Making Input-Output Tables for Environmental Analysis for India: 1993/94 and 1998/99 *

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Abstract

Energy input-output tables expressed in natural and thermal units were estimated to extend original Indian I-O tables for the years of 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.

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1 Intruduction

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 of reducing these harmful emissions, there is high priority placed on the economic development of the country. The fact is that, in 2001, India ranked fifth in the world in carbon emissions with 251 million metric tons of carbon equivalent emitted, behind the United States, China, Russia and Japan. Between 1990 and 2001, India's carbon emissions increased by an astonishing 61%, a rate surpassed only by China's 111% increase during the same period. Further, India's contribution to world carbon emissions is expected to increase in coming years, with an estimated average annual growth rate between 2001 and 2025 of 3.0% in the Energy Information Administration (EIA) International Energy Outlook 2003 reference case (compared to 3.4% in China and 1.5% in the United States). (Energy Information Administration, Country Briefs on India, February 2004)

Considering the increasing carbon emission rates for India, it may be vital to review the existing energy use patterns and to bring on the agenda, the policies that will reduce greenhouse gas emissions in the future. In this context, a proper estimation of CO_2 emissions based on the existing energy usage profile for India requires a good scientific understanding.

Therefore, energy input-output tables expressed in natural and thermal units were estimated to extend original Indian I-O tables for the years of 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.

Input-output models are used to analyze alternative scenarios on the future technologies, households' life style and so on; the scenarios on energy consumption are often measured in natural units. However I-O tables expressed in natural units are rarely available. The International Energy Agency (IEA) regularly prepares energy balances among supply, transformation, and final consumption of several energy commodities for OECD and over 100 non-OECD countries. The energy commodities and sectors adopted in the energy balances should be converted into those of I-O tables in order to fit the energy balances into economic analysis.

First, we examined the consistency of the IEA's energy balances—constructing individual energy balances with the data obtained from several statistical sources and comparing both of balances—and replaced the figures of the IEA when it was deemed necessary. Next, we checked 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. Since the monetary values in the Indian I-O tables are evaluated in basic prices, we calculated the basic prices using the micro data of Annual Survey of Industries for certain energy commodities, in addition to seek 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 into our estimates; typical examples are the value of electricity inputs in agriculture and household—the effective subsidies to these sectors are extremely high. We performed these examinations with aggregated sectors whose consumption of energy are obtained from available statistics. Finally, these aggregated figures of individual energy commodities were disaggregated into 115 industries of the Indian I-O tables. For manufacturing sectors we used the information obtained by the micro data of Annual Survey of Industries.

In fact, there is a long history of I-O compilation in India and I-O analyses for Indian economy. We first review the literature concerning the interaction between energy–environment and economic activities using several I-O models. Then we explain our methodology for making the energy I-O tables for India. We followed our experiences to compile the I-O tables for environmental analysis and it is explained in Appendix briefly.

2 Literature Review

Estimation of carbon emission using I-O tables has been done by various authors for several countries all over the world. In the history, notable work was done by Cumberland (1966), Ayres and Kneese (1969), Bullard and Herendeen (1975), Griffin (1976) amongst others. In the recent years, much attention has been focused on extending the Leontief input-output framework to account for energy use and other activities such as environmental pollution associated with inter-industry activity.

■Snapshot of literature on I-O model and its applications world-wide Common and Salma (1992) sets out a methodology using I-O model for allocating Australia's total emissions across deliveries to final demand and for decomposing changes in total emissions over time into components attributable to changes in final demand, fuel mix, and in technology. The paper discusses the problems in data availability and undertakes some sensitivity analysis with regards to few parameters used in the model. A paper by Bossier and Rous (1992) evaluates the consequences of introduction of carbon tax for the Belgian economy. The authors study two scenarios using I-O tables where the first scenario introduces a carbon tax of about 23.5 ecus (European Currency Units) per ton of CO_2 emitted and the second scenario combines the tax with incentives to energy savings investments. The results suggest that the tax, alone, is not sufficient to meet the international requirements as far as a stabilization of CO_2 emissions is required. The authors, therefore, suggests to achieve policy-mix of pure taxation measures with various forms of subsidies to investments.

Proops et al. (1993) carries out historical changes in CO_2 emissions for the US and the European Community, which by 1980s were falling by 1-2% per year, as a result of the energy intensity of output falling at a faster rate than that at which output was growing. These reductions in CO_2 emissions were decomposed further into fuel mix effects and sectoral output mix effects. Such decomposition gave further insights into what is actually causing CO_2 emissions to change. However, this analysis just takes into account different sectors with direct use of fuel and ignores many sectors that use intermediate manufactured goods with embodied energy.

Gay and Proops (1993) have used a model based on the U.K. input-output tables for 1984, but at a higher level of aggregation. The authors, in their paper, discusses the possibility of using the model to explore the effect of varying the balance between fossil fuel and other forms of electricity generation and of changing the composition of final demand for goods and services. Another paper by Korres (1996) measures the extension and the direction of structural and technological change for the Greece economy. The impact of structural and technological changes on sectoral gross output was computed by breaking down the total change into the part due to changes in input-output coefficients (technological change) and the part due to changes and composition of final demand.

While, Lin and Chang (1996) uses the Divisia index approach to decompose emission changes of SO_2, NO_x and CO_2 from major economic sectors in Taiwan during 1980 to 1992. Their study highlights the interrelationships between energy use and environmental quality, and provides insights for the policy making. The emission changes are decomposed into five components viz., pollution coefficient, fuel mix, energy intensity, economic growth and industrial structure. Of all components analyzed, economic growth had the largest positive effect on emission changes for Taiwan's major economic sectors. Emissions of SO_2 in industry and other sectors showed a decreasing trend due to fuel quality improvements and pollution control. However, NO_x and CO_2 emissions increased sharply in all sectors. Comparisons were also made with Germany, Japan and USA. This paper has shown that improvement in energy efficiency, pollution control and fuel substitution are major options to reduce SO_2, NO_x and CO_2 emissions.

Another paper by Chang and Lin (1998) employed input-output structural decomposition analysis to examine emission trends and effects of industrial CO_2 emission changes in Taiwan during 1981-1991. Results indicate that the primary factor for the increase of CO_2 emission is the level of domestic final demand and exports. However, the effect of an increasing rate of added value is less obvious. On the other hand, the effects of a decreasing industrial CO_2 intensity is a main reducing factor, next is the structure of domestic final demand and the rate of domestic production to intermediate input also has partial reducing effects for CO_2 emission. Besides, the structure change of exports has only low reducing effects. The paper hopes to provide valuable information regarding the characteristics and key factors of CO_2 emission in the industrial development process and serve as a basic reference for the CO_2 reduction plan in Taiwan.

Lin (1998) analyzes the inter-relationship of energy development and environmental constraints in China. The effects of economic development, investment, energy trade and environmental limitations in shaping energy development are examined. The tensions between institutions involved in energy development, energy conservation and environmental protection are highlighted and concludes that total fuel mix in China will be diversified in the future. The share of coal in primary energy production and consumption will increase in the short time span till 2020, and diminish gradually thereafter, being largely replaced by gas, nuclear and renewables. China will become a big oil importer, due to increase in demand and resource limitations. Meanwhile, coal export will increase in the long run. SO_2 and CO_2 emissions will become potentially larger in the future, because of the speed of economic growth and lack of effective control measures. Institutional bottlenecks, and political preference to solving local environmental problems, will affect actions to eliminate global environmental risks. Further, it says that there exist huge investment potentials for energy development from both international and domestic private investment funds. Energy efficiency will continue to improve, associated with gradual decline of non-commercial energy use and increasing share of commercial energy in final consumption. Energy conservation holds the key for sustainable energy development, which should be promoted at the national and local levels with demand management as a focus in policy implementation.

Rolke et al. (1998) describes direct and indirect primary energy and greenhouse gas requirements for a given set of Australian final consumption. It considers sectoral disparities in energy prices, capital formation and international trade flows and it accounts for embodiments in the Gross National Expenditure as well as the Gross Domestic Product. Primary energy and greenhouse gas intensities in terms of MJ/$ (Mega joules per US Dollar) and kg CO_2-e/$ (CO_2 equivalent per US Dollar) are reported, along with national balances of primary energy consumption and greenhouse gas emissions.

Munksgaard and Pedersen (1999) in their article demonstrate the consequences of using two basic accounting principles: a production versus a consumption principle. The distinction between the two principles is whether the producer or the consumer is responsible for the emitted CO_2. By subtracting total emissions based on the two accounting principles, they developed the concept of a "CO_2 trade balance". Using Denmark as a case, they have shown that from 1989 to 1994 the CO_2 trade balance has changed dramatically turning into a deficit of 7 million tonnes from a surplus of 0.5 million tonnes in 1987. Another paper by Liaskas et al. (2000) aims at identifying the factors that have influenced changes in the level of industrial CO_2 emissions of European Union countries. By means of an algebraic decomposition method the observed changes are analyzed into four different factors: output level, energy intensity, fuel mix and structural change. The results show that CO_2 emissions are possible to decrease without negatively affecting economic growth. In this sense, they confirm the decoupling of economic growth from energy consumption realized in the developed countries and prove that this detachment holds true also for the atmospheric emissions associated with energy use.

Machado (2000) evaluates the impacts of foreign trade on the energy use and CO_2 emissions of 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 to the Brazilian economy for the years 1985, 1990 and 1995. Total energy and carbon intensity coefficients by commodity are derived and applied to the actual trade statistics of Brazil to appraise the energy and carbon embodied in the non-energy foreign commerce of the country. The effects of the trade liberalization on the patterns of energy use and CO_2 emissions of Brazil are discussed. Another author,Hann (2001), conducted a study using Structural Decomposition Analysis in which annual changes in a number of air pollutants and solid waste decomposed according to their causes for Netherlands for the period 1987- 1998. The results of this paper discusses macro economic development including the results from the industry level as well as a comprehensive overview of origin and destination of pollution in the Dutch economy including the environmental consequences of consumption and international trade.

Cruz (2002) defines the economic structure, in an input-output approach, in terms of sectors, making particularly explicit the link between the level of economic activity in a country, its corresponding impact on the environment, and/or the corresponding energy interactions. He suggests that such an approach provides a consistent and systematic tool to evaluate impacts of measures regarding the achievement of both pollution control and sustainable development. The paper presents an empirical input-output application of the energy-economy-environment interactions for Portugal, especially concerning the energy intensities and CO_2

emissions derived from fossil fuels use. It also presents a description of the appropriate modifications to the basic input-output model, followed by an outline of the data used. Finally, some results on (direct and indirect) energy requirements and CO_2 emissions are reported, the study's main conclusions are presented, and the limitations and needs for future research are discussed by the author.

Tuyet and Ishihara (2005)) analyzed, the changes of embodied energy intensity in Vietnam from 1996 to 2000 using the structural decomposition and its power series expansion. By illustrating the change of causal relationship between direct energy consumption and embodied energy consumption, the change of hidden energy flow, which indicates how the changing embodied energy builds up the change of direct energy consumption in every sector, is shown. The case study on rice processing sector, one of the important food processing sectors, in Vietnam is focused. By drawing a diagrammatic map for the change of hidden energy flow, it is clarified that in the case of raising embodied energy intensity, cultivation sector and trade and repaired service sector are the main contributors, and on the contrary, in the case of reducing embodied energy intensity, paper pulp sector is the main contributor. Another paper by Alcantara and Padilla (2006) presents an approach that allows the identification of the "key" productive sectors responsible for CO_2 emission. They developed an input-output methodology from a supply perspective. The focus is on the impact of an increase in the value-added of the different productive sectors on total CO_2 emissions and identifies the productive sectors responsible for the increase in CO_2 emissions when there is an increase in the income of the economy. The approach shows the contribution of the various sectors to CO_2 emission from a production perspective and allows identifying the sectors that deserve more consideration for mitigation policies. This analysis complements input-output analysis from a demand perspective applied to Spanish economy.

While, Tunc et al. (2006) estimates the CO_2 emissions for the Turkish economy using an extended I-O model using 1996 data in order to identify the sources of CO_2 emissions.

Besides this, 'CO_2 responsibility', which takes into account the CO_2 content of imports, is estimated for the Turkish economy. The sectoral CO_2 emissions and CO_2 responsibilities are compared and these two notions are linked to foreign trade volume. One of the main conclusions of the paper is that the manufacturing industry has the first place in both of the rankings for CO_2 emissions and CO_2 responsibilities, while agriculture and husbandry holds the last place.

Another paper by Lise (2006) argues that the emission growth in Turkey, over the period 1980-2003, was for almost 80% as a result of the growing economy, for 13% as a result of structural change towards more energy-intensive sectors, for 13% as a result of an increase in the carbon intensity of energy, while decreasing energy intensity offset these increases by 7%.

Mongelli et al. (2006) argues that the absence of GHGs commitments of developing countries (non-Annex I) in Kyoto Protocol and more flexible terms of implementation which are allowed to countries shifting toward a market economy (transition economies) will lead to the absence or to less constraining national measures and policies of reduction of GHGs emissions which, in turn, may determine a comparative advantage in the production of highest energy/carbon intensive commodities for these countries. The author suggests that the developing countries may become a haven for the production of not environmental-friendly commodities and in this case, the so-called Pollution Haven Hypothesis, due to freer international trade the comparative advantage may change the economic structure and consequently the trade patterns of the countries linked by trade relationships, may occur. This, in turn, may lead to the increase of transfers of energy and carbon embodied in traded commodities from developing countries and transition economies toward Kyoto constrained countries. This paper aimed to verify if, for Italy, evidence of a change in the trade patterns, occurred on the basis of the Pollution Haven Hypothesis, and estimated the magnitude of the under-estimation of the carbon actually emitted (the carbon leakage). The input-output model has been used to calculate the intensities of energy consumption and the related GHG emission, for each Italian economic sector.

Another paper by Munksgaard et al. (2006) shows how the input-output approach can be used to enumerate the problem of sustainable consumption. The measures of carbon dioxide emissions at different spatial levels: nation, city, and household, are undertaken. Further, more environmental effects are taken into account and the concept of environmental efficiency by combining input-output modeling and data envelopment analysis is introduced. Finally, the paper discusses the policy relevance of different measures. The article demonstrates 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.

Another author, Marriott (2007), builds upon an existing economic input-output tool, by adding details about the electricity industry, specifically by differentiating among the various functions of the sector and different means of generating power. The analysis show that the generation assets in a region have a large impact on the environmental impacts associated with electricity consumption and interstate trading tends to make the differences smaller. The results show that most sector mixes are very close to the U.S. average due to geographic dispersion of industries, while some sectors are different and they tend to be important raw material extraction or primary manufacturing industries.

In addition to the above-mentioned papers, the literature on the Japanese experiences to understand the energy and environment issues using I-O model was collected. The history of Japanese I-O model dates back to 1970 and has been very detailed that is in use even now in order to understand the environmental situation. More details on developments with respect to Japanese I-O are elaborated in Appendix attached at the end of the paper.

■Snapshot of literature on I-O model and its application for India The review of secondary data for India suggests that there is very weak literature available on the estimation of carbon emissions using I-O model. In fact, there have been more usual approaches adopted by most of the authors for India, in which case, the carbon emissions are calculated using emission factors for energy resources directly without following the detailed methodology of constructing the material table or price approach from the available I-O tables.

This section mainly reviews the work of various authors who adopted I-O model approach to understand energy and environmental issues for India either by way of calculating energy intensity of various industries or by estimating carbon and other emissions. It has been concluded that there exist very little literature for India in which detailed methodology, as is used for this paper, is adopted.

In fact, this paper derives quantity data (described in detail as 'material table' in methodology section of this paper) from Indian I-O tables for the years 1993/94 and 1998/99, which are provided in monetary units and the same is checked for consistency with actual data provided by the Indian government (from various sources such as departments and ministries related to this work) and the energy balances' tables of IEA. While reviewing the literature, it has been observed that very few studies on the estimation of carbon emission using approach described in this paper are undertaken for India.

A study by Parikh and Gokarn (1993) present an analysis of CO_2 emissions in the Indian economy using price approach and examine the implications of alternative policies to reduce them. It examines flows of energy in the economy through a 60 sector I-O model. The authors show that 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 indicates that, in addition to energy efficiency, improving construction efficiency could also lead to CO_2 savings. The paper highlights 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 for only 10% of energy saving.

Another paper by Parikh and N.S. Murthy (1997) highlights consumption pattern differences across income classes in India, namely the top 10%, middle 40% and bottom 50% of the population in rural and urban areas. The analysis is based on I-O model that uses consumption expenditure distribution data from various sources. It examines direct and indirect demand on resources and CO_2 emissions due to consumption of each of these income classes. Out of a 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 implies that the net effect is that the rich have a more carbon intensive lifestyle. In a scenario where private consumption expenditure is expected to reach twice the 1990 level by 2010, CO_2 emissions are projected to rise to 502mtC indicating that the low purchasing power of the poor results in their dependence on nature and environment.

In another paper by Murthy et al. (1997b), the authors investigate the linkages between economic growth, energy consumption and CO_2 emissions by analyzing the structure of production and consumption in the Indian economy. They examine the consumption pattern of six different income classes, three each in urban and rural India, and then estimate the direct and indirect energy and CO_2 emission coefficients for supporting production in various sectors. This provides a basis for estimating the energy and emission content of the consumption baskets of the different income classes in India. 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 which corresponds to a GDP growth rate of 5.5% per annum. They then analyze scenarios of technology improvement in which emissions are reduced to 0.47 tC per capita in 2020. The projection methodology takes into account the changes in aggregate consumption pattern due to mobility of the population across the income classes and from rural to urban areas, besides the increase in per capita consumption of all classes. While, Murthy et al. (1997a) analyses the energy consumption using an input-output model for 1990 and for 2005 with alternative energy efficiency programs. The authors highlight that ambitious poverty reduction programs would increase the growth rate of CO_2 emissions about 1%, but energy efficiency programs would nearly compensate.

Few other papers where use of I-O tables have been made to understand carbon emission estimates from energy usage patterns for India include Mukhopadhyay and Chakraborty (2000), Mukhopadhyay (2002b), Mukhopadhyay (2002c) and Mukhopadhyay (2002a), Nag and Parikh (2005), amongst others.

?? investigates the pattern of energy consumption changes during reform period i.e. 1991-92 to 1996-97 and various factors responsible for these changes based on input-output model. They develop Structural Decomposition Analysis (SDA) identifying six different factors: i) technical changes) final demand structure, iii) interaction term between technical change and final demand structure, iv) changes in energy exports, v) changes in energy imports, vi) changes in energy change in stock. Then, they separate technical changes and final demand structure again, which explain the energy consumption changes. The most significant role as revealed from the empirical results has been played by the final demand structure, technical changes, and interaction term between final demand structure and technical changes. Paper by Mukhopadhyay (2002b) addresses the issue of energy and environment in India. It is an exhaustive treatment of energy consumption changes and CO_2 emissions from fossil fuel combustion in India 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 Structural Decomposition Analysis and estimates and discusses CO_2 emissions and also forecasts energy consumption and CO_2 emissions during Tenth Five Year Plan. Policies are suggested for efficient utilization of energy and mitigation of CO_2 emissions.

Mukhopadhyay and Chakraborty (2002)'s paper aims at contributing to environment trade debate by evaluating the impacts of international trade on emissions of CO_2, SO_2 and NO_x in the Indian economy during 90s using input-output techniques. The paper has constructed an index of pollution in terms of trade. Using the input-output table of 1991-92 and 1996-97, they have computed pollution terms of trade for the content of CO_2, SO_2 and NO_x. Results show that the indices are below 100 indicating that India produces goods that are more environment friendly than goods it imports thus indicating a large inflow of pollution embodied in trade. The paper offered explanations for these results which challenge the pollution haven hypothesis.

Mukhopadhyay (2002c) tries to estimate the relationship between information technology and energy during 1973-74 to 1996-97 for India. More specifically it tries to assess whether the substitution of information and energy is possible for India or not. It tries to justify 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 up to the extent like US.

A paper by Nag and Parikh (2000) tries to analyze the commercial energy consumption evolution patterns in India in terms of primary energy requirements and final energy consumption and their implications for overall carbon intensity of the economy. The relative contribution and impact of different factors such as activity levels, structural changes, energy intensity, and fuel mix and fuel quality on the changes in aggregate carbon intensity of the economy has been studied, taking into account coal quality which has declined drastically in the last two decades.

Another paper of Mukhopadhyay and Forsell (2002) estimates the trend of CO_2, SO_2 and NO_x between the periods 1973-74, 1983-84, 1991-92 and 1996-97. Input-output Structural Decomposition Analysis approach is used to find out their sources of changes. They also estimate these emissions for the year 2001-2 and 2006-7. A link between emission of pollutants and their impact on human health is analyzed. CO_2 emission in India has increased from 191 mt of CO_2 in 1973-74 to 767 mt of CO_2 in 1996-97. The estimated SO_2 emission has also rose from 9.49 mt of SO_2 to 20.47 mt of SO_2. In the same manner, the NO_x has also increased from 5.69 to 21.67 mt of NO_x. The study categorizes the changes in the amount of CO_2, SO_2 and NO_x emissions into four factors: the pollution intensity, the rate of technical coefficient, changes in the volume of final demand structure and changes in the composition of final demand. The main factors for these changes were the volume of final demand and changes in rate of technical coefficient. The paper also reports the results from the selected surveys and statistical data from Health Statistics of India which reveal that respiratory infections like asthma and bronchitis and other respiratory diseases gradually increased due to the intensive effect of SO_2, NO_x and CO_2 and policies to that affect are suggested by the authors.

Mukhopadhyay (2002a) concentrates on the CO_2, SO_2 and NO_x emission from fossil fuel combustion only. It estimates the trend of CO_2, SO_2 and NO_x between the periods 1973-74, 1983-84, 1991-92 and 1996-97. Input-output Structural Decomposition Analysis approach is used to find out their sources of changes. Five sources which have been identified as responsible for changes in emissions are the rate of added value, the intensity of pollution, the rate of technical coefficient, changes in final demand structure and joint effects. The main factors for these increases are the rate of added value and changes in final demand structure. On the other hand, a main reducing factor is the changes in intensity. The paper estimates emissions of CO_2, SO_2 and NO_x for the year 2001-2 and 2006-7 and also suggests some policies.

Nag and Parikh (2005) provide (i) 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 (ii) 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. The 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 estimates and projects the carbon emission coefficient per unit of final consumption of electricity that can be used for conducting cost benefit of emission reduction potential for several electricity conserving technologies and benchmarking policy models.

Sengupta and Bhardwaj (2004) highlights policy discussions for sharing the global responsibility for abatement of GHG emissions by individual countries that take account neither of the pattern of their final consumption nor of the role of globalization through trade in the leakage of GHGs across national boundaries. This paper gives the methodology of estimating the total emissions of a GHG, which is imputable to the consumption pattern of a country and the effect of trade on the net leakage of such gas. The paper estimates the effect of trade on the net leakage of carbon dioxide and methane from India. It shows a significant net leakage of carbon dioxide from India for the observed consumption pattern in the 1990s. In spite of the difficulty of application of the method of estimating the leakage due to data constraints regarding regularly updated input-output tables for the different countries, the results point to the necessity of using some policy measure to influence globally the preference structure of the people in favor of eco-friendly consumption patterns.

In conclusion, a review of literature for India on I-O model suggests that most of the studies undertaken so far, have estimated carbon and other pollutant's emissions either for the various sectors or for the economy as a whole, based on the emission factors available and using Indian I-O tables directly. It has been unlike an attempt made in this paper, where material table is prepared for more detailed understanding of sectoral data. Secondly, most of these studies mainly cover only the fossil fuel combustion or use of commercial energy in the analysis. However, this paper has attempted to cover biomass and limestone, in addition to the conventional energy sources, as part of the fuels and sources of CO_2 emissions in order to reflect the actual pattern of energy use in the country. In fact, this paper develops detailed material (quantity) tables, as described earlier, using Indian input-output tables collected from the Indian government for the years 1993/94 and 1998/99. This table is checked for consistency with IEA energy balance statistics and with the statistics available from various government organizations in India. The energy sources include use of biomass along with conventional energy sources in order to estimate the CO_2 emissions for economy, sector-wise. Finally, the paper compares the estimates derived for CO_2 emissions from this model with CO_2 emission estimates available from other studies/models. Table2 provides the CO_2 emission estimates compiled from various studies/papers:

Table. 1 Estimate of CO_2 Emission from Various Studies

Title	Approach	Year	CO_2 Emissions
Parikh and N.S. Murthy (1997)	I-O using consumption expenditure	1989-90 (Base year) 2010 (projected year)	167mtC 502mtC
Murthy et al. (1997b)	Production (direct and indirect) and consumption (based on income classes) structure of economy. Two scenarios: one based on 5.5% GDP growth rate and second based on technology improvement	1990 (base year) 2020 (for scenario 1 and 2 respectively)	0.18 tC per capita 0.62 and 0.47 tC per capita
Mukhopadhyay and Forsell (2002)	I-O Structural Decomposition analysis approach	1973/74 (base year) 1996/97 (projected year)	191 mtC 767 mtC
International Energy Annual, 2003. Global warming reports	EIA model	2003	0.96 tC per capita
Sustainable forestry in India for carbon mitigation, Current Science. 2000. 10(5): 563–567	Carbon emissions from fossil fuel burning and cement manufacturing in India	2000	0.272Gt

3 Construction of Energy Input-Output Tables for India

3.1 Characteristics of the Indian Input-Output Tables

Since the first release of the Indian I-O table for the year 1968/69, the Central Statistical Organisation(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 marices[*1], and the symmetric I-O tables are derived by the industry technology assumption.

The most detailed matrices are at 115×115 sector classification, which are identical to those adopted since 1978/89 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 the 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 distinguish features of the 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,

[*1] Use table is refered as *input matrix* and make table as *output matrix* in the IOTT documation.
[*2] Again, basic price is refered as *factor cost* in the document.
[*3] In consequence, the value added for each industry is defined as the difference between the values output and

any side 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 in the case of many developing countries.

In the following sections, we describe how to adjust the discrepancy between the price–quantity data obtained outside of the IIOT and the monetary values in the IOTT.

3.2 Structure of Energy Input-Output Table

The objective of this study is to compile energy input-output table for India of 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, as much as possible.

Energy input-output table in our study 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 Government of India (CSO (2000, 2005)). [*4] Material table is compiled based on energy balance data from IEA and other energy statistics of India, with much cautions 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.

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

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

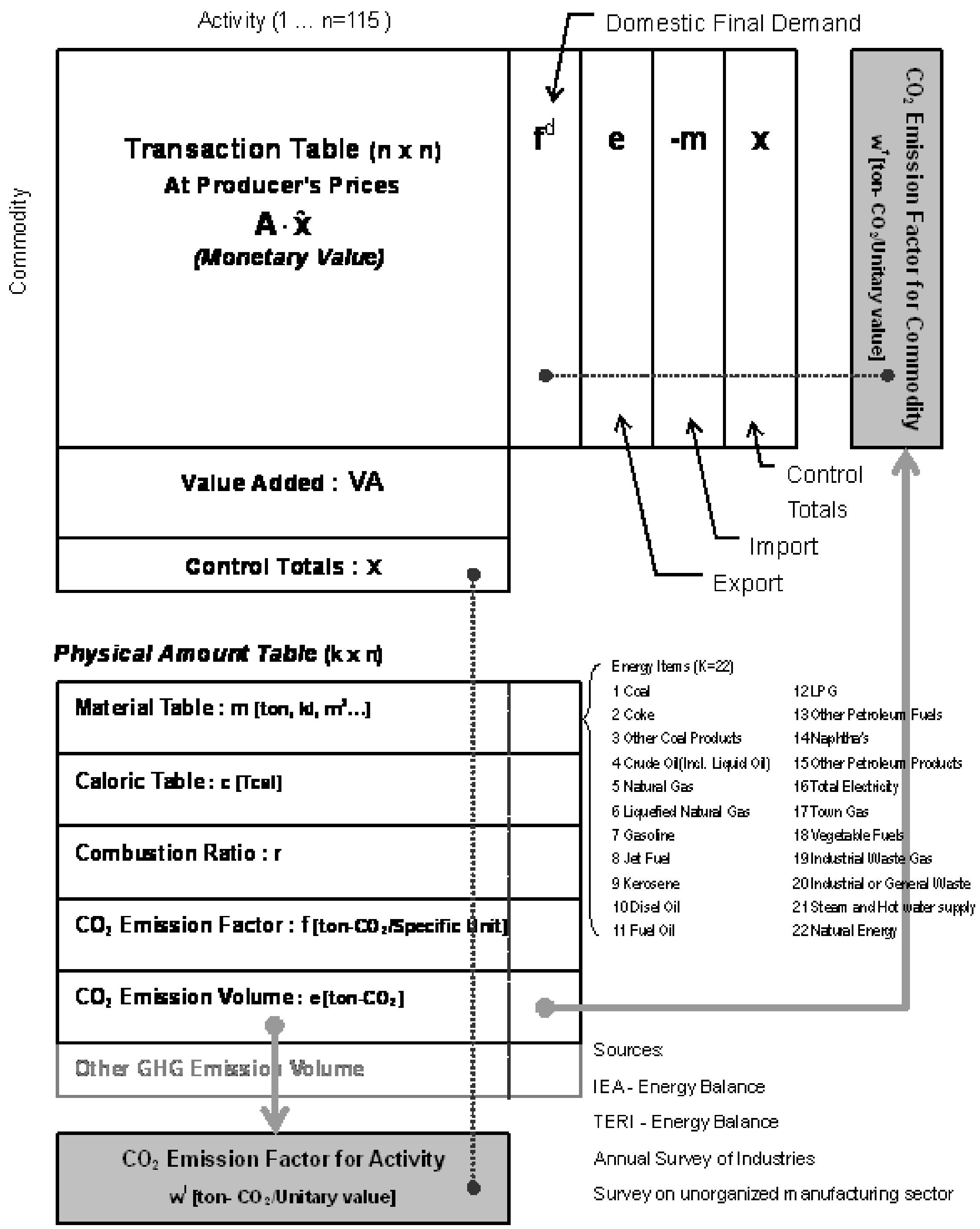

Fig. 1 Energy Input-Output Table

■CO_2 Emission Using Energy Input-Output Table In a steady condition, balance of system requires

$$x = Ax + f \tag{1}$$

x: Control Totals (Gross Output) vector in commodity classification (in former section, shown as $x^c om$)

When coefficient matrix A and final demand vector f are given, the solution for Gross Output x is available as follows (we assume that A is square matrix):

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

CO_2 emission Y is estimated as follows:

$$Y = W^i x + W^f f^d + W^r RM \tag{3}$$

W^i: row-vector of CO_2 emission factor for intermediate sectors. Emission factor w_i^i [ton- CO_2 /unitary production (Rs-Lhaks)] is defined as CO_2 emission amount occurred from unitary output of i-th activity.

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.

f^d: vector of Domestic final demand, f = fd + e - m

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.

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 R = (I - A)$^{-1}$, and $W^r = W^i$. Then,

$$\begin{aligned} Y &= W^i(I - A)^{-1}(f + m) + W^f F^d = W^i(I - A)^{-1}(f^d + e) + W^f f^d \\ &= \{W^i(I - A)^{-1} + W^f\} f^d + W^i(I - A)^{-1} e \end{aligned}$$

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

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

Before explaining the procedure of compilation of material table, we exlpain the relationship of Energy balance data and input-output table.

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.

■Unit of Measurement: I-O is recorded at monetary base in general, while the unit of EB is physical base, 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 sings as followings by convention;

Primary energy supply: production (+), export (-), import (+), increase in inventory (-)
Energy Transformation: inputs (-), generation (+)
Final consumption: inputs (+)

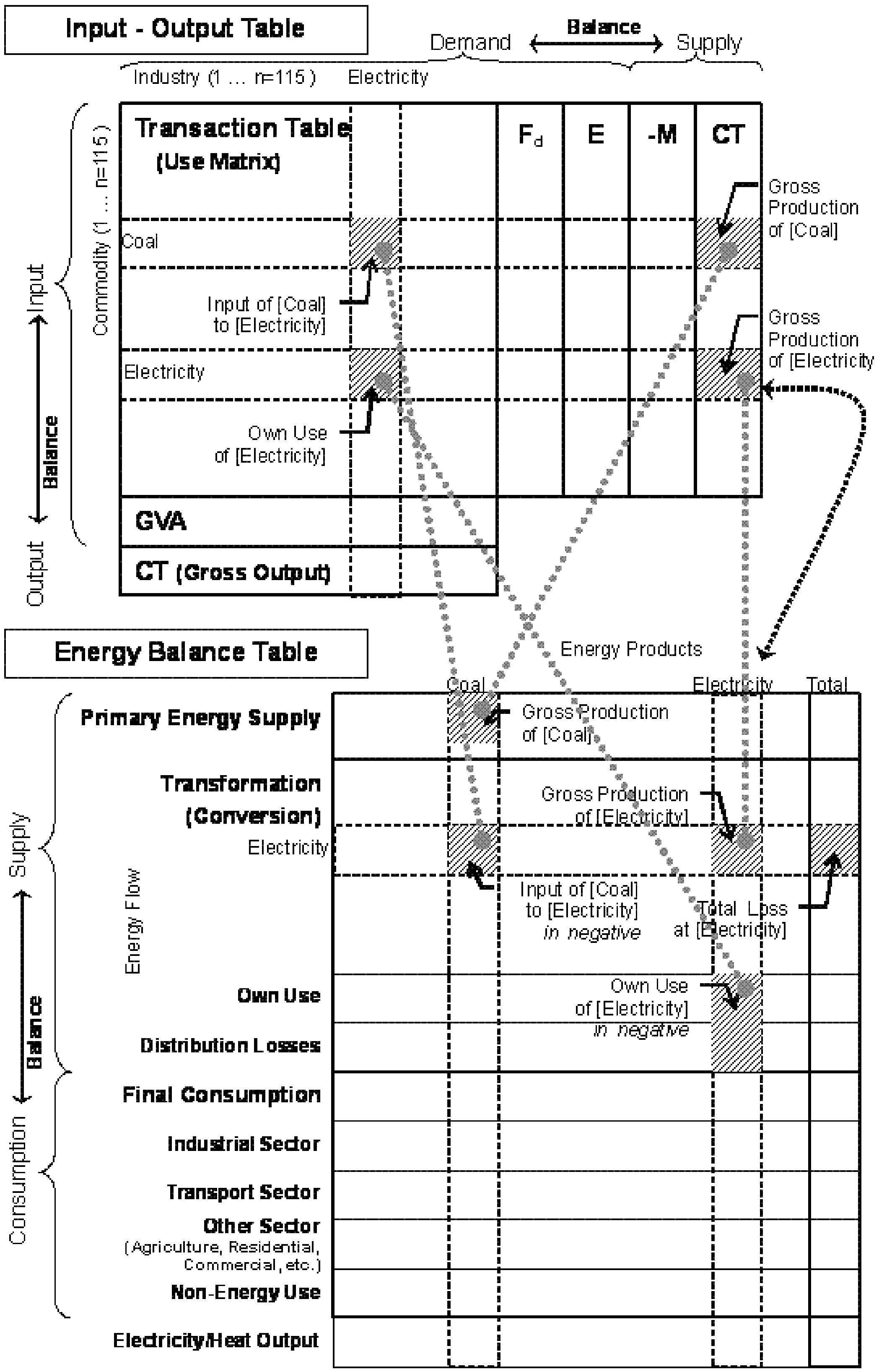

Fig. 2 Input-Output Table and Energy Balance Table

■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 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-transportaion.

■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:

- The output value of primary energy product (such as Coal, Crude Oil) on I-O correspond with the Primary Energy Production on EB
- The output value of secondary energy product (such as Coal/Petroleum products, electricity) on I-O correspond with the produced amount in Transformation sector on EB
- The input value of energy products to other energy production on I-O correspond with the consumed amount in Transformation sector on EB
- The diagonal value on I-O correspond with the Own-Use/Distribution-Losses in Transformation sector on EB
- The other input values of energy products to non-energy sector on I-O correspond with

the amount in the

- Final Consumption sector on EB

■Criteria for the Consistency In our study, we define the consistency of I-O and IEA-EB in the following senses.

1. Balance: For each energy item, total inputs (consumption) and total outputs (production) must equal in both of quantity and monetary units.
2. Coverage: The coverage of each activity in EB must be consistent with that of I-O.
3. 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.
4. 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 in available publications and intuition of researchers and statisticians.

3.4 Compilation Procedure

3.4.1 Steps for the Compilation in General

1. Construct individual energy balances for energy commodities from several official statistics (Annex II, III, IV). 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.
2. 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.

3. Disaggregation into 115 sectors using nominal share of I-O
4. Attach other information to calculate sectoral CO_2 emissions, such as calorific table, combustion ratio.

3.4.2 Energy Balance for Individual Energy Commodities

■Coal, Lignite and Coal Products Energy balance table for this type of commodities is shown in Annex II. This sector includes Raw Coal, Lignite, Coke, (Tar,) Coal Gas, etc. We 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 III.

Natural Gas The input to Agriculture is the consumption in Tea Plantation. It must be used for dry the leaves.

Crude Oil

1. Transfer from NGL to LPG and Naphtha
   (a) NGL output → [Petr. &NG, Petr. Prod.]
   (b) LPG input → [LPG, Gross Output]
   (c) Naphtha input → [Naphtha, Gross Output]
2. Statistical Differences → [Stock Changes]

Petroleum Products

1. Statistical Differences → [Stock Changes]
2. LPG, Non-energy Use Products: Disaggregate in Industry and commercial.
3. 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 IV.

■Biomass Production or consumption data of biomass is rarely available because most of the biomass are not traded commercialized way, thus overall picture is not captured by statistics. In our study, we construct biomass balance table, with limited survey on consumption data. For this 1st edition, we take the amount of IEA-EB and disaggregate the total amount of domestic consumption using the values of Forestry sector of I-O table.

3.4.3 The Consistency of I-O with Physical Amount (Electricity Sector)

For the first step, we choose electricity sector to compare of them, because we don't need to care about product variety or conversion factor on electricity.

■Data sources We check the data source of I-O and IEA-EB in Electricity sector to confirm the condition 2 of [Coverage]. I-O is composed on the concept of National Account Statistics (NAS). We also investigate the data source of NAS.

■Compare the Values of Electricity between I-O and IEA-EB Activities of I-O table are more detailed than those of IEA-EB, however, energy-related commodities are aggregated only to 6 sectors (Coal and lignite, Crude petroleum, natural gas, Petroleum products, Coal tar products, Electricity) in I-O table. We take the following scheme for the first step.

1. Aggregate the activities of I-O to Flow sectors of EB
2. Convert the physical amount of EB to monetary value using unitary price of electricity.

■Aggregate the activities of I-O to Flow sectors of EB First, we aggregated I-O table to IEA-EB (aggregated) sector. (See Annex I-1) Most of activities in I-O will be aggregated. In IEA-EB table, there are no detailed consumption data in Industry sectors. We guess that they could not get sector-wise consumption data of electricity from CEA General Review. We confirm that we can get such kind of data for Non-Utilities sectors but it's impossible for Utility sectors in General Review. [Other transport services] of I-O corresponds to several transport sectors in EB such as International Aviation, Domestic Aviation, Road, Pipeline

Table. 2 Consumer Category-wise Average Tariff and Average Cost

	1993/94 (paise/kwh)	1998/99 (paise/kwh)	1998/99 (Rs-Lakhs/Gwh)
Domestic	84.3	139.1	13.9
Commercial	186.3	330.2	33.0
Agriculture	17.9	21.0	2.1
Industry	198.2	322.8	32.3
Traction	216.4	410.3	41.0
Outside States	84.5	163.8	16.4
Overall(1)	116.7	186.8	18.7
(Cost)	149.1	263.1	26.3

Annual Report 2001-02 on the working of State Electricity Boards and Electricity Departments, Planning Commission, Table 4.4 &4,5

Table. 3 Basic Price of Electricity for 1998/99

	Agriculture	Domestic	Sales Average
(1)Quantity [GWh]	97,195	64,973	309,734
(2)Average Tariff [Rs lakhs/GWh]	2.1	13.91	18.68
(3)Value in terms of purchasers' price [Rs lakhs] : (1) * (2)	204,110	903,774	5,785,832
Indirect tax [Rs lakhs]			
(4)Gross indirect tax	0	0	-
(5)Subsidy	2,069,387	633,248	-
(6)Net indirect tax : (4) - (5)	-2,069,387	-633,248	-1,500,260
(7)Value in terms of basic price [Rs lakhs] : (3) - (6)	2,273,497	1,537,022	7,286,092
(8)Basic price [Rs lakhs/GWh] : (7) / (1)	23.39	23.66	23.52

General Review 1998-99, CEA &Annual Report 2001-02, Planning Commission

Transport, Domestic Navigation, Non-specified Transport (except Railway). We took Non-specified Transport to represent of them. Also Import sector on EB represents Import and International Marine Bunkers.

■Convert the physical amount of EB to monetary value The electricity price in India is available only from the Annual Report of Planning Commission shown as follow. The coverage of this report is State Electricity Boards (SEBs) and Electricity Departments (EDs). Central sector, Private sector, and Non-utility sector are excluded from this report. And the values of generation or sales of SEBs are different from CEA General Review. We guess the sources are different each other.

Above table shows the basic prices computed from the price and subsidy data of Annual

Report of Planning Commission. The purchaser's price is so different between Agriculture sector and Domestic sector, however the basic price which excludes net indirect tax became almost same value.

In Annex I-2, first column is the amount in physical unit [GWh] which is taken from IEA-Energy Statistics. We converted them into monetary value using the basic prices of which result are shown in column (1). The value of Generation (Electricity Plants) is fixed with the value of I-O table. The statistical difference is included in Own Use and Distribution Losses. Column (2) is monetary values from U-table (Absorption Matrix). The values are very different from I-O especially in Transport, Agriculture, and Residential sector.

■Other problems We found some other problems on I-O Table.

Captive electricity generation in industries There are captive generations in several industries like Iron&Steel or Aluminum. The output of electricity coming from industries other than Electricity industry, relates to electricity generated and sold by those industries. These electricity output should appear in Make Matrix (V Table). However, in I-O 1998-99, they were not shown separately in the matrix, due to non-availability of separate data. In such cases that output is merged with the products and by products of respective industries.

Input of Electricity to Other transport services in Use Table There is big input of electricity to "104 Other transport services", (ex. 1,154,619Rs-Lhaks in 98/99) which is almost 10% of Gross output of Electricity Sector. This value excludes the electricity-input to Railway Sector off course. We' checked "Sector Specification" Table, however we couldn't identify the consumer with such big amount of electricity. And from the statistics of "General Review, CEA", we couldn't get any information about it. It must be in the range of 3-5 % of Gross Electricity Generation.

Input of "Petroleum &Natural Gas" for Electricity Sector The Crude Petroleum &Natural Gas is inputted 326938 Rs-Lakhs to Electricity Sector in Absorption Matrix of 93/94, however it is 36 Rs-Lakhs in 98/99. This could be due to misclassification among various petroleum products or for some other reasons. We should make adjustments among sectors 23,24,58 and 100. Also the input of Petroleum products in 1993/94 looks too small compared with data of 1998/99.

Gross Value Added in 1998/99 We convert using mathematical scheme to confirm the Symmetric Matrix (X table). In 1998/99, we cannot get same result with published matrix. We have to revise the original I-O table to solve these problems.

3.4.4 Disaggregate EB amount

We disaggregated EB amount to I-O sector using the share of I-O value. This scheme is for 1st edition of I-O—EB Table. Now we are processing the Annual Survey of Industries datasets which includes all inventories of consumption item and produced item for respective manufacturing sector. We will switch to the result in the future.

The scheme of disaggregation

We disaggregate the physical quantity on IEA-EB using the share of I-O value. We'll show the scheme for coal to distribute Chemical sector for example,

- Step1: prepare the physical quantity which is corresponded to Chemical sector.
  a[coal, petr prod] = b[coal, 1602 Petrochemical Industry] + b[coal, 2200 Chemical and Petrochemical]
  - a[i, j]: input of i-product to j-sector in physical unit
  - b[i, j]: input of i-product to j-sector in IEA-energy balance table
- Step2: prepare the disaggregate share using monetary value on I-O table.
  s[i, j] = xij / sum (xij)
  - s[i, j]: share of i-product input to j-sector in the sectors correspond to Chemical Industry.
  - i = 23 Coal and lignite, j = 60 Inorganic heavy chemicals 68 Other chemicals
- Step3: disaggregate to I-O classification.

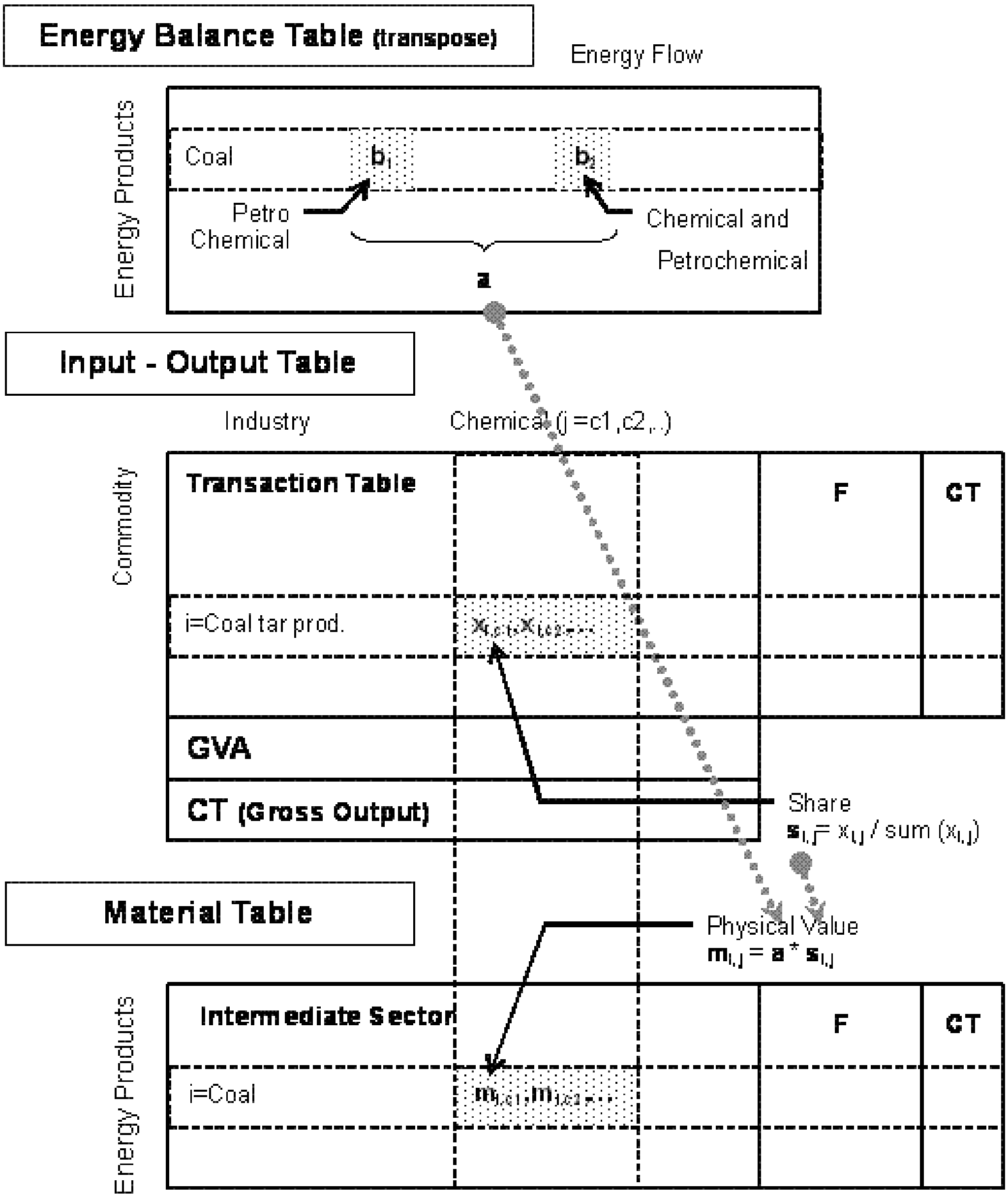

Fig. 3　Figure 6 The scheme of disaggregation

m[coal, j] = a[coal, petr prod] x s[23, j]

- m[i, j]: input of i-product to j-sector in I-O material balance table
- i = Coal and lignite, j = 60 Inorganic heavy chemicals　68 Other chemicals

Table. 4 CO_2 Emission in India [Million ton-CO_2]

		1993/94	1998/99
E-IO Results			
	from Intermediate Consumption	709.4	928.9
	from Final Consumption	68.5	79.1
	Total	778	1,008.00
IEA			
	Reference Approach	719.3	909.5
	Sectoral Approach	698.5	882

[Source] IEA CO_2 Emissions from Fuel Combustion (2005 ed.)

4 Conclusion

We have completed the 1st edition of Energy I-O table of India for the years of 1993/94 and 1998/99. Summary version, which is aggregated in 11 intermediate sectors, are shown in Annex V. However, there are still many data issues on which we are working. Data will be revised accoringly. Follwoings are summary of data issues and future scope of our study.

Table4 shows the result of our estimation. The total amounts are bigger than the amounts which are estimated by IEA. Mainly the differences come from Limestone. In the process of Iron production, limestone emits vast amount of CO_2.

■Data issues

Yield in petroleum refinery According to the energy balance (EB) table, the yield in petroleum refinery is more than 100%. The reason might come from erroneous conversion factors or inaccurate statistics. Though we tried to change the conversion factor, the yield was not improved.

Own use and loss

- Own use and loss The EB table hardly reports the own use of energy. There are tendencies to make no distinction between own use and loss of energy and to only report loss.

- Loss of blast furnace The difference between inputs of coke and outputs of blast furnace gas is reported as the loss in the EB table. However, since coke is used as energy of iron and steel production, the difference should be moved from the loss to inputs to the iron and steel.
- Own use in oil products The own use in the oil product industry consists of the heavy fuel oil (67%) and the refinery gas (33%) in the EB table. However, according to the expert of TERI, most energy in the refinery plant is refinery gas.

Non-energy use The non-energy use of natural gas and naphtha is not reported in the EB table. Making the detailed table of non-energy use is required.

Scraps and by-products The transaction table and V table in the I-O table report outputs of blast furnace gas and coke oven gas, only when these gases are reused. If the actual price is not observable, the opportunity cost must be estimated by imputation. The method is to estimate production cost or to substitute with competitive goods price.

Coal products In the EB table, coke, blast furnace gas and coke oven gas are supplied to the iron and steel industry, and coal tar is not reported. Thus, we converted inputs of coke, blast furnace gas and coke oven gas in the EB table into these inputs to the iron and steel industry in the I-O table. We assumed that coal tar is supplied to the other industry except for the iron and steel.

Oil products

- Transport by private cars Inputs of oil products to the other transport include inputs to transport by private cars in the EB table. We disaggregated the data using monetary value of oil product inputs in the I-O table. However, we might overestimate the inputs to transport by private cars in some industries which use oil products as fuel or feedstock, such as the petrochemical industry.
- Non-energy use and statistics differences We converted the non-energy use and

statistics differences of oil products in the EB table into inputs in manufacturing industries and stock changes in the I-O table, respectively.

Biomass The gas works gas in the EB table might be consistent with the gobar gas in the I-O table. Investigating the gas works gas and the primary solid biomass in the EB table is needed. The estimates of sectorwise supply and demand data of biomass fuel using available statisitcs, by constructing biomass balance table, will complement IEA data.

■**Future scope** This type of energy input-output table can be best utilized in scenario analysis, as technological and physical information can be directly used in the framework. Moreover, as the energy input-output table developed by our study has 115 sectors, scenario devloping with detaild information will be possible.

This study has not been completed and some users may find problems. However, finding problems will be the most desirable opportunity for us to revise data for more reasonable and proper way.

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 CO2, 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 CO2 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 CO2, 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 CO2 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 CO2 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)).

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