Statistics Finland *Official Statistics of Finland* *Environment 1998:1*

THE ECONOMY, ENERGY AND AIR EMISSIONS

Ilmo Mäenpää

Helsinki 1998

For further information:
Kari Grönfors
(09) 17 341

ISSN 0784-8455
= Ympäristö (Environment)
ISBN 951-727-445-9

Oy Edita Ab, Helsinki 1998

FOREWORD

This publication is based on a study conducted by the Thule Institute of Oulu University. The team was headed by Ilmo Mäenpää, a specialist and lecturer at the Institute, who has also written the text. The calculation programs were written by Kimmo Kuusipalo MBA.

The data on energy consumption and air emissions on which the study is based were produced in a detailed branch breakdown by Kari Grönfors, Senior Statistician of Statistics Finland's environment and energy unit. The publication has been edited by Mia Suokko, Senior Statistician at Statistics Finland.

The study was financed by the energy department of the Ministry of Trade and Industry. Contacts were through Pekka Tervo, Senior Adviser.

Helsinki, March 1998
Kaija Hovi

CONTENTS

ABSTRACT

This publication prensents an overview of how the structure of the economy correlates with the consumption of energy and emission of air pollutants. Energy consumption and air emissions are examined both by industry and by commodity. The examination focuses on the amounts of energy consumed and air emissions generated by various industries. So that different industries could be compared with each other, each industry's energy consumption and air emissions are proportioned to the value added that industry produces. The amounts of energy tied up and emissions released throughout the production processes of commodities are also examined. The energy consumption and air emissions relating to the commodities have been rendered comparable with each other by examining them in proportion to the industry's total value of production. A further area of study is the distribution of the commodities' final use between different groups: private consumption, public consumption, capital formation and export.

The research method used was the input-output model of the national economy, which describes how commodities flow between different industries and are divided between the main final product user groups. The model shows what proportion of each industry's production has been tied up in the production process of each final product commodity. The total energy tied up in the final product commodities and the corresponding air emissions can then be established from this. Finally, the study also shows how the energy consumed in the production of the commodities is, in the final analysis, tied up with the structures of their final use. The study is based on data from 1993 and is a sequel to its predecessor based on data for 1990.

ANNEX 2

THE MATHEMATICS OF INPUT-OUTPUT ANALYSIS

This Annex describes the link between the analysis of energy and emissions and input/output analysis.

1 Commodity flows

Symbols used:

x = n-vector, total output by branch;
m = n-vector, imports by importing branch;
A = n x n matrix, branch by branch matrix of intermediate consumption input coefficients; the element ij in matrix **A** shows how much of branch i's output is used as input by branch j per unit output;
y = n-vector, final consumption of the branches' products. This can be broken down further into the following GDP components:
$\mathbf{y}^C$ = private consumption by branch of production, which is further made up of consumption expenditure by households and to a small extent of intermediate consumption by private non profit institutions;
$\mathbf{y}^G$ = public intermediate consumption;
$\mathbf{y}^I$ = gross fixed capital formation by branch of production ("investment");
$\mathbf{y}^V$ = changes in inventories + statistical error, and
$\mathbf{y}^E$ = exports.

The basic formula for input/output analysis – the commodity flow balance sheet – takes the form:

1) $\mathbf{x+m = Ax+y = Ax+y^C+y^G+y^I+y^V+y^E}$,

where the left side, $\mathbf{x + m}$, is the total supply of commodities by branch and the right side is the total demand for commodities. This basic formula can also be written in the form:

2) $\mathbf{x = Ax+y-m = Ax+y^C+y^G+y^I+y^V+y^E -m}$.

Gross domestic product is made up of the following items:

3) GDP=C+G+I+V+E-M.

The vectors $\mathbf{y^C, y^G, y^I, y^V, y^E, -m}$ show the commodity content of the GDP components at producer's prices but do not correspond to the value of the GDP components, since these also include other cost components such as labour costs, repayments on capital, taxes etc.

Equation (1) yields the following for total output **x**:

4) $\mathbf{x = (I-A)^{-1} (y-m)} \iff \mathbf{x = B (y-m)}$,

where $\mathbf{B = (I - A)^{-1}}$ is the inverse Leontief matrix. The element ij shows how much of branch i's output is entirely accounted for, directly or indirectly, by the production by branch j of one unit of its final output.

Equation (4) also yields:

5)
$$\begin{aligned}\mathbf{x} &= \mathbf{B (y-m)}\\ &= \mathbf{B (y^C+y^G+y^I+y^V+y^E -m)}\\ &= \mathbf{By^C+By^G+By^I+By^V+By^E -Bm}\\ &= \mathbf{x^C+x^G+x^I+x^V+x^E-x^M},\end{aligned}$$

hence:

6) $\mathbf{x} = \mathbf{x}^C + \mathbf{x}^G + \mathbf{x}^I + \mathbf{x}^V + \mathbf{x}^E - \mathbf{x}^M$,

i.e. total output by a branch is broken down on the basis of how much of the branch's output is entirely accounted for, directly or indirectly, by each of the GDP components. The breakdown of the use of total output $\mathbf{x}^C, \mathbf{x}^G, \mathbf{x}^I, \mathbf{x}^V, \mathbf{x}^E, -\mathbf{x}^M$ can also be obtained directly by means of the matrix operation:

7) $[\mathbf{x}^C + \mathbf{x}^G + \mathbf{x}^I + \mathbf{x}^V + \mathbf{x}^E, -\mathbf{x}^M] = [\mathbf{y}^C + \mathbf{y}^G + \mathbf{y}^I + \mathbf{y}^V + \mathbf{y}^E, -\mathbf{m}]$.

2 Basic inputs

The analysis is now extended to include energy and emissions, where

P = the m x n matrix of energy input and emission coefficients by branch, in which the rows m show the types of energy input and emission coefficients and the columns n show the branches.

This can be expressed more concisely and more generally as:

P = the m x n matrix of the basic input coefficients.

The total basic inputs can be calculated directly as the product of total output and the matrix **P**:

8) $\mathbf{p} = \mathbf{P}\mathbf{x}$,

where **p** is the total amount of basic inputs per type, the m-vector.
By combining (8) and (5) we obtain:

9) $$\begin{aligned}\mathbf{p} &= \mathbf{Px} = \mathbf{PB}(\mathbf{y}-\mathbf{m}) = \mathbf{PB}\,(\mathbf{y}^C + \mathbf{y}^G + \mathbf{y}^I + \mathbf{y}^V + \mathbf{y}^E - \mathbf{m}) \\ &= \mathbf{PBy}^C + \mathbf{PBy}^G + \mathbf{PBy}^I + \mathbf{PBy}^V + \mathbf{PBy}^E - \mathbf{PBm} \\ &= \mathbf{p}^C + \mathbf{p}^G + \mathbf{p}^I + \mathbf{p}^V + \mathbf{p}^E - \mathbf{p}^M,\end{aligned}$$

in which the basic inputs are divided over the various GDP components on the basis of how much of the basic inputs are used in the production of each of the components.
The breakdown can be obtained directly in tabular form by applying the matrix equation:

10) $[\mathbf{p}^C, \mathbf{p}^G, \mathbf{p}^I, \mathbf{p}^V, \mathbf{p}^E, -\mathbf{p}^M] = \mathbf{PB}\,[\mathbf{y}^C, \mathbf{y}^G, \mathbf{y}^I, \mathbf{y}^V, \mathbf{y}^E, -\mathbf{m}]$.

The final consumption vectors are combined to produce the matrices:

$$\mathbf{P}^Y = [\mathbf{p}^C, \mathbf{p}^G, \mathbf{p}^I, \mathbf{p}^V, \mathbf{p}^E]$$
$$\mathbf{Y} = [\mathbf{y}^C, \mathbf{y}^G, \mathbf{y}^I, \mathbf{y}^V, \mathbf{y}^E].$$

Equation (10) is then condensed to read:

10) $[\mathbf{P}^Y, -\mathbf{p}^M] = \mathbf{PB}[\mathbf{Y}, -\mathbf{m}]$.

The matrix product **PB**, which is an m x n matrix, is interesting in itself. The element hj shows how much of the basic input h is directly or indirectly accounted for by a unit of branch j's output.

3 Indigenous production and imports

In the input/output tables, commodity flows are divided into indigenous production and imports. For the sake of clarity, this distinction was not yet made in Sections 1 and 2. However it provides vital additional information, particularly for the analysis of basic inputs.

Further information is collected on the components of the import figures considered so far:

m = imports by branch of production, n vector;
$\mathbf{x}^M$ = amounts per branch of indigenous products directly or indirectly replaced by imports, n vector;
$\mathbf{p}^M$ = amounts of indigenous basic inputs replaced by imports, m vector.

Indigenous commodities are indicated below by a superscript D and imported commodities by a superscript M. The commodity flows are distinguished as follows:

$\mathbf{A} = \mathbf{A}^D + \mathbf{A}^M$: division of the input coefficients matrix into indigenous and imported inputs;

$\mathbf{y} = \mathbf{y}^D + \mathbf{y}^M$: breakdown of final consumption into indigenous products and imports; the breakdown can be made separately for each item of final consumption.

The basic equation (1) now takes the form:

11) $\mathbf{x+m} = (\mathbf{A}^D+\mathbf{A}^M)\mathbf{x}+(\mathbf{y}^D+\mathbf{y}^M)=(\mathbf{A}^D+\mathbf{y}^D)+(\mathbf{A}^M\mathbf{x}+\mathbf{y}^M)$,

which can be divided into indigenous and imported commodity flows:

12) $\mathbf{x} = \mathbf{A}^D\mathbf{x}+\mathbf{Y}^D$

and

13) $\mathbf{m} = \mathbf{A}^M\mathbf{x}+\mathbf{Y}^M$.

Indigenous production can be determined from equation (12) by applying the method used in equation (4):

14) $\mathbf{x} = (\mathbf{I}-\mathbf{A}^D)^{-1}\mathbf{y}^D \Leftrightarrow \mathbf{x}=\mathbf{B}^D\mathbf{y}^D$,

where $\mathbf{B}^D$ is now the inverse Leontief matrix of indigenous inputs.

The basic inputs contained in the GDP components can determined by dividing up equation (14) in the same way as (9):

15) $\mathbf{p} = \mathbf{PB}^D\mathbf{y}^D=\mathbf{PB}^D(\mathbf{y}^{DC}+\mathbf{y}^{DG}+\mathbf{y}^{DI}+\mathbf{y}^{DV}+\mathbf{y}^{DE})$
$= \mathbf{PB}^D\mathbf{y}^{DC}+\mathbf{PB}^D\mathbf{y}^{DG}+\mathbf{PB}^D\mathbf{y}^{DI}+\mathbf{PB}^D\mathbf{y}^{DV}+\mathbf{PB}^D\mathbf{y}^{DE}$
$= \mathbf{p}^{DC}+\mathbf{p}^{DG}+\mathbf{p}^{DI}+\mathbf{p}^{DV}+\mathbf{p}^{DE}$.

There is no analytical tool of the inverse Leontief variety for imports separately. Since there are no simultaneous dependent variables in the imports equation (13), it is an explicit function. The indirect effects of imports can be included in the analysis only in conjunction with the indigenous commodity flows, as in Sections 1 and 2. The separate effects of imports can be determined as the difference between the results of the total analysis and of the separate analysis of indigenous commodity flows. (This is true of input/output analysis in general: indirect effects cannot be determined directly from the formulae but only as the difference between total effects and direct effects.)

Equation (9) is rewritten in the form:

16) $\mathbf{p} = \mathbf{PBy} = \mathbf{PB}\,(\mathbf{y}^C+\mathbf{y}^G+\mathbf{y}^I+\mathbf{y}^V+\mathbf{y}^E-m)$
$= \mathbf{PBy}^C+\mathbf{PBy}^G+\mathbf{PBy}^I+\mathbf{PBy}^V+\mathbf{PBy}^E - \mathbf{PBm}$
$= \mathbf{p}^C+\mathbf{p}^G+\mathbf{p}^I+\mathbf{p}^V+\mathbf{p}^E - \mathbf{p}^M$.

The inverse Leontief matrix **B** and the final consumption vectors **y** in equation (16) now also contain imported inputs.

In equation (16), the result **P** comprises the basic inputs used in Finland, i.e. the same as in equation (15), which contained only indigenous commodity flows. This is because on the right side of equation (16) imported indirect basic inputs are subtracted – in other words:

17) $\mathbf{p}^{M} = \mathbf{PBm}$.

What imported indirect basic inputs actually comprise demands closer interpretation. In equation (17), both the basic input coefficients **P** and the coefficients in the inverse Leontief matrix have been estimated on the basis of Finland's economy. The imported indirect basic inputs (17) can therefore be interpreted in two ways:

- Imported indirect basic inputs = how much imports offset the need for indigenous basic inputs - in other words, how much more basic inputs would be required if imports were replaced by indigenous production.
- Imported indirect basic inputs = the use of basic inputs in other countries caused by imports if the production methods applied are exactly the same as in Finland.

Thus even if imported indirect basic inputs are purely calculated amounts, they bear two different very reasonable interpretations.

The result of equation (16) is rewritten as:

18) $\mathbf{p}+\mathbf{p}^{M}=\mathbf{p}^{C}+\mathbf{p}^{G}+\mathbf{p}^{I}+\mathbf{p}^{V}+\mathbf{p}^{E}$.

$\mathbf{p} + \mathbf{p}^{M}$ in equation (18) is the sum of indigenous and imported indirect basic inputs, and the right side shows how this is distributed over the various GDP components. The imported indirect basic inputs to the GDP components can be determined as the difference between equations (18) and (15):

19) $$\begin{aligned}\mathbf{p}^{M} &= (\mathbf{p}+\mathbf{p}^{M}) - \mathbf{p} = (\mathbf{p}^{C}+\mathbf{p}^{G}+\mathbf{p}^{I}+\mathbf{p}^{V}+\mathbf{p}^{E}) - (\mathbf{p}^{DC}+\mathbf{p}^{DG}+\mathbf{p}^{DI}+\mathbf{p}^{DV}+\mathbf{p}^{DE}) \\ &= (\mathbf{p}^{C} -\mathbf{p}^{DC}) + (\mathbf{p}^{G} -\mathbf{p}^{DG}) + (\mathbf{p}^{I} -\mathbf{p}^{DI}) + (\mathbf{p}^{V} -\mathbf{p}^{DV}) + (\mathbf{p}^{E} -\mathbf{p}^{DE}) \\ &= \mathbf{p}^{MC}+\mathbf{p}^{MG}+\mathbf{p}^{MI}+\mathbf{p}^{MV}+\mathbf{p}^{ME}.\end{aligned}$$

4 Analysis of groups of household consumer goods

Intermediate consumption by non profit institutions can be eliminated from the private final consumption vector $\mathbf{y}^{C}$ to leave the value at producer's prices of the goods, by branch of production, which make up household consumption expenditure. Household consumption expenditure is otherwise recorded by group of consumer commodities at purchaser's prices. Let this be vector **c**.

There are no directly corresponding elements in vectors $\mathbf{y}^{C}$ and **c**: for example, the group household appliances includes, at producer prices, products of the branches manufacture of wood products, manufacture of metal products and manufacture of textiles. In addition to these, the group of consumer goods at purchaser's prices includes trade margins on furniture and indirect taxes.

However, drawing up the input/output tables involves constructing a conversion matrix $\mathbf{A}^{C}$, which converts the basket of consumer goods at purchaser's prices to products by branch at producer's prices:

20) $\mathbf{y}^{C} = \mathbf{A}^{C}\mathbf{c}$.

The basket of consumer goods can be further broken down into indigenous and imported products:

21) $\mathbf{y}^{DC}+\mathbf{y}^{MC} = (\mathbf{A}^{DC}+\mathbf{A}^{MC})\mathbf{c}=\mathbf{A}^{DC}\mathbf{c}+\mathbf{A}^{MC}\mathbf{c}$.

By combining equations (15) and (21), we can now determine the indigenous basic inputs in the groups of household consumer commodities:

22) $\mathbf{p}^{DC}=\mathbf{PB}^{D}\mathbf{y}^{DC} =\mathbf{PB}^{D}\mathbf{A}^{DC}\mathbf{c}$,

and similarly the matrix of indigenous basic input coefficients of consumer commodities:

23) $\mathbf{P}^{DC} =\mathbf{PB}^{D}\mathbf{A}^{DC}$.

Equations (16) and (20) yield the indirect indigenous and imported basic inputs:

24) $\mathbf{p}^{C} = \mathbf{PBy}^{C} = \mathbf{PBA}^{C}\mathbf{c}$,

and the matrix of basic input coefficients:

25) $\mathbf{P}^{C} = \mathbf{PBA}^{C}$.

5 Summary of formulae

The formulae for the various basic inputs are as follows:

Basic input coefficients by branch
Cumulative coefficients

$\mathbf{P} =$	coefficients of indigenous direct basic inputs by branch;
$\mathbf{P}^{XD} = \mathbf{PB}^{D} = \mathbf{P(I\text{-}A}^{D})^{-1}$	coefficients of indigenous direct and indirect basic inputs;
$\mathbf{P}^{X} = \mathbf{PB} = \mathbf{P(I\text{-}A)}^{-1}$	direct and indirect coefficients of indigenous and imported basic inputs.

Additive coefficients:

$\mathbf{P}$	direct
$\mathbf{P}^{XD}\text{-}\mathbf{P}$	indirect indigenous
$\mathbf{P}^{X}\text{-}\mathbf{P}^{XD}$	indirect imported

Total:

$$\mathbf{P}^{X} = \mathbf{P} + (\mathbf{P}^{XD} - \mathbf{P}) + (\mathbf{P}^{X} - \mathbf{P}^{XD})$$

Basic inputs in GDP components

$$\mathbf{Y} = [\mathbf{y}^{C}, \mathbf{y}^{G}, \mathbf{y}^{I,}\mathbf{y}^{V}, \mathbf{y}^{E}, \mathbf{Y}^{D}] = [\mathbf{y}^{DC}, \mathbf{y}^{DG}, \mathbf{y}^{DI}, \mathbf{y}^{DV}, \mathbf{yD}^{E}\mathbf{Y}^{D}]$$
$$\mathbf{P}^{Y} = [\mathbf{p}^{C}, \mathbf{p}^{G}, \mathbf{p}^{I,}\mathbf{p}^{V}, \mathbf{p}^{E}\mathbf{P}^{DY}] = [\mathbf{p}^{DC}, \mathbf{p}^{DG}, \mathbf{p}^{DI,}\mathbf{p}^{DV}, \mathbf{p}^{DE}]$$

hence

$\mathbf{P}^{DY} = \mathbf{PB}^{D}\mathbf{Y}^{D}$	indigenous basic inputs in GDP components
$\mathbf{P}^{Y} = \mathbf{PBY}$	indigenous and imported indirect basic inputs in GDP components
$\mathbf{P}^{MY} = \mathbf{P}^{Y} - \mathbf{P}^{DY}$	imported indirect basic inputs in GDP components

Basic inputs in household consumption expenditure
Basic inputs:

$\mathbf{P}^{DC} = \mathbf{PB}^{D}\mathbf{A}^{DC}$	indigenous basic inputs
$\mathbf{P}^{C} = \mathbf{PBA}^{C}$	indigenous and imported indirect basic inputs
$\mathbf{P}^{MC} = \mathbf{p}^{C} - \mathbf{p}^{DC}$	imported indirect basic inputs

Basic input coefficients:

$\mathbf{P}^{DC} = \mathbf{PB}^{D}\mathbf{A}^{DC}$	indigenous basic input coefficients
$\mathbf{P}^{C} = \mathbf{PBA}^{C}$	indigenous and imported indirect basic input coefficients
$\mathbf{P}^{MC} = \mathbf{p}^{C} - \mathbf{p}^{DC}$	imported indirect basic input coefficients

6 Changes to the input/output model

In the formulae given above we have disregarded the additional problem that results from direct use of basic inputs in final products. Of course, direct basic inputs in final products can be added later to the final consumption groups, but this runs counter to the basic logic of input/output analysis and entails extra calculations. In the subsequent calculations, therefore, the following changes have been made to the basic structure of the input/output model based on the national accounts.

The direct consumption of energy by housing included in household consumption expenditure – in the form of both basic inputs and intermediate consumption measured in FIM – has been transferred in its entirety to the housing ownership branch.

The total output, intermediate consumption and basic inputs of public services and non profit institutions have been transferred from final products to the columns and rows of the input coefficient matrix. Sales of commodities (as negative amounts) and the link with total output remain in the corresponding final use columns. This also makes it possible to establish the connection between the total output of these branches and consumption expenditure determined as a GDP component.

However, there is still one type of energy use which cannot be linked to use by any branch - i.e. direct purchases of fuels for private vehicles. In the calculations these are added later to household expenditure consumption.