International Journal of Advanced Scientific Research
ISSN: 2456-0421; Impact Factor: RJIF 5.32
www.allscientificjournal.com
Volume 2; Issue 3; May 2017; Page No. 34-37

Energy/Carbon Nexus: An input-output approach to the Indian case

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Abstract
In recent years, the increase in the economic activity of modern societies has led to an increase in the standard of living and welfare. Economic development is linked to growing pressure on the environment, mainly as the result of the exploitation and use of energy and natural resources, but also as the result of an increase in population, motor vehicle transportation, and new techniques for making agriculture more productive or industry more efficient. One of the major problems of resource analysis is the relative lack of energy products and the fact that some of them are not renewable (for example, petroleum, natural gas).
Input–output analysis is a well-established linear economic model often used to account for economic, environmental consequences or impacts following a change in the total output produced by the economy. Economic input-output analysis allows determination of effect of final consumption of a certain commodity on its direct and indirect inputs.
In this study, input-output analysis is used for the analysis of CO_2, emission. Further the study uses input-output tables of the Indian economy for the years 2003-04 and 2006-07 prepared by the Planning Commission to estimate direct emission from the use of oil and gas resources.
The analytical approach used in this study, gives appealing results that can help to design policies that help in identifying the ways to reduce the intermediate consumption of energy, and to reduce the amount of atmospheric pollution that may be caused by inappropriate use of energy.
The main objective of this study is to examine the levels of direct emission of CO_2 by different sectors by using oil and gas as an input.

Keywords: input-output, direct and indirect emissions, pollutants, fossil fuels

Introduction
Input–Output analysis is a well-established linear economic model often used to account for economic /or environmental consequences or impacts following a change in the total output produced by the economy. Input–Output analysis is a well-established linear economic model often used to account for economic, environmental impacts which makes subsequent change in the total output produced by the economy. The Input–Output model is used as an analysis tool either at macro- or micro-level.
Economic input-output analysis allows determination of effect of final consumption of a certain commodity on its direct and indirect inputs.
The environmental input-output framework integrates the economic and ecological relations that take place within the production system. In recent decades, the input-output model has become a useful tool for calculating environmental burdens such as energy consumption and pollution generation, caused by normal activity of productive sectors (Llop 2007) [8].

Objective
The main objective of this study is to explore the levels of direct emission by different sectors by using oil and gas as an input. The CO_2, emission $_{from}$ fossil fuel combustion can be analysed with the help of input –output table of the Indian economy.

Methodology
In the Input–Output model, the relationships among economic sectors are described through the use of a system of linear equations, which represent for each sector the identity between the total outputs produced, the input purchased and consumed by all the other sectors of the system plus the consumers. In other words, everything produced by a sector is purchased and consumed respectively by the other ones as inputs or by the consumer as final demand (Mongelli and Notarnicola 2006) [10]. Mathematically, the basic equation is expressed as

$$X= AX+ Y \quad (1)$$

With X as the n-vector of goods required for total output. Y as the n vector of goods that satisfies the final demand and AX is the n-vector of intermediate demand. A is the n×n matrix of technical coefficients, on a fixed ratio (constant), that reflect the inputs required (from all sectors) for the production of each particular sector.
Reorganisation of expression (1) yields

$$X= (I-A)^{-1} Y \quad (2)$$

Where I is a unit matrix of order n and $((I-A)^{-1}$ is the Leontief inverse, which converts final demand into total output. It is well known that, the inverse $(I-A^{-1})$ of (I-A). Where A represents the structural (input coefficient) matrix of a given economy, describes the total, that is, direct and indirect effects of Rupees 1 million worth increase in the final demand for the products of any given industry on the total output of this and every other industry.

As far as 2006-2007, I-O data are concerned only Input and output table of commodity-by- industry information exist. Hence by using the software MATLAB, the coefficients are obtained by the following formula

$$aij = Xij / Xj \quad (3)$$

Where Xij is the monetary input coming from sector i and used by sector j, while Xj is the total output of sector j. The input coefficient aij thus indicates in million Rupees (mrs) of commodity i per million Rupees (mrs) of output of commodity j. Further the (I-A), $(I-A)^{-1}$ are also calculated to arrive at direct and indirect energy consumption.

For estimation of CO_2 emission, the above conventional method of input-output framework is extended to compute CO_2 emission that takes place in the production of a commodity at various levels. The fuel specific carbon, sulphur and nitrogen emission factors to the row vector of fossil fuel sector (oil and gas and converted gas into oil equivalent) of the respective Input-Output table to estimate the total CO_2 emitted by the oil sector.

The next step is to calculate the CO_2 emission, from fossil fuel combustion. This has been estimated by the Inter-governmental Panel on Climate Change (IPCC) guidelines (2006) [5]. It is assumed that all the oil and natural gas are combusted whenever they are used as an intermediate input, generating CO_2emission. This methodology is based on the study undertaken by Mukhopadhyay (2005) [13].

Sources Data

This study uses the Indian I-O tables of 2003-2004 and 2006-2007. In case of 2003-2004, the Central Statistical Organisation has provided with the ready information on I-O coefficient matrix and Leontief inverse matrix.

Review of Literature

Developed a static input-output framework for analysing energy issues in the short run. The input-output model is also presented to deal with the impact arising from the primary input supply restriction. The study applied multiplier analysis to evaluate the wholesale price change on the economic system due to the cost change of import energy.

Machado *et al* (2001) [9] examined the energy and carbon coefficients for the Brazilian economy by using a hybrid input-output model in 1995. It is based on commodity-by- industry approach. The results show that the total energy embodied in the exports of non-energy goods of Brazil equals 831 PJ, while total carbon embodied is 13.4 MtC.

Giljum and Hubacek (2003) [3] applied input- output analysis based on a physical input-output modelling order to calculate direct and indirect land appropriation of EU-15 exports. As a PIOT for the EU-15 does not yet exist, they have developed a table from already published national studies.

Mukhopadhyay (2001) [11] in this study applied input-output model to identify the CO_2 emission from fossil fuel combustion. 'Structural Decomposition Analysis' was used to study the changes that take place in the economy. The study considered three energy sectors, coal, crude oil and natural gas and electricity. Input-output table for the years 1973-1974, 1983-84, 1991-1992 and 1996-1997 have been used to study the emissions. The study reveals that the CO_2 emission from coal combustion rate is highest among all periods with 9.7 % per annum.

Mukhopadhyay (2005) [13] estimated the industrial emissions of CO_2, SO_2 and NO_x in India. This study, also examined the sources of change of CO_2, SO_2 and NO_x in India generated by different income groups especially by the lower income groups. It covered the period of 80s and 90s.

Discussed and clarified the concept of different kinds of inputs and outputs of economic systems. They then presented the details of the new approach. The study used the new approach for land appropriation. They concluded that the newly defined multiplier, played an important role in the new approach, it acted as a bridge between the total input and the final demand in PIOT, just like the traditional Leontief inverse in MIOT. The equivalence of the three approaches and the equivalence of non-waste part and waste part multiplier of the new approach are also proved.

Proposed a methodology named hybrid physical input-output model for energy analysis (HPIOMEA) to study the energy metabolism, for Suzhou in China. It calculated energy resources in both energetic and mass units and air pollutants in the mass units to find the perspective energy balance and mass balance from the input-output tables for energy. The results show that the CO_2 emission is the main sources of climate change and acid rain. The water vapour has little effect on the atmospheric environment in Suzhou. Coal dominates the primary energy consumption. Suzhou generated 67.28 million tons of carbon dioxide and 0.12 million tons of sulphur dioxide and 0.44 million tons of nitrogen oxide and 42.74 million tons of other pollutants in 2005.

Construction of the Energy Input-Output Tables

The original input-output table were aggregated into 60 sector tables in which 17 sectors from which most of the atmospheric pollution comes are described in a relatively detailed way by incorporating the 3 pollutants. In this analyses a comparative study of the emission status of these industries are done by using Input-output tables from the Central Statistical Organisation. The Indian I-O tables for 2003-04, 2006-07 are analysed here. As for as 2006-07 data are concerned only input and output table are available. Hence using software MATLAB, the coefficients, I-A, $(I-A)^{-1}$ are calculated. Based on the above tables the contribution of direct CO_2, emission is arrived at.

Direct Emission

CO_2 Emission

There are considerable discussions over the issue of the presence of CO_2 in the atmosphere which causes rise in temperature. The large scale utilisation of fossil fuels for energy generation by the growing population and industries has increased the level of carbon oxide in the atmosphere. This has resulted in global warming. In the post industrial revolution period due to the excess burning of fossil fuels in a variety of human activities, there has been a marked increase in the emission. Oil and natural gas contain a lot of carbon, when they are burned in electricity power stations, in private boilers or in engines, they emit CO_2.

Table 1: Direct Emission CO_2

		CO_2 (mt) 2003	%	CO_2 (mt) 2007	%
1	Coal and lignite	0.001	0.01	0.017	0.05
2	Natural Gas	0.002	0.01	0.012	0.03
3	Textile products	0.023	0.13	0.262	0.79
4	Petroleum products	15.65	91.7	18.47	65.6
5	Coal and tar products	0.026	0.15	0.299	0.9
6	Inorganic heavy chemicals	0.002	0.01	0.017	0.05
7	Organic heavy chemicals	0.002	0.01	0.018	0.05
8	Fertilizers	0.409	2.4	4.267	12.8
9	Paints, varnishes and lacquers	0.014	0.08	0.151	0.45
10	Pesticides, drugs and chemicals	0.157	0.92	1.635	4.92
11	Cement	0.029	0.17	0.329	0.99
12	Non-metallic mineral products	0.001	0.01	0.015	0.04
13	Iron and steel industry	0.234	1.37	3.178	9.57
14	Other basic metal industry	0.040	0.23	0.089	0.27
15	Other machinery	0.024	0.14	0.321	0.97
16	Electrical electronic machinery & appliances	0.001	0.01	0.163	0.49
17	Electricity	0.445	2.6	3.964	11.9
	Total	17.06	100	33.21	100

Source: Calculated by the author by using the method described above.

The table 1 shows that the CO_2 emissions from Petroleum Product Sector, Electricity, and Fertilizers during 2003-04 are 15.65 mt, 0.44 mt, 0.40 mt, respectively. In this category the Petroleum Product Sector emits high carbon dioxide. It is evident that, fossil fuels are diminishing due to extensive and continuous use by increasing population and rising level of development. Moreover, burning of fossil fuels (oil and gas) is the principal cause of CO_2 emissions leading to air pollution and environmental degradation.

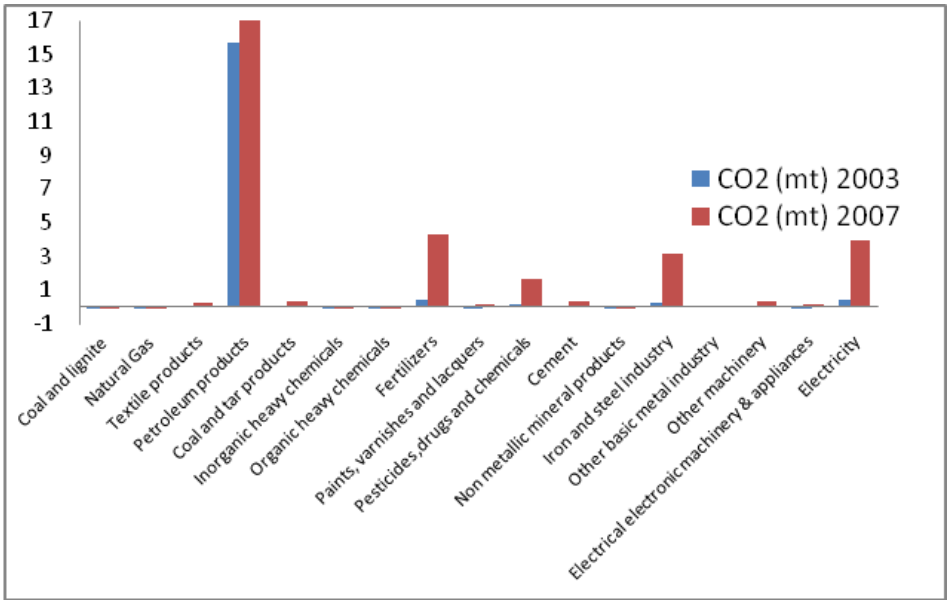

Fig 1: Direct emission of CO_2

The figure 1 displays that the direct emission of CO_2 in various sector. It shows that the Fertiliser, Iron and steel industry Pesticides and drugs, Electricity and Petroleum products emits higher CO_2 in 2007 when compared to 2003.

Table 2: Ranking of the industrial sectors (top five polluters) in 2003-04 and 2006-07

Rank	Industrial sector	Emission type	Contribution % in 2003	Contribution% in 2007
		CO_2		
1	Petroleum products		91.74	65.62
2	Electricity		2.60	11.94
3	Fertilizers		2.39	12.85
4	Iron and steel industry		1.36	9.56
5	Pesticides and drugs		0.15	4.92

***Source*:** Compiled by author

Table 2 shows the ranking of top five most polluting industrial sector. It can be seen that some industrial sectors, namely, Petroleum products, Fertilizers, Pesticides and drugs, electricity and iron and steel industry, are common in the top five lists. These are clearly the most polluting industries. It also gives the comparative picture of the CO_2, emissions for the years 2003-04 and 2006-07.

Findings

a. It is to be noticed that CO_2 emission in the Petroleum products industry is very high (91.7% in 2003-04 and in 2006-07 it has declined to 65.62%) when compared to others in the environment.
b. Further the Electrical sector contribution to CO_2 in the environment is the second highest when compared to Fertiliser (2.39% in 2003-04) and increased to 12.84% in 2006-07.
c. For all the sectors 2006-07 there is a hike in the CO_2 emission except petroleum products this may be due to the environmental regulations and the techniques used by these industries.

Conclusion

This chapter has shown how an input-output analysis is used to find out CO_2, emissions that are arising from the use of oil and gas resources in India. It also compares the direct emission effects of CO_2, in 2003-04 and 2006-07. The results derived from the study lead us to conclude that in India the direct CO_2 emission from the fossil fuel combustion is very high in five industries, which are Petroleum products, Electricity, Fertilisers, Iron and Steel industry and Pesticides and Drugs. Apart from this, the direct emission calculation from the Input-Output analysis (IO) enables us to know the impact of energy on the environment. Input- Output analysis is a useful tool in understanding the physical structure of an industrial system and its interdependence with its environment. The economy and the environment are connected through material and energy flows. These flows are the key cause of environmental problems and can serve as an indirect indicator of pressure on the environment.

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