industrialized country (Annex B countries in the Protocol) should reduce its greenhouse gas emissions by a weighted average of 5.2%, based on the 1990 greenhouse gas emissions, to be achieved by the end of the five-year period, 2008 to 2012. However, India does not have any such commitments to reduce its emissions of carbon and green house gases (GHGs) as it is not a signatory to the Kyoto Protocol.

While, Indian government recognizes the need to reduce these harmful emissions, there is high priority placed on the economic development of the country. The facts display that India ranked fourth in the world in carbon emissions in 2003 with 348 million metric tons of carbon equivalent emitted, behind the United States, China and Russia. It achieved this place from its fifth position in 2001 very fast. It is estimated that between 1990 and 2003, India's carbon emissions increased by an astonishing 4.6%, a rate which is only comparable with China (of 4%) during the same period (http://cdiac.ornl.gov/ftp/trends/emissions/ind.dat). In fact, India's contribution to emissions in the world emissions has increased from about 2.9% in 1990 to about 4.3% in 2003 and it is expected that it will further increase to 10.6% in 2010 (WEO 2005, IEA).

Therefore, considering the situation of increasing carbon emission rates for India, it becomes extremely vital to review the existing energy use patterns which have direct bearing on emissions and bring on the agenda, the policies that reduce the greenhouse gas emissions in the coming years from India. In this context, it becomes pertinent to undertake estimation of CO_2 emissions using some model which has good scope of analyzing scenarios on various energy/technology options in an economy and so, Input-Output model was considered as one of such scientific tools.

Snapshot of the Indian energy sector

Relationship between energy consumption and economic growth is now well established in the literature (Kraft and Kraft, 1978; Erol and Yu, 1987; Hwang, Dennis, Burel, 1991 and Cheng, Benjamin and Lai, 1997). More so, in the case of India with energy consumption increasing with one of the fastest rates in the world due to high growth in population and economic development of the country (Bhattacharya and Paul, 2001). This has become an area of concern for India. With a targeted GDP growth rate of 8% during the Tenth Five year Plan (2002-2007), the energy demand is expected to grow at 5.2%. Driven by the rising population, expanding economy and a quest for improved quality of life, the total primary

energy consumption is expected to be about 412 mtoe and 554 mtoe in the terminal years of the Tenth (2007) and Eleventh FYP (2012) respectively (Planning Commission 1999).

Reviewing India's position in terms of energy, India holds 4th position in the world covering 8.6% of the proven global coal reserves estimated as 9,84,453 million tonnes by the end of 2003. India's annual crude oil production peaked at about 32 million tonne as against the current peak demand of about 110 million tonnes. In fact, in 2003- 04, the oil imports accounted for 21 billion USD which stood at about 70% of India's crude needs, imported mainly from the gulf nations. In terms of sector-wise petroleum product consumption, transport sector accounts for 42% followed by domestic and industry with 24% and 24% respectively. While, the current demand for natural gas in India is about 96 million cubic metres per day (mcmd) as against availability of 67 mcmd. Further the gas reserves are estimated at 660 billion cubic meters and gas accounts for about 8.9 per cent of energy consumption in the country (Source: British Petroleum (BP) Statistical Review of World Energy, June 2004).

In the world, out of 9741 million tonnes of oil equivalent (Mtoe) of global primary energy consumption estimates available at the end of 2003, India holds only 3% of the world, 14% of USA, 62.5% of Japan but 1.1, 1.3, 1.5 times that of Canada, France and U.K respectively (Figure 1). The per capita energy consumption is too low for India as compared to developed countries. It is just 4% of USA and 20% of the world average. Similar is the

Figure 1: Comparison of India's per capita total primary energy consumption with other countries (in Kilogram oil equivalent)

India's per capita TPES Consumption (Kgoe)
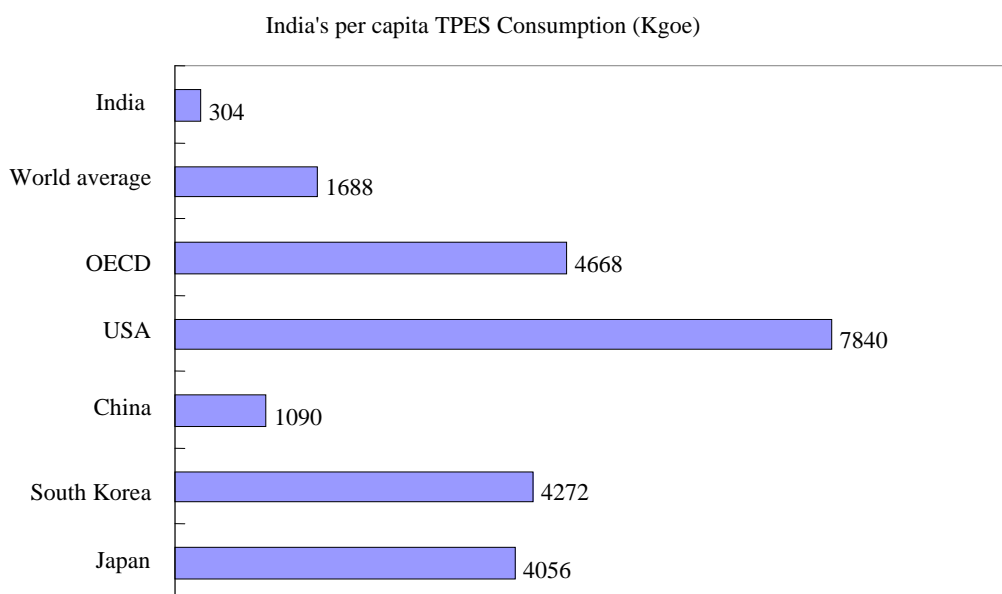
Figure 2: Comparison of India's per capita electricity consumption with other countries (in Kilowatt-hours)

India's per capita electricity consumption (KWh)
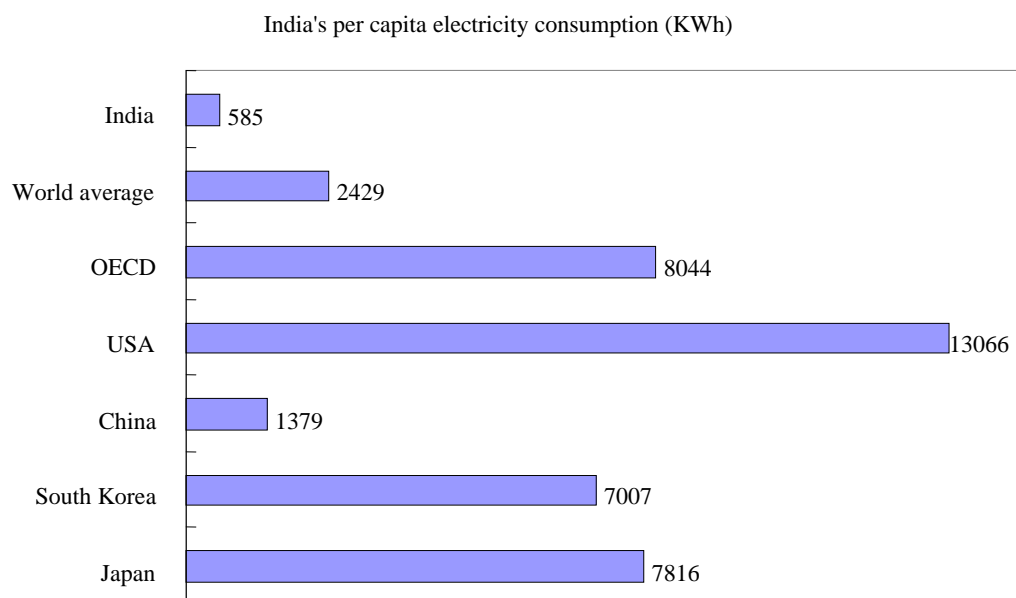
situation with electricity consumption which is much lower than the world average (Figure 2). However, the per capita consumption is likely to grow in the country with the growth in economy thus increasing the energy demand.

Figure 3 shows that coal dominates the energy mix, contributing about 55% of the total primary energy production in India. Over the years, there has been a marked increase in the share of natural gas in primary energy production from 10% in 1994 to 13% in 1999. There has been a decline in the share of oil in primary energy production from 20% to 17% during the same period. All India installed capacity of electric power generating stations under utilities was 1,12,581 MW as on 31st May 2004, consisting of 28,860 MW (26%) - hydro, 77,931 MW (69%) - thermal, 2,720 MW (2.4%) - nuclear, 1,869 MW (1.7%) - wind and 1,201MW (1.1%) - others (Ministry of Power). The gross power generation in the year 2002-03 stood at 531 billion units (kWh). India is endowed with a vast and viable hydro potential for power generation of which only 15% has been harnessed so far. The share of hydropower in the country's total generated units has steadily decreased and it stood at 25-26% as on 31st May 2004. It is assessed that exploitable potential at 60% load factor is 84,000 MW.

Price of energy does not reflect the true cost to the society in case of India. The basic assumption underlying efficiency of market place does not hold, since energy prices are undervalued and pricing practices like many other developing countries are influenced by political, social and economic compulsions at the state and central level. More often than not,

Figure 3: Share of various fuels in energy mix of India

India's primary energy resources
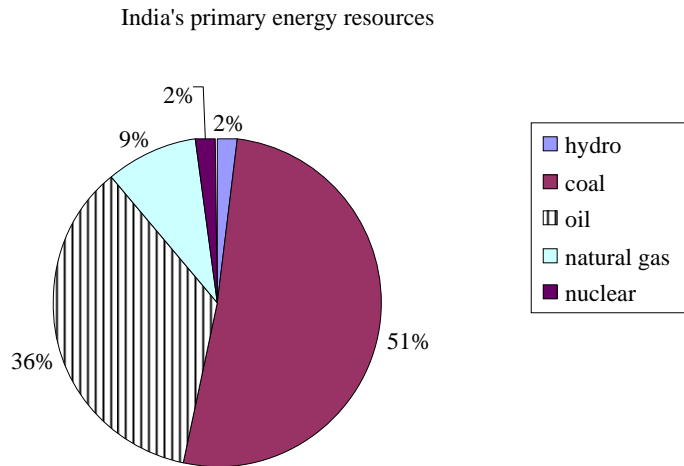
this has been the foundation for energy sector policies in India. The Indian energy sector offers many examples of cross subsidies e.g., diesel, LPG and kerosene being subsidized by petrol, petroleum products for industrial usage and industrial, and commercial consumers of electricity subsidizing the agricultural and domestic consumers.

As part of the energy sector reforms, the government has attempted to bring prices for many of the petroleum products (naphtha, furnace oil, LSHS, LDO and bitumen) in line with international prices. The most important achievement has been the linking of diesel prices to international prices and a reduction in subsidy. However, LPG and kerosene, consumed mainly by domestic sectors, continue to be heavily subsidized. Subsidies and cross-subsidies have resulted in serious distortions in prices. The government has been the sole authority for fixing the price of natural gas and has also been taking decisions on the allocation of gas to various competing consumers.

Electricity tariffs are structured in a relatively simple manner. While high tension consumers are charged based on both demand (kVA) and energy (kWh), the low-tension (LT) consumer pays only for the energy consumed (kWh) as per tariff system. The price per kWh varies significantly across states as well as customer segments within a state. Tariffs in India have been modified to consider the time of usage and voltage level of supply. In addition to the base tariffs, some State Electricity Boards have additional recovery from customers in form of fuel surcharges, electricity duties and taxes. For example, for an industrial consumer the demand charges may vary from Rs. 150 to Rs. 300 per kVA, whereas the energy charges may vary anywhere between Rs. 2 to Rs. 5 per kWh. As for the tariff adjustment mechanism, even when some States have regulatory commissions for tariff review, the decisions to effect changes are still political and there is no automatic adjustment mechanism, which can ensure recovery of costs for the electricity boards.

Since the initiation of economic reforms in 1991, there has been a growing acceptance to deepen these reforms in several economic sectors including energy sector, which was essentially in the hands of the government for several decades. As a result of this, the government has recognized the need for new coal policy initiatives and rationalization of the legal and regulatory framework that would govern the future development of this industry. One of the key reforms is that the government has allowed importing of coal to meet our requirements. Private sector has been allowed to extract coal for captive use. In petroleum sector, since 1993, private investors have been allowed to import and market liquefied petroleum gas (LPG) and kerosene freely; private investment is also been allowed in lubricants, which are not subject to price controls. Prices for naphtha and some other fuels have been liberalized. In 1997 the government introduced the New Exploration Licensing Policy (NELP) in an effort to promote investment in the exploration and production of domestic oil and gas. In addition, the refining sector has been opened to private and foreign investors in order to reduce imports of refined products and to encourage investment in downstream pipelines. Attractive terms are being offered to investors for the construction of liquefied natural gas (LNG) import facilities.

While, in the electricity sector, following the enactment of Electricity Regulatory Commission Legislation, the Central Electricity Regulatory Commission (CERC) was set up, with the main objective of regulating the Central power generation utilities. State level regulatory bodies have also been set up to set tariffs and promote competition. Private investments in power generation were also allowed. The State Electricity Boards have been asked to switch over to separate generation, transmission and distribution corporations. There are plans to link all SEB grids and form a unified national power grid.

While, on the other hand, new and renewable sources of energy have also emerged in India, though since 1970s but more emphasis has been laid in recent years due to the issues of increasing global warming and energy security. The Ministry of Non- Conventional Energy Sources (MNES) supports implementation of a large broad-spectrum of programmes covering the entire range of new and renewable energies. Such programmes seek to supplement conventional fossil fuel- based power, penetrate renewable energy, including electricity to remote rural areas for a variety of applications like water pumping, for irrigation and drinking water purposes, drying farm produce, improved chulhas and biogas plants, energy recovery from the urban, municipal and industrial wastes. In addition, exploitation of hydrogen energy, geothermal energy, tidal energy and biofuels for power generation and automotive applications has also been pushed. It is expected that the share of renewable power in the power generation capacity to be added during the 10th and 11th Plan periods would be around 10%. However, renewable presently contribute about 4800 MW, which represents about 4.5% of the total installed capacity. Wind power contributes about 2483 MW, while biomass power and cogeneration account for 613 MW and the share of small hydro power is 1603 MW (Overview of Power Sector in India 2005 (revised edition): Indiacore Publishing).

The above description of Indian energy scenario clearly shows that fossil fuels captures a large share of total energy use by the Indian economy and therefore, the energy sector plays an important role in the causing environmental concerns in India. The policy makers of India have recognized this and now the issues of sustainable development and concern for environment are major concerns and driving force behind the Indian planning process.

In the following paragraphs, details on steps followed to compile energy input-output tables for India using the Indian Input - Output Transaction Tables (IOTT) for 1993-94 and 1998-99 are described.

2.　Energy Input-Output tables and its application for India

Energy input-output tables for India are estimated in physical and thermal units to extend original Indian I-O tables provided by Central Statistical Office (CSO), Government of India for the years of 1993-94 and 1998-99. Further, the International Energy Agency (IEA) data is used to understand the information, sector-wise and energy commodity wise. The IEA regularly prepares energy balances among supply, transformation, and final consumption of several energy commodities for OECD and over 100 non-OECD countries. Therefore, the energy commodities and sectors adopted in the energy balances are converted into those of I-O tables in order to fit the energy balances into economic analysis. First, consistency of the IEA's energy balances is examined by constructing individual energy balances with the data obtained from several statistical sources and then it is compared with IEA statistics and the figures in IEA data are replaced, wherever deemed necessary.

Next, the inconsistency between the quantities and monetary values in the I-O tables is checked. The unit prices computed from the quantities and the values must be within acceptable range if they are compared with those in the available statistics. Since the monetary values in the Indian I-O tables are evaluated in basic prices, the basic prices using the micro data of Annual Survey of Industries for certain energy commodities is calculated, in addition to seeking the price figures exclusive of any taxes, subsidies and margins through available resources.

This resulted in replacing certain monetary values in the original I-O tables with new estimates; typical examples are the value of electricity inputs in agriculture and household—the effective subsidies to these sectors are extremely high. These examinations are performed with aggregated sectors whose consumption of energy is obtained from available statistics. Finally, these aggregated figures of individual energy commodities are disaggregated into 115 industries of the Indian I-O tables. For the manufacturing sectors, information obtained from the micro data of Annual Survey of Industries is used.

As a next step, the quantity and value tables derived in physical and monetary units respectively from the Use/ Absorption matrix is converted into X table using industry technology assumption, the way it is done by the CSO. The induced carbon emissions are finally derived using this table and other assumptions, described later in the paper. The modified I-O tables for 1998-99 are used to simulate or generate scenarios are described for the domestic sector based on the trend analysis of per capita energy consumption data of National Sample Survey Organization (NSSO) available energy commodity-wise. Such analysis is dealt with using micro level for urban and rural areas separately.

Finally, the results from I-O analysis are compared with the CO_2 emission estimates available from other sources such as IEA and EIA and this is followed by a few policy recommendations rather corrective actions required to be undertaken to control energy

intensive path followed by the country and some suggestions on future scope of work on this model is elaborated.

2.1 Literature survey

Estimation of carbon emissions using I-O tables has been done by various authors for several countries in the world. History reveals that notable work was done by Cumberland (1966), Ayres-Kneese (1969), Bullard-Herendeen (1975), Griffin (1976) amongst others. In the recent years, much attention has been given to extend Leontief input-output framework to account for energy use and environmental pollution associated with inter-industry activities. This section reviews papers on a) estimation of carbon emissions using I-O models and b) application of I-O models in analyzing the estimated carbon emissions. This section is divided into two parts: part one discusses the world-wide literature, while part two covers the relevant literature for India.

Snapshot of literature on I-O model and its applications world-wide

Lin (1998) analyzed the effects of economic development, investments, energy trade and environmental limitations in shaping China's energy development using I-O model. He highlighted that the share of coal in the primary energy production and consumption will increase till 2020 and then will be largely replaced by gas, nuclear and renewables. China is expected to become a big oil importer and exporter of coal in the long run. The estimates of SO_2 and CO_2 emissions for China are presented. While, Rolke, et.al. (1998) estimated direct and indirect primary energy requirements and associated greenhouse gases for a given set of Australian final consumption estimates. The author considered sectoral disparities in energy prices, capital formation and international trade flows and reported the estimates for primary energy and greenhouse gas intensities using the model.

Munksgaard, Pedersen (1999)'s paper discussed the possibility of reducing carbon emissions for Denmark by demonstrating the consequences of using two basic accounting principles: production versus consumption. By subtracting total emissions based on two principles, the authors developed the concept of "CO_2 trade balance" and has shown that CO_2 trade balance has changed dramatically turning into a deficit of 7 million tonnes from a surplus of 0.5 million tones from 1989 to 1994. Machado (2000) evaluated the impacts of foreign trade on energy use and CO_2 emissions for the Brazilian economy. A commodity by industry I-O model in hybrid units (energy commodities in physical unit and non-energy commodities in monetary unit) is applied for the years 1985, 1990 and 1995. Total energy and carbon intensity coefficients by commodity are derived and applied to the actual trade statistics to appraise the energy and carbon embodied in the non-energy foreign commerce of the country. Effects of trade liberalization on the patterns of energy use and CO_2 emissions of

Brazil are also discussed. Cruz (2002) defined economic structure, in an input-output approach, by establishing the explicit link between level of economic activity, its corresponding impact on the environment and/or the corresponding energy interactions. The paper estimated the energy intensities and CO_2 emissions derived from fossil fuel use in Portugal.

Tunc, et.al (2006) estimated CO_2 emissions for Turkish economy using an extended I-O model for the year 1996. Authors identified the sources of CO_2 emissions and 'CO_2 responsibility', which take into account the CO_2 content of imports and linked these to the foreign trade volume. The paper concluded that the major contributor of emissions is manufacturing industry followed by agriculture and husbandry sectors. While, Mongelli et.al (2006) highlighted the importance of including developing countries or economies in transition in the commitments towards Kyoto Protocol. Authors have used I-O model to calculate the intensities of energy consumption and the related GHG emission, for all the economic sectors of Italy and discussed the implication of trade relations of Italy with economies in transition and its results on carbon leakage. A paper by Alcantara,Padilla (2006) presented an approach to identify the "key" productive sectors responsible for CO_2 emission for Spain. Authors developed an I-O methodology from a supply perspective and focused on the impact of an increase in value-added of different productive sectors on total CO_2 emissions and discussed contribution of various sectors to CO_2 emission from production perspective and suggested the sectors that deserved more consideration for adopting the mitigation policies.

Paragraphs below discuss the application of I-O models for understanding carbon emission estimates for an economy. Common, Salma (1992) described I-O models for allocating Australia's total emissions across deliveries to final demand and decomposed changes in total emissions over time into components attributable to the changes in final demand, fuel mix and technology. Paper by Bossier, Rous (1992) evaluated the consequences of introduction of carbon tax for the Belgian economy by studying two scenarios using I-O tables: a) Introduction of a carbon tax of about 23.5 ecus (European Currency Units) per ton of CO_2 emitted and b) Combination of tax with incentives to energy savings investments. The results suggested that a policy-mix of taxation measures with various forms of subsidies to investments is required to meet the international requirements for stabilizing CO_2 emissions. Proops, et.al (1993) studied historical changes in CO_2 emissions for the U.S. and the European Community by decomposing economy as per fuel mix effects and sectoral output mix effects. While, a paper by Gay, Proops (1993) have used I-O tables of U.K. for the year 1984 to explore the effects of varying balance between fossil fuel and other forms of electricity generation and of changing the composition of final demand for goods and services.

Korres (1996)'s paper measured extension of structural and technological changes for the Greece economy by breaking down the total change into parts a) due to the changes in

input-output coefficients (technological change) and b) due to the changes and composition of final demand. For Taiwan, Lin, Chang (1996) used the Divisia index approach to decompose emission changes of SO_2, NOx and CO_2 from major economic sectors during the period from 1980 to 1992. The emission changes are decomposed into five components viz., pollution coefficient, fuel mix, energy intensity, economic growth and industrial structure. The authors highlighted interrelationships between energy use and environmental quality and provided insights for the policy making by recommending that improvement in energy efficiency, pollution control and fuel substitution as major options to reduce emissions for Taiwan.

Another paper by Chang, Lin (1998) employed input-output structural decomposition analysis (SDA) to examine emission trends and effects of industrial CO_2 emission changes in Taiwan during 1981-1991. Results indicated that the primary factor for increase of CO_2 emission is the level of domestic final demand and exports, while industrial CO_2 intensity over this period has reduced. While, paper by Liaskas, et.al (2000) identified factors that influenced changes in the level of industrial CO_2 emissions for European Union countries. By using decomposition method the observed changes are analyzed into four different factors: output level, energy intensity, fuel mix and structural change and results show that reduction in CO_2 emissions are possible without negatively affecting economic growth.

Hann (2001) conducted a study using SDA and discussed annual changes in number of air pollutants and solid waste decomposed according to their causes for Netherlands for during 1987 to 1998. Tuyet, Ishihara (2005) analyzed the changes of embodied energy intensity in Vietnam during 1996 to 2000 using the SDA and its power series expansion for the rice processing sector. While a paper by Lise (2006) argued that the growth of emissions in Turkey, over the period 1980-2003, was for almost 80% as a result of growing economy with 13% as a result of structural change towards more energy-intensive sectors, 13% as a result of an increase in the carbon intensity of energy and decreasing energy intensity offset these increases by 7%.

Munksgaard, et.al (2006) showed the use of I-O approach to enumerate problems of sustainable consumption. The paper demonstrated that input-output modeling has a wide range of life-cycle oriented applications when combined with other data sources such as detailed trade statistics, foreign input-output and environmental statistics and household expenditure data. While, Marriott (2007) built upon an existing economic input-output tool for the U.S., by adding details about the electricity industry, specifically by differentiating among the various functions of the sector and different means of generating power. His analysis showed that the generation assets in a region have a large impact on the environmental impacts associated with electricity consumption, while interstate trading makes the differences smaller.

An up-to-date literature collection on Japanese experiences using I-O models to understand the energy and environment issues has also been undertaken highlighting the history of Japanese I-O model that dates back to 1970. There has been very detailed

understanding on the environmental situation using such models for Japan (Appendix A)

Snapshot of literature on I-O model and its application for India

Review of available literature suggests that there is very weak database of papers on the estimation of carbon emissions using I-O model for India. Authors have mostly estimated CO_2 emissions using emission factors for various energy resources directly without adopting a detailed methodology of constructing material table. Parikh, Gokarn (1993) presented an analysis of CO_2 emissions for Indian economy using price approach through a 60 sector I-O model and examined the implications of alternative policies to reduce emissions. Direct emissions of CO_2 are highest in the electricity sector followed by iron and steel, road, air transport and coal tar. If a similar analysis by final demand is carried out, incorporating direct and indirect emissions, the highest emitting sector is construction, followed by food crops, road and air transport and so on. It is indicated that in addition to energy efficiency, improving construction efficiency will also lead to CO_2 savings. The paper highlighted that by generating alternative energy policy scenarios, if India saves energy from coal rather than from imported oil to reduce CO_2 emissions, then savings foregone are more than Rs 5634 million (about USD 135 million) for only 10% of the energy savings.

Parikh, et.al (1997) highlighted consumption patterns across different income classes in India: top 10%, middle 40% and bottom 50% in the rural and urban areas. The authors used consumption expenditure distribution data from various sources and examined direct and indirect demand on resources and CO_2 emissions due to consumption in each of these income classes. It estimated that out of total of 167 mtC of carbon emissions in 1989-90, 62% was due to private consumption, 12% from direct consumption by households and remaining 50% due to indirect consumption of intermediates like power, steel and cement, while the rest was attributed to the investments, government consumption and exports. The paper analyzed a scenario where private consumption expenditure reaches twice the 1990 level by 2010 and the CO_2 emissions were projected to rise to 502 mtC indicating that the low purchasing power of the poor results in their dependence on the nature and environment.

Murthy, et.al (1997a) investigated linkages between economic growth, energy consumption and CO_2 emissions by analyzing the structure of production and consumption patterns. They examined the consumption pattern of six different income classes, three each in urban and rural India and then estimated the direct and indirect energy and CO_2 emission coefficients for supporting production in various sectors. CO_2 emissions are projected to increase from 0.18 tonnes of carbon (tC) per capita in 1990 to about 0.62 tC per capita in 2020 under the reference scenario of GDP growth rate of 5.5% per annum. The authors have also analyzed the scenarios of technology improvement in which emissions are reduced to 0.47 tC per capita in 2020. In a paper by Murthy, et.al (1997b), the energy consumption using an I-O model for 1990 and 2005 with alternative energy efficiency programs is analyzed. It suggested that energy efficiency programs reducing the growth rate of CO_2 emissions by

about 1% will be compensated by the ambitious poverty reduction programs of the Indian government.

Mukhopadhyay, Kakali and Debesh Chakraborty (2000) investigated the patterns of energy consumption changes during reform period i.e. 1991-92 to 1996-97 and various factors responsible for these changes. SDA is developed to identify six different factors: a) technical changes b) final demand structure c) interaction term between technical change and final demand structure d) changes in energy exports e) changes in energy imports f) changes in energy change in stock. It suggested that final demand structure, technical changes, and interaction term between final demand structure and technical changes play most significant role in setting patterns of energy consumption in the Indian economy. Paper by Mukhopadhyay (2002a) addressed the issues related to energy consumption changes and CO_2 emissions from fossil fuel combustion during pre oil crisis to economic reform period (1968-69 to 1996-97). The author identified the sources of energy consumption changes using input-output SDA and estimated the CO_2 emissions. Policies are suggested for efficient utilization of energy and mitigation of emissions.

Mukhopadhyay, Chakraborty (2002)'s paper aimed to evaluate the impacts of international trade on emissions of CO_2, SO_2 and NOx for India during 90s using input-output techniques. An index of pollution is constructed in terms of trade using the I-O tables of 1991-92 and 1996-97. The results showed for indices below 100 that India produces goods that are more environment friendly than goods it imports thus indicating a large inflow of pollution embodied in trade. Mukhopadhyay (2002b) tried to estimate relationship between information technology and energy during 1973-74 to 1996-97 for India. The paper tried to assess the substitutability of information and energy for India. It justified the fact that less energy activities leads to less CO_2 emission and the results indicate that the Indian economy is walking on a path of gradual informatization process but not to the level of U.S.

A paper by Nag, Parikh (2000) attempted 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. The relative contribution and impact of different factors such as activity levels, structural changes, energy intensity and fuel mix and fuel quality on the changes in aggregate carbon intensity of the economy has been studied, taking into account the coal quality. While, another paper of Mukhopadhyay, Forsell (2002) estimated the trends of CO_2, SO_2 and NOx between the periods 1973-74, 1983-84, 1991-92 and 1996-97. Input-output SDA approach is used to find out their sources of changes. Estimated CO_2 emissions in India have increased from 191 mt to 767 mt from from 1973-74 to 1996-97, SO_2 emission has risen from 9.49 mt to 20.47 mt, while NOx has also increased from 5.69 to 21.67 mt.

Mukhopadhyay (2002c) concentrated on the CO_2, SO_2 and NOx emissions from the fossil fuel combustion only during the periods 1973-74, 1983-84, 1991-92 and 1996-97. Input-output SDA approach is used to find out their sources of change including sources such

as rate of added value, intensity of pollution, rate of technical coefficient, changes in final demand structure and joint effects. The paper estimated emissions of CO_2, SO_2 and NOx for 2001-2 and 2006-7 and suggested some key policies. Nag, Parikh (2005) provided a) time series estimates of indirect carbon emissions per unit of power consumption (which can also be thought of as emission coefficient of power consumption) and b) baseline emissions for the power sector till 2015. Annual time series data on Indian electricity generating industry, for 1974-1998, has been used to develop emission projections till 2015. Impacts of generation mix, fuel efficiency, transmission and distribution losses and auxiliary consumption are studied in a Divisia decomposition framework and their possible future impacts on baseline emissions are studied through three scenarios of growth in power consumption. The study also estimated the carbon emission coefficient per unit of final consumption of electricity.

In conclusion, the literature review clearly conveys that most of the papers have either used I-O approach to estimate carbon emissions using emission factors directly or have applied I-O approach in understanding the structural changes using SDA. Therefore, the present paper attempts to add value to the existing approaches in 3 ways. Firstly, since most of the existing studies mainly cover fossil fuel combustion, this paper covers biomass and limestone, as source for CO_2 emissions in order to reflect the actual pattern of energy use in the economy. Secondly, a detailed material (quantity) table is developed using Indian input-output tables collected for 1993-94 and 1998-99, after checking for the consistency with IEA energy balance statistics and statistics of individual Departments of Indian government. Finally, the paper discusses the scenario on household energy consumption patterns till the end of Kyoto Protocol abatement period using detailed material table derived and matched with I-O tables from CSO, GoI. Such an attempt confirms the application of I-O approach in analyzing various scenarios on the energy use as the physical or monetary values of various activity/sectors can be directly used in such framework. Further, the paper compares the carbon emission estimates from this paper with the estimates of CO_2 emissions available from other sources at the national level.

2.2 Construction of Energy Input-Output tables for India

Since the first release of the I-O table for the year 1968-69, the Central Statistical Organization (CSO) has been regularly compiling the Indian Input-Output Transaction Tables (IOTT) almost every five year(1973-74, 1978-79, 1983-84, 1989-90, 1993-94 and 1998-99). The Indian IOTTs are grouped as the UN SNA type I-O so that the Indian I-O account consists of use and make matrices[1] and the symmetric I-O tables are derived by the industry technology assumption.

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[1] Use table is referred as input matrix and make table as output matrix in the IOTT documentation.

The most detailed matrices are at 115×115 sector classification, which are identical to those adopted since 1983-84 tables. The first 32 sectors belong to agriculture, forestry, fisheries, and mining, the next 66 sectors represent manufacturing related industries, and the remaining 17 sectors cover service activities. The classification of manufacturing industries generally correspond to 4–digit level of National Industrial Classification (NIC) which is employed in the Annual Survey of Industry. Among the 115 sector classification, 6 sectors relate to energy products—023 coal and lignite, 024 crude petroleum, natural gas, 058 petroleum products, 059 coal tar products, 100 electricity, and 101 gas.

One of the most distinguishing features of Indian IOTT is that the inter-industry transactions are evaluated in terms of basic prices[2], i.e. excluding trade margins, domestic freight, and net indirect tax. One of the advantages to adopt the basic price system is that the transaction values in money term do not fluctuate in response to policy changes like tax reforms. To make the energy I-O tables we need price data to calculate the quantity in natural and thermal units by dividing the monetary values in the IOTT by the basic prices[3]. However, any additional information to convert the basic prices to the producer's and purchaser's prices such as the indirect tax and subsidy matrices are not attached. The market prices obtained from the other data sources are usually valued in terms of producer's or purchaser's prices and detailed information on them is rarely available in India as is the case with many developing countries.

The following sections describe how to adjust the discrepancy between the price–quantity data obtained outside of the Indian IO Tables and the monetary values in the IOTT.

Structure of Energy Input-Output Table

In order to achieve the first objective of compiling energy input-output table for India for 1993-94 and 1998-99, while bearing in mind the consistencies among Indian published input-output table, Energy balance table of IEA (International Energy Association) and other energy statistics of India, are used, as much as possible.

Energy input-output table in this paper consists of 1) Input-output transaction matrix in monetary unit 2) material table which shows detailed sectoral energy inputs in physical unit 3) calorific table 4) combustion ratio table 5) CO_2 emission factor table and 6) CO_2 emission volume table. Indian Input-output transaction matrix in monetary unit is available from CSO (2000) and CSO (2005)[4]. Material table is compiled based on energy balance data from IEA and other energy statistics of India, with much caution taken for the consistencies with monetary Input-output table. CO_2 emission factor, emission per output, can be derived from material table, caloric table, and combustion ratio.

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[2] Again, basic price is referred as factor cost in the document.
[3] In consequence, the value added for each industry is defined as the difference between the value of output and intermediate inputs in terms of basic price and is not separated into individual items such as compensation of employees, consumption of fixed capital and so on.
[4] http://mospi.nic.in/cso rept pubn.htm

With this type of input-output table, it is expected to calculate induced CO_2 emission volumes, corresponding to the level of final demand. Moreover, here, the idea is to estimate the changes in emission factor by applying scenario analysis on energy mix in material table as the physical information can be directly used in such tables.

Energy Balance Table (EB) and Input-Output Table (I-O)

Before explaining the procedure of compilation of material table, the relationship of Energy balance data and input-output table is explained. The EB shows the flow of energy commodities, while I-O shows the flow of goods and services, in one economy. As they have different origins and purposes, there are several differences in the presentations, concepts and treatment between EB and I-O as follows:

- Unit of Measurement: I-O is recorded in monetary values, while the unit of EB table is given in physical values, thousand tonnes of oil equivalent (ktoe).
- Format: In the transaction matrix or use matrix of I-O, column wise sectors are demand sectors (or users) of goods and services, while row sectors are suppliers. In EB, users of energies are listed in rows and energy commodities are listed in columns. In a very simplistic explanation, EB must be transposed to fit with I-O format.
- Classification of sectors: In EB, energy related sectors are more segregated than in I-O, while other sectors are more aggregated than I-O. To reformat EB into I-O format, part of energy commodities must be aggregated, while several non energy sectors must be segregated. General segregation principle is using the nominal input share in I-O.
- Sign of values: In general, every commodity inputs except decrease in inventories and import are entered in positive value in I-O. On the other hand, in EB, values have signs with following convention:
  - Primary energy supply: production (+), export (-), import (+), increase in inventory (-)
  - Energy Transformation: inputs (-), generation (+)
  - Final consumption: inputs (+)
- Captive electricity generation in industries: In EB, captive electricity generation is included in one of energy transformation sectors- Electricity plants. In I-O, there are several ways to treat this kind of activity, i) included in the output of industries where it is generated as primary output ii) included in the output of industries where generated as secondary output iii) output and associated inputs are transferred to electricity sector and iv) output and associated inputs are transferred to factious industry representing own-electricity.
- Energy use for own transportation: In EB, all energies used for the purpose of transportation, whether used in transportation sector, other industries or household,

are entered in transportation sector. In I-O, there are several ways to treat this kind of activity i) included in the output of industries as primary output ii) included in the output of industries as secondary output iii) output and associated inputs are transferred to transport sector and iv) output and associated inputs are transferred to factious industry representing own-transportation.

- Energy sector own use: In EB, energies used in energy sectors for non-transformation purposes are entered in the heading of own use under energy transformation. In I-O, those inputs are entered in the diagonal cell: energy inputs by energy sector.

Mapping of EB and I-O

I-O table is compared with the EB table of IEA in order to understand the detailed information for energy commodities. The mapping reveals as follows:

- The output value of primary energy product (such as coal, crude oil) in I-O corresponds with the primary energy production of EB.
- The output value of secondary energy product (such as coal/petroleum products, electricity) in I-O corresponds with the produced amount in transformation sector in EB.
- The input value of energy products to other energy production in I-O corresponds with the consumed amount in transformation sector in EB.
- The diagonal value in I-O corresponds with the own-use/distribution losses in transformation sector in EB.
- The other input values of energy products to non-energy sector in I-O correspond with the amount in the final consumption sector on EB.

Criteria for the consistency

In this paper, the consistency of I-O and IEA-EB is defined in the following sense.

- Balance: For each energy item, total inputs (consumption) and total outputs (production) must be equal in both the quantity and monetary units.
- Coverage: The coverage of each activity in EB must be consistent with that of I-O.
- Consistencies in entries: The entries in physical I-O must be consistent with those of the I-O in monetary unit. For example, if an energy input of an activity is 0 in one of the tables, the corresponding input in the other must be also 0.
- Prices: The unit prices computed from the quantities in EB and monetary values in I-O must be within acceptable range compared with the values available in publications and intuition of researchers and statisticians.

Compilation Procedure

The following section describes the steps followed for the compilation in general.

- Construct individual energy balances for energy commodities from several official statistics (Annex I, II, III). Compare the values constructed with the data of IEA EB and complement and modify the data either of IEA-EB or constructed one, where necessary.
- Reformat energy balance data into I-O format at aggregated level. Check the inconsistency between the quantities and monetary values in the I-O tables. The unit prices computed from the quantities and the values must be within acceptable range, if they are compared with those in available statistics.
- Disaggregate into 115 sectors using nominal share of I-O.
- Attach other information to calculate sectoral CO_2 emissions, such as calorific table, combustion ratio.

Energy Balance for Individual Energy Commodities

Data from I-O is also checked for consistency by constructing individual energy balances for various energy commodities as given below:

- Coal, lignite and coal products
  Energy balance table for this type of commodities is shown in Annex I. This sector includes raw coal, lignite, coke, (tar) coal gas, etc. It is assumed that most of the consumption (except Steel Plant) is non-energy use as tar, as the availability of data of coal products is very low.
- Petroleum, natural gas
  The balance table of this sector is shown in Annex II.
- Natural gas
  The input of natural gas in agriculture is assumed mainly for drying of leaves for tea plantation.
- Crude oil
  The treatment of transfer from Natural Gas Liquid (NGL) to Liquefied Natural Gas (LPG) and Naphtha is accounted as:
  - NGL output is considered into petroleum and natural gas production
  - LPG input into LPG and gross output
  - Naphtha input into naphtha and gross output
  - Statistical differences are considered in stock changes
- Petroleum products
  - Statistical differences are considered in stock changes
  - LPG, non-energy use products are taken as disaggregate in industry and commercial sectors
  - Non-specified transport: This amount includes the transport by private cars. Disaggregate to whole sector.
- Electricity

The Balance table of this sector is shown in Annex III.

- Biomass

Production or consumption data of biomass is rarely available because most of the biomass is not traded in the commercialized way, thus overall picture is not captured by the statistics.

Figure 4: Energy Input-Output table
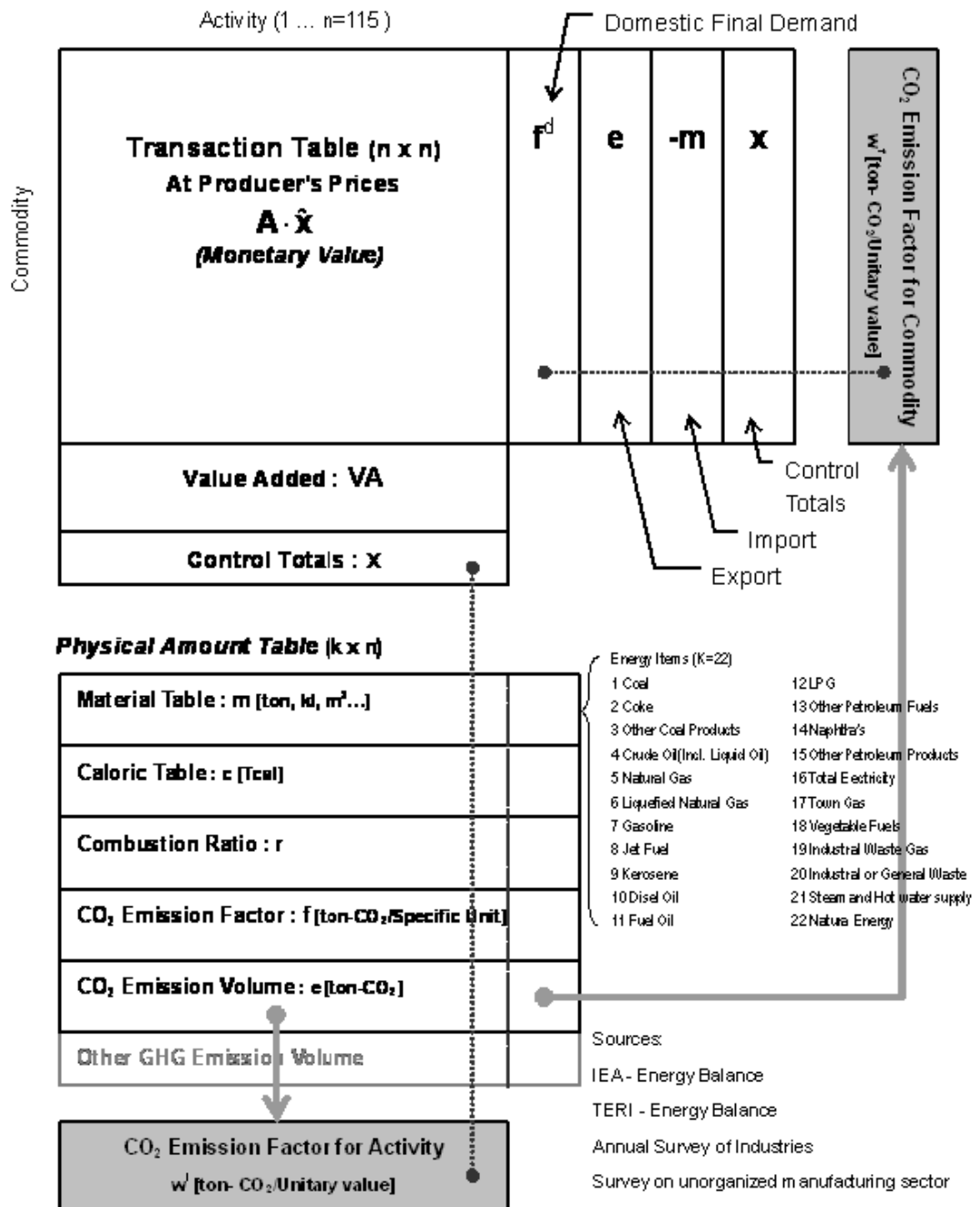
Figure 5: Input-Output table and energy balance table
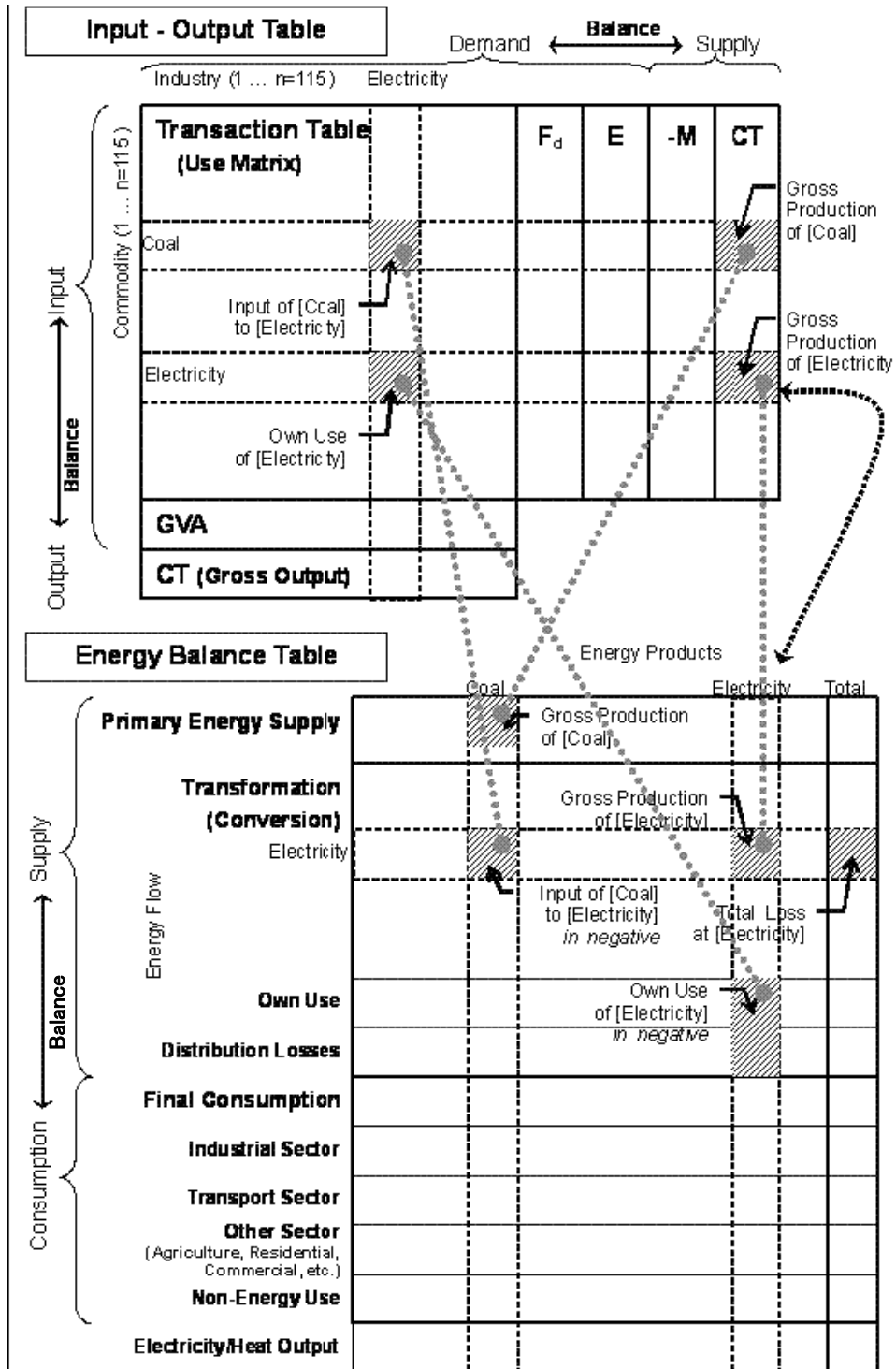
3. Methodology on estimation of CO_2 emissions using Energy Input-Output tables

Following section discusses the estimation procedure followed to calculate CO_2 emissions for India.

i) $(\mathbf{I} - \mathbf{A})^{-1}$ type

In a steady condition, balance of system requires

$$\mathbf{x} = \mathbf{A}\mathbf{x} + \mathbf{f} \qquad (1)$$

$\mathbf{x}$: Control Totals (Gross Output) vector in commodity classification

When coefficient matrix $\mathbf{A}$ and final demand vector $\mathbf{f}$ are given, the solution for Gross Output $\mathbf{x}$ is available as follows (in the case that A is square matrix):

$$\mathbf{x} = (\mathbf{I} - \mathbf{A})^{-1} \mathbf{f} \qquad (2)$$

$(\mathbf{I} - \mathbf{A})^{-1}$: Leontief inverse

$$= (\mathbf{I} + \mathbf{A} + \mathbf{A}^2 + \mathbf{A}^3 + \mathbf{A}^4 \dots)\mathbf{f}$$

$$= \mathbf{f} + \underline{\mathbf{A}\mathbf{f} + \mathbf{A}^2\mathbf{f} + \mathbf{A}^3\mathbf{f} + \mathbf{A}^4\mathbf{f}\dots} \qquad \text{indirect and infinity repercussion}$$

$\mathbf{A}\mathbf{f}$: Primary Repercussion, $\mathbf{A}^2\mathbf{f}$: Secondary Repercussion,...

CO_2 emission Y is estimated as follows:

$$Y = \mathbf{W^i}\,\mathbf{x} + \mathbf{W^f}\,\mathbf{f^d} + \mathbf{W^r}\,\mathbf{R}\,\mathbf{M} \qquad (3)$$

$\mathbf{W^i}$: row-vector of CO_2 emission factor for intermediate sectors. Emission factor w^i_i [ton-CO_2 /unitary production (Rs-Lakhs)] is defined as CO_2 emission amount occurred from unitary output of i-th activity.

$\mathbf{W^f}$: row-vector of CO_2 emission factor for final demand sector. Emission factor w^f_i is defined as CO_2 emission amount occurred from unitary consumption of i-th commodity in final demand.

$\mathbf{f^d}$: vector of Domestic final demand, $\mathbf{f} = \mathbf{f^d} + \mathbf{e} - \mathbf{m}$

$\mathbf{W^r}$: row-vector of CO_2 emission factor for external sectors to produce imported commodity. Emission factor w^r_i is defined as CO_2 emission amount occurred from unitary output of i-th activity in the Rest of the World.

$\mathbf{R}$: matrix of production induction coefficient at the Rest of the World.

Under the assumption that all imported commodities are produced in the same way as domestic, it can be assumed that $\mathbf{R} = (\mathbf{I} - \mathbf{A})^{-1}$, and $\mathbf{W^r} = \mathbf{W^i}$.

Then, $\quad Y = \mathbf{W^i}(\mathbf{I} - \mathbf{A})^{-1}(\mathbf{f} + \mathbf{m}) + \mathbf{W^f}\mathbf{f^d} = \mathbf{W^i}(\mathbf{I} - \mathbf{A})^{-1}(\mathbf{f^d} + \mathbf{e}) + \mathbf{W^f}\mathbf{f^d}$

$$= \quad \mathbf{W^i}(\mathbf{I} - \mathbf{A})^{-1} + \mathbf{W^f} \quad \mathbf{f^d} + \mathbf{W^i}(\mathbf{I} - \mathbf{A})^{-1}\mathbf{e}$$

$\mathbf{W^i}(\mathbf{I} - \mathbf{A})^{-1}$:embodied CO_2 emission factor vector for domestic products.

ii) $[\mathbf{I} - (\mathbf{I} - \hat{\mathbf{m}})\mathbf{A}]^{-1}$ type (Competitive import model)

Input-Output table means domestic industrial structure in one country. The flow value on the existing facilities in the country is evaluated. Additionally, the imported products are examined. The production process of these does not exist in this country. By the following method, influence of domestic products and imported products is evaluated.

In a steady condition, balance of system requires

$$\mathbf{x} = \mathbf{A} \cdot \mathbf{x} + \mathbf{f}^{d} + \mathbf{e} - \mathbf{m} \tag{4}$$

$$\mathbf{m} = \hat{\mathbf{m}} \cdot (\mathbf{A} \cdot \mathbf{x} + \mathbf{f}^{d}) \tag{5}$$

where $\hat{\mathbf{m}}$ = diagonal matrix with diagonal elements as import coefficient. import coefficient of i-th commodity is defined as $\dfrac{m_i}{\sum_j (a_{ij} \cdot x_j) + f_i^{d}}$

$\mathbf{f}^{d}$: Vector of Domestic final demand, $\mathbf{e}$: Vector of Exports and the domestic production $\mathbf{x}$ is solved as follows

$$\mathbf{x} = [\mathbf{I} - (\mathbf{I} - \hat{\mathbf{m}})\mathbf{A}]^{-1}[(\mathbf{I} - \hat{\mathbf{m}})\mathbf{f}^{d} + \mathbf{e}] \tag{6}$$

CO_2 emission Y is estimated as follows:

$$Y = \mathbf{W^i}\,\mathbf{x} + \mathbf{W^f}\,\mathbf{f}^d + \mathbf{W^r}\,\mathbf{R}\,\mathbf{m} \tag{7}$$

$\mathbf{W^i}$: row-vector of CO_2 emission factor for intermediate sectors. Emission factor w_i^i is defined as CO_2 emission amount occurred from unitary output of i-th activity.

$\mathbf{W^f}$: row-vector of CO_2 emission factor for final demand sector. Emission factor w_i^f is defined as CO_2 emission amount occurred from unitary consumption of i-th commodity in final demand sector.

$\mathbf{W^r}$: row-vector of CO_2 emission factor for external sectors to produce imported commodity. Emission factor w_i^r is defined as CO_2 emission amount occurred from unitary output of i-th activity in the Rest of the World.

$\mathbf{R}$: matrix of production induction coefficient at the Rest of the World. Under the assumption that all imported commodities are produced in the same activities with domestic, we can put $\mathbf{R} = (\mathbf{I} - \mathbf{A})^{-1}$, and $\mathbf{W^r} = \mathbf{W^i}$.

4. Scenarios constructed for simulation of EIO model

Scenarios are useful tools used for the scientific assessments, for learning about complex systems behavior and for policy making. Each scenario is an alternative image of how the future can unfold. These are neither predictions nor forecasts. In this paper, scenarios on the future energy use profile of Indian households are discussed in order to study its impact on the carbon emissions from India by 2011-12.

As per Census 2001 of Government of India (GoI, 2001), the population of India was around 1.027 billion in 2001. In order to undertake scenario analysis, population projections of Population Foundation of India (PFI) are used. These projections are based on the 'Component method[5]' where PFI estimates the growth rate to be 1.37 percent for the period 2001-2011. The reason for using PFI estimates is that PFI relies on more country specific details and these population projections are used by the Office of Registrar general of India that conducts the population census in the country after every ten years. Moreover, Planning Commission also adopts the population projections provided by PFI for formulation of various national plans and policies in India.

Though India's population has more than doubled during 1951-2001 from 361 million in 1951 to 1027 million in 2001, its rural-urban distribution has undergone structural changes over the period. India's rural population has more than doubled (about 2.5 times) from 298 million during 1951 to 740 million by the year 2001, whereas population in urban areas has increased more than four times (about 4.6 times) from 62 million to 287 million during the same period. The percentage shares of population residing in urban and rural areas as projected by the PFI are adopted in this analysis to ensure consistency with the set of population projections. Percentage shares of rural and urban populations have also been assumed to change on the basis of 10-yearly CAGR (Compound Annual Growth Rate). Total population data for years between these has been interpolated on the basis of 10-yearly Compound Annual Growth Rate (Table 1).

Table 1: Actual and projected population and urban -rural distribution in percentage

Year	1993-94	1998-99	2004-05	2008-09	2011-12
Urban (in million)	226	249	296	328	377
Urban (in %)	26	27	28	30	32
Rural (in million)	653	719	769	788	800
Rural (in %)	74	73	72	70	68

Source: PFI and Census of India

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[5] The component method for population projections separately studies drivers of future size of the population such as fertility, mortality and migration rates.

The main reason for selection of domestic sector is that it is the largest consumer of energy accounting for 40-50% of the total energy consumption in India. Though, bulk of it consists of traditional fuels in the rural households (Source: NSSO). Rapid urbanization and diverse urban growth patterns have led to many structural changes in the economy that have important ramifications for energy use. Such as growth in income is leading to an increased demand for energy - particularly electricity end use - and energy-intensive products and services and this is shown in the increased per capita energy use consequence (NSSO). In fact, the domestic sector in India is responsible for 13.3% of the total commercial energy use (TEDDY 2003-04). Figure 6 shows that use of petroleum products (including LPG, SKO and others) has been growing rapidly in domestic sector that is much more than the rate of increase in production of crude oil.

Data from NSSO reveals that energy services make up a sizeable part of the total household expenditure in India. Composition of consumption expenditure for 2004-05 in the rural and urban India show that food comprises of 55% and 43% respectively and this is

Figure 6: Domestic consumption and production of crude oil
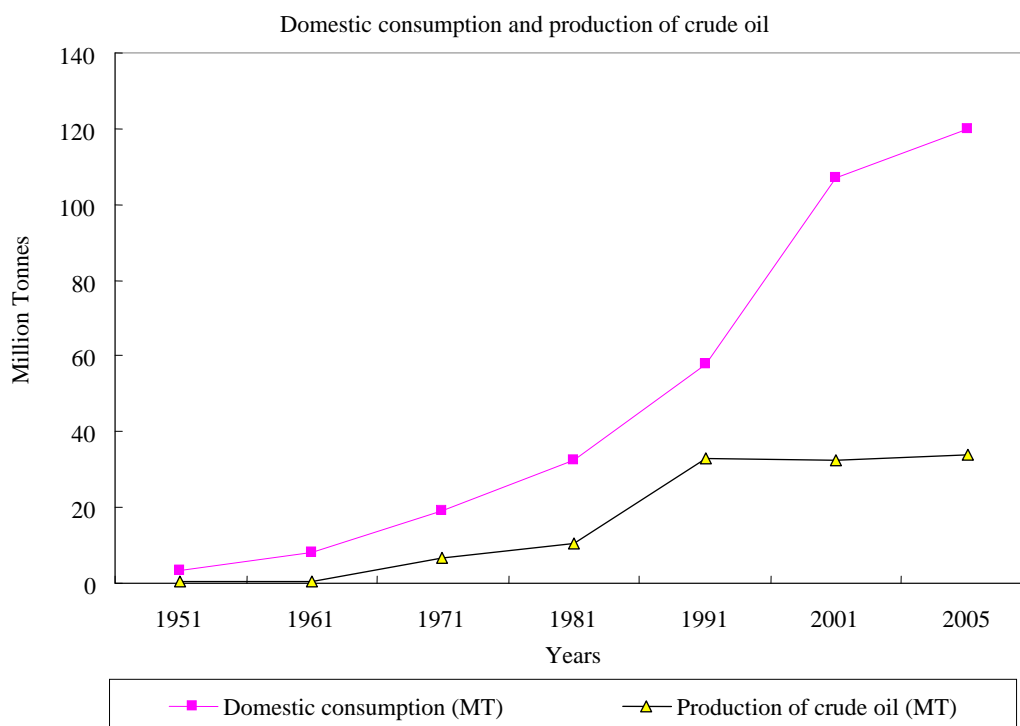
Source: Ministry of Petroleum and Natural Gas, Government of India

followed by fuel and light[6] that takes up about 10% of the total consumer expenditure. It is worth noticing that the share of fuel and light in total consumer expenditure in India has risen from under 6% to 10% in both rural and urban areas between 1972-73 and 2004-05. In addition, information on the use of other indirect energy commodities such as petrol, diesel and other conveyance[7] has also been collected and analysed. It was observed that conveyance expense also holds 4% and 7% of total expenditure by rural and urban household as on 2004-05 (NSSO). However, detailed mapping of various means of conveyance and its patterns of change has not been integrated with I-O framework in this paper. In this paper it has been assumed that the same percentage share of expense on conveyance continues over the projection period as well.

The direct energy in domestic sector is required for lighting, cooking, lighting, water heating and other purposes. Information on per capita use of various energy commodities including kerosene, LPG, fuel wood and chips, biogas, coal, coke, cow dung and electricity has been analyzed to study changing patterns of fuel consumption for mainly cooking and lighting activities in India.

In fact, energy mix for cooking shows that traditional fuels are predominantly used. In the rural areas, households mainly use three primary sources for cooking- firewood and chips, dung cake and LPG. In 2004-05, firewood and chips continued to be the most important source of energy used for cooking in rural India, with 75% of the rural households dependent upon it. Only 1% of rural households have switched away from this source since 1999-2000. In the urban sector, kerosene (10%), firewood and chips (22%), and LPG (57%) are the important sources of energy used for cooking and there has been an increase of about 13 percentage points in the use of LPG and a decrease of 12 percentage points in the use of kerosene since 1999-2000 (NSSO).

Significant changes in use of fuels have taken place in rural and urban India between 1993-94 and 2004-05. Prevalence of LPG use has doubled in urban India from 29.5% (percentage of consuming households) in 1993-94 to 59% in 2004-05. In rural India, the increase in use of LPG from a smaller base level of about 2% to 11.7% of households may be considered even more spectacular. A five- or six-fold increase in per capita. LPG consumption is also indicated in the rural sector, while in the urban sector the increase is about 80%. While the rise of LPG in urban areas appears to be at the expense of kerosene, per capita consumption of which has dropped from 1.42 litres per month to 0.62 litres, no such decline is seen in rural India. Rural electricity consumption in kwh per person per month has increased to two and a half times its level in 1993-94 (from 2.27 to 5.67). In urban areas, too, per capita consumption of electricity has more than doubled. Households using electricity

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[6] The fuel and light expenditure includes expenditure incurred on coke, firewood and chips, electricity, dung cake, kerosene-(PDS and other sources), coal, LPG, charcoal, gobar gas and other fuels.

[7] The conveyance expenditure includes expenses made towards air travel, railway travel, bus/tram fare, taxi, auto-rickshaw, steamer, boat, rickshaw (hand drawn & cycle), horse cart, porter charges, petrol, diesel, lubricating oil, school bus/van and other conveyance expenses.

formed about 34% of rural households in 1993-94 and as much as 54% in 2004-05. In urban areas the proportion of households using electricity rose from 74% to 90% during the same period.

At the national level, electricity and kerosene together served about 99% of the households as primary source for lighting in both rural and urban areas. There has been an increase in proportion of households using electricity as major source of lighting by 7 percentage points (from 48% to 55%) in rural areas and by 3 percentage points (from 89% to 92%) in urban India between 1999-2000 and 2004-05. There was a drop in the percentage of households using kerosene as primary source of energy for lighting from 51% to 44% in rural India and from 10% to 7% in urban India, since 1999-2000.

Therefore, in scenario analysis, it has been assumed that patterns of energy consumption stay very much the way it is and for this data from various NSSO rounds (from 1987-88 till 2004-05) are used to determine estimates for final demand of various energy commodities in physical and monetary terms based on trend method and using population estimates detailed above. It has also been assumed that the proportions of expenses including that on direct energy use for a household in rural and urban settings stays the same, as was it for the year 1998-99.

An attempt is made to map commodities in NSSO and I-O classification. However, it was found that such mapping was rather difficult and there exist huge differences between the way data is collection in NSSO and in I-O. Therefore, some approximations were used and future demand figures for various energy commodities are applied in EIO framework, which is prepared in physical quantity and monetary values, to estimate induced CO_2 emissions from India for the years 2004-05, 2008-09 and 2011-12. Further, analysis on scenarios is progressing and it is felt that couple of scenarios can be piled one above the other in order to compare results in terms of CO_2 emissions for India.

Scenarios that can be considered include increase in share of electricity over kerosene for lighting due to the reason that a policy on introduction of Rajiv Gandhi Grameen Vidyutikaran Yojana by the Government of India in the electricity sector is introduced (April 2005,MoP). This expects that all the households will have access to electricity by the year 2010-11. However, assuming that a metered connection in every household will only happen by the year 2020 or so, it is better to assume that about 90% of the rural population will have electricity for lighting by the year 2011-12. It reflects that there will be decline in the use of kerosene for lighting and that share will be picked up by the electricity. Similarly for cooking, it can be assumed that inferior fuels like firewood and kerosene will be displaced by cleaner fuels such as LPG to certain extent.

5. Analysis and discussions

At the moment one scenario is analyzed for this paper. The results of this scenario provide the following estimates of induced CO_2 emission for India. It can be seen clearly from the model that carbon emissions estimates are increasing for India and if no corrective measures are undertaken to control existing energy use patterns in the economy, there may be serious consequences of that.

It can be seen from table 2 that carbon emission estimates from this model are comparable for the years 1993-94 and 1998-99. However, it is somewhat different for the future years, which may be because of assumptions used in this paper vis-a-vis assumptions used in estimating in other sources. Therefore, it is important to understand the assumptions used by other sources while comparing estimates from I-O framework and it is not correct to just follow the figures. However, it is also important to integrate the parameters of technology, its' efficiency and others such as price changes etc. to run this model for estimation of future CO_2 emissions.

There are few keys recommendations that flow from this paper such as:

- Confirmation of induced CO_2 emission estimates for the base years (1993-94 and 1998-99) using I-O shows that such an exercise is worthwhile as a research tool to be explored further by the researchers.
- Scenarios for the future years and simulation of this model will be more realistic, if detailed data on not just fuel demand (which has been changed in final demand by household sector in I-O framework and rest of the assumptions such as technology etc. kept constant) but also on proper technology (efficiency parameters, etc.), investments and share of people using various technologies etc. are integrated.

Table 2: Estimates on induced CO_2 emissions (in Million Metric Tonnes of Carbon) from I-O model and its comparison with other estimates

Years	IEA	EIA	I-O
1993-94	192	187	200
1998-99	239	235	200
2004-05	296	293	282
2008-09	334	331	420
2011-12	365	362	580

Source: World Energy Outlook, 2005 for IEA
      International Energy Outlook by Energy Information Administration, U.S. for EIA
      Author's Calculation for I-O

Note: The estimates of CO_2 emissions from IEA and EIA are interpolated for the years such as 1993-94, 1998-99 and other forecasting periods considered in this study so that it can be compared with the results from I-O model.

6. Future scope of work

This paper is an attempt to modify the Indian IOTT into EIO so that it can be best utilized for the scenario analysis as technological and physical information can be directly used in this framework. It looks more at the potential application of I-O models. Moreover, the energy input-output table for India has 115 sectors presently, the scenario development with more detailed information will be possible. Additionally, I-O table data for the latest year 2003-04 is still awaited from Government of India and once that is made available; some more improvements can be done in the model and assumptions used in the scenarios to arrive at carbon emissions in the future for India.

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Appendix A

The Input-Output Table for the Analysis of Energy and Environment in Japan

In 1971, the Ministry of International Trade and Industry (MITI) constructed "the Input-Output Table for the Analysis of Environmental Pollution in 1968". This attempt to make the input-output table for the analysis of environmental pollution was the first case in the world. Subsequently, MITI created "the Input-Output Table for the Analysis of Environmental Pollution in 1973" in 1976. The former was a regional table, while the latter was a national table. The subjects of investigation were SOx, COD, suspended solids and industrial wastes. The research group headed by Yoshioka in Keio Economic Observatory (KEO), Keio University, in 1992, compiled "the Input-Output Table for Environmental Analysis in 1985" which targeted at CO_2, SOx and NOx (Yoshioka et al. (1991, 1992), Hayami et al. (1993, 1997)). They estimated energy inputs, heat inputs and emissions by sectors as the additional table of the input-output transaction table. The table has been used for the lifecycle assessment (LCA) of various technologies -power generation, steel production, motor vehicle production, recycling process and so on, the analysis of the relationship between consumers' behavior and environment and the estimation of CO_2 emissions embodied in the bilateral trade (Asakura et al. (2001), KEO (2002a), Hayami et al. (2005), Lenzen et al. (2006), Hayami and Nakamura (2007)). Following this study, various research institutes and firms started making the input-output tables for the analysis of energy and environment. The National Institute for Environmental Studies (NIES) (Moriguchi et al. (1993), Kondo et al. (1996), Nansai et al. (2002, 2003)) and the Central Research Institute of Electric Power Industry (CRIEPI) (Hondo et al. (1999a,b, 2002)) are leading institutes. The former institute estimated not only CO_2, SOx and NOx but also SPM. The latter one also expanded the table and estimated energy inputs for extraction, production and shipping of imported goods, and the other greenhouse gases such as NH4 and N2O. They have ample experience of the LCA of various technologies (Moriguchi et al. (1993), Terazono et al. (2000), Makuta et al. (2000), Nanasai et al. (2001), Hondo (2005)). The research group in NIES has combined the input-output analysis with the material flow analysis (Moriguchi (1999)) and recently developed the indicator for eco-efficient consumption activity (Nansai et al. (2007b,a)). "Hybrid LCA" or "Related Process model" is currently used as the methodology of LCA which combines the top down input-output model and the bottom up process analysis (Yoshioka et al. (1998), Matsuhashi et al. (2000), Dowaki et al. (2002), Kudoh et al. (2003), Shima et al. (2005)). Regarding environmental assessment of joint production, Yoshida et al. developed "the Three-Dimensional Input-Output Table" (Yoshida et al. (2000)). Nishimura et al. of the CRIEPI applied the law of conservation of matter to the input-output framework and analyzed the joint production (Nishimura et al. (1996, 1997)). Developing the international input-output table including Japan which represents the interdependency of global economy is needed to

estimate accurate environmental load of imported goods. In 1995, the Research Institute of International Trade and Industry, MITI constructed "the Japan-China's Input-Output Table for the Analysis of Energy and Air Pollutants Using Comparable Industry Classification in 1985" aimed at CO_2 and SOx, collaborated with KEO, the National Bureau Statistical of China, and the State Environmental Protection Administration of China (Hayami and Kiji (1997)). MITI, New Energy and Industrial Technology Development Organization (NEDO), the Institute of Energy Economics, Japan (IEEJ), and the Institute of Developing Economies, Japan External Trade Organization (IDE-JETRO) made the input-output tables for the analysis of energy and environment in the

East Asian countries (NEDO (1999a,b)). Following these attempts, KEO and the National Statistics Bureau in the East Asian countries jointly compiled "the Economic Development and Environmental Navigator (EDEN)" table which was the Chenery-Moses type table (KEO (2002a,b)). Shimpo developed the EDEN table to the Isard type international input-output table (Shimpo (2002b)). He also constructed the multi-sectoral economic model using this database and ran a simulation of CO_2 emission limitation in Japan (Shimpo (2002a)). There are many study examples used the input-output table for the analysis of energy and environment as the database of the multi-sectoral econometric model and CGE model (Yajima and Uchida (1991), Shimpo (1993), Itoh et al. (1993), Kuroda and Shimpo (1993), Kuroda and Nomura (1998, 2001)). The research group centered on Nakamura in Waseda University focused on municipal and industrial wastes and developed "the Waste Input-Output Table" (Kondo et al. (2002), Nakamura and Kondo (2002b,a, 2006b,a), Kondo and Nakamura (2004, 2005), Takase et al. (2005), Nakamura and Nakajima (2005)). They estimated not only lifecycle environmental load of technologies but their lifecycle cost. Ikaga and Tonooka built the fixed capital formation matrix into the intermediate transaction and assessed the environmental impacts of buildings and plants (Ikaga and Tonooka (2000b,a)). Kagawa et al. made the decomposition analysis for structure change of energy demand (Kagawa and Inamura (2001), Inamura and Kagawa (2004)). They also conducted the national and regional input-output model for waste analysis (Kagawa et al. (2003, 2004)).

Annex I-1 Energy Balance of Coal & Lignite & Coal Products in 1993-94

1993-94 (Million Tonnes)	Raw Coal	Coking	Non-Coking (Steam Coal)	Lignite	Washed Coking Coal	Middlings (coking coal Washery)	Hard Coke	Soft Coke	CIL Coke	Coke Fines	Tar	Coal fines	Ledo Coke	Urea	Others	Coke Oven Gas (TJ)	Blast Furnace Gas (TJ)
	Solid Fossil Fuel				**Coal Products**												
Production	248.687	44.659	204.028	18.098	12.125	6.613	12.199	0.428	0	0	0	0	0	0	0.976	91,896	106,026
Opening Stock	51.392	15.836	35.556	1.06													
Availability	300.079	60.495	239.584	19.158	12.125	6.613	12.199	0.428	0	0	0	0	0	0	0.976	91,896	106,026
Pit-Head Closing Stock	50.748	14.762	35.986	1.182													
Stock Changes	-0.644	-1.074	0.43	0.122													
stat. diff.	0.355	0.426	-0.07095	0													
Off-take	248.976	45.307	203.669	17.976	12.125	6.613	12.199	0.428	0	0	0	0	0	0	0.976	91,896	106,026
Colliery Consumption	3.825	0.696	3.129	0.087													
Despatches	245.151	44.611	200.54	17.889	12.125	6.613	12.199	0.428	0	0	0	0	0	0	0.976	91,896	106,026
Import	7.33	6.936	0.394				0.175										
Export	-0.1		-0.1														
Net Availability	252.381	51.547	200.834	17.889	12.125	6.613	12.374	0.428	0	0	0	0	0	0	0.976	91,896	106,026
Stats. Diffs.	0.491			0	0	0	1.9007	0	0	0	0	0	0	0	0	1,020	2,894
Consumption Total	251.89	18.806	6.232	17.889	12.125	6.613	10.473	0.428	0	0	0	0	0	0	0.976	90,876	103,131
Steel and Washery	37.63	18.806	6.232				10.473									90,876	103,131
Railway (Loco)	2																
Electricity	154.41			12.054													
Cement	11.07																
Cotton	1.81																
Jute	0																
Paper	2.9																
Brick (by Railway)	1.54																
Coal for soft coke	0.56																
Fertilizer	4.85																
Brick Kilns, Textiles, Chemicals, Paper, Other Industries	0																
Other industries	0																
Total	216.77	18.806	6.232	12.0538	0	0	10.473	0	0	0	0	0	0	0	0	90,876	103,131
Domestic	0.44																
Other consumers	34.68			5.835	12.125	6.613		0.428							0.976		

Annex I-2 Energy Balance of Coal & Lignite & Coal Products in 1998-99

1998-99 (Million Tonnes)	Solid Fossil Fuel				Coal Products											Coke Oven Gas (TJ)	Blast Furnace Gas (TJ)
	Raw Coal	Coking	Non-Coking (Steam Coal)	Lignite	Washed Coking Coal	Middlings (coking coal Washery)	Hard Coke	Soft Coke	CIL Coke	Coke Fines	Tar	Coal fines	Ledo Coke	Urea	Others		
Production	296.508	39.176	257.332	23.419	9.719	7.161	13.038	0.01	0.111	0.049	0.2624	0.1925	0.2053	0.0678		107,862	114,608
Opening Stock	41.466	12.113	29.353	0.254													
Availability	337.974	51.289	286.685	23.673	9.719	7.161	13.038	0.01	0.111	0.049	0.2624	0.1925	0.2053	0.0678	0	107,862	114,608
Pit-Head Closing Stock	40.097	8.24	31.857	0.398													
Stock Changes	-1.369	-3.873	2.504	0.144													
stat. diff.	6.035	2.750	3.285	0	0	0	0	0									
Off-take	291.842	40.299	251.542	23.275	9.719	7.161	13.038	0.01	0.111	0.049	0.2624	0.1925	0.2053	0.0678	0	107,862	114,608
Colliery Consumption	2.893	0.3995	2.4935	-0.092													
Despatches	288.949	39.9	249.049	23.367	9.719	7.161	13.038	0.01	0.111	0.049	0.2624	0.1925	0.2053	0.0678	0	107,862	114,608
Import	16.535	10.023	6.512				1.569										
Export	-0.823	-0.385	-0.438				-0.001										
Net Availability	304.661	49.538	255.123	23.367	9.719	7.161	14.606	0.01	0.111	0.049	0.2624	0.1925	0.2053	0.0678	0	107,862	114,608
Stats. Diffs.	4.316			0	0	0	3.731	0	0	0	0	0	0	0	0	1,733	3,600
Consumption Total	300.345	21.706	6.838	23.367	9.719	7.161	10.875	0.01	0.111	0.049	0.2624	0.1925	0.2053	0.0678	0	106,129	111,008
Steel and Washery	33.893	21.706	6.838				10.875									106,129	111,008
Railway (Loco)	0																
Electricity	215.385			17.259													
Cement	13.467			0.16													
Cotton	2.821																
Jute	0																
Paper	3.014																
Brick (by Railway)	3.403																
Coal for soft coke	0																
Fertilizer	4.11																
Brick Kilns, Textiles, Chemicals, Paper, Other Industries	0																
Other industries	0																
Total	276.093	21.7056	6.838	17.419	0	0	10.874	0	0	0	0	0	0	0	0	106,129	111,008
Domestic	1.249																
Other consumers	23.003			5.948	9.719	7.161		0.01	0.111	0.049	0.2624	0.1925	0.2053	0.0678			

Annex II-1 Energy Balance of Crude Oil & NG & Petroleum Products in 1993-94

1993-94	Primary Crude Oil	NG	NGL	Secondary 1 Light Distillates				
				LPG	Motor Gasoline	Naphtha	SBPS(Special Boiling Point Spirit), Hexane	Others
	(k ton)	(Mm^3)	(k ton)	(k ton)	(k ton)	(k ton)	(k ton)	(k ton)
Production	27,026	16,445	2,855					
from Crude Oil				1,314	3,843	4,666	120	175
from NG				1,385		153		
Import	30,822			410		0		4
Export			-782	-9		-1,625		-803
International Bunkers								
Supply Total	57,848	16,445	2,073	3,100	3,843	3,194	120	-624
stats. Diffs. (Stock Change)	3,552	0	388	-13	9	0	-24	-912
Consumption Total	54,296	16,445	1,685	3,113	3,834	3,194	144	288
Oil&Gas Extruaction(Own Use)		2,382						
Oil Refinery(Transfer)	51,084		1,685					
Refinery Fuel	2,836							
Loss	376							
Final Consumption	0	14,063	0	3,113	3,834	3,194	144	288
Domestic		189		2,423				
Commercial/Industry				635				
Transport								
Road Transport								
Aviation								
Shipping								
Railways								
Other Transport (incl. Agri. Retal Trade)								
Plantation/Food								
Tea plantation		121						
Sugar Mill								
Other (incl. Plan. of Food)								
Power Generation		4,785				3		
Industry								
Iron & Steel								
Textile & Fiber								
Cement								
Ceramic & Glass								
Chemicals & Allied (incl. Petrochemical)		675	0			1,013		
Aluminum								
Mining & Quarrying								
Engg.(Mech & Elec)								
Fertilizers		6,499				2,172		
Other Industries & Construction		1,794						
Miscellaneous services (incl. DGS&D)								
Others		0		55		6		
Private Party Sales								

1993-94	Secondary 2 Middle Distillates							
	SKO(Superior Kerosene Oil)	ATF(Aviation Turbine Fuel)/RTF/Jet A-1	HSDO+LDO	HSDO	LDO (Regular)	JBO	MTO	Others
	(k ton)	(k ton)	(k ton)	(k ton)	(k ton)	(k ton)	(k ton)	(k ton)
Production								
from Crude Oil	5,270	1,788	20,283	18,809	1,474	74	145	239
from NG								
Import	3,946	0	7,555	7,555	0			0
Export			-155	-155	0			-137
International Bunkers			42	13	29			
Supply Total	9,216	1,788	27,725	26,222	1,503	74	145	102
stats. Diffs. (Stock Change)	512	47	528	358	170	-3	1	-130
Consumption Total	8,704	1,741	27,198	25,865	1,333	77	144	232
Oil&Gas Extruaction(Own Use)								
Oil Refinery(Transfer)								
Refinery Fuel								
Loss								
Final Consumption	8,704	1,741	27,198	25,865	1,333	77	144	232
Domestic								
Commercial/Industry								
Transport								
Road Transport			2,130	2,129	1			
Aviation			18	17	1			
Shipping			222	186	36			
Railways			1,443	1,441	2			
Other Transport (incl. Agri. Retal Trade)			19,286	19,273	13			
Plantation/Food								
Tea plantation								
Sugar Mill			85	84	1			
Other (incl. Plan. of Food)			445	410	35			
Power Generation			297	115	182			
Industry								
Iron & Steel			136	88	48			
Textile & Fiber			206	167	39			
Cement			176	165	11			
Ceramic & Glass			75	30	45			
Chemicals & Allied (incl. Petrochemical)			259	114	145			
Aluminum			23	6	17			
Mining & Quarrying			587	578	9			
Engg.(Mech & Elec)			255	146	109			
Fertilizers			12	9	3			
Other Industries & Construction			408	209	199			
Miscellaneous services (incl. DGS&D)			1,135	698	437			
Others								
Private Party Sales								

1993-94	Secondary 3 Heavy Ends									Refinery Total
	FO+LSHS/HHS	FO (Regular)	LSHS/HHS	Lube Oils	Bitumen	Petroleum Coke	Paraffin Wax	Other Waxes	Others	
	(k ton)	(k ton)	(k ton)	(k ton)	(k ton)	(k ton)	(k ton)	(k ton)	(k ton)	
Production										
from Crude Oil	10,304	6,163	4,141	489	1,874	233	45	47	175	51,084
from NG										1,538
Import	0	0	0	132					29	
Export	-1,288	-1,288	0						-17	
International Bunkers	116	116								
Supply Total	9,132	4,991	4,141	621	1,874	233	45	47	187	
stats. Diffs. (Stock Change)	56	81	-25	-67	50	101	45	-72	46	
Consumption Total	9,076	4,910	4,166	688	1,824	132	0	119	141	
Oil&Gas Extruaction(Own Use)										
Oil Refinery(Transfer)										
Refinery Fuel										
Loss										
Final Consumption	9,076	4,910	4,166	688	1,824	132	0	119	141	
Domestic										
Commercial/Industry										
Transport										
Road Transport	7	7								
Aviation	3	3								
Shipping	188	176	12							
Railways	16	16								
Other Transport (incl. Agri. Retal Trade)	87	87								
Plantation/Food										
Tea plantation										
Sugar Mill	15	15	0							
Other (incl. Plan. of Food)	211	171	40							
Power Generation	2,166	490	1,676							
Industry										
Iron & Steel	465	368	97							
Textile & Fiber	714	376	338							
Cement	115	62	53							
Ceramic & Glass	162	86	76							
Chemicals & Allied (incl. Petrochemical)	1,053	678	375							
Aluminum	175	110	65							
Mining & Quarrying	66	58	8							
Engg.(Mech & Elec)	177	145	32							
Fertilizers	2,212	1,160	1,052							
Other Industries & Construction	830	560	270							
Miscellaneous services (incl. DGS&D)	414	342	72							
Others										
Private Party Sales										

Annex II-2 Energy Balance of Crude Oil & NG & Petroleum Products in 1998-99

1998-99	Primary Crude Oil	NG	NGL	Secondary 1 Light Distillates LPG	Motor Gasoline	Naphtha	SBPS(Special Boiling Point Spirit), Hexane	Others
	(k ton)	(Mm^3)	(k ton)	(k ton)	(k ton)	(k ton)	(k ton)	(k ton)
Production	32,722	24,817	3,883					
from Crude Oil				1,724	5,573	6,081	127	271
from NG				1,914		1,566		
Import	39,808			1,722		2,407		251
Export			-77	0		-720		0
International Bunkers								
Supply Total	72,530	24,817	3,806	5,360	5,573	9,334	127	522
stats. Diffs. (Stock Change)	3,992	0	-269	8	66	0	-30	228
Consumption Total	68,538	24,817	4,075	5,352	5,507	9,334	157	294
Oil&Gas Extruaction(Own Use)		2,417						
Oil Refinery(Transfer)	64,544		3,745					
Refinery Fuel	3,700							
Loss	294							
Final Consumption	0	22,400	330	5,352	5,507	9,334	157	294
Domestic		193		4,148				
Commercial/Industry				817				
Transport								
Road Transport								
Aviation								
Shipping								
Railways								
Other Transport (incl. Agri. Retal Trade)								
Plantation/Food								
Tea plantation		147						
Sugar Mill								
Other (incl. Plan. of Food)								
Power Generation		8,714				443		
Industry								
Iron & Steel								
Textile & Fiber								
Cement								
Ceramic & Glass								
Chemicals & Allied (incl. Petrochemical)		1,472	330			1,332		
Aluminum								
Mining & Quarrying								
Engg.(Mech & Elec)								
Fertilizers		8,869				3,648		
Other Industries & Construction		3,005						
Miscellaneous services (incl. DGS&D)								
Others		0		76		1,672		
Private Party Sales				311		2,239		

1998-99	Secondary 2 Middle Distillates							
	SKO(Superior Kerosene Oil)	ATF(Aviation Turbine Fuel)/RTF/Jet A-1	HSDO+LDO	HSDO	LDO (Regular)	JBO	MTO	Others
	(k ton)	(k ton)	(k ton)	(k ton)	(k ton)	(k ton)	(k ton)	(k ton)
Production								
from Crude Oil	5,341	2,289	28,052	26,716	1,336	81	194	211
from NG								
Import	7,066	3	10,231	10,231	0			0
Export			0	0	0			0
International Bunkers			25	9	16			
Supply Total	12,407	2,292	38,308	36,956	1,352	81	194	211
stats. Diffs. (Stock Change)	164	180	-162	-252	90	4	3	-1
Consumption Total	12,243	2,112	38,470	37,208	1,262	77	191	212
Oil&Gas Extruaction(Own Use)								
Oil Refinery(Transfer)								
Refinery Fuel								
Loss								
Final Consumption	12,243	2,112	38,470	37,208	1,262	77	191	212
Domestic								
Commercial/Industry								
Transport								
Road Transport			19,712	19,710	2			
Aviation			20	19	1			
Shipping			239	210	29			
Railways			1,421	1,419	2			
Other Transport (incl. Agri. Retal Trade)			13	0	13			
Plantation/Food								
Tea plantation								
Sugar Mill			118	116	2			
Other (incl. Plan. of Food)			7,073	7,034	39			
Power Generation			2,746	2,576	170			
Industry								
Iron & Steel			202	124	78			
Textile & Fiber			749	686	63			
Cement			252	233	19			
Ceramic & Glass			99	67	32			
Chemicals & Allied (incl. Petrochemical)			530	371	159			
Aluminum			14	11	3			
Mining & Quarrying			648	633	15			
Engg.(Mech & Elec)			382	285	97			
Fertilizers			39	35	4			
Other Industries & Construction			1,585	1,409	176			
Miscellaneous services (incl. DGS&D)			2,628	2,270	358			
Others			0					
Private Party Sales			0	0	0			

1998-99	Secondary 3 Heavy Ends									Refinery Total
	FO+LSHS/HHS	FO (Regular)	LSHS/HHS	Lube Oils	Bitumen	Petroleum Coke	Paraffin Wax	Other Waxes	Others	
	(k ton)	(k ton)	(k ton)	(k ton)	(k ton)	(k ton)	(k ton)	(k ton)	(k ton)	
Production										
from Crude Oil	11,030	6,407	4,623	586	2,419	286	40	63	176	64,544
from NG										3,480
Import	1,696	1,696	0	396					0	
Export	0	0	0						0	
International Bunkers	75	75								
Supply Total	12,801	8,178	4,623	982	2,419	286	40	63	176	
stats. Diffs. (Stock Change)	365	279	86	-115	7	-107	4	-13	-1	
Consumption Total	12,436	7,899	4,537	1,097	2,412	393	36	76	177	
Oil&Gas Extruaction(Own Use)										
Oil Refinery(Transfer)										
Refinery Fuel										
Loss										
Final Consumption	12,436	7,899	4,537	1,097	2,412	393	36	76	177	
Domestic										
Commercial/Industry										
Transport										
Road Transport	8	8								
Aviation	2	2								
Shipping	182	177	5							
Railways	11	11								
Other Transport (incl. Agri. Retal Trade)	77	77								
Plantation/Food										
Tea plantation										
Sugar Mill	16	16	0							
Other (incl. Plan. of Food)	346	303	43							
Power Generation	1,868	571	1,297							
Industry										
Iron & Steel	491	450	41							
Textile & Fiber	727	557	170							
Cement	447	402	45							
Ceramic & Glass	199	131	68							
Chemicals & Allied (incl. Petrochemical)	1,369	1,016	353							
Aluminum	140	140	0							
Mining & Quarrying	117	95	22							
Engg.(Mech & Elec)	271	179	92							
Fertilizers	2,852	942	1,910							
Other Industries & Construction	1,191	912	279							
Miscellaneous services (incl. DGS&D)	916	704	212							
Others	0									
Private Party Sales	1,206	1,206	0							

Annex III-1 Energy Balance of Electricity in 1993-94

1993-94		Operating Data						Energy Balance (GWh)		
		Hydro	Steam	Gas	Diesel	Wind	Nuclear	Utility Total	Non-Util. Total	Grand Total
Utility										
Fuel Consumption										
Coal	(ton)		156,860,023							
Lignite	(ton)		12,053,811							
Furnace Oil	(kLtrs)		614,250							
Diesel Oil (LDO/HSD)	(kLtrs)		336,046	66,066	76,253					
LSHS & HHS	(kLtrs)		1,740,281							
Natural Gas	(Mm^3)		197	4,066						
Refinery Gas	(ton)		326,708							
Naphtha	(kLtrs)			5,042						
Heat Input Total	(Tcal)		649,757	37,612	654					
Generation	(GWh)	70,463	233,151	14,728	260	51	5,398	324,050	32,285	356,335
Efficiency			30.9%	33.7%	34.2%					
Auxiliary	(GWh)	577	21,995	295	12	2	788	23,670	3,646	27,316
		0.82%	9.43%	2.00%	4.76%	4.76%	14.60%	7.30%	11.29%	7.67%
Availability	(GWh)	69,886	211,156	14,433	247	49	4,610	300,380	28,639	329,018
Non-Utility										
Fuel Consumption										
Coal	(kton)		14,803							
Natural Gas	(Mm^3)			935						
Diesel	(kton)				1,026					
Heat Input Total	(Tcal)		68,539	7,742	10,616					
Generation	(GWh)	15	25,409	3,150	3,705	6			32,285	
Efficiency			31.9%	35.0%	30.0%					
Import								1,547		1,547
Export								-101		-101
Net Availability								301,825	28,639	330,464
Non-Util. -> Util.								1,754	-1,754	0
Distribution Losses								65,010	0	65,010
Consumption										
Domestic								43,372		43,372
Commercial								14,144		14,144
Industrial Power								94,503	26,862	121,365
Low & Medium Voltage								19,986		19,986
High Voltage								74,518		74,518
Railways								5,620	22	5,643
Agriculture								70,699		70,699
Others								10,230		10,230
Public Lighting								1,939		1,939
Public Water Works & Sewage Pumping								4,838		4,838
Miscellaneous								3,453		3,453
Total								238,569	26,885	265,454

1998-99		Operating Data						Energy Balance (GWh)		
		Hydro	Steam	Gas	Diesel	Wind	Nuclear	Utility Total	Non-Util. Total	Grand Total
Utility										
Fuel Consumption										
Coal	(ton)		204,061,000							
Lignite	(ton)		17,259,000							
Furnace Oil	(kLtrs)		559,113							
Diesel Oil (LDO/HSD)	(kLtrs)		297,848	209,295	270,674					
LSHS & HHS	(kLtrs)		1,949,983							
Natural Gas	(Mm^3)		0	9,005						
Refinery Gas	(ton)		505,000							
Naphtha	(kLtrs)			649,696						
Heat Input Total	(Tcal)		854,906	87,155	2,019					
Generation	(GWh)	82,923	310,014	41,303	1,304	1,079	11,923	448,544	48,380	496,924
Efficiency			31.2%	40.8%	55.5%					
Auxiliary	(GWh)	685	28,428	899	28	23	1,360	31,423	4,212	35,635
		0.83%	9.17%	2.18%	2.17%	2.17%	11.41%	7.01%	8.71%	7.17%
Availability	(GWh)	82,238	281,585	40,404	1,275	1,055	10,563	417,121	44,168	461,289
Non-Utility										
Fuel Consumption										
Coal	(kton)		19,390							
Natural Gas	(Mm^3)			2,634						
Diesel	(kton)				2,265					
Heat Input Total	(Tcal)		87,062	21,807	23,440					
Generation	(GWh)	80	31,200	8,872	8,179	48			48,380	
Efficiency			30.8%	35.0%	30.0%					
Import								1,385		1,385
Export								-270		-270
Net Availability								418,236	44,168	462,404
Non-Util. -> Util.								2,982	-2,982	0
Distribution Losses								111,484	0	111,484
Consumption										
Domestic								64,973		64,973
Commercial								19,799		19,799
Industrial Power								105,080	41,159	146,240
Low & Medium Voltage								22,995		22,995
High Voltage								82,085		82,085
Railways/Tramways								7,307	26	7,333
Agriculture								97,195		97,195
Others								15,380		15,380
Public Lighting								2,781		2,781
Public Water Works & Sewage Pumping								6,561		6,561
Miscellaneous								6,038		6,038
Total								309,734	41,185	350,919