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MIET 3.0 User Guide

An Inventory Estimation Tool for Missing Flows using Input-Output Techniques

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New features : IO table and environmental data are updated using 1998 data sources. Detailed table (500X500) is used. Toxic emissions by the establishments under the threshold are estimated. GWG emission data has been improved. Nutrients emission and natural resources consumption has been improved. Land use category is newly added.

MIET is now included in SimaPro 6 that has been developed to enable matrix calculation. US environmental input-output data part only can be separately ordered through CML.

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Definition of symbols

^ a symbol which makes a diagonal matrix when placed on a column vector where the diagonal shows the elements of the column vector.

$\tilde{\mathbf{A}}$ a commodity×commodity matrix derived from **U** and **V** matrices. The diagonal shows net production of each commodity per a dollar worth gross production of that commodity, and an off-diagonal element $\tilde{a}_{ij}$, which is non-positive, shows the amount of commodity *i* used to produce a dollar worth of commodity *j*.

x a column vector which shows the total commodity output (x^C) or industry output (x^I) required to meet given final demand

I an identity matrix.

A an industry×industry matrix of which diagonal shows net production of each industry per a dollar worth of gross industry output, and an off-diagonal element a_{ij}, which is non-positive, shows the amount of industry output from industry *i* used by industry *j* per a dollar worth of its output.

B a commodity×industry matrix of which an elements b_{ij} shows the amount of commodity *i* used by industry *j* per a dollar of output.

U a commodity×industry matrix of which element u_{ij} shows the amount of commodity *i* used by industry *j*.

g a column vector which shows the amount of total industry output including scrap.

W an industry×commodity matrix of which element shows the proportion of commodity *j* produced by industry *i* in total production of commodity *j* by all industry which is adjusted for scrap produced by industries.

p a column vector that shows the portion of the value of scrap produced by the industry in total industry output.

D an industry×commodity matrix of which element d_{ij} shows the proportion of commodity *j* (except for scarp) produced by industry *i* in the total production of commodity *j* by all industry.

V an industry×commodity matrix of which element v_{ij} shows the amount of commodity *j* produced by industry *i*. if *j*=non-comparable imports or scrap, v_{ij}=0.

q a column vector which shows the amount of total commodity output

y a column vector which shows the amount of final demand of each commodity ($y^C{}_x$) or industry output ($y^I{}_x$). Subscript *x* indicates total final demand including total private consumption and capital investment, total governmental consumption and capital investments and exports.

M environmental intervention×commodity (with superscript *C*) or intervention×industry (with superscript *I*) matrix of which element m_{ij} shows the physical amount of *i*th environmental intervention caused by given production volume of *j*th commodity($m^C{}_{ij}$) or industry output($m^I{}_{ij}$). Subscript *x* shows the environmental intervention by total final demand of commodity or industry output including exports.

i a column vector contains all 1s. Summation operator.

P an environmental intervention×commodity (with superscript *C*) or environmental intervention× industry (with superscript *I*) matrix of which an element p_{ij} shows the amount of environmental intervention *i* caused by the production of 1 dollar worth of commodity *j* ($p^C{}_{ij}$) or industry output of sector *j* ($p^I{}_{ij}$).

1. Introduction

Production of any functional output that Life Cycle Assessment (LCA) deals with involves near infinite number of processes through direct and indirect input/output relations. For example, a motor vehicle is produced using various parts and equipment, and this parts and equipment also requires numerous raw and ancillary materials as well as energy and capital and so on. This connection in ‘commodity flow web’ will be proliferated through upstream processes although the importance of flows may be tapered off as they reach far upstream indirect relations. In practice, most LCAs only deal with a part of processes - hopefully important ones – involved in the production of given functional output. In that sense, most Life Cycle Inventories (LCIs) are truncated to certain extent ignoring some marginal processes, which should be proved to be negligible. How can we distinguish important processes from negligible ones? ISO (1998) suggests to use three criteria in determining those processes at the beginning of iterative procedure. Those criteria are;

1) Mass
2) Energy
3) Environmental relevance

Among these three cut-off criteria, mass and energy are frequently used although mass is found to be a poor indicator in some case studies. In most cases environmental relevance has very limited applicability to be considered as a cut-off criterion, since the very problem in selecting ‘promising processes’ is laying on the fact that the importance of flows are normally not known before actual collection of detailed data. The basic problem of cut-off is that we should choose something between what we do not know what exactly they are (see Suh et al. 2002 for detailed discussion).

One of the most popular approach to solve this problem is based on the assumption of existence of reliable and facile traits that intimate overall environmental importance of a process. If such a global trait exists, it can be directly employed as an efficient cut-off criterion for every process. Raynolds *et al*. (2000a) analyzed the most simple traits, mass and energy contents, and concluded that those two traits can not be used as reliable indicators in general. In addition to mass and energy, Raynolds *et al*. (2000a, 2000b) combined economic factor with system boundary selection process. This approach seems to have reasonable ground since every cost driver involves certain economic activities which are very likely to be related to environmental intervention.

However, considering the different origins and large variability on environmental impacts of pollutants, generalization of the relationship between a few simple traits and overall environmental impacts based on some deductive inference seems to be very difficult.[1] Hunt *et al.* (1998) tested 10 different methods to streamline LCI and concluded that the validity of such a trait can be judged case-by-case basis only.[2]

In general, it is very difficult to justify any omission of flows although it is required by ISO (1998). Thus, it is necessary to cover the omitted flows then cutting them off. On the other hands, it is, in practice, impossible to gather all the site-specific data for every single process involved in the production of given functional output. Therefore, a model that is simple enough to be operational and, at the same time, complex enough to represent modern commodity-flow web is required. Such a model can be realized by linking process-based system with input-output system, which is generally referred as *hybrid IO-LCA* (for details on different hybrid methods, see Suh and Huppes 2003; Suh 2002; Suh *et al*. 2002).

MIET is an operational tool for missing flows estimation in LCA using extended Input-Output Analysis (IOA). Input-output accounts provides more complete upstream relations based on national account system. If adopted with environmental data, input-output technique can be utilized to calculate total direct and indirect environmental emissions and resources use caused by certain final demand. However, there are some limitations in input-output based inventory as an independent LCI. First, the resolution of commodity classification is too coarse. Normally the maximum number of commodities classified In national account system do not exceed 700. In US. the most detailed input-output table distinguishes around 500 commodities. Considering the variety of commodities and production technologies, a product category in an input-output account can contain commodities that have very different environmental profile per unit quantity. Second, the result of IOA normally shows only pre-consumer stages of product life cycle omitting final consumption and disposal of products. Therefore, the application of MIET is limited within missing flows in the upstream processes attached to process-specific and more reliable data.

In the next chapter, 'Basics of Input-Output Analysis' general calculus used in IOA is dealt with. Chapter three, 'Derivation of environmental matrix-two allocation method' is devoted to the mathematical background of environmental matrix calculation based on explicit distinction between commodity and industry. Users who are not interested in the theoretical background may skip chapter two and three. In chapter four, 'Data sources and calculation procedure', detailed data sources and data transformation procedure is described.

[1] Raynolds *et al*. also limited the application area of their method within common combustion related air emissions.

[2] On the other hand, if there exists a reliable indicator perfectly correlated with overall environmental consequences, the indicator is better to be utilized to calculate the inventory than cutting them off.

2. Basics of Input - Output Analysis

2.1. Leontief multiplier

Input-output analysis shows how industries are inter-linked through supply and use of commodities. It starts with input-output coefficient table[3] which is derived from inter-industry transaction records. Each column of input-output table consists of coefficients that represent the relative amount of inputs required to produce one dollar worth of output of an industry. By fixing this coefficients it is assumed that any magnitude of output of given industry will require inputs from other industries proportional to the fixed coefficients. This is the proportionality assumption in input-output convention. Then the question is that what is the required amount of inputs to meet the final demand of a product. This question is not easy to answer with a few simple steps of addition, since each industry outputs required to produce given product also requires other industry's outputs and so on. If every industry has *N* number of inputs then the number of input paths at *k*th tier will be N^k.

W. Leontief elegantly solved this problem using a few assumptions and simple matrix inversion known as Leontief multiplier (Leontief 1970). The solution model of Leontief can be summarized as a system of non-homogeneous equations (1).

$$
\begin{aligned}
&a_{11}x_1 + a_{12}x_2 + a_{13}x_3 + \cdots + a_{1j}x_j + \cdots + a_{1m}x_m - y_1 = 0 \\
&a_{21}x_1 + a_{22}x_2 + a_{23}x_3 + \cdots + a_{2j}x_j + \cdots + a_{2m}x_m - y_2 = 0 \\
&a_{31}x_1 + a_{32}x_2 + a_{33}x_3 + \cdots + a_{3j}x_j + \cdots + a_{3m}x_m - y_3 = 0 \\
&\cdot \quad \cdot \\
&(1) \\
&a_{i1}x_1 + a_{i2}x_2 + a_{i3}x_3 + \cdots + a_{ij}x_j + \cdots + a_{im}x_m - y_i = 0 \\
&\cdot\ \cdot \\
&a_{m1}x_1 + a_{m2}x_2 + a_{m3}x_3 + \cdots + a_{mj}x_j + \cdots + a_{mm}x_m - y_m = 0
\end{aligned}
$$

x_i is the total quantity of the *i*th commodity produced; y_i is the quantity of the *i*th commodity consumed by non-industry consumers. Off-diagonal elements of $a_{ij}x_j$, which is generally non-positive are the quantity of the *i*th commodity used in producing the *j*th commodity. In case of *i*=*j*, that is diagonal elements of $a_{ji}x_j$, represent the quantity of net production from each industry which have positive sign. The equation says that the total industry outputs produced are equal to the total products consumed by industry and end consumers. This can be rewritten as:

[3] Here after 'input-output table' referrers to only the intermediate part of input-output table.

$$\sum_{j=1}^{m} a_{ij}x_j - y_i = 0, \qquad (i=1,\cdots, m) \quad (2)$$

with,

$a_{ij}<0$, for all $i \neq j$; $0<a_{ii}\leq 1$, $y_i>0$ for all i (i, j=1,···,m)

Or briefly;

$$\mathbf{Ax} - \mathbf{y} = \mathbf{0} \qquad (3)$$

The matrix **A** shows the inter-industry interdependence of the economy in given area and time. We can calculate industry wide total requirement, $\mathbf{x}$ required to meet arbitrary final demand, **y** by;

$$\mathbf{x} = \mathbf{A}^{-1}\mathbf{y} \qquad (4)$$

A^{-1} is known as Leontief multiplier.[4] Leontief solution model is a linear equations system where some constraints on the coefficients were imposed. **A**$^{-1}$ has the same result that will be obtained after infinite tier of add-on calculation shown in equation (5) (Miller and Blair 1985) (*cf*. Heijungs and Suh 2002).

$$\mathbf{I} + \sum_{n=1}^{\infty} (\mathbf{I} - \mathbf{A})^n \qquad (5)$$

(**I**-**A**) denotes the net direct inputs of coefficient matrix, and (**I**-**A**)^2 and (**I**-**A**)^3 are 1st and 2nd tier of indirect requirements, respectively and so on.

Using Leontief multiplier, various economy wide analysis is possible. Total energy requirement per arbitrary final demand, **y** can be calculated using diagonal primary energy requirement vector, $\hat{\mathbf{e}}_\mathbf{P}$ which represents primary energy input (MJ) per $ output of each sector (Bullard et al. 1978).

$$\mathbf{E} = \hat{\mathbf{e}}_\mathbf{P}\mathbf{A}^{-1}\mathbf{y} \qquad (6)$$

Equivalently, economy wide environmental emissions per arbitrary final demand **y** is calculated as equation (7) (Hayami et al. 1993; Lave et al. 1995).

$$\mathbf{M} = \mathbf{PA}^{-1}\mathbf{y} \qquad (7)$$

[4] Note here that **A** in this equation stands for the coefficient matrix with positive diagonal and non-positive off-diagonal, which is generally noted with (**I** - **A**) in many input-output literatures.

M denotes direct and indirect environmental intervention due to arbitrary final demand **y**, and diagonal matrix, **P** does direct pollutant emission per $ worth of output of each sector. If good environmental statistics is supported, input-output technique provides reliable information on economy-wide environmental interventions during pre-consumer stages of product life cycle.

2.2. Supply and Use framework

Generally, total direct and indirect requirement of industry output to meet certain final demand is calculated using Leontief inverse;

$$\mathbf{x}^{I} = \mathbf{A}^{-1}\mathbf{y}^{I} \qquad (8)$$

Equation (8) does not provide information on ‘commodity’ requirements, but only on ‘industry output’ requirements. From the LCA perspective the utility of information on industry output is unclear, since LCA is a function-based evaluation system regardless where the commodity is being produced, and furthermore, each industry produces considerable amount of secondary products as well as primary product in US economy (Miller and Blair 1985). Supply and use framework facilitates methodological ground to properly deal with ‘commodity’ in input-output system.

Since the System of National Accounts (SNA) (United Nations 1968), many countries have employed supply and use framework for their national accounts system. Supply and use framework was developed with contributions by R. Stone who received the Nobel Prize in 1984. Since 1972, U.S. DOC has prepared supply, use, and the total requirement table, which is derived by using supply and use matrices. The utility of supply and use framework is that first, this method greatly improves the statistical quality, because the products and services used and produced by each establishment are better known than the industries from where they came. Second, this framework gives explicit distinction between commodity and industry output that enables appropriate treatment of secondary products and scrap.

This study utilizes commodity×commodity total requirement matrix derived from supply and use table using industry-technology assumption. General calculus used to derive total requirement matrix is shown below (BEA 1995b). Detailed description on the derivation procedure can be found at Stone *et al*. (Stone et al. 1963).

$$\mathbf{x}^{C} = (\mathbf{I} - \mathbf{BW})^{-1}\mathbf{y}^{C}{}_{x} = \widetilde{\mathbf{A}}^{-1}\mathbf{y}^{C}{}_{x} \qquad (9a)$$

$$\mathbf{B} = \mathbf{U}\hat{\mathbf{g}}^{-1} \qquad (9b)$$

$$\mathbf{W} = (\mathbf{I} - \hat{\mathbf{p}})^{-1}\mathbf{D} \qquad (9c)$$

$$\mathbf{D} = \mathbf{V}\hat{\mathbf{q}}^{-1} \qquad (9d)$$

Commodity×commodity total requirement matrix, $\tilde{\mathbf{A}}^{-1}$ is calculated by $(\mathbf{I}\text{-}\mathbf{BW})^{-1}$. $\mathbf{y}^{C}{}_{x}$ contains private consumption and capital investment, governmental consumption and capital investments and exports ($\mathbf{y}_{x}=\mathbf{y}_{pc}+\mathbf{y}_{pi}+\mathbf{y}_{gc}+\mathbf{y}_{gi}+\mathbf{y}_{ex}$). Commodity classification that is used in this study is 496X496 details.

2.3. Limitations of IOA

Input-output based analysis has inherent problems as well as advantages. Lave *et al.*, (1995) addressed inability of input-output approach for detailed analysis. Since the most detailed input-output table contains different commodities into one classification, input-output based analysis can provide comparison only between generic sector level. Therefore Input-output based techniques are inadequate for the analysis like identification of key processes or supply chain management within the same industry classification.

More fundamentally, IOA is based on proportionality assumption in fixing **A** matrix in equation (3). It means that there is no 'economy or diseconomy of scale'. Two economies of scale can be considered. One is input intensity and the other is emission intensity. Generally the amount of inputs and emissions per unit output decrease as scale of plant increases while input-output based analysis will give the same amount of resources use and emissions released per $ output regardless of scale.

Another source of uncertainty is temporal deference between input-output table and study using the table. Due to the dynamic nature of modern economy, several years old economic structure already deviates from current one. In addition to the production technology, rapidly developing environmental emission control technology and regulation between the two time period can not be counted. Though the error caused by the temporal difference can be mitigated by using the most recent input-output table, for some rapidly changing sectors, this might be insufficient.

Another major source of potential error is the economic convention in treating capital goods (Bullard et al. 1978). In input-output table, capital goods such as buildings, durable machinery are counted as net outputs rather than inputs. That is to say, if a chemical industry build a new plant and purchased durable machinery, the environmental interventions caused by the capital goods are not included in direct and indirect environmental emission per $ worth output from chemical industry. Thus, environmental burden associated with the inputs of capital goods will be omitted in the result of input-output based inventory model. Monetary presentation can also cause potential errors. Any analysis using Leontief inverse assumes that the monetary flows in input-output table represents the actual physical flows between industry. This assumption implies perfect price homogeneity, which is not the case in practice. Secondly, monetary values should be converted into physical units for LCA, and it requires accurate valuation considering inflation rates, whereas physical input-output table may be independent from this problem.

Although input-output technique considerably extends the upstream reach, the system boundary is, in principle, not yet complete, since national economy is linked with international trade. This truncation can be significantly lower the utility of IOA for the countries that heavily rely on trade. In this study it was assumed that imported goods has been produced using exactly the same technology of US.

Nevertheless the shortcomings, it is clear that input-output based model offers useful information based on more complete picture of inter-industry interactions inasmuch as it covers the national economy.

3. Derivation of environmental matrix - two allocation methods

Generally, economy wide direct and indirect environmental interventions caused by given final demand of commodity, **y** is calculated by equation (10);

$$\mathbf{M} = \mathbf{P}\tilde{\mathbf{A}}^{-1}\mathbf{y} \qquad (10)$$

Since commodity×commodity matrix, $\tilde{\mathbf{A}}$ is utilized, the dimension of **P** should be intervention×commodity. For instance, equation (11), which can be found in some literatures, is simply a wrong equation.

$$\mathbf{M}^{*} = \mathbf{P}^{I}\tilde{\mathbf{A}}^{-1}\mathbf{y} \qquad (11)$$

$\mathbf{P}^{I}$ is the environmental intervention×industry matrix showing the amount of environmental intervention caused by production of 1 dollar worth of industry output which comprises primary and secondary products as well as scrap, while $\tilde{\mathbf{A}}^{-1}$ is commodity×commodity matrix showing direct and indirect requirement of commodities to produce 1 dollar worth of each commodity. Although the right-hand side of equation (11) may generate certain numerical values, the analytical meaning of the result is confusing.

The consequence of the confusion between industry and commodity in equation (11) can be significant at least in U.S. where the portion of secondary products in each industry is considerable (Miller and Blair 1985). For example, a column of $\mathbf{P}^{I}$ may show the environmental intervention caused by 1 dollar of output from the industry, ‘plastics and synthetic materials’. This industry produces a set of secondary products, ‘broad and narrow fabrics, yarn and thread’, ‘miscellaneous textile goods and floor coverings’, ‘industrial and other chemicals’, ‘agricultural fertilizers and chemicals’, ‘cleaning and toilet preparations’ and ‘paints and allied products’ as well as the primary product. The amount of secondary products produced by the industry, ‘plastics and synthetic materials’ shares 12.5% of the total industry output according to 1996 annual input-output table of U.S (BEA 2000). Therefore, certain portion of environmental intervention occurred to produce 1 dollar worth industry output by the industry, ‘plastics and synthetic materials’ has been generated to produce other products then ‘plastics and synthetic materials’. Furthermore, other industries are also producing the commodity, ‘plastics and synthetic materials’. For example, 10.8% of total market of the commodity ‘plastics and synthetic materials’ is shared by the industry, ‘industrial and other chemicals’.

According to the recent input-output table prepared by Department of Commerce, up to 77.8% of market share of each commodity is dependent upon industries that are not producing the commodity as primary product. Furthermore, the portion of secondary products produced by each industry can be up to 88.6% of the total industry output in monetary terms in U.S. economy. Here, a method to treat secondary products and scrap in relation to the environmental intervention matrix are further elaborated.

Economy wide direct and indirect environmental intervention by given final demand of commodity using input-output technique is calculated as;

$$\mathbf{M}^{C} = \mathbf{P}^{C}\tilde{\mathbf{A}}^{-1}\mathbf{y} \qquad (12)$$

Note that $\mathbf{P}^{C}$ is environmental intervention per unit dollar output of each commodity. However, the information on environmental intervention is compiled mostly based on industry instead of commodity. Therefore, $\mathbf{P}^{C}$ should be derived from $\mathbf{P}^{I}$ by assigning the total environmental intervention by an industry to its secondary products and scrap as well as its primary product. Many allocation methods has been proposed and used to ascribe given environmental intervention to co-products in LCAs (Huppes et al. 1994; Guinee et al. 2002; Frischknecht 2000). It is the best if the allocation procedure can be performed based purely on the physical causality between environmental intervention and production of secondary and primary products. However, it is not always possible to find exact physical causality between industry outputs and environmental interventions. Therefore, economic value based allocation has been widely used in LCAs, since the economic value of process output reflects the driving force of the process operation.

Assuming that total environmental intervention by industry is proportionally assigned to its primary and secondary products based on their economic value, the average environmental intervention by a dollar worth commodity can be calculated based on market share;

$$\mathbf{P}^{C}{}_{I} = \mathbf{P}^{I}\mathbf{D} \qquad (13)$$

The result of equation (13) shows the amount of environmental intervention by industries that are involved in the production of given commodity in the ratio of the market share.

Alternatively, one can assume that each commodity has its own characteristics in generating environmental intervention irrespective of industry where it is produced. Then the environmental intervention of a primary product of an industry is calculated by subtracting the amount of environmental intervention by secondary products referring to the industries that produce the secondary products as primary products. This method is referred as ‘avoided impact’ allocation method in LCA (Guinee et al. 2002).

Followings are the derivation of direct environmental intervention by commodity using avoided impact type of allocation method. A general relationship between $\mathbf{P}^I$ and the total environmental intervention by industry, $\dot{\mathbf{M}}^I{}_x$ is defined as;

$$\dot{\mathbf{M}}^I{}_x = \mathbf{P}^I \hat{\mathbf{g}} \qquad (14)$$

$\dot{\mathbf{M}}^I{}_x$ in equation (14) contains the portion of environmental intervention generated for scrap production. This portion can be subtracted by;

$$\mathbf{M}^I{}_x = \mathbf{P}^I (\mathbf{I} - \hat{\mathbf{p}})\hat{\mathbf{g}} \qquad (15)$$

$\mathbf{M}^I{}_x$ shows the total environmental intervention by industries excluding the portion for scrap based on its economic value, resulting total environmental intervention that is purely caused by the production of primary and secondary products by each industry. Let $\mathbf{P}^C{}_C$ be the pollutants emission and resources use to produce a dollar worth of commodity calculated based on avoided impact allocation method. Then the total direct and indirect environmental intervention by commodity is calculated as;

$$\mathbf{M}^C{}_{x,C} = \mathbf{P}^C{}_C \hat{\mathbf{q}} \qquad (16)$$

The portion of environmental intervention generated for the production of scrap is not included in $\mathbf{M}^C{}_{x,C}$ since scrap is not counted as a commodity in vector **q**. In a closed economy, the total environmental intervention by commodity in equation (16) can be converted into total environmental intervention by industry where the portion for scrap production is subtracted by assigning environmental intervention by commodity according to the market share.

$$\mathbf{M}^I{}_x = \mathbf{M}^C{}_{x,C} \mathbf{D}' \qquad (17)$$

Rearranging (17) using (15) and (16) and substituting square and non-singular matrix, $\hat{\mathbf{q}}\mathbf{D}'$ by $\mathbf{V}'$, $\mathbf{P}^C{}_C$ is defined by means of $\mathbf{P}^I$ as;

$$\mathbf{P}^C{}_C = \mathbf{P}^I (\mathbf{I} - \hat{\mathbf{p}})\hat{\mathbf{g}}\mathbf{V}'^{-1} \qquad (18)$$

$\mathbf{P}^C{}_C$ derived represents the direct and indirect environmental intervention per unit dollar output of each commodity using avoided impact type of allocation method in which the amount of environmental interventions due to secondary products are subtracted assuming that those secondary products require the same amount of environmental intervention as they are produced as primary products.

The total direct and indirect environmental intervention by given final demand on commodity in equation (12) is calculated using the two methods derived above.

$$\mathbf{M}^{C}{}_{I} = \mathbf{P}^{I}\mathbf{D}\tilde{\mathbf{A}}^{-1}\mathbf{y}^{C} \qquad (19a)$$

$$\mathbf{M}^{C}{}_{C} = \mathbf{P}^{I}(\mathbf{I}-\hat{\mathbf{p}})\hat{\mathbf{g}}\mathbf{V}'^{-1}\tilde{\mathbf{A}}^{-1}\mathbf{y}^{C} \qquad (19b)$$

Note, an identity, $\mathbf{M}^{I}{}_{x}\mathbf{i}=\mathbf{M}^{C}{}_{x,I}\,\mathbf{i}=\mathbf{M}^{C}{}_{x,C}\,\mathbf{i}$ holds in closed economy, so that the total environmental intervention by industry is fully allocated to each commodity. Except for $\mathbf{P}^{I}$, all matrices and vectors in right-hand side of equation (19a) and (19b) are available from DOC as parts of national accounts.[5] MIET 3.1 is prepared using equation (19a).

[5] It is notable that the allocation methods described here is essentially equivalent to the methods used to treat secondary products based on, so called, 'industry-technology assumption' and 'commodity-technology assumption'. The discussion related to this long-standing issue is not going to be dealt with in this guide but can be found in literatures like ten Raa *et al*. 1984, ten Raa 1984, Steenge 1990 and Konjin 1994.

4. Data sources and calculation procedure

4.1. Input-Output data

US 1998 annual input-output tables are used (BEA 2002). Calculation procedure follows the standard US make and use framework that can be found in BEA (1995a).[6]

In addition to the standard input-output table as default, an alternative matrix that includes capital flows is constructed. Users may chose this table and corresponding inverse matrix to see the effect of capital goods.

The most recent capital flow matrix is the one from 1992 (BEA 1995c). Although the decision on making use of the 1992 capital flow data is made based largely on data availability problem, it is considered reasonable to assume that the capital goods invested in 1992 were still in use in most industries but rapidly developing sectors such as information technology (IT) sector. For those rapidly developing sectors, current estimation based on 1992 capital investments may be misleading. The amount of capital goods used by each sector has been inflated or deflated depending on the gross output differences between 1992 and 1998 of each sector.

In 1992 benchmark survey by Bureau of Economic Analysis (BEA), use of 163 capital goods by 64 industries are compiled based on Standard Industry Classification (SIC) code. They are reassigned into relevant IO classification, and then are absorbed into use matrix. The assignment process is done by constructing two permutation matrices and pre and post multiplying them to the original capital flow matrix. Two matrices, commodity-by-capital flow matrix and SIC industry-by-IO industry matrix, are compiled for such assignment.

4.2. Green House Gas emissions

4.2.1. Carbon dioxide

The total Green House Gas (GHG) emission including Carbon Dioxide (CO_2) in U.S. is rather well known, but individual sector level data is not easily found besides the CO_2 emission data from utility sector, which is compiled by EIA and EPA. Thus the rest of the estimation procedure for combustion-oriented CO_2 emission focuses on other sectors than electricity utility sector. The CO_2 emission from the transportation first should be separated into two: household transportation and industry transportation. Here it is assumed that all trucks,

[6] Basic principles of input-output analysis including the make and use framework are well summarized in a book by Miller and Blair (1985).

buses, air, boat and vessels and locomotive are industrial use. CO_2 emissions from international bunker fuel combustion, construction equipment and agricultural vehicles are also assigned to industrial use. Industrial and commercial combustion-oriented CO_2 emissions are assigned based on the fuel use data from BEA and the combustion oriented CO_2 emission by each fuel type data by EPA (EPA, 2002a). Non-combustion oriented CO_2 emissions are assigned based on the source process referring to EPA (2002a).

Table 1. Direct Carbon Dioxide emission by industries in U.S.[7]

	Aggregated sector	Sources	Amount (Tg CO_2)	Share
Combustion oriented	Electric utility	Electric utility	2160.3	46%
	Industry (based on fuel consumption)	Coal	137.8	21%
		Natural Gas	484.1	
		Petroleum	194.2	
		Lubricant oil	12.7	
		Other petroleum	171.3	
	Transportation	Light duty trucks	356.4	24%
		Other trucks	257.9	
		Buses	12.4	
		Aircraft	183.0	
		Boat and vessels	47.8	
		Locomotives	33.8	
		Construction and agricultural equipment	93.0	
		International bunker fuel	112.9	
	Commercial (based on fuel consumption)	Coal	8.7	5%
		Natural gas	163.5	
		Petroleum	47.2	
Non-combustion oriented	Industrial processes	Iron and steel	67.4	4%
		Cement manufacturing	39.2	
		Waste combustion	20.3	
		Ammonia manufacturing	20.1	
		Limestone and dolomite	21.9	
		Natural gas flaring	6.3	
		Soda ash manufacturing	5.8	
		Titanium dioxide	4.3	
		Ferroalloys	1.8	
		CO2 consumption	1.4	
Total			4665.5	100%

GHG emissions from the sources under 'industry' sector and 'commercial' sector are to be assigned to each IO industry based on transaction records of relevant commodities. Rest of the emission sources can be directly assigned to corresponding IO industry sector.

4.2.2. Methane

Methane (CH_4) was responsible for 9.3% of the total (or 627.1 Tg CO_2-equivelent) GHG emission in 1998. Industrial processes such as landfills natural gas systems, coal mining are dominant sources, except for enteric fermentation, and they can be easily assigned to relevant IO classification.

[7] Based on EPA (2002a), EIA (2002) and own calculation.

Most of the sources, but ‘stationary sources’ and ‘mobile source’ can be directly assigned to IO industry sector. Since ‘stationary sources’ for CH_4 are mainly residential coal combustion, only part of it should be assigned to intermediate industries. Referring to the emission factors of CH_4 from residential coal and commercial coal, which is 300 and 10, respectively, and the share of coal use by residential and commercial sector in 1998, which was 13Tbtu and 92TBtu, respectively, only 19% of the CH_4 emission from ‘stationary’ source is assigned to the intermediate industry based on coal consumption (EPA 2002a and EIA 2002). According to the EPA (2002a) 42% of CH_4 emission from mobile sources came from passenger car. Assuming other transportation means can be assigned to the intermediate industry, 58% of the mobile emission of CH_4 is assigned based on the transaction records of transportation services.

Table 2. Industrial Carbon Dioxide emission in U.S. based on direct emission[8]

Sources		Amount (Gg CH_4)	Amount (Tg CO_2-eq.)	Share (%)
Landfills		9571	216.6	41%
Natural gas system		5820	125.7	24%
Coal mining		3235	73.5	14%
Manure management	Diary cattle	624	34.8	7%
	Swine	864		
	Beef cattle	161		
	Sheep	2		
	Goats	1		
	Poultry	130		
	Horses	29		
Wastewater treatment		1326	26.8	5%
Petroleum systems		1114	24.2	5%
Stationary sources		334	8.2	2%
Rice cultivation		376	7.6	1%
Mobile sources		123	4.8	1%
Petrochemical production		78	1.5	0%
Agricultural residue burning		37	0.7	0%
Total		23984	524.4	100%

4.2.3. Nitrous Oxide (N_2O)

Due to their very low contribution to overall GHG emissions only two N_2O sources are considered to be meaningful: ‘Agricultural soil management’ and ‘mobile sources’, each of which contributes 1.0Tg and 0.2Tg of CO_2-equivelent GHG emission (963 Gg and 191 Gg as N_2O), respectively. Following the same reasoning as CH_4, 46% of the N_2O emissions from mobile sources are assigned to the intermediate industries based on the transportation service utilization.

[8] Based on EPA (2002a).

4.3. Criteria Pollutants

Criteria pollutants in U.S. refers to six air pollutants including carbon monoxide (CO), nitrogen oxides (NOx), sulfur dioxide (SO_2), Particulate Matter (PM), Ozone (O_3) and Lead (Pb). Four of the six, including CO, NOx, SO_2 and PM have been compiled and maintained by U.S. National Emission Trend (NET) database, which is now being absorbed by National Emission Inventory (NEI) database together with National Toxic Inventory (NTI) database for Hazardous Air Pollutants (HAPs) (EPA 2002c, 2002d). The NET database covers both point sources and non-point sources including area sources and mobile sources. Point source emissions compiled in NET database provides detailed information on the emission sources at the level of facility, which also shows the Standard Industry Classification (SIC) code that the facility belongs to. Thus point source part of the database can be easily assigned to each industry based on SIC codes. Then the emission by SIC code data is transformed into emission by BEA industry code based primarily on the standard comparison between SIC and BEA code prepared by BEA. If there is a SIC classification that is shared by more than one classification by BEA, then additional data sources such as the main source facility types or total amount of industry output data are used. Non-point sources does not provide SIC code, but the sources are described in fairly detail so that it is possible to relate them to IO industry classification code.

4.4. Volatile Organic Compound (VOC) and Ammonia

These two pollutants are also covered by NET database and the procedure and data sources that are used to compile these pollutants are similar to those of criteria pollutants.

4.5. Toxic Pollutants

Toxic pollutants part is the most challenging part of the database even in US, where monitoring and reporting system of toxic chemicals is probably the most advanced in the world. That is because, among others, first, unlike carbon dioxide emission, for instance, estimation through input side is very difficult, and second, the emission is usually occurring in a very dilute form, so that measuring the amount of emission subjects to relatively high uncertainty compared to bulk emissions. Third, the number of toxic pollutants generated by an establishment can be very high, so that accurate detection and measurement of all toxic pollutants by a small establishment can be practically infeasible due to its cost.

Constructing an accurate toxic emissions inventory for US is by no means the objectives of this study. The aim is rather the right order of magnitude than the precise values. Two data sets are prepared for toxic emissions: one based only on existing databases and the other also with estimates by current study. Users can select either of the two.

In US, toxic emissions are dealt with under a number of different initiatives, including Toxic Releases Inventory (TRI), National Toxics Inventory (NTI) and National Center for Food and Agricultural Policy (NCFAP) database (EPA 2002b, 2002c, 2002d, NCFAP 2000). Those databases contain extensive list of toxic chemicals: TRI98 does 535, NTI 188 and NCFAP 235. Despite the extensive list, there could be some important chemicals that are missing. However, the list is based on the current knowledge on toxic chemicals, and identification and quantification of other toxic chemical releases are not considered as the priority in this study. Thus, only those chemicals listed in these databases are considered in this study, except for the chemicals that are compiled by other initiatives such as NET databases.

More attention is paid to the source coverage issues. Table 3 summarises the scope of the three databases in terms of emission source types, industries, environmental media and emissions from facilities under threshold limit.

Table 3. Coverage by toxic emission databases

Scope of databases		TRI	NTI	NCFAP
Source type	Area		V	V
	Mobile		V	
	Point	V	V	
Industry	Agricultural and mining	*	v	V
	Manufacturing	V	V	
	Services	*	V	
Environmental medium	Air	V	v	
	Water	V		
	Soil	V		v**
Coverage within industries	Reports from larger facilities only	v	V	
	Estimation for facilities under thresholds		V	
	Chemical use data			V

* Some of these activities are covered by TRI since 1998.
** Whether the pesticide applied is an emission to air, water or soil depends very much upon the properties of the applied chemical, the climate conditions, etc. However, here the arguments are postponed to the specifications in impact assessment methods, and the emission itself is regarded as an emission to soil.

Glancing the table 3 indicates that there is no database that covers emissions to water and land (other than pesticide) by mobile and areas sources, since NTI covers only Hazardous Air Pollutants (HAPs) and TRI mainly cover only point sources. While toxic pollutant emissions to environmental media other than air by mobile sources are not considered significant, those by area sources such as leachate emission from landfill area could be considerable. These loopholes are, however, fairly well filled in by recent extension of TRI databases, especially to mining (SIC1021 to SIC1474), logistic services (SIC4212 to SIC4581), Sewerage and refuse system (SIC4952 and SIC4953) and Solid waste management (SIC 9511). In addition to these sectors, most of major chemical-handling sectors are also included in TRI database since 1998 and on, thus industry coverage of TRI database seems quite complete, although it cannot be 100 per cent.

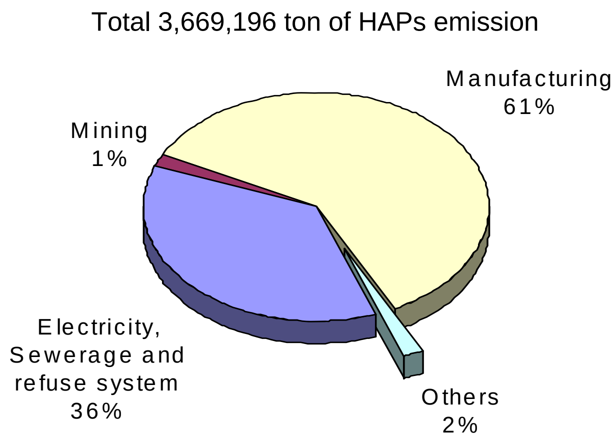

Figure 1. Contribution by industries to NTI database by mass in 1996

This is confirmed at least for air emissions. According to NTI database, total 3,669,196 ton of HAPs was emitted in US in 1996, and manufacturing industries (SIC 20 – SIC 39) and electricity, sewerage and refuse systems (SIC 49) contributed around 97% of them emitting 2,202,304 ton and 1,338,170 ton, respectively. Thus major industries that generate most but two per cent of HAPs are within the scope of extended TRI database.

Still, the Emission reports for TRI database are collected only from those facilities employ 10 or more full-time equivalent employees or manufacture or process more than 25,000 pounds or otherwise uses more than 10,000 pounds of any listed chemical during the reporting year. Emissions from each individual facilities that does not meet those conditions might be also small, however, all together, they can be quite considerable.

The completeness of TRI is examined using NTI database and establishment size distribution by Bureau of Census (2001). NTI database estimates HAPs emissions using reports as well as emission factors and activity rates regardless of the size of facilities. Thus a comparison between TRI and NTI for overlapping chemicals can provide an idea about the truncation of TRI by the facilities below the threshold condition. The comparison showed that there are, indeed, significant systematic truncation in TRI showing only 17.2% of the HAPs emission, on average, compared to NTI. This strongly suggests that using only TRI can significantly underestimate the potential impacts by toxic releases.[9] An explanation could be the size distribution of establishments. Due to the type of processes involved, each industry has different establishment size distribution characteristics. For instance, North American Industry Classification System (NAICS) 323, 'Printing and related support activities' is dominated by establishments with less than 10 employs accounting for 66% of the total 42,863

[9] This results also confirms, to some extent, Ayres and Ayres (1998).

establishments, while the share by those smaller establishments in the sector 'Paper manufacturing' (NAICS 322), accounts only for 20% of the total 5,868 establishments (US Census Bureau, 2001). As the number of smaller establishments in an industry increases it is more likely that the TRI data for the sector is less complete. That is because of the way that the threshold limit is set, but also because the emission standards are generally less strict to small-sized establishment, and, although individual establishment may generate smaller volume of toxic emissions, sum of them over the whole establishments can be considerable.[10]

Regression study was further extended to each industry level in order to reflect the differences in establishment size distribution. TRI values of each sector represent, on average, 4.4% to 29.4% of the HAPs compared to NTI depending on the industry sectors at stake.[11] These results does not support the argument that TRI can still indicate the relative magnitude of toxic impacts although the absolute values are misleading as the truncation is made homogeneously.

In this study, relatively complete data sources such as HAPs by NTI are utilised as much as available. Otherwise the amount of sectoral toxic emissions are projected based on TRI and the relationships between TRI and NTI values derived for each industry group. If such sectoral relationships can not be identified due either to the sample size or to poor regression results, more general relationship between TRI and NTI is used instead.

For mobile and area sources, NTI database are directly used without further estimation procedure, as it is considered to cover most of major emissions. The NTI database other than point source emissions includes emissions from natural processes and post-production stages such as wild fire, household product usage, etc., and these emissions are excluded from subsequent assignment over industry.

For pesticide emissions, NCFAP database is also directly used. The NCFAP database compiles the amount of 235 pesticides applied for 88 crop types. Assuming the application of pesticide equals emission, pesticide emission data are directly assigned to BEA industry code based on the crop types.

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[10] Using the data from Bureau of Census (2001) the relationship between the completeness of TRI and the portion of small-to-medium sized establishments in each industry. The results show that there are negative relationship between the two.

[11] The coefficients of regression equations lie between 2.1 to 7.1 depending on the sector. Some significant differences between TRI 98 and NTI for 1996 are observed for SIC 49, "Utilities", although there hasn't been much changes in technology and regulation between the two time periods. Formaldehyde and Chlorine emissions, for instance, are reported to be 57.7 and 23.0 ton, respectively, by TRI98, while NTI for 1996 reports, for the same chemicals, 15,965.5 and 1,514.0 ton, respectively.

4.6. Land use

In this database, uses of land only by major land-covering activities are accounted in square meter. Ie., only occupation of land is considered and neither differences in land-use intensity nor those in land transformation are accounted. Fig 2. shows major uses of land in U.S.

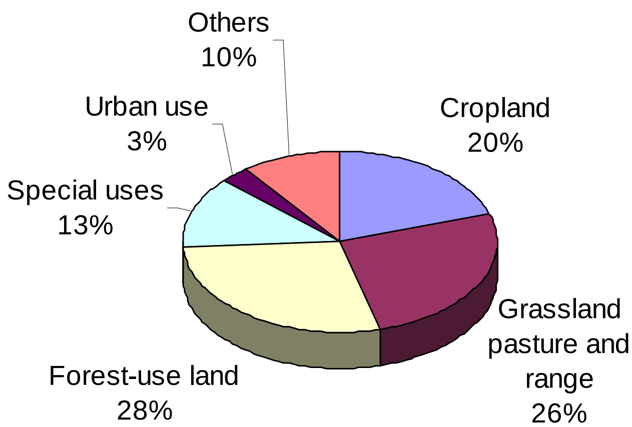

Figure 2. Major uses of land in U.S. (USDA, 2002)
Total Use of land in U.S. was 2.3billion acres in 1997.

The "Special uses" in fig. 2 includes parks, wilderness, wildlife and related uses, transportation and national defense areas and the "Others" does deserts, wetlands and barren land. Uses of land that can be related to industrial production are croplands, grassland, part of special uses (recreation, transportation and defense) and part of urban land (for industrial installations). Urban land here includes industrial complexes and service areas other than agricultural uses as well as urban residential areas. Most of the industrial activities in U.S. are taking place in urban area, which covers around 3%. Therefore the average land coverage by each BEA sector is less than 0.006% at best, and they are not included in this database.[12] In special uses, natural parks are the largest "industrial" uses, however, they are not considered as an environmental intervention and, thus, are not included in this database either. Remaining industrial uses of land are all allocated directly to BEA codes.

[12] Furthermore, no statistics on land use that can be allocated to detailed 6digit BEA industry level was found. However, the land use intensity by urban area is considered to be relatively high, and, thus, it is desirable to further compile data on urban uses, especially if relevant impact assessment methods that can properly account for the land use intensity are available.

Table 4. Industrial uses of land in U.S.

	Detailed use	Million square meter	Share in total industrial use (%)
Cropland	Soybeans	408777.4	10.68
	Corn for grain	397729.3	10.39
	All wheat	303821	7.94
	Cotton	75494.92	1.97
	Sorghum for grain	47874.83	1.25
	Corn silage	34985.45	0.91
	Barley	27620.09	0.72
	Rice	20254.73	0.53
	Sunflower	20254.73	0.53
	Oats	14730.72	0.38
	Dry edible beans	11048.04	0.29
	Sugarbeets	9206.698	0.24
	Peanuts for nuts	7365.358	0.19
	Potatoes	7365.358	0.19
	Canola	5524.019	0.14
	Sugarcane	5524.019	0.14
	Tobacco	3682.679	0.10
	Millet	3682.679	0.10
	Rye	1841.34	0.05
	Sorghum silage	1841.34	0.05
	Noncitrus fruits	11048.04	0.29
	Fresh market vegetables	11048.04	0.29
	Processing vegetables	9206.698	0.24
	Cirtus fruits	5524.019	0.14
	Tree nuts	3682.679	0.10
	Other crops	40509.47	1.06
Grassland pasture and range	Grassland pasture and range	2339108	61.09
Special uses	Transportation	101172.5	2.64
	National defense	60703.5	1.59

Land use data for the year 1998 was not available from the data sources considered, and 1997 data was used instead (USDA, 2002). According to the trend analyses by USDA (2002), however, the uses of land by different activities were rather stable, and, therefore, no further treatments were made to estimate the values for the year 1998. There are a few land use activities that are to be allocated into different industries. Both industrial activities and household activities are responsible for the use of land for transportation, therefore the share by industrial activities in transportation is estimated based on CO_2 emission from passenger cars and other automobiles such as trucks and buses. According to EPA (2002a) passenger cars are responsible for 36% of the total CO_2 emission by automobile-related transportation activities. Thus only 64% of the total land use by transportation are allocated to transportation sectors based on their total production values.[13] Grassland pasture and range is allocated to live stock industries based on their total production values.

[13] There are some "within-industry" use of transportation that are not visible in input-output table. However, it is assumed that the uses of transportation service from transportation industry reflects the relative magnitude of transportation activities by each industry.

4.7. Nutrification

Major pollutants for nutrification are nitrogenous and phosphorus compounds to air, fresh water and soil. Main sources of emission include combustion gases (for NOx to air) and fertilizer and manure applications (for nitrogenous and phosphorus compounds emission to fresh water). The NOx and NH_3 emissions from these sources are all taken into account by NET database. Although the nitrogenous emissions by manure application are subject to follow a series of biological processes, known as nitrification and denitrification, which consecutively forms Nitrite (NO_{2P}^-), Nitrate (NO_{3P}^-) and Nitrogen gas (N_2), they are mainly in form of NH_3 or NH_4^+ depending on the pH (or organic nitrogen that are to be converted into these two forms) when they are applied. Therefore, the NH_3 inventory by NET database is considered to be relevant for nitrogenous emissions.

The phosphorus compounds emission is not easily available from major statistical archives, and, therefore, is estimated as phosphorus equivalency based on a number of statistics. Phosphorus emissions by manure application and phosphorus run-off from phosphate fertilizer application are considered in this inventory.

Table 5. Major phosphorus emission from livestock*

	Number (thousand)	g of P excreted / yr per each	Estimated loss (%)	Annual emission (kg / yr)
Beef cattle	33885	18.23	15	92648.88
Dairy cattle	9199	9.9426	15	13719.3
Chicken	425045	53.0272	15	3380842
Swine	62206	26.5136	15	247395.8
Turkey	5549	46.3988	15	38618.66
Total				3773225

* Own calculation based on Natural Resources Conservation Service (NRCS) (2000) and National Agricultural Statistics Service (NASS) (2003).

NRCS (2000) provides data on average mass excreted per day by each livestock type, its P content and average run-off ratio. These data is applied together with the statistics by NASS (2003) on the number of livestock in US in 1998 to estimate the annual emission of P to fresh water by manure application.

More than half of the phosphate fertilizer applied in US is in form of ammonium phosphate (NH_4HPO_4) with 88-90% of active ingredient. The phosphorus content in ammonium phosphate fertilizer is, therefore, around 22% by mass. NASS (1998, 1999, 2000, 2003) provides data on the amount of phosphate fertilizer application to each type of crops, fruits, vegetables and nuts. By applying average run-off rate of phosphorus in soil estimated by NRCS (2000), the amount of phosphorus loss in soil is estimated.

Table 6. Phosphorus emission from fertilizer application**

	Phosphate fertilizer applied (millions pound)	P contents (kg)	P run-off (kg)	Share in total (%)
Corn	3236.50	3.23E+08	4.85E+07	51.07
Wheat	1326.40	1.32E+08	1.99E+07	20.93
Soybean	763.60	7.63E+07	1.14E+07	12.05
Cotton	378.20	3.78E+07	5.67E+06	5.97
Grapes	306.04	3.06E+07	4.59E+06	4.83
Sorghum	54.50	5.44E+06	8.17E+05	0.86
Oranges	35.94	3.59E+06	5.38E+05	0.57
Lettuce	35.41	3.54E+06	5.31E+05	0.56
Tomatoes	35.25	3.52E+06	5.28E+05	0.56
Melons	25.72	2.57E+06	3.85E+05	0.41
Onions	14.91	1.49E+06	2.23E+05	0.24
Corn	13.06	1.30E+06	1.96E+05	0.21
Carrots	12.38	1.24E+06	1.85E+05	0.20
Almonds	11.77	1.18E+06	1.76E+05	0.19
Beans, Samp, Proc.	8.93	8.92E+05	1.34E+05	0.14
Cabbage	8.91	8.90E+05	1.33E+05	0.14
Peas	8.84	8.82E+05	1.32E+05	0.14
Broccoli	8.13	8.12E+05	1.22E+05	0.13
Beans, Sanp, Fresh	6.91	6.90E+05	1.03E+05	0.11
Celery	4.71	4.71E+05	7.06E+04	0.07
Peppers	4.65	4.65E+05	6.97E+04	0.07
Grapefruit	4.57	4.56E+05	6.85E+04	0.07
Apples	3.88	3.88E+05	5.82E+04	0.06
Cucumbers	3.17	3.17E+05	4.75E+04	0.05
Spinach	3.00	3.00E+05	4.50E+04	0.05
Strawberries	3.00	2.99E+05	4.49E+04	0.05

** Own calculation based on NASS (1998; 1999; 2000; 2003) and NRCS (2000).

4.8. Resources depletion

Only fossil fuels, iron ore, copper ore and sand and gravel are considered. Compilation of other mineral resources was not considered to be less meaningful due to the homogeneity assumption and the level of aggregation of current IO table. For instance, any purchase from "inorganic chemicals" sector will be recognized as a blend of all kinds of mineral resources from gold to silicon regardless of the specific material that is actually purchased. While energy sector and iron and steel industry is reasonably homogeneous compared to other natural-resource-utilizing industries.

EIA (2003a) was used for figures for natural gas extraction. EIA (2000) provides figures for crude oil consumption. Data for coal was extracted from EIA (2003b). Information on iron ore, copper ore and sand and gravel extraction was found in USGS (2000).

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