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A QUANTITATIVE ASSESSMENT & MATHEMATICAL MODEL OF EMBEDDED ENERGY AND TOTAL CO2 EMISSIONS FOR FUTURE PROJECTIONS

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Abstract In the present study the GHG emissions from energy final consumption are considered which includes energy in the producing sector in addition to the indirect energy embedded in other inputs for the energy intensive sectors. The embedded energy which emits GHG during conversions of energy in the whole energy chains is also included. The Input–Output Analysis (IOA) approach is used to calculate energy intensities and GHG emission factors of various final consumptions in the economy. The Intergovernmental Panel for Climate Change (IPCC) guidelines are applied to sectoral derivation of carbon dioxide emissions from the Indian economy. Emission factors have been estimated based on the sectoral energy consumption patterns. The sample calculations of a particular year are superimposed on the time series data to generate the matrices on energy consumption and related carbon dioxide emissions. The elements of the matrices are modeled to give the future projections.

1 INTRODUCTION

To support the GHGs mitigation options among energy activities effectively, it is necessary to quantify the total consumption in each commodity in terms of full energy chain analysis. In order to produce a final consumption, not only energy in the producing sector, but also indirect energy embedded in other inputs for the sector is required to estimate the embedded GHG emissions during conversions of energy in the whole energy chains. Input–Output Analysis (IOA) is an approach for full-energy-chain-analysis applied by many authors [1, 2, and 3]. In the present study same IOA is applied to full-energy-chains analysis in the estimation of GHG emissions from energy activities in all producing chains, of final consumptions of economic sectors. The flows of materials, services and energies are traced back through infinite transactions within the economy, and GHG emissions embedded in the flows are quantified. The IOA is used to calculate energy intensities and GHG emissions of various final consumptions in the economy to fill the truncated sub processes up to infinite process chains by assigning an economic sector to represent all commodities produced from the same sector. The IPCC guidelines [4–6] are applied for sectoral derivation of carbon dioxide (CO_2) emissions. Emissions from the Indian economy have been estimated based on the Input–Output (I–O) tables, structured through the data provided by the National Statistical Organization of India. Comparison of total GHG emissions among different energies in terms of full-energy-chains analysis is also done by applying the results from IOA. In addition, not only emissions from material but also services have been taken into account in the IOA. The sample calculations of a particular year are superimposed on the time series data to generate the matrices on energy consumption and related carbon dioxide emissions. The elements of the matrices are modelled to give the future projections.

2 METHODOLOGY

The concept of Input–Output Analysis (IOA) was introduced in 1986 by Wassily Loentief [8] and it was presented by Miller and Blair [9] in energy input–output analysis. It has been widely applied for derivation of energy intensity by Bullard and Herendeen [10], Wright [11] and Chapman [12]. We have applied this method for studying the carbon dioxide emissions in India. As far energy inputs to Indian economy is concerned, the system can be considered to be formed of five energy intensive sectors. Out of them the four sectors Agriculture, Residential, Industrial and Transport are consumers of fossil fuels like Coal, Oil and Natural Gas, where as the fifth sector the power sector is considered in terms of hydro, thermal and nuclear. Generally, fuel is usually combusted in a sector, but in some particular processes a fuel requirements purpose is for feedstock beyond the combustion. A particular economic sector requires various inputs starting from implementation, operation to decommissioning stages including services, energy and materials. The energy consumed in each sector for all the inputs has been obtained and arranged in form of a matrix E_{si}. The Emission factors of each of the fossil fuel are worked out on the basis of the IPCC guide lines to form the matrix E_f. Direct and indirect emissions are derived by the physical amount of each type of fossil fuel that is directly combusted within the sector. Than the indirect energy flows are truncated to modify the energy consumption. Finally total emissions generated from all production sectors are derived. The matrix of total energy consumptions E_{si} is of order [s x i] in which column s=3 is formed of sectors and the rows i=5 are the consumptions of the fuels in respective sectors. It can be defined to have elements as

$$E_{si} = \begin{bmatrix} \text{Fuel} \Rightarrow \text{Coal} & \text{Oil} & \text{N. Gas} \\ \text{Sector} \Downarrow & & \end{bmatrix}$$

And the emission factors are given by the Matrix E_f as

$$E_f = \begin{bmatrix} E_{f\,coal} & E_{f\,oil} & E_{f\,N.\,Gas} \end{bmatrix}$$

Where $E_{f\,coal}$ is the emission factor of coal, gives the carbon dioxide emission by per ton of combustion of coal. Similarly $E_{f\,oil}$ and $E_{f\,N.\,Gas}$ are emission factors for oil or total petroleum products and natural gas respectively.

And the emissions of carbon dioxide are obtained as

$$f = [\,E_f\,]\,[E_{si}]$$

This matrix 'f' gives the total carbon dioxide emission in a particular year from all the sectors. The CO_2 emissions for the years 1980 to 2007 are being calculated by the same methodology using software 'METLAB'. The time series data on energy consumptions of Fuels I-[coal, oil & N. gas] in a particular year have been generated to give three new matrices E_c , E_o, and $E_{n.g}$ respectively. The mathematical logistic models of the elements of each of these matrices have projected the future energy consumptions and related CO_2 emissions to give the matrix Ee. The elements of which are the time series data and projections of energy related CO_2 emissions of a particular year.

3. DATA PREPARATION

Indian energy consumption tables, available in four sectors, are published by many authorities; out of which we referred are annual reports of Indian Statistical organisation [16], Central Electricity Authority – CEA [17], Coal Authority of India – CAI [8], the 'The Energy Research Institute' (TERI) – a directory titled TERI Energy Data Directory Yearbook (TEDDY) [19]. In order to assign each sector and represent average energy consumption I–O approach is applied for the analysis. The data provided by TEDDY has been analysed to gives recent disaggregated statistics for construction of the matrix E_{si} for the period 1980 to 2007, in accordance with the IPCC guide lines. The I–O table is tailor-made for a structural matrix can be direct input to the MATLAB programs. Each element of the matrix provides the sum of the 'whole range of energy inputs' of particular type. Prior calculations are made for finding the element of E_f, the elements of E_{si} & $E_{c,o}$ & $E_{n.g.}$ are obtained by IOA. There after, the emission factors were calculated to construct E_f.

4. CONCLUSIONS AND DISCUSSIONS-

The IOA study reveals the implications of the indirect as well as the direct energy related GHG emissions in the Indian economy. The energy intensities and total GHG emissions in final consumptions found in this study could be further applied for comparative assessment in other energy projects in India. Though the energy related GHG have to be derived from the amount of energy consumption, but there is no proportionality between 'energy intensity' and 'greenhouse gases intensity'. There are two explanations for this observation: firstly, disparity of GHG emissions from combustion of different fuels, and secondly, GHGs could be emitted in some other activities rather than combustion of fuels. Delineation of most sectors into sub process orders and activities reveals that we could not neglect indirect effects beyond the direct combustion in the conversion stage of any commodities' production.

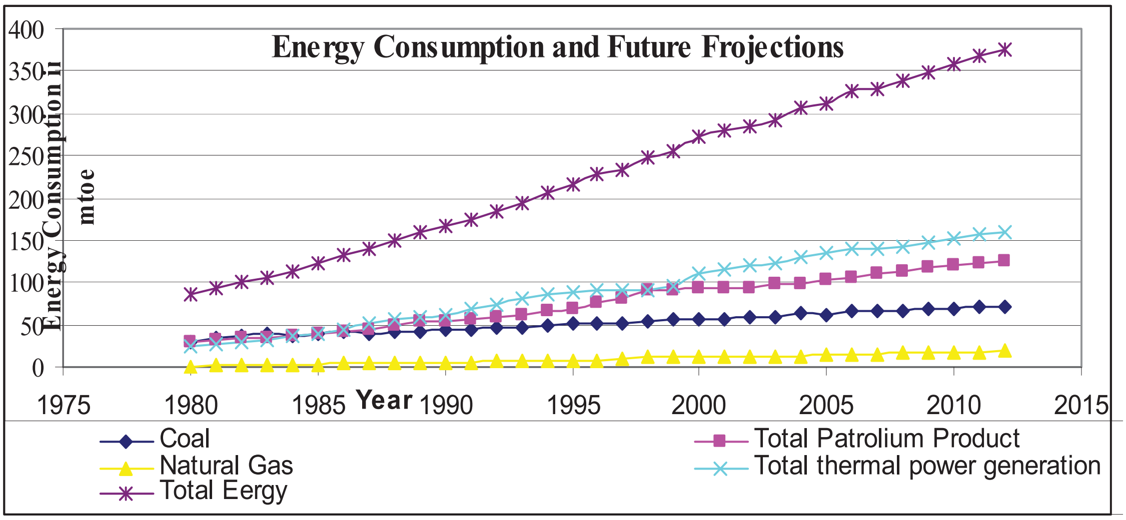

Fig.1. The sectoral energy consumption in India obtained by I-O Analysis and Model projections

The highest GHG intensive sector in the Indian economy is the transportation sector having emissions from fossil fuel combustion and production processes. The electricity sector is the highest energy intensive sector and the second highest GHG intensity sector due to a large contribution of direct GHG emission from fossil-fuel combustion.
The high emission factor of the electricity sector indirectly induces high emission factors in most dominating coal fired thermal power generation, since electricity is the basic requirement for other sectors in the Indian economy.

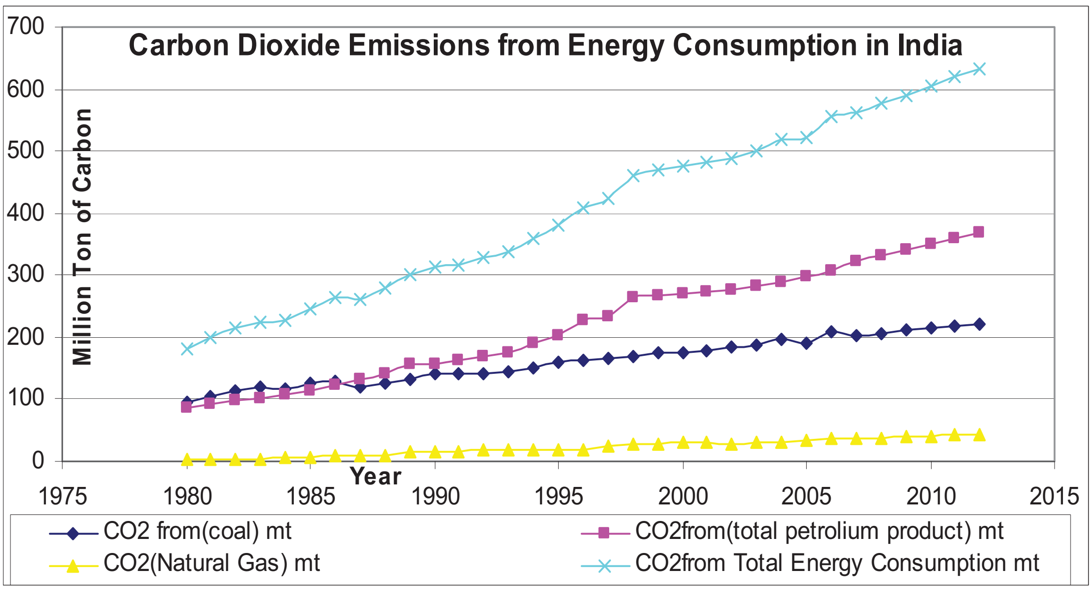

Fig.2. Estimated Carbon Dioxide emissions from energy consumption and projections modelled as per the IPCCC Guide lines.

This paper also copes with the embedded GHG emissions from indirect emissions. At the higher sub process order, it needs embedded energy and total GHG emission factors from IOA to evaluate the remaining energy and GHG emissions in extended boundary layers.

However, to improve the accuracy of the full-energy-chain analysis, large extension on field surveys of relevant industrial sectors is required. Each extension level requires energy and emissions auditing on all production processes of all input requirements in the previous level.

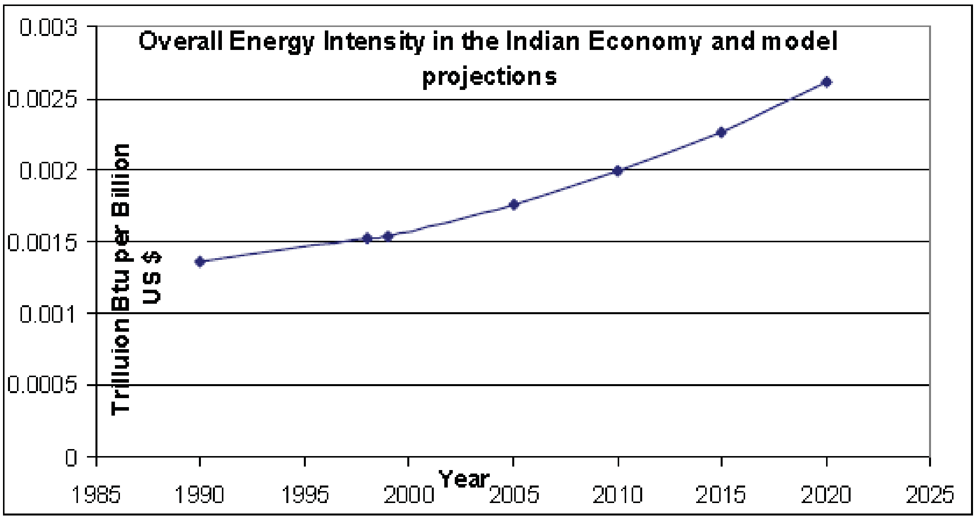

Fig.3. The Energy Intensity scenario in Indian economy predicted in the whole energy chain analysis.

The assessment of GHG emissions from the selected case studies reveals that input requirements in the operating stage directly affect the life-cycle GHG emission factors in terms of direct and indirect emissions and energy intensities. As the global warming is an important issue, long-term policy making on a lower GHG emitting project should be done in terms of full-energy-chains analysis.

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