# Global Greenhouse Gas Emissions: Fixing Responsibility

Geetesh Bhardwaj*

Ramprasad Sengupta**

**Abstract:** All the policy discussions in the international forum on the sharing of the global responsibility of abatement of greenhouse gas (GHG) emissions by individual countries centre on the current flow of total emissions by them. The basis for fixing responsibility takes account neither of the pattern of their final consumption which is the ultimate determinant of the global warming nor of the role of globalisation 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. It illustrates the proposed method by an Indian case study, which estimates the net leakage of carbon dioxide and methane from the country in 1991-92 and 1996-97 for the observed consumption pattern in nineties.

* Project Associate, Environmental cell, National Institute of Public Finance and Policy, New Delhi and Ph.D. Student, Jawaharlal Nehru University, New Delhi.

** Professor of Economics, Indian institute of Management Calcutta.

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## 1. Introduction

Greenhouse gases (GHGs) include gases like carbon dioxide ($CO_2$), methane ($CH_4$), nitrogen oxides ($NO_x$), chlorofluorocarbons (CFCs) and hydrocarbons, and almost every sector of an economy directly or indirectly contribute to their emissions. Every country would thus have a share in the anthropogenic emissions, which are supposed to be responsible for climate change to a greater or lesser extent. Climate change resulting from excessive greenhouse gas emissions is a global problem. Global nature of the problem calls for a global response. Individual nations are too small to have any unilateral impact on the problem, and their incentives for doing so are also inadequate given the global nature of the public good. Any attempt to take a collective action brings one to the question of deciding the responsibility of individual nations. There are three-fold issues involved in this context:

(a) At what level the emissions and concentration of the GHGs should be stabilised, and in what time framework.

(b) How the total global abatement of GHGs should be allocated among the individual countries.

(c) How the cost of abatement should be financed and shared by the different economies.

The answer to the issue (a) is to be obtained from the models of climatology along with the global models of optimal growth involving emissions and their adverse feedback effect through climate change on economic growth. The ideal answer to the issue (b) should be guided by the distribution of opportunities of efficient or cost effective abatement across the different countries. The distribution of abatement opportunities according to the marginal cost of abatement is quite different from the distribution of the emissions of GHGs across the different countries. Although the developing economies cause lower level of absolute emission, they often have lower marginal cost and abundance of physical opportunities of abatement of these gases because of the prevalence of outmoded technologies and capital equipment.

However, while the developing countries may have opportunities of abatement, they may not have the ability to pay for the cost of abatement, because of the low levels of development and lack of financial resources. In view of the divergence between the distribution of opportunities of abatement and ability to pay for its costs, global transfer of resources across countries through some global environmental fund facility becomes an imperative. The existing approach of the Framework Convention on Climate Change (FCCC) of grandfathering as implicit in the policy of bringing down emission levels by each country to the level of its emissions in a particular year like 1990 as stipulated, would also require resource transfer, but possibly of relatively lower order than what global cost optimisation would warrant.

What can be basis of contribution of the nations to any fund facility or for financing the abatement in the developing countries? This can be a combination of ability to pay and the share in the global emissions (see Smith et. al 1993), the latter being warranted by the polluter pays principle. Since higher level of absolute flow of emissions (or cumulative emissions) would correspond to higher level of manmade capital stock and income, the sharing of the cost of global abatement as per the share in the global emissions would combine both the considerations as mentioned above.

## 2. Fixing responsibility

How should the share of global GHG emissions for which a country is responsible, be determined? The conventional approach has been to make the actual emission of GHGs occurring at the sources within the geographical boundary of a country as the basis. However a country may continue to enjoy the benefits of the same consumption by changing the trade and production pattern i.e., importing GHG intensive products and reducing their production and thereby at the same time reducing the burden of cost sharing. Any such reduction of emissions by one country by reducing production and raising imports of the GHG emission intensive products from another country would amount to exporting the same pollution to the country exporting the GHG intensive products. Since inter country flow of emissions does not amount to global abatement, the strategy of use of trade by an individual country for abatement does not as such contribute to the global abatement. Besides, any development of trade also encourages movement of unclean industries including the GHG intensive ones from the developed countries to the developing ones.

In view of the income elasticity of demand for environmental services, the differential income effect of gains from trade in the different countries in terms of varying level of stringency of environmental regulation results in the inter country differences in the relative costs of production and such specialisation in production and trade. Since the emission intensity of the same product is likely to be higher in developing countries than developed ones due to lack of access to modern technologies by the former the movement of polluting industries (including the relatively GHG intensive ones) from the developed to the developing countries would act as a force against the very objective of global abatement of GHGs. In the context of abatement targets fixed as per following whatever principle, trade is likely to induce such global relocation of industries that the economically powerful countries are able to manage with minimum adjustment in their consumption pattern.

The strict application of the principle of polluter pays thus requires the ascertaining of responsibility of global emissions that can be imputed to the consumption pattern of a country and not the actual emission arising from within the country. This estimate of imputation would therefore be the total emission of GHGs occurring within the geographical boundaries of the country plus the emission arising in the rest of the world for producing the imports of the concerned country less the emissions arising within the country for producing its exports. However it is not just the direct emissions, but the total direct and indirect emissions including the shares arising from the production of intermediate inputs required to support the final demand which needs to be considered for obtaining the true estimates for fixing the responsibility of individual countries. We therefore present here both the methodology and results of estimation of such emissions, which is imputable to the consumption pattern of a country. The methodology would essentially require estimation of the GHG emissions that would have been involved for meeting given consumption demand of a country in the absence of trade. The excess of this estimate over the actual one in the presence of trade would yield the estimate of the amount of the GHG leakage from the country. It may be noted here that as all the capital goods have to be indigenously produced in the absence of trade, the investment demand of a country for a year in an autarkic regime would be different from its historically observed investment. It would therefore also involve endogenisation of investment by relating it with growth of consumption which would be exogenously given.

so that the share of the emissions for the differential pattern of investment in an autarkic regime vis-à-vis the actual one be duly taken into account in the calculation of the GHG leakage.

We use an off-line investment model of determining incremental capital output ratio and capital formation to support some given growth of consumption. We also use an input-output framework of analysis for working out the precise implication of a given time series of consumption stream with sectoral break-up in terms of pattern of sectoral gross output and GHG emissions. We illustrate the method by a case study of India and provide estimates of leakage of two GHG gases – $CO_2$ and $CH_4$ – for 1991-92 and 1996-97 as imputed by the growth of India's consumption pattern since mid-eighties. We shall also discuss in conclusion the policy implications of these results obtained for India.

## 3. Methodology

Let us consider two scenarios, one in which a country is trading with rest of the world, and the other a hypothetical situation of autarky with the same consumption levels as observed in the case when the country is trading. We have to estimate total emission for the second scenario while it is given for the first as observed data, so that the difference between the two can yield an estimate of leakage. For the situation of autarky we need to endogenise investment by relating it with the growth of consumption over time and then estimate investment required in absence of trade ($I^*$) to meet the observed consumption of $\overline{C}$. To obtain $I^*$ the incremental capital output ratio (ICOR) is an important data requirement.

The common procedure to estimate ICOR is to take the ratio of change in capital stock to change in output. This method may not give an estimate of the appropriate gestation lag. In case the lag distribution structure is not taken, the value of estimated ICOR will be generally higher than actual. The following specification of a model used by planning commission in India and explained in detail in the sixth plan technical note to estimate ICOR, takes the lagged distribution structure into account:

Assumptions of the model are:

- Investment to output gestation lag is assumed to be L (to be estimated).
- Total investment in any year is composed of investments in ongoing projects initiated in the years ranging from -1 to -L+1 year, and new investments started this year.

- Total investment made in any project is distributed equally over its gestation period.
- Output in any period t will be the result of all investments made in projects, which are now complete.

The above model gives:

$$I(t) = b\left[\{Y(t+L) - Y(t)\}\Big/L\right] \qquad (1)$$

'b' in the above equation will give an estimate of the ICOR. Above equation can be econometrically estimated by assuming different values of gestation lag 'L'.

Using the estimated value of ICOR ($\hat{b}$) and gestation lag ($\hat{L}$) we have:

$$Y(t + L) - Y(t) = [\hat{L}/\hat{b}]I(t) \qquad (2)$$

Again the national income identity for a closed economy gives us:

$$Y = C + I \qquad (3)$$

or

$$Y(t) = C(t) + I(t) \qquad (4)$$

and

$$Y(t + \hat{L}) = C(t + \hat{L}) + I(t + \hat{L}) \qquad (5)$$

Using the equations (2), (4) and (5) we have

$$\{I(t + \hat{L}) - I(t)\} = \{(\hat{L}/\hat{b})I(t)\} - \{C(t + \hat{L}) - C(t)\} \qquad (6)$$

The above equation gives the relation between investment growth and consumption growth, it can be used to generate an investment series I* for a given consumption series.

$$I^*(t + \hat{L}) = \{(1 + \hat{L}/\hat{b})I(t)\} - \{C(t + \hat{L}) - C(t)\} \qquad (7)$$

where: $\hat{b}$ ~ the estimated value of ICOR i.e. rate of increase in capital divided by increase in value added

$\hat{L}$ ~ the estimated gestation lag

$t$ ~ the time period

$I^*()$ ~ investment required in absence of trade

$I()$ ~ observed investment

$\overline{C}()$ – observed consumption

In a multisector framework the scalar investment estimate $I^*$ is broken up into sectoral components and presented as a vector of investment by origin ($Inv^*$). This can be compared with the actual investment vector ($Inv$) by origin for the concerned year for which we estimate the leakage. Given the actual consumption vector with multisector break-up ($C$) for the concerned year along with the estimated vector of investment by origin in the absence of trade for the same year, one can derive the implication of such pattern of final demand in terms of sectoral gross output levels by using Leontief's input-output model. This gross output vector ($X^*$) when compared with actual ($X$) will indicate the difference in the pattern of production between trade and an autarkic situation. To put it formally if '$X$' denotes any gross output vector, '$A$' the Leontief's input-output matrix and '$d$' the final demand with multisectoral break-up then:

$$X = (I - A)^{-1}d \tag{8}$$

'$d$' will vary between our two scenarios and accordingly so will '$X$'. In scenario 1 i.e. actual trade situation as historically observed we have: $d = C + Inv + E - M$, where 'E' denotes export vector with multisector break-up and 'M' the import vector. Whereas for scenario 2 i.e. no trade situation: $d = C + Inv^*$, thus:

$$X^* = (I - A)^{-1}(C + Inv^*) \tag{9}$$

In order to derive the implication of difference between $X$ and $X^*$ in terms of GHG leakage, we would here assume the use of similar technologies by trading partners in the absence of data on the input output tables of the various trading partner economies.

The emissions from a sector depend either on its level of production or total use (called apparent consumption). The apparent consumption is defined as production plus import minus export of a sectoral product of the economy, i.e.

$$Z_i = X_i + M_i - E_i \tag{10}$$

In autarkic situation $Z_i^* = X_i^*$. Where $Z_i^*$ is the apparent consumption in the autarkic situation.

If a particular emission is involved in the process of production (not at the stage of final use) of a sectoral item, then in a linear fixed coefficient technology regime as assumed by us, the concerned emission (say $e_i$) arising from the i[th] sector will be proportional to $X_i$. In an autarkic situation if $X_i^*$ is the estimated output level of i[th] product in a certain year required to support a given time stream of consumption vector, then $\alpha_i = \left( X_i^* / X_i \right)$ will denote the factor by which observed $e_i$ will have to be multiplied to yield the estimate of emission due to i[th] product in the absence of trade. It may be noted:

$$\alpha_i = \frac{u_i(I-A)^{-1}(C+Inv)}{u_i(I-A)^{-1}(C+Inv+E-M)} \qquad (11)$$

Where $u_i$ is the i[th] unit vector.

On the other hand, if a particular gaseous waste is emitted from the final use of a sectoral product and not during the process of production itself, then the emission of concerned pollutant (say $e_i$) arising from the total use of the concerned product irrespective of whether produced indigenously or not, will be proportional to $Z_i$. Then the ratio $\beta_i = \left( Z_i^* / Z_i \right)$ when applied to the level of emission $e_i$ as a multiplicand would yield the total emission due to the final use of i[th] sector product in the absence of trade.

$$\beta_i = \frac{u_i(I-A)^{-1}(C+Inv)}{u_i(X+M-E)} \qquad (12)$$

It is now the difference between $e_i\alpha_i$ and $e_i$ or between $e_i\beta_i$ and $e_i$ which would represent the leakage of concerned gaseous emission from a country in the concerned year from the i[th] sector, depending upon whether the emission arises due to production or consumption of the concerned sectoral product.

## 4. The Data

We apply the above method to obtain the leakage of $CO_2$ and $CH_4$ from India due to trade effect for the years 1991-92 and 1996-97. We use the sixty sector input-output matrix for the year 1991-92 from, "A technical note on the Eighth plan of India", published by the Perspective Planning Division of the Planning Commission, Government of India. The data on the historical values of consumption, investment, export and import vectors with multisectoral break-up are also obtained from the same source.

We have used the data on gross domestic product and gross domestic capital formation reported in "National Accounts Statistics" published annually by Central Statistical Organisation, Government of India, to obtain the estimate of I* for 1991-92 and 1996-97. The estimates of investment as obtained by using the model of equation *(1)* are given below.

**Table 1 Actual and estimated investment levels**

Figures Rs. Million (91-92 prices)

| Year | I | I* | I* - I |
|---|---|---|---|
| 1991-92 | 1303044.0 | 1432892.2 | 129848.2 |
| 1996-97 | 1591695.1 | 2359462.9 | 767767.8 |

The ICOR (*b*) for Indian economy and the gestation lag (*L*) were obtained to be 3.0 and 5.0 respectively, using the national accounts data as referred to. The investment by origin break-up has been obtained by using the investment structure of the year 1991-92. We have assumed the same investment structure for the year 1996-97 to get the break-up of I* (this assumption is necessary, as we do not have the capital coefficient matrix for Indian economy). The estimate of apparent consumption ratio $\beta_i$ and the output ratio $\alpha_i$ for some of the environmentally significant sectors are given below (also see Annexure 1).

**Table 2: Apparent consumption and output ratios**

| Sector | 1991-92 | | 1996-97 | |
|---|---|---|---|---|
| | $\beta_i=(Z_i^*/Z_i)$ | $\alpha_i=(X_i^*/X_i)$ | $\beta_i=(Z_i^*/Z_i)$ | $\alpha_i=(X_i^*/X_i)$ |
| Paddy | 0.999 | 0.986 | 0.987 | 0.971 |
| Animal husbandry | 0.991 | 0.997 | 0.998 | 1.007 |
| Forestry & logging | 1.038 | 1.109 | 1.147 | 1.270 |
| Coal & lignite | 1.102 | 1.178 | 1.099 | 1.120 |
| Crude Petroleum & Natural Gas | 1.274 | 2.586 | 1.620 | 2.543 |
| Cement | 1.103 | 1.104 | 1.445 | 1.444 |

## 5. Investment requirement vs. Intermediate consumption requirement

The difference between apparent consumption in the two scenarios (Z* and Z) of various resources is attributed to trade of commodities that use these resources, this difference can be written as

$$Z^* - Z = (I - A)^{-1}(Inv^* - Inv) + A(I - A)^{-1}(M - E) \qquad (13)$$

The first factor i.e. $(I - A)^{-1}(Inv^* - Inv)$ will capture investment reallocation across the industries in two scenarios. The second factor i.e. $A(I - A)^{-1}(M - E)$ shows the apparent consumption difference that comes as a result of change in the intermediate demand of various commodities due to stopping of trade.

The following table gives the result for some environmentally significant sectors.

**Table 3 Apparent consumption difference, the break-up.**

Figures Rs. Million

| | 91 - 92 | | 96 - 97 | |
|---|---|---|---|---|
| | $(I-A)^{-1}(Inv^*-Inv)$ | $A(I-A)^{-1}(M-E)$ | $(I-A)^{-1}(Inv^*-Inv)$ | $A(I-A)^{-1}(M-E)$ |
| Coal & Lignite | 1665.22 | 4294.33 | 3888.8 | 4211.94 |
| Crude petro. & N. gas | 2399.75 | 28902.56 | 16394.32 | 58477.54 |
| Cement | 3614.42 | 904.59 | 22780.09 | 1013.42 |
| Iron & Steel | 27829.84 | 52120.39 | 155676 | 61141.06 |
| Construction | 59009.97 | 2201.67 | 304271.5 | 2236.9 |
| Electricity | 7543.84 | 15813.39 | 47779.64 | 12204.34 |
| Rail transport | 3068.58 | 4908.16 | 17870.29 | 5015.52 |
| Other transport | 6712.3 | 1242.21 | 39549.33 | -10113.76 |

For sectors like coal and lignite, and crude petroleum and natural gas the difference arises mainly due to increase in their demand for intermediate consumption as a result of absence of trade. On the other hand a look at the break-up for the sectors like cement, iron and steel, construction, electricity and transport reveals that the dominant part of the difference is due to the changed investment requirements. The above method. gives the break-up of the difference between Z* and Z into investment requirement and changed output demand for changed intermediate consumption. The break-up is important to draw policy lessons about whether we need resource conservation in intermediate input use or capital use of resources. As the focus of this paper is estimation of GHG leakage we will not explore this point further.

## 6. Estimation of Greenhouse gas emission leakage

### 6.1 Carbon Dioxide Emissions

6.1.1 Solid Fuels: Carbon dioxide emissions from coal result at the stage of consumption of coal. Carbon burned is estimated by multiplying the carbon fraction with the coal consumed. If we are to have true usage of coal in Indian economy then the apparent consumption $Z_i$ (for i = coal) is to be raised to $Z_i^*$. Multiplying the carbon dioxide emissions due to solid fuels with the apparent consumption ratio ($\beta_i$) of coal sector we get the true emission from solid fuels.

6.1.2 Liquid Fuels: Here again the carbon emissions are determined by multiplying the consumption figures for each petroleum fraction with its carbon fraction. Hence for liquid fuels again it is the consumption of crude petroleum that matters. Multiplying the carbon dioxide emissions due to liquid fuels with the apparent consumption ratio ($\beta_i$) of crude petroleum and natural gas sector we get the true emission from liquid fuels.

6.1.3 Gas Combustion: An estimate of carbon dioxide here again is based on the consumption of natural gas. However as no natural gas was traded in the period of our coverage the emissions can be related with the production level of gas. While in the input-output table crude petroleum and natural gas is treated as one sector, we have to use the output ratio ($\alpha_i$) for gas as the one given for the petroleum and natural gas sector to obtain the total emissions of $CO_2$ from natural gas in the absence of trade.

6.1.4 Gas Flaring: Most of the natural gas flared is the associated gas at oil wells due to lack of infrastructural facilities like pipelines etc. It is the production of natural gas associated with oil production that leads to gas flaring. Hence in the case of gas flaring the ideal ratio to use will be the output ratio $\alpha_i$. The true carbon dioxide emissions from gas flaring is obtained by multiplying carbon dioxide emissions from gas flaring with the output ratio $\alpha_i$, for i = petroleum and natural gas sector.

6.1.5 Cement Manufacturing: Production of cement involves a calcining process whereby limestone disassociates to form calcium oxide (CaO) and carbon dioxide. Hence carbon dioxide emissions from cement sector clearly has nothing to do with consumption of its output cement. To get the true emission levels from cement manufacturing we need to multiply the reported emissions from cement sector with its output ratio.

6.1.6 Land Use Change: When forest biomass is harvested the carbon contained in the biomass as well as the part of carbon in the underlying soil are oxidised and released in the air. While the demand and the use of forestry products cause carbon dioxide emissions, carbon is recycled to the extent there is a growth of plant biomass in the concerned year or period. The net growth of carbon dioxide in atmosphere would thus depend on the change in the plant biomass stock, which often corresponds to the change in land use. Since it is not possible to link land use change in any systematic manner with the variation in the sectoral output of forestry and logging sector we ignore $CO_2$ emissions from land use change in our present empirical context.

The results of the above discussion are summarised in Annexure 2. In table 4 below we have the reported carbon dioxide emissions, the relevant ratios to be used and have generated the carbon dioxide emissions due to total resource use embodied in consumption basket.

**Table 4 Reported and true carbon dioxide emission levels**

| Source | 1991 | | | 1996 | | |
|---|---|---|---|---|---|---|
| | Reported* $CO_2$ Emissions '000 tons | Relevant Ratio | True $CO_2$ emissions '000 tons | Reported $CO_2$ Emissions '000 tons[1] | Relevant Ratio | True $CO_2$ emissions '000 tons |
| | (A) | (B) | C = A* B | (A) | (B) | C = A* B |
| Solid fuels | 551897.0 | 1.102 | 608190.5 | 778174.8 | 1.099 | 855214.1 |
| Liquid fuels | 151583.0 | 1.274 | 193116.7 | 160223.2 | 1.620 | 259561.6 |
| Natural gas | 19540.0 | 2.586 | 50530.4 | 26714.1 | 2.543 | 67933.9 |
| Gas flaring | 10968.0 | 2.586 | 28363.2 | 14993.3 | 2.543 | 38128.0 |
| Cement manufacturing | 24915.0 | 1.104 | 27506.2 | 30421.2 | 1.444 | 43928.2 |
| Total | 758903.0 | | 907707.1 | 1004466.0 | | 1264765.7 |

* Source: Tata Energy Research Institute (1998). Teri Energy Data Directory and Yearbook 1998-99.

### 6.2 Methane Emissions:

6.2.1 Wet rice Agriculture: Methane is released by water logged soils in paddy fields due to anaerobic decomposition of organic matter. It is at the production stage at which methane is released and not at the stage of consumption. True methane emissions from wet rice agriculture can be calculated by multiplying the output ratio ($\alpha_1$) for paddy by the reported methane emissions due to wet rice agriculture.

6.2.2 Livestock: Methane is produced in herbivores as a by-product of enteric fermentation. Methane emissions are calculated by multiplying the average annual population of each sub category of animals with their respective emission factors. Each animal can be considered as a production unit using fodder and producing output covered by the food sector (e.g. milk, meat, egg etc.) and transport sector (draught animals). Methane emission from livestock is taken as arising from production activities of the animal husbandry sector. Hence in this sector we will use the output ratio ($\alpha_2$) of the animal husbandry sector.

6.2.3 Coal Mining: Methane generated due to chemical reactions is entrapped in coal bed. This methane is released when new seams are opened up. Hence the reason for methane emissions from coal sector is related to

[1] Though we have the reported emissions for only the year 1991 we can generate the corresponding figures for the year 1996 as we have the output and apparent consumption figures for both the years. Using the understanding of carbon dioxide generation mechanism

the production of coal. For obtaining the estimate of true methane emissions due to coal mining we will use the output ratio ($\alpha_c$) of coal sector.

6.2.4 Natural gas venting and leakage: Methane is released into the atmosphere during the process of production and distribution of natural gas due to leakage. However the leakage occurring from distribution lines account for the bulk of loss of natural gas. Though methane is emitted at production stage also, the bulk of it comes through the loss of gas during distribution. Since no natural gas is imported, the distribution of gas would compound to its production only. In order to obtain the true emissions of methane due to natural gas venting and leakage we therefore use the output ratio ($\alpha_s$) of the oil and natural gas sector.

6.2.5 Solid Waste: The calculation of methane emissions due to solid waste is based on the fraction of the total municipal solid waste (MSW) landfilled. MSW depends on a lot of factors like population of the country, industrial residue particularly of paper, food processing and small-scale industries. As it is not possible to incorporate solid waste in the kind of macro-multisector framework that we have developed. We do not calculate methane emissions from solid waste.

The results of the above discussion are summarised in Annexure 3. In table 5 we have the reported methane emissions, the relevant ratios to be used and have generated the methane emissions due to total resource use embodied in consumption basket.

**Table 5 Reported and true methane emission levels**

| | 1991 | | | 1996 | | |
|---|---|---|---|---|---|---|
| Source | Reported* $CH_4$ Emissions '000 tons | Relevant Ratio | True $CH_4$ Emissions '000 tons | Reported $CH_4$ emissions '000 tons | Relevant Ratio | True $CH_4$ Emissions '000 tons |
| | (A) | (B) | C = A* B | (A) | (B) | C = A* B |
| Wet rice agriculture | 19000.0 | 0.986 | 18734.0 | 23275.0 | 0.971 | 22600.0 |
| Live stock | 12000.0 | 0.997 | 11964.0 | 15360.0 | 1.007 | 15467.5 |
| Coal mining | 1800.0 | 1.178 | 2120.4 | 2660.4 | 1.120 | 2979.6 |
| Natural gas venting and leakage | 160.0 | 2.586 | 413.8 | 169.1 | 2.543 | 430.1 |
| Total | 32960.0 | | 33232.2 | 41464.5 | | 41477.3 |

* Source: Tata Energy Research Insitute (1998). Tedi Energy Data Directory and Yearbook 1998-99.

that we have developed in the last section, we can generate the carbon dioxide emissions if we make the assumption that the underlying structure of these environmentally significant sectors has not changed.

## 7. Conclusion

It is interesting to note that India had a carbon leakage of as high as 19.61 per cent of its reported carbon emissions in 1991-92 and the same proportion went up to 25.91 per cent in 1996-97 (see table 6). First of all, it is revealing that India's consumption causes net pollution export to other countries. The common impression regarding the relocation of pollution intensive industry in developing countries due to environmental considerations is not fully corroborated by such results. If India as a developing country had been a significant receiver of investment in $CO_2$ intensive goods for exports to developed countries, one would have expected a negative or negligible leakage of such pollution. However the significance of leakage of such gas also depends on the extent of liberalisation of an economy. A country with liberalised import, trade deficit and foreign indebtedness is likely to have more of export of pollution via its imports than an import of same from rest of the world via its exports. The rise of leakage of carbon dioxide from Indian economy from 19.61 per cent in 1991-92 to 25.91 per cent in 1996-97 can in fact be explained by the increased liberalisation of imports in India between 1991 and 1996.

**Table 6 Greenhouse gas leakage from India**

| Year | Carbon dioxide leakage as a % of reported emissions | Methane leakage as a % of reported emissions |
|---|---|---|
| 1991 | 19.61% | 0.83% |
| 1996 | 25.91% | 0.03% |

In the case of methane we find the leakage to be of much smaller percentage. India had a methane leakage of 0.83 per cent of its actual carbon emissions in 1991-92 and the same proportion went down to 0.03 per cent in 1996-97. This indicates that our traded commodities involve less methane emission intensity directly and indirectly.

One may, however, point out that the above estimates of leakage have been obtained by assuming India's technical coefficients of production to be valid for the trading partner economies, in the absence of appropriate data as required for such analysis. To the extent the technology of India's trade partners is more efficient in the use of energy and in respect of emission intensity of the concerned gases, our estimates of leakage would be overestimates of true leakage. Nevertheless, the order of around 25 per cent leakage suggests that both the restructuring of technology as well as that of demand pattern are important for the abatement of global emissions. For a given state of technology in the world economic system, the abatement of GHG emissions would require conservation of use of resources in meeting demand. Which in turn would warrant restructuring of the preferences of the people in favour of ecofriendly products and technology. It is the shift in the preference pattern away from the GHG intensive goods, which can contribute to a significant extent to abatement of global warming.

In order to amend the role of trade in redistributing pollution across the countries without any impact on demand pattern or global emission levels, policy initiatives may be warranted to contain the distorting effect of trade on global environment. In order to discourage imports of pollution intensive products for observing global emission quota restriction for a country, one can think of imposing countervailing import duty on the pollution content of such product if such pollution tax is prevalent in the importing country but not so in the country exporting such pollution intensive imports. While the convergence of environmental standards across the countries would be an ideal solution for handling such leakage problem, countervailing measures on imports from pollution heavens may be a medium term solution until the preference structure for environmental quality change to be more ecofriendly and uniform across the different regions. The world bodies like FCCC while deciding the responsibility of individual nations towards global GHG abatement need to take account of such leakage of pollution, which travel across national boundaries.

## References


- Government of India, Central Statistical Organisation (1997). *National Accounts Statistics 1997*. New Delhi: Central Statistical Organisation.
- Government of India. Ministry of Finance (1997). *Economic Survey 1996-97*. New Delhi: Ministry of Finance.
- Government of India. Planning Commission (1981). *A Technical Note on the Sixth Plan of India*. New Delhi: Perspective Planning Division. Planning Commission.
- Government of India. Planning Commission (1997). *A Technical Note on the Eighth Plan of India*. New Delhi: Perspective Planning Division. Planning Commission.
- Leontief, W.W. (1966). *Input-Output Economics*. New York: Oxford University Press.
- Nordhaus. W.D. (1992). *Managing the Global Commons: The Economics of Climate Change*. Cambridge. Massachusetts: MIT Press.
- Indira Gandhi Institute of Developmental Research (1991). *Consumption Patterns: The Driving Force of Environmental Stress*. Bombay: Indira Gandhi Institute of Developmental Research.
- Smith. K.R., J. Swishes and D.R. Ahuja (1993). *Who Pays*. In P. Hayes & K. Smith (eds.), *The global Greenhouse Regime: Who Pays*. Tokyo: United Nations University Press.
- Tata energy Research Institute (1998). *Teri Energy Data Directory and Yearbook 1998-99*. New Delhi: Tata Energy Research Institute.

Annexure I: Apparent consumption and output ratios

| | | 1991-92 | | 1996-97 | |
|---|---|---|---|---|---|
| Sl. No. | COMMODITY SECTOR | $\beta_i=(Z_i^*/Z_i)$ | $\alpha_i=(X_i^*/X_i)$ | $\beta_i=(Z_i^*/Z_i)$ | $\alpha_i=(X_i^*/X_i)$ |
| 1 | Paddy | 0.999 | 0.986 | 0.987 | 0.971 |
| 2 | Wheat | 0.997 | 0.998 | 0.969 | 0.968 |
| 3 | Other Cereals | 1.000 | 1.000 | 1.000 | 0.999 |
| 4 | Pulses | 1.006 | 1.047 | 1.009 | 1.054 |
| 5 | Sugarcane | 0.998 | 0.998 | 1.012 | 1.012 |
| 6 | Jute | 0.885 | 0.899 | 0.955 | 0.970 |
| 7 | Cotton | 0.877 | 0.733 | 0.824 | 0.704 |
| 8 | Tea | 0.977 | 0.977 | 1.020 | 1.020 |
| 9 | Coffee | 0.977 | 0.295 | 1.020 | 0.479 |
| 10 | Rubber | 0.860 | 0.873 | 0.856 | 0.865 |
| | | | | | |
| 11 | Other Crops | 0.996 | 0.959 | 1.002 | 0.955 |
| 12 | Animal Husbandry | 0.991 | 0.997 | 0.998 | 1.007 |
| 13 | Forestry and Logging | 1.038 | 1.109 | 1.347 | 1.270 |
| 14 | Fishing | 0.997 | 0.750 | 1.004 | 0.744 |
| 15 | Coal & Lignite | 1.102 | 1.178 | 1.099 | 1.120 |
| 16 | Crude Petroleum & Natural Gas | 1.274 | 2.586 | 1.620 | 2.543 |
| 17 | Iron Ore | 1.327 | 0.380 | 1.652 | 0.443 |
| 18 | Other Metallic Minerals | 1.528 | 1.305 | 1.644 | 1.273 |
| 19 | Non Metallic Minor Minerals | 1.125 | 8.539 | 1.355 | 2.683 |
| 20 | Sugar | 1.001 | 0.997 | 1.025 | 1.022 |
| | | | | | |
| 21 | Khandsari | 0.984 | 0.984 | 1.015 | 1.015 |
| 22 | Hydrogenated Oil | 1.002 | 1.007 | 1.027 | 1.033 |
| 23 | Other Food & Beverage Ind. | 1.002 | 0.977 | 1.034 | 1.020 |
| 24 | Cotton Textiles | 0.954 | 0.877 | 0.927 | 0.824 |
| 25 | Woolen Textiles | 0.964 | 0.996 | 0.942 | 0.976 |
| 26 | Art Silk and Synthetic Fibers | 0.986 | 0.961 | 1.095 | 1.061 |
| 27 | Jute Hemp Mesta Textiles | 0.995 | 0.887 | 1.039 | 0.934 |
| 28 | Other Textiles | 0.925 | 0.496 | 0.831 | 0.332 |
| 29 | Wood and Wood Products | 1.061 | 1.068 | 1.196 | 1.207 |
| 30 | Paper & Paper Products | 1.086 | 1.224 | 1.160 | 1.359 |
| | | | | | |
| 31 | Leather & Leather Products | 0.712 | 0.320 | 0.440 | 0.249 |
| 32 | Rubber Products | 1.026 | 0.892 | 1.030 | 0.918 |
| 33 | Plastic Products | 1.053 | 1.010 | 1.520 | 1.441 |
| 34 | Petroleum Products | 1.103 | 1.276 | 1.201 | 1.619 |
| 35 | Coal Tar Products | 1.184 | 1.252 | 1.503 | 1.627 |
| 36 | Fertilizers | 0.986 | 1.230 | 0.982 | 1.275 |
| 37 | Pesticides | 0.915 | 0.928 | 1.057 | 1.021 |
| 38 | Synthetic Fiber & Resin | 1.043 | 2.208 | 1.851 | 3.244 |
| 39 | Other Chemicals | 1.078 | 1.098 | 1.084 | 1.033 |
| 40 | Cement | 1.103 | 1.104 | 1.445 | 1.444 |
| | | | | | |
| 41 | Other Non Metallic Mineral Products | 1.079 | 1.058 | 1.270 | 1.253 |
| 42 | Iron and Steel | 1.247 | 1.535 | 1.511 | 1.637 |
| 43 | Non Ferrous Metals | 1.283 | 1.553 | 1.621 | 1.969 |
| 44 | Tractor and other Agricultural Machinery | 1.056 | 1.051 | 1.242 | 1.234 |
| 45 | Machine Tools | 1.107 | 1.177 | 1.589 | 1.673 |
| 46 | Other Non Electrical Mach. | 1.185 | 1.996 | 1.682 | 3.796 |
| 47 | Electrical Machinery | 1.154 | 1.242 | 1.521 | 1.734 |
| 48 | Communication Equipment | 1.166 | 1.342 | 1.401 | 1.624 |
| 49 | Electronic Equipment | 1.058 | 1.869 | 1.141 | 2.141 |
| 50 | Rail Equipment | 1.058 | 1.080 | 1.385 | 1.423 |

| Sl. No. | COMMODITY SECTOR | 1991-92 | | 1996-97 | |
|---|---|---|---|---|---|
| | | $\beta_i=(Z_i^*/Z_i)$ | $\alpha_i=(X_i^*/X_i)$ | $\beta_i=(Z_i^*/Z_i)$ | $\alpha_i=(X_i^*/X_i)$ |
| 51 | Motor Vehicles | 1.072 | 1.082 | 1.197 | 1.198 |
| 52 | Other Transport Equipment | 1.106 | 1.568 | 1.452 | 2.146 |
| 53 | Other Manufacturing | 1.101 | 0.987 | 1.166 | 0.812 |
| 54 | Construction | 1.087 | 1.087 | 1.332 | 1.332 |
| 55 | Electricity etc. | 1.088 | 1.088 | 1.158 | 1.159 |
| 56 | Rail Transport Service | 1.070 | 1.010 | 1.146 | 1.014 |
| 57 | Other Transport Service | 1.016 | 1.085 | 1.043 | 1.182 |
| 58 | Communication | 1.027 | 1.047 | 1.059 | 1.099 |
| 59 | Trade | 1.035 | 0.966 | 1.105 | 0.930 |
| 60 | Other Services | 1.021 | 0.990 | 1.037 | 1.034 |
| | | | | | |
| 61 | TOTAL | 1.049 | 1.067 | 1.136 | 1.145 |

Annexure 2: $CO_2$ emission sources and the relevant ratio to be used for generating true emissions

| Source | Relevant Ratio |
|---|---|
| Solid fuels | Apparent Consumption Ratio |
| Liquid fuels | Apparent Consumption Ratio |
| Natural gas Combustion | Output Ratio |
| Gas flaring | Output Ratio |
| Cement manufacturing | Output Ratio |

Annexure 3: $CH_4$ emission sources and the relevant ratio to be used for generating true emissions

| Source | Relevant Ratio |
|---|---|
| Wet rice agriculture | Output Ratio |
| Live stock | Output Ratio |
| Coal mining | Output Ratio |
| Natural Gas venting and leakage | Output Ratio |