AIR POLLUTION AND INCOME DISTRIBUTION IN INDIA

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Concern over the environmental effects of fossil fuels in India has been growing as domestic consumption levels increase. Along with industry, households are major consumers of commercial energy and, consequently, major contributors to the total energy use in India. Emission levels in the country are gradually increasing.

The present study estimates emissions related to fossil fuel combustion in India and also identifies the factors responsible for changes in those emissions during the 1980s and 1990s. Results show that the factor relating to changes in final demand, which reflect increased economic growth, had the greatest influence on emission levels.

The study disaggregates households into three income groups, examining the contribution each makes to fossil-fuel-based pollution in India with respect to the various factors identified. Analysis indicates that higher- and middle-income groups generated more pollution due to excessive and inefficient consumption of commercial energy. The paper concludes with a discussion of policy implications.

I. INTRODUCTION

Industrialization and urbanization have resulted in a profound deterioration of the air quality in India. While the country's gross domestic product has increased 2.5 times over the past two decades, vehicular pollution has increased eight times, and pollution from industries has quadrupled.

Environmental problems range from the hazards of ever-increasing levels of pollutants to ecosystem degradation. Global warming is not the only problem

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associated with major energy sources and usage patterns; other related environmental issues include air pollution, acid precipitation, ozone depletion, forest destruction and the emission of radioactive substances. Pollutants such as sulphur dioxide (SO_2), mono-nitrogen oxides (NO_X) and carbon dioxide (CO_2) are produced mainly through the combustion of fossil fuels, such as coal, crude oil and natural gas. Increasing consumption levels add to the growing concerns about the environmental effects of these fuels; in recent years, the effect of air pollution on health has been a major focus of attention.

Although fossil fuel use in developing countries is still half that of developed countries, it is expected to increase 120 per cent by the year 2010. It has been estimated that, if control measures are not implemented, by the year 2020 more than 6.34 million deaths will occur in developing countries due to ambient concentrations of particulate air pollution (Romieu and Hernandez 1999).

In a survey conducted by the Central Pollution Control Board of India, 23 Indian cities were identified as critically polluted (India 2000a). The survey reported that 12 major metropolitan cities in India produced 352 tons of nitrogen oxides, 1,916 tons of carbon monoxides from vehicular emissions and 672 tons of hydrocarbons per year. The levels of CO_2, SO_2 and NO_X in the ambient air of India are above the limit established as safe in the World Health Organization annual mean guidelines for air quality standards. Those limits are set at 90 micrograms per cubic meter for total suspended particulates and 50 micrograms per cubic meter each for sulphur dioxide and nitrogen dioxide (World Bank 1999). But the levels of SO_2 and NO_x in urban air pollution from major cities in India are growing rapidly. Needless to say, at these levels, such pollution is likely to have a serious impact on health. According to the United States of America Energy Information Agency, the World Health Organization named the capital city of New Delhi as one of the 10 most polluted cities in the world in 1998 (see Corrosion Doctors website, http://corrosion-doctors.org/AtmCorros/mapIndia.htm).

People who live in poverty are exposed to the worst environmental and health risks. Somewhere between 25 and 33 per cent of the global burden of diseases can be attributed to environmental factors (Kjellén 2001). In India, about one third of the population is below the poverty line (India 2001c) and, consequently, among those at a high risk of being affected by environmental hazards.

Because development requires energy use, increased development will inevitably affect health. The present study examines the above issues in the context of the need to control and regulate the emission of pollutants.

Households are major consumers of energy and, consequently, major contributors to the total energy use of the nation. At present, households in India account for about 40 per cent of the use of total direct commercial and non-commercial indigenous energy (Pachauri and Spreng 2002). If one takes into account the indirect or embodied energy in all goods and services purchased by households, then about 70 per cent of the total energy use of the economy can be related to the household sector; the remaining 30 per cent comprises the energy requirements of Government consumption, investments and net imports (Pachauri and Spreng 2002). The distribution of energy consumption with regard to the population shows that over 60 per cent of households have a per capita total household energy requirement of less than 0.5 kilowatts per year. In addition to the wide disparities among households in the quantities of energy used, there are large variations in the types of energy used and the patterns of consumption.

During the past few decades, India has experienced many changes in its energy consumption patterns, both in quantitative and qualitative terms (Centre for Monitoring Indian Economy 2001). This is due to a natural increase based on population growth, as well as to the increase in economic activity and development. As mentioned, the household sector is one of the largest users of energy in India. The pattern of household energy consumption represents the status of welfare and the stage of economic development of the country. As the economy develops, more and cleaner energy is consumed. Moreover, household energy consumption patterns are likely to vary according to income distribution and its change over time. Household energy consumption is expected to increase along with economic growth and rises in per capita income. The projected increases in household energy consumption are expected to result from changes in lifestyles (Pachauri 2004). In this connection, a study is needed to estimate the air pollution generated from fossil fuel combustion, disaggregated by income group in India.

The core objective of the present paper is to estimate what the industrial emissions of CO_2, SO_2 and NO_X were in India during the period 1983/84 to 1998/99. The sources of change in industrial CO_2, SO_2 and NO_X emissions are investigated through input-output structural decomposition analysis (SDA)[1] for that period. A breakdown of the emissions contributed by different income groups during the study period is also calculated.

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[1] Structural decomposition analysis (SDA) is a technique for studying period-to-period changes. It has become a major tool for disentangling the growth in some variables over time, separating the changes in the variable into constituent parts. SDA is used to distinguish major sources of change in the structure of the economy, broadly defined by means of a set of comparative static changes in key parameters of an input-output table.

Section II briefly reviews the literature on air pollution and health at the national and international levels. In section III, a model is formulated to estimate the industrial emissions of CO_2, SO_2 and NO_X in India, the changes in emission levels and the major factors behind the changes. The data sources and processing methodology used are presented in section IV. In section V, detailed empirical findings on changes in emission levels are analysed with respect to the factors responsible for changes in energy consumption during the period 1983/84 to 1998/99. The contribution of emissions made by different income groups is also discussed. Policy implications are discussed in the conclusion.

II. LITERATURE REVIEW

The literature on the estimation of emissions, particularly in a country framework, is extensive. A brief discussion on developed and developing countries, including India, follows.

Several researchers have estimated the direct and indirect energy requirements of households in developed countries, such as New Zealand (Peet, Carter and Baines 1985), Germany (Weber and Fahl 1993), the Netherlands (Vringer and Blok 1995, Wilting 1996) and Australia (Lenzen 1998).

In one paper indicative of this literature, Wier and others (2001) evaluate the correlation between the consumption patterns of various household types and their CO_2 requirements in Denmark, using an integrated modelling framework, and relate differences in household types to differences in both private consumption and CO_2 emissions. They identify household characteristics that have a significant influence on CO_2 emissions. Comparing their results with those of other studies, Wier and others state that national variations in climate and population densities can affect the levels to which households contribute to CO_2 emissions. Finally, national differences in income and expenditure elasticities of both energy and CO_2 are found to be due to the disparity in CO_2 intensities among commodities as well as to the assumptions regarding foreign technology that were included in the model. In another paper, Munksgaard, Pedersen and Wier (2000) trace the environmental impacts of consumption in Denmark. They include impacts originating from production layers of infinite order (capturing the entire economy). The authors present measures of CO_2 emissions at different spatial levels: the nation, city and household. Furthermore, they introduce the concept of environmental efficiency by combining input-output modelling and data envelopment analysis. The policy relevance of the different measures is also discussed.

Studies on developing countries, however, are much fewer in number. A World Resources Institute study (1998) shows that air pollution levels in China are among the world's highest. This is due to the country's growing consumption of coal. Coal burning, a primary source of the high SO_2 emissions in China, accounts for more than three quarters of the country's commercial energy needs, compared with 17 per cent in Japan and a world average of 27 per cent. The study finds that the energy and industrial sectors are the major contributors to urban air pollution in China. Emissions from the transport sector are also increasing.

Jiang and O'Neill (2006) study the impacts of economic growth and demographic changes on residential energy consumption and the environmental consequences of such consumption in China. Using the Rural and Urban Socio-economic Household Survey data sets for China in the 1990s as well as historical socio-economic, demographic and macrodata on energy use, the authors analyse the relative importance of changes in residential energy use to the general trends of overall energy consumption, and study the relationship between population, income and energy consumption and the latter's consequent emission of pollution. Through a statistical analysis of Chinese rural and urban household energy consumption, Jiang and O'Neill stress the importance of urbanization in the energy transition from biomass to modern fuel. Combining population and household projection results, the authors simulate the impacts of household compositional changes and urbanization on future residential energy consumption under different socio-economic and demographic scenarios.

Some studies focus on the transport sector (which is also a part of household energy consumption) as a major polluter. Others analyse indoor energy consumption, and show that it is responsible for the bulk of household emissions. Most of the studies focus on air pollution and its related health impacts, exploring sources and different sectors, especially transport and industry. Very few studies attempt to estimate the levels of pollution generated by different income groups.

Chaudhuri and Pfaff (2003) estimate the fuel-choice decisions of households in a poor developing economy, in particular the choice between dirtier traditional fuels (wood, dung and other biomass) and cleaner modern fuels, such as kerosene and natural gas. These choices directly influence the levels of indoor air quality enjoyed by the households. Results provide empirical support for a household production framework in which non-monotonic environmental Engel curves can arise quite naturally. Furthermore, estimates yield an inverted-U relationship between indoor air pollution and income, mirroring the environmental Kuznets curves.

Researchers at the Indira Gandhi Institute of Developmental Research carried out in-depth studies using input-output analysis and aggregated household expenditure survey data to calculate the CO_2 emissions from energy consumption for different groups of households in India for the year 1989/90 (Murthy, Panda and Parikh 1997a and 1997b and Parikh, Panda and Murthy 1997).

Pachauri (2004) analyses the variation in the pattern and quantum of both direct and indirect household energy requirements, using microlevel household survey data from India for the year 1993/94. Results reveal that household socio-economic, demographic, geographic, family and dwelling attributes influence the total household energy requirements. It shows that total household expenditure or income level is the most important explanatory variable causing variation in energy requirements across households. In addition, the size of the household dwelling and the age of the head of the household are related to higher household energy requirements.

Reddy (2004) analyses the dynamics of energy end-use in the household sector in India. It is observed that large variations in the use of energy exist across different sections of households, such as urban/rural and low/high-income groups. The paper further explores the energy-poverty nexus, impacts of household energy use on livelihood and gender issues. The positive effects of the innovation of energy efficiency and specific policies to achieve the potential for energy efficiency are also discussed.

Gupta, Keswani and Malhotra (1997) estimate greenhouse gas emissions for three reference years: 1980/81, 1985/86 and 1987/88, using a simple spreadsheet model. Bose (1998) has constructed a transport simulation model to evaluate automotive energy use and control of emissions for four Indian metropolises (Bangalore, Mumbai, Calcutta and Delhi) during the period 1990-2011. Sikdar and Mondal (1999) suggest that air quality management aimed at reducing stationary- and mobile-source emissions will help mitigate air pollution and improve quality of life. Chitkara (1996) explains the factors affecting air pollution, emission discharges and their sources (vehicular, domestic, industrial and energy use related). The Energy and Resources Institute (1997) has made a few estimates of the effects of SO_2, particulate matter, carbon monoxide and carboxyhaemoglobin at various concentrations (parts per million) and exposures (time) and then estimated the corresponding health effects.

In one study, Sinha and Bandyopadhyay (1998) attempt to capture the metallic constituents of aerosol present in the biosphere which have been identified as potential health hazards. They conclude that controls on emissions from industrial operations would help keep the metallic concentration within limits in the ambient air. Mukhopadhyay and Forssell (2005) estimate air pollution from fossil fuel combustion in India. The input-output SDA approach is used to find out the sources of changes in emissions. A link between the emission of pollutants and their impact on human health is analysed. The authors find that pollution and health impacts have a close linear relationship in India.

The studies above focus on household energy consumption from a developing country perspective. But a discussion of the generation of pollution in India, particularly when disaggregated by income class and economic factor, is rare in the literature; these aspects are examined in the present paper.

III. MODEL FORMULATION

In the present study, a model is developed based on the input-output SDA for the estimation of pollutant emissions (CO_2, SO_2 and NO_x) and factors responsible for changes in emissions. The model is further extended to incorporate different income groups.

Model 1 is founded on the basic concepts of the input-output framework of Leontief (1951). Mathematically, the structure of the input-output model can be expressed as

$$X = A + Y. \tag{1}$$

The solution of (1) gives

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

where X is a vector of output, Y is a vector of final demand and $(I - A)^{-1}$ is the matrix of total input requirements. For an energy input-output model, the monetary flows in the energy rows in equation (2) are replaced with physical flows of energy to construct an accounting identity which conforms to the energy balance condition (Miller & Blair 1985). We apply a hybrid method based on Miller and Blair (1985); it always conforms with energy conservation conditions.

On the basis of the estimated parameters we calculate the direct as well as the total (direct and indirect) CO_2, SO_2 and NO_x emission coefficients (see annex). An emission model is used to calculate the CO_2, SO_2 and NO_x emissions attributable to fossil fuel combustion in production activities in India (see annex). Then, an SDA is developed to estimate the changes in emissions in each period as well as to capture the factors responsible for such changes. The factors identified are: (a) changes in emission intensity, (b) changes in technology and (c) changes in the final demand of various industries (see annex).

In Model 2, Model 1 has been extended to calculate the contribution to emission changes by income group.[2] Model 2 also estimates the degree to which emissions among each income group are influenced by selected factors (see annex).

IV. DATA SOURCES AND PROCESSING

To implement the model and to conduct the SDA of energy consumption changes among different income groups, we require input-output data, price indices, energy-flow and emissions data and the consumption expenditure of various commodities for different expenditure classes (India 1984, 1991, 1995 and 2001b).

Data from input-output tables for the Indian economy for the years 1983/84, 1989/90, 1993/94 and 1998/99, prepared by Central Statistical Office (India 1990, 1997a, 2000b, 2005),[3] are used. Input-output tables are commodity-by-commodity tables consisting of 115 by 115 sectors. Those have been aggregated to 47 sectors on the basis of the nature of the commodities and energy intensiveness.

We use 1993/94 as a base year and adjust the 1989/90, 1993/94 and 1998/99 tables (India 1991, 1995 and 2001) to 1993/94 prices using suitable price indices available from the National Accounts Statistics.

We convert the monetary units of energy sectors into physical units from the energy data published by the Centre for Monitoring Indian Economy (1991, 1995, 1999 and 2003). Three energy sectors—coal, crude petroleum and natural gas, and electricity—have been converted into one common unit: million tons oil equivalent. Estimates of CO_2, SO_2 and NO_x emissions are made on the basis of the Intergovernmental Panel on Climate Change guideline.

Data from National Sample Survey rounds 38 (1983/84), 45 (1989/90), 50 (1993/94) and 55 (1999/00)[4] were compiled from the National Sample Survey Organization, New Delhi (India 1984, 1991, 1995, 2001b) and converted from raw data to the required format using the SPSS 10.0 computer programme. Data sets from the National Sample Survey Organisation have been arranged in terms of

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[2] Income groups have been classified according to their expenditure levels.

[3] The 1998/99 Commodity-by-Commodity table is prepared from the make matrix and use matrix of the Central Statistical Office.

[4] Though the present study considered the 1998/99 input-output table, the data coverage of the National Sample Survey for that year is not sufficient to carry out a study. Thus, the National Sample Survey data for 1999/00 has been used, due to its extensive data coverage of more than 10 million households.

item code, expenditure on those items and then monthly per capita expenditure (specific item codes for different blocks and the required block levels for our purpose are extracted from the comprehensive data set). Data were arranged and sorted according to expenditure class, and further disaggregated by income group (lower, middle and higher). This classification was made for the year 1993/94. Consumption expenditure for the years 1983/84, 1989/90 and 1999/00 is provided at the respective year's prices. Necessary deflators have been used to study the income groups for the years 1983/84, 1989/90 and 1999/00 at 1993/94 prices. The income group classifications at those prices are as follows: the lower-income group comprises incomes of Rs 0 to Rs 6,000; the middle-income group, Rs 6,000 to Rs 12,000; the higher-income group, Rs 12,000 and above. These categories are used to disaggregate the sectoral private consumption expenditure recorded in the input-output table.

V. MODEL ESTIMATION AND ANALYSIS OF RESULTS

Results based on model 1

Model 1 is used to examine the emission levels of $CO_{2,}$ SO_2 and NO_x. Aggregated hybrid input-output tables for the years 1983/84, 1989/90, 1993/94 and 1998/99 have been used to compute direct and total emission coefficients using equation (A1), provided in the annex.

Total emissions

The total industrial CO_2, SO_2 and NO_x emissions have been calculated using the input-output data for the respective years. Total emissions for the three air pollutants were computed using equation (4) of the model (see annex).

Table 1. Total emissions of carbon dioxide, sulphur dioxide and mono-nitrogen oxides, selected years
(Millions of tons)

Years	*Total emissions*		
	Carbon dioxide	*Sulphur dioxide*	*Mono-nitrogen oxides*
1983/84	369.50	2.69	4.98
1989/90	588.41	4.04	8.86
1993/94	759.44	5.63	9.91
1998/99	1 150.95	8.53	15.32

Source: Author's calculation, based on data from India (1990, 1997a, 2000b, 2005), using model 1.

It is evident from table 1 that emissions of all three pollutants tended to increase over the period covered; those increases can be seen clearly in table 2.

Table 2. Growth rate of emissions in India during 1983/84 to 1998/99
(Percentage)

Period	*Total emissions*		
	Carbon dioxide	*Sulphur dioxide*	*Mono-nitrogen oxides*
1983/84 to 1989/90	59.24	50.18	77.91
	(7.26)	(9.83)	(2.96)
1989/90 to 1993/94	29.06	39.35	11.85
	(5.81)	(7.87)	(2.37)
1993/94 to 1998/99	51.55	51.50	54.59
	(10.31)	(10.3)	(10.91)
1983/84 to 1998/99	211.48	217.10	207.63
(15 years)	(14.09)	(14.47)	(13.84)

Source: Author's calculation based on data from India (1990, 1997a, 2000b, 2005), using model 1.

Note: Terms in parentheses denote average increase per annum.

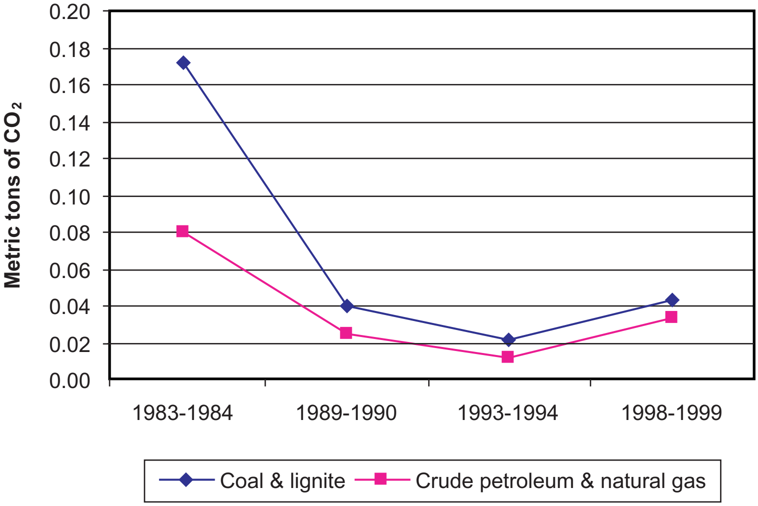
Levels of all three emissions, especially NO_x, increased significantly during the first period considered, but the rate of increase declined quite a bit in the second period. During the third period, growth rates of emissions were high once again.

Sector-specific intensity of major pollutants during selected periods

The overall sector-specific direct and total requirements of CO_2, SO_2 and NO_x were high for energy sectors, particularly the coal and lignite, crude petroleum and natural gas, and electricity sectors. Of these, the electricity sector, which is based largely on coal, had both the highest total intensity and the highest direct intensity of CO_2, SO_2 and NO_x. The use of higher grades of coal, which release less CO_2, could lower the CO_2 intensity coefficient of the electricity sector.

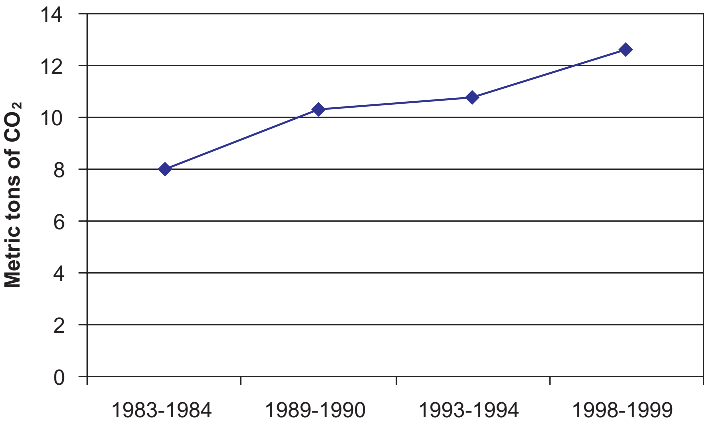
A comparison of two periods (1983/84 to 1989/90 and 1989/90 to 1993/94) shows that the total intensity value was higher in the first period; it then dropped, maintaining somewhat lower levels (figure 1). The composition of the contribution of energy sectors towards total requirement of CO_2 underwent changes over time. A sharp fall in the values of crude oil petroleum and natural gas in the period before 1991 is observed; the values then stabilize, during a period of economic reform in India (figure 2). The drop was due to the increase in the direct and intermediate use of electricity in the economy. But values picked up again in the latter half of the 1990s. The growth pattern of CO_2 emissions in the coal sector remained similar to that in crude oil and natural gas (figure 1).

Figure 1. Total intensity of carbon dioxide in coal and crude petroleum and natural gas



Source: Based on the results from model 1.

Figure 2. Total intensity of carbon dioxide in electricity



Source: Based on the results from model 1.

Among other energy intensive sectors, construction sector emissions fluctuate throughout the period under consideration, but cement has improved. Improvement in the cement sector occurred in conjunction with the installation of relatively expensive new technologies, such as pre-calcining facilities, high efficiency roller mills and variable speed motors. The improved technology and the greater efficiency it affords served to lower the sector's intensity of carbon emissions. The direct intensity of the construction sector was the lowest among all sectors, because it does not take much fossil-fuel-based energy to construct a building or a road. However, the sector uses many energy-intensive materials, such as bricks, cement, iron, steel, aluminium, glass and asbestos, which translates into a high value of total CO_2 intensity. Other sectors that reflect such an indirect effect include textiles, trade, agriculture and transport. Given their higher values for indirect coefficients and larger volumes of activity, those sectors were responsible for the most CO_2 emissions in India in terms of total (direct and indirect) emissions due to final demand.

The direct SO_2 emission coefficients tended to be higher for sectors such as petroleum products; electricity; chemicals and chemical products; basic metal, metal products and machinery; trade; and other services, but they varied among periods. In terms of the coefficients of direct NO_x emissions, the electricity sector contributed more than any other sector. The rate of the emissions increase in most sectors dropped slightly, except in the iron and steel sector. The total emission coefficient of NO_x shows that the electricity sector was responsible for the highest increase. The coal and lignite sector and the crude oil sector also ranked relatively high.

Results based on structural decomposition analysis

The total changes in estimated CO_2, SO_2 and NO_x emissions from 1983/84 to 1998/99 have been decomposed into effects caused by three components: emission intensity (S),[5] technical coefficient (R), and final demand (Y), following equation (11), provided in the annex.

The results of these SDAs are shown in table 3. The rate of total changes in CO_2 and NO_x emissions dropped slightly during the second period (1989/90-1993/94). But the growth rates of all three pollutants increased during the latter half of the 1990s. The first term of equation (11), $\Delta S\, R_t\, Y_t$, reflects the CO_2, SO_2 and NO_x emission changes due to the changes in the intensity of these pollutants across various industries. The second term of equation (11), $S_0\, \Delta R Y_t$, defines the

[5] Emission intensity is considered as direct intensity, that is, emissions generated per unit of output.

CO_2, SO_2 and NO_x emission changes due to changes in technology calculated using the technical coefficient matrix. The third term of equation (11), $S_0 R_0 \Delta Y$, refers to the CO_2, SO_2 and NO_x emission changes due to changes in the final demand of various industries.

As shown in table 3, changes in total CO_2 emissions during the pre-reform period (1983/84 to 1989/90) were due mainly to the change in final demand (about 60 per cent). Change in technology was also responsible, but to a lesser extent (about 36 per cent). Change in intensity level (about 4 per cent) had only a small influence. The scenario changed drastically during the period 1989/90 to 1998/99. During this reform period, the share of intensity change increased, adding to total CO_2 emissions, whereas the much stronger influence of the technological factor served to reduce the increase in total emissions. On the other hand, the effect of change in final demand increased, thus aggravating emission levels during the economic reform period.

Table 3 shows that total emissions of SO_2 increased overall between 1983/84 and 1998/99, primarily due to changes in final demand and in intensity. The increase in total emission change would have been greater had it not been for the negative change in the technology factor.

Table 3. Structural decomposition analysis of carbon dioxide, sulphur dioxide and mono-nitrogen oxides during the period 1983/84 to 1998/99

(Millions of tons)

Period	*Pollutants*	*Total emission change (ΔTE)*	*Comparative static change*		
			Change in intensity ΔS)	*Change in technology (ΔR)*	*Change in final demand (ΔY)*
1983/84 to 1989/90	CO_2	227.47	9.23	77.69	131.99
	SO_2	1.35	0.02	0.40	0.93
	NO_X	3.88	0.36	1.68	1.84
1989/90 to 1993/94	CO_2	171.03	54.99	-185.82	301.86
	SO_2	1.59	1.02	-1.39	1.96
	NO_X	1.05	-1.54	-2.15	4.74
1993/94 to 1998/99	CO_2	391.51	131.48	-30.83	290.75
	SO_2	2.90	2.71	-2.98	3.23
	NO_X	5.41	2.89	-2.09	4.62

Source: Author's calculation based on model 1.

The analysis of NO_x (table 3) shows that the total emission change fell during the period 1983/84-1993/94, from 3.88 million down to 1.05 million tons, and that this was due to greater-than-proportionate decreases in the intensity and technology factors. During that period, increases in final demand—which was up from 1.84 million to 4.74 million tons—were outweighed by the other two factors. But the picture changed completely during the period 1993/94-1998/99, and final demand became the stronger influence.

Change in intensity

As shown in table 3, changes in intensity throughout the period 1983/84 to 1993/94 were positive for all sectors. This indicates that industries were using energy-intensive technology or were emission intensive. Direct- and total-intensity results reveal that the electricity sector had the highest CO_2 emissions. This was due to the large amounts of low-grade coal consumed and the inefficiency of the process of coal-produced electricity (Mukhopadhyay and Chakraborty 1999). The direct and total intensity results show that the transport, iron and steel, and construction sectors increased their CO_2 emissions significantly. The intensities of SO_2 and NO_x emissions followed a pattern of change similar to that of CO_2, except in the second period, when the intensity of NO_x contributed negatively. Changes in intensity further increased during the period 1993/94-1998/99.

Change in technology

The effect of the rate of change in technology on CO_2, SO_2 and NO_x emissions was positive up to 1989/90, but in the reform period it became negative. This drop was attributable to a shift to a more moderate consumption of coal (4.8 per cent per annum) and crude oil (5.6 per cent per annum) during the period 1991/92-1996/97 (Mukhopadhyay 2002). In the oil sector, technical changes that minimized the risks of exploration and facilitated an optimal mix of exploration, energy conservation and interfuel substitution had taken place. In the coal sector, technologies that have increased the efficiency of exploration, exploitation, utilization and mining have played an important role (Mukhopadhyay 2002). In fact, the change in emissions due to technology occurred largely in the electricity sector. This was due to the low thermal efficiency of power plants in India, which are generally small. The low capacity utilization of thermal power plants also decreased overall energy efficiency. The average annual load factor of all thermal plants in India was 53.8 per cent in 1990/91. This is largely attributable to inefficient operation and maintenance (India 1992).

Moderate technical changes helped reduce energy consumption, particularly in the coal and oil sectors, which in turn lowered emissions. New technologies for mining coal were introduced with a fair degree of success. The slight technical improvement in the oil and natural gas sector was possible due to the minimization of the risks of exploration in different basins in India. Vigorous measures for energy conservation and interfuel substitution have also been taken. The creation and utilization of capacity in the oil sector was very low in the 1980s, but improved substantially, particularly in the early 1990s. Due to technical improvement in capacity utilization, the growth rate of crude throughput also performed well, reaching 58.6 per cent in 1995/96 (4 per cent higher than in 1991/92) (Mukhopadhyay 2002). The trend in technological change was not significant during the period 1993/94-1998/99. However, alternative technologies introduced by the top polluting industries helped reduce emissions to some extent during that period. Various environmental policies adopted and implemented by the Government of India also contributed to the reduction (Mukhopadhyay 2002).

Changes in final demand

Changes in the final demand dominate all other factors. For all pollutants, the contribution of this factor doubled between 1989/90 and 1993/94. This is attributable to high energy consumption by the final demand sector: 6.9 per cent more energy per year was consumed during the 1993/94 period, as compared to the 1989/90 period. The increment was similar during the 1993/94-1998/99 period. The proportions of increase attributable to individual sectors were 9 per cent for coal, 5.47 per cent for crude oil and natural gas and 7.85 per cent for electricity.

The demand for electricity expanded rapidly in the household sector, as the pressure of urbanization continued to increase and the availability of consumer durables continued to expand. Several of the relatively newer and faster-growing industries, such as gems and jewellery, garments and electronics, were more energy intensive. The rapid pace of urbanization and diverse urban-growth patterns involved many basic structural changes to the economy, which in turn had major implications on energy use and CO_2 emissions. Urbanization brought changes in the way resources were collected, distributed and used. The rising per capita income associated with urbanization increased demands for both end-use energy and energy-intensive products and services.

Overall, the most important factor is changes in final demand, the aspect that dominates throughout. It reflects the increase in household consumption as well as that in other final demand components, such as Government consumption and imports and exports. As stated above, household energy consumption is increasing, and the pollution generated from it cannot be ignored. Thus, we estimate the emissions generated by households, covering different income groups and the contributions of the responsible factors, as shown below.

Results based on model 2

Household energy consumption trends

Before focusing on the contribution of household emissions by income group, we highlight the commercial energy consumption pattern of the household sector in India during the period 1980-2000.

The household sector is responsible for a significant proportion of total primary energy use in India. Commercial energy use increased by almost four times between 1980 and 2000, from 323 to 1,257 petajoules. This reflects a change in the fuel mix. By 2000, the portion of secondary energy use was about 3 times that of 1980 levels (table 4).

Table 4. Household commercial energy consumption, 1980-2000
(Petajoules)

Energy carrier	*1980*	*Percentage of total*	*1990*	*Percentage of total*	*2000*	*Percentage of total*
Kerosene	234.67	72.50	380.48	63.68	559.17	44.46
Liquefied petroleum gas	53.79	16.62	111.75	18.70	286.37	22.77
Electricity	35.22	10.88	105.2	17.60	411.91	32.75
Total	**323.68**	**100.00**	**597.43**	**100.00**	**1 257.45**	**100.00**

Source: Reddy (2004).

Disparities in household energy use exist between high- and low-income groups in India. Energy consumption (1983-2000) demonstrates various characteristics. In urban areas, kerosene, electricity and liquefied petroleum gas (LPG) were the major energy carriers, used for purposes such as cooking, water heating and lighting. Many households once used wood for those purposes.

The income of a household influences energy consumption in many ways. With increased income, fuel price is less of a constraint. Households prefer to use a convenient form of energy, such as LPG. Due to the use of efficient devices, the total consumption of energy will not increase significantly. High-income households have opted for "modern" energy carriers such as electricity or LPG. Many households use a mixture of modern and traditional fuels, each matched to a specific end use, such as cooking with LPG and heating water with electricity. High-income households also purchase other high-grade fuels, such as electricity, which are used for a greater variety of end uses (other than heating), such as air conditioning and refrigeration. Structural differences in energy carriers for cooking, lighting, transport and other durables are observed among different income categories in India.

As the data show (table 4), the contribution of the various energy carriers to the energy mix vary according to income group. With increasing disposable income and changes in lifestyles, households tend to move up the energy ladder (in terms of quality, convenience of use and cost): from biomass to kerosene and then to LPG/electricity. The energy consumption patterns of urban households change significantly, possibly due to the increase in the various appliances, such as televisions, microwaves and air conditioners. The main factors that determine the selection of energy carriers include: the prices of fuels and the corresponding utility devices; the disposable income of households; the availability of fuels; and cultural preferences (Reddy and Reddy 1994). With technological advances, associated end-use devices are also moving in the same direction. But inefficient energy use is significant in most cases.

Reddy (2004) observes a positive relationship between growth in per capita income and household demand for commercial fuels. In most developing countries, demand for commercial fuels has risen more rapidly than per capita incomes since 1970. This reflects an increasing desire for comfort as well as discretionary energy consumption. Reddy (2004) observes an association between occupation and energy use: attaining higher employment status is correlated with a shift to modern energy carriers. However, this is applicable largely to urban regions where the availability of modern energy carriers is high. For example, 45 per cent of the households in the mid-level employee category use LPG. Similar results were found for other categories also (table 5).

Causes of emission changes, by income group

The changes in intensity are identified for each group in table 6. The overall intensity effect increased sharply from the first period (1983/84 to 1989/90) to the second period (1989/90 to 1993/94) but the contributions made by each of the three groups significantly declined. The change-in-intensity value was inflated by the other final demand components, including exports, imports and Government consumption expenditure. In the first period, the negative contribution of the other final demand elements helped reduce the overall change in intensity of CO_2, SO_2 and NO_x. By the following period, the negative value of change in this area was

Table 5. Energy use by occupation
(Percentage)

Occupation	Biofuels	Kerosene	Electricity	LPG	Total
Executives	15.76	11.64	1.90	70.70	100
Middle-level employees	30.82	22.25	1.41	45.51	100
Lower-level employees	42.71	18.41	0.88	38.00	100
Labourers	56.87	24.81	1.10	17.23	100
Others	48.51	18.81	0.67	32.00	100

Source: Reddy (2004).

Abbreviation: LPG, liquefied petroleum gas

Table 6. Contributions of lower-, middle- and higher-income groups to changes in intensity of carbon dioxide, sulphur dioxide and mono-nitrogen oxide emissions
(Millions of tons)

Period	Pollutants	Change in intensity (ΔS)	Comparative static change			
			Lower-income groups	Middle-income groups	Higher-income groups	Other final demand components
1983/84 to	CO_2	9.23	12.036	53.89	100.50	-148.64
1989/90	SO_2	0.02	0.234	-1.335	1.03	0.099
	NO_X	0.36	0.112	-0.564	0.815	1.154
1989/90 to	CO_2	54.99	10.88	26.59	39.99	-22.48
1993/94	SO_2	1.02	0.025	-0.034	1.005	0.029
	NO_X	-1.54	0.003	-1.234	0.607	-0.924
1993/94 to	CO_2	131.48	11.27	46.68	54.81	18.70
1998/99	SO_2	2.71	0.026	-0.06	1.37	1.36
	NO_X	2.89	.023	-1.29	1.83	2.37

Source: Author's calculation, based on model 2.

much smaller. It follows, then, that the other final demand components are becoming more pollution-intensive. This may be due to final consumption expenditure of the Government, or exports.

The increased intensity effect during the study period of 1993/94 to 1998/99 was distributed among all income groups, reflecting an increasing trend. The higher-income group contributed 41 per cent of the CO_2 emissions, the middle-income group 35 per cent, and the rest was distributed among lower and other final demand elements. During the whole study period (1983-1999), the change in the emission intensity of lower-income groups fluctuated, reaching a high of 12.03 and a low of 10.88. In the middle-income group, intensity declined during the period 1989/90 to 1993/94, but increased again in the next period (1993/94-1998/99), despite the reform strategy on energy implemented by the Government of India. The higher-income group was responsible for this increased intensity effect, which in turn was the main driver behind the increase in emissions.

As noted above, technological change helped improve the situation during the period under consideration. The influence on overall technical change varied according to income group, as shown in table 7; the higher-income group had the most influence. The overall contribution attributed to change in technology was positive in the period 1983/84 to 1989/90, but negative in the other two periods studied. The greatest fluctuation was in the category of other final demand elements. For the period 1993/94 to 1998/99, the technology effect reduced all the three emissions.

Table 7. Contributions of lower-, middle- and higher-income groups to changes in technology of carbon dioxide, sulphur dioxide and mono-nitrogen oxide emissions

(Millions of tons)

Period	*Pollutants*	*Change in technology (ΔR)*	*Comparative static change*			
			Lower-income groups	*Middle-income groups*	*Higher-income groups*	*Other final demand components*
1983/84 to	CO_2	77.69	5.33	-7.21	-13.11	92.66
1989/90	SO_2	0.40	0.097	-0.054	0.853	-0.407
	NO_X	1.68	0.004	-0.076	1.012	0.756
1989/90 to	CO_2	-185.82	-15.76	-41.29	-78.33	-50.25
1993/94	SO_2	-1.39	0.016	-0.97	0.045	-0.49
	NO_X	-2.15	0.17	-1.97	0.153	-0.52
1993/94 to	CO_2	-30.83	-1.81	-21.72	-36.65	29.35
1998/99	SO_2	-2.98	1.02	-0.058	-2.85	-1.092
	NO_X	-2.09	-1.09	-2.58	-1.12	2.78

Source: Author's calculation based on model 2.

The contribution attributed to the change in final demand is the highest among all change factors (table 8). The contribution of the lower-income group was reduced slightly in this respect, but slight increases in the middle-income group and more significant increases in the higher income group kept the overall values high. The patterns revealed after combining the contributions of each factor are similar to the patterns of the individual factors. During the period 1993/94-1998/99, the change in final demand for CO_2 was slightly lower, but slightly higher in the case of SO_2; the change in final demand remained steady for NO_x. The higher-income group contributed the bulk of the increase in emissions (61 per cent) in regard to this factor. A negative change in other final demand elements helped reduce the overall change in emissions.

Table 8. Contributions of lower-, middle- and higher- income groups to changes in final demand of carbon dioxide, sulphur dioxide and mono-nitrogen oxide emissions

(Millions of tons)

Period	*Pollutants*	*Change in final demand (ΔY)*	*Comparative static change*			
			Lower-income groups	*Middle-income groups*	*Higher-income groups*	*Other final demand components*
1983/84 to 1989/90	CO_2	131.99	23.52	58.19	81.99	-31.79
	SO_2	0.93	0.431	0.219	0.607	-0.268
	NO_X	1.84	0.006	0.007	0.765	1.066
1989/90 to 1993/94	CO_2	301.86	14.41	65.01	129.44	92.72
	SO_2	1.96	0.015	0.218	1.004	0.739
	NO_X	4.74	0.125	0.649	1.903	2.066
1993/94 to 1998/99	CO_2	290.75	14.92	114.15	177.39	-15.72
	SO_2	3.23	0.015	0.38	1.37	1.46
	NO_X	4.62	0.129	1.139	2.607	0.74

Source: Author's calculation based on model 2.

In the case of middle- and higher-income groups, the trend of the contributions of different factors remains almost same for all periods. The only notable point is the shift in the intensity effect, the contribution of which decreases during the study period. The trend in the lower-income group was quite different. In the case of SO_2 emissions, the contribution of the lower-income group fell sharply during the study period. A change in the relative influence of responsible factors (changes in intensity and changes in technology) was observed in the middle-income group. A steady growth in the contribution attributable to each factor was observed for higher-income groups, except with regard to the technological change factor, which was comparatively higher in the first period than in the third.

Levels of change in NO_x emissions were greatest in the higher-income group, regardless of the factor. The contribution of the middle-income group was negative and not as significant in the first period, but the same contribution increased subsequently during the other subperiods. The contribution of the lower-income group was negligible in all three periods.

As noted in the introduction to the present paper, somewhere between 25 and 33 per cent of the global burden of diseases can be attributed to environmental factors. This proportion is larger in conditions of poverty, where more environmental hazards are present in the living and working environments, people have less capacity to protect themselves against exposure and effects of harmful and unpleasant pollutants, and the environmental threats tend to be more directly hazardous to human health. The incidence of poverty is high in India; about one third of the population is below the poverty line and largely affected by environmental hazards.

However, the overall assessment from the figures above reveals that the contribution made by the lower-income group to changes in emissions was not significant, and that the higher-income group dominated for all emissions and almost all factors. According to the present study, the higher-income group was responsible for generating more than 75 per cent of the change in emissions; 20-22 per cent was attributable to the middle-income group. Unfortunately, it is the lower-income group that suffers seriously due to pollution.

VI. CONCLUSION AND POLICY IMPLICATIONS

In the current study, we estimated the emissions of CO_2, SO_2 and NO_X in India for the period 1983/84 to 1998/99. We investigated the changes in emissions and the effects of various sources of change in industrial CO_2, SO_2 and NO_X emissions using input-output SDA. Further, we examined the contribution made by different income groups to those emissions.

The present analysis was based on an input-output, SDA approach. The data used were input-output tables for various years, aggregated into 47 sectors from 115 sectors, at constant 1993/94 prices. Our framework assumed fixed-coefficient Leontief technology, which is a special case of constant elasticity of substitution of production function. The effect of the assumption of fixed coefficient production function on the results is much discussed in the literature (Economic Systems Research, various issues). However, this assumption is not likely to affect the results in the present paper as we have considered the effect of change in technology over time in the decomposition analysis and no future forecast is made based on an assumption of fixed coefficient technology.

The study showed that the industrial emissions of air pollutants increased considerably in India during the period 1983/84 to 1998/99 (14.06 per cent per annum for CO_2, 14.47 per cent per annum for SO_2 and 13.8 per cent per annum for NO_x). The main factors for these increases were the changes in the final demand throughout the period. The change in intensity also increased, quite considerably, from 9.23 to 54.99 (between 1983/84 and 1993/94) and jumped again to 131.48 (between 1993/94 and 1998/99). The change in technology was also positive and quite significant in the first period, but had a negative effect on emissions in the second period. This reduction continued in the third period, at a less significant rate. These effects helped reduce the total changes in emissions for the second period.

The results of decomposition showed that, during the period covered, the Indian economy was moving towards more energy- and pollution-intensive industries. Though attempts to integrate more efficient technology into the economy were being made, the growth of energy consumption, its intensity and the technology effect failed to achieve the target of the reforms.

Results of the different income groups revealed that the higher-income households were responsible for most changes in emissions. This was due to their high levels of energy consumption. The middle-income group also contributed. However, the lower-income group was a minor player. Considering the contribution by different income groups to different change factors, the higher-income groups had the greatest influence on the intensity and the final demand effect. The contribution of the middle-income group was also considerably higher than that of the lower-income group. On the other hand, the technology effect was significantly negative, which helped reduce overall emission changes, though with fluctuations.

The overall assessment revealed that the lower-income group made an insignificant contribution to air pollution, while the higher-income group was a major source of all emissions with regard to almost all factors. The higher-income group tended to use commercial energy inefficiently, while households in the lower-income group were still not in a position to increase consumption of commercial energy. The income level of the average household had increased in India after reforms, but this increase was not reflected in the commercial energy consumption of the lower-income group. For this reason the contribution to changes in emissions by the lower groups was still negligible.

One of the greatest tasks at present is to tackle the generation of emissions by the higher-income group. The results of our study serve to help target pollution measures with respect to the four factors related to air pollution from fossil fuel combustion. We suggest that priority be given to energy conservation. The

Government of India must ensure strict implementation of the Energy Conservation Act (2001) in various levels of the economy, targeting change at the household level as well as at the industry level. Energy efficiency and conservation are possible through interfuel substitution, which can help mitigate the carbon problem. The main task is to increase awareness in the household sector regarding the efficient use of energy in cooking, lighting and transport.

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ANNEX

Model 1

Let C = C(j), (A1)

where C is a vector of fossil fuel emission coefficients representing the volume of CO_2, SO_2 and NO_x emissions per unit of output in different sectors (j). That is, dividing the sectoral volume of CO_2, SO_2 and NO_x emissions by sectoral output gives us the direct CO_2, SO_2 and NO_x emission coefficient. The direct and indirect carbon, sulphur and nitrogen emission coefficient of sector j can be defined as Cjrij, where rij is the (i, j)th element of the matrix $(I - A)^{-1}$. The direct and indirect CO_2, SO_2 and NOx emissions of a sector are defined as emissions caused by the production vector required to support final demand in that sector. This would depend not only on the direct and indirect emission coefficient of that sector but also on the level of sectoral final demand.

Emission model

Now, in equation form, CO_2, SO_2 and NO_x emissions from fossil fuel combustion can be calculated from industrial fuel data in the following manner:

$$F = C_t L1X = C_t L1(I - A)^{-1} Y \quad (3)$$

where F is a vector, representing the total quantity of CO_2, SO_2 and NO_x emissions from fossil fuel combustion only; C is a vector of dimension m (m x 1) of coefficients for CO_2, SO_2 and NO_x emissions per unit of fossil fuel burnt; L1 is a matrix (m x n) of the industrial consumption in energy units of m types of fuel per unit of total output of n industries; and t denotes the transpose of this vector.

In equation (3), C_t L1 = S represents only direct requirement of CO_2, SO_2 and NO_x intensities from industries, and $C_t L1(I - A)^{-1}$ gives the direct as well as indirect requirement of CO_2, SO_2 and NO_x intensities from industries. So, equation (3) explains the CO_2, SO_2 and NO_x emissions due to fossil fuel combustion from production activities in India.

Structural decomposition analysis approach

The total industrial CO_2, SO_2 and NO_x emissions (TE) can be expressed as:

$$TE = \Delta F = SRY = S(I - A)^{-1} Y, \quad (4)$$

where $R = (I - A)^{-1}$ and S represents the industrial CO_2, SO_2 and NO_x intensities.

According to the structural decomposition analysis method, the change in total CO_2, SO_2 and NO_x emissions between any two years, such as year 0 and year t, can be identified as:

$$TE = \Delta F = S_t (I - A_t)^{-1} Y_t - S_0 (I - A_0)^{-1} Y_0 \quad (5)$$

$$= S_t R_t Y_t - S_0 R_0 Y_0 \quad (6)$$

$$= S_t R_t Y_t - S_0 R_t Y_t + S_0 R_t Y_t - S_0 R_0 Y_0 \quad (7)$$

$$= \Delta S R_t Y_t + S_0 R_t Y_t - S_0 R_0 Y_0 \quad (8)$$

$$= \Delta S R_t Y_t + S_0 R_t Y_t - S_0 R_0 Y_{t -} + S_0 R_0 Y_t - S_0 R_0 Y_0 \quad (9)$$

$$= \Delta S R_t Y_t + S_0 \Delta R Y_t + S_0 R_0 Y_t - S_0 R_0 Y_0 \quad (10)$$

$$= \Delta S R_t Y_t + S_0 \Delta R Y_t + S_0 R_0 \Delta Y \quad (11)$$

The first term of equation (11) reflects the CO_2, SO_2 and NO_x emission changes due to the changes of CO_2, SO_2 and NO_x intensity in various industries. The second term of the equation defines the CO_2, SO_2 and NO_x emission changes due to the changes in the technical coefficient matrix. The third term refers to the CO_2, SO_2 and NO_x emission changes due to the changes in the final demand of various industries. Here, t refers to the current period and 0 defines the previous period.

It should be noted that only fuel NO_x was considered; thermal NO_x is not included here.

Model 2

The final demand vector Y was treated separately, by breaking down the total final demand as:

$$Y = Y_1 + Y_2,$$

where $Y_1 = Cl + Cm + Ch$ (12)

$$Y_2 = Y_2 \quad (13)$$

The term Cl carries the vector of household consumption belonging to lower-income groups; Cm, the vector of household consumption belonging to middle-income groups; and Ch, the vector of household consumption belonging to higher-income groups. The term Y_2 signifies the vector of other final demand components, such as Government consumption, change in stock, investments, exports and imports.

We introduced equation (12) and (13) into equation (11) as follows:

$$= \Delta S\, R_t\,(Cl_t + Cm_t + Ch_t + Y_{2t}) + S_0\,\Delta R\,(Cl_t + Cm_t + Ch_t + Y_{2t}) + S_0\,R_0\,\Delta\,(Cl + Cm + Ch + Y_2) \quad (14)$$

The first term of equation (14), denominated as (14a), reflects the changes in intensity of CO_2, SO_2 and NO_x by considering the different final demand groups.

$$= \Delta S\, R_t\, Cl_t + \Delta S\, R_t\, Cm_t + \Delta S\, R_t\, Ch_t + \Delta S\, R_t\, Y_{2t} \quad (14a)$$

Likewise, the second term of equation (14), denominated as (14b), covers the changes in the technical coefficients of CO_2, SO_2 and NO_x by considering the different final demand groups.

$$= S_0\,\Delta R\, Cl_t + S_0\,\Delta R\, Cm_t + S_0\,\Delta R\, Ch_t + S_0\,\Delta R Y_{2t} \quad (14b)$$

Finally, the third term of equation (14), equation (14c), reflects the changes in final demand of CO_2, SO_2 and NO_x by considering the different final demand groups.

$$= S_0\, R_0\,\Delta\, Cl + S_0\, R_0\,\Delta\, Cm + S_0\, R_0\,\Delta\, Ch + S_0\, R_0\,\Delta\, Y_2 \quad (14c)$$

The contributions to $CO_{2,}$ SO_2 and NO_x emissions from each income group and the category comprising the rest of final demand can be calculated using equations (14a), (14b) and (14c). Through this categorization we can estimate the degree of responsiveness of the responsible factors for all emissions among each income group:.

$$L = \Delta S\, R_t\, Cl_t + S_0\,\Delta R\, Cl_t + S_0\, R_0\,\Delta\, Cl \quad 15\ (a)$$

$$M = \Delta S\, R_t\, Cm_t + S_0\,\Delta R\, Cm_t + S_0\, R_0\,\Delta\, Cm \quad 15\ (b)$$

$$H = \Delta S\, R_t\, Ch_t + S_0\,\Delta R\, Ch_t + S_0\, R_0\,\Delta\, Ch \quad 15\ (c)$$

$$Y_2 = \Delta S\, R_t\, Y_{2t} + S_0\,\Delta R Y_{2t} + S_0\, R_0\,\Delta\, Y_2 \quad 15\ (d)$$

Equations (15 a, b, c and d) combine the total responsible factors effect for each income group.