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Report

Energía-industria-empleo: metodología *Input/Output*

Eloy Álvarez Pelegry
Ana Carmen Díaz Mendoza
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Autores

Eloy Álvarez Pelegry, Director de la Cátedra de Energía de Orkestra-Instituto Vasco de Competitividad
Ana Carmen Díaz, Investigadora de la Cátedra de Energía de Orkestra-Instituto Vasco de Competitividad
Manuel Alejandro Cardenete, Catedrático de Economía Aplicada en la Universidad Pablo Olavide
Mari Carmen Delgado, Profesora Asociada de la Universidad Pablo de Olavide de Sevilla
Francisco Parra, Jefe del servicio de Estadísticas del Instituto de Estadística de Cantabria
Unai Castro, Facilitador de Investigación de la Cátedra de Energía de Orkestra-Instituto Vasco de Competitividad
Carmen Ramos Carvajal, Profesora Titular de Universidad del Departamento de Economía Aplicada de la Universidad de Oviedo
Agustín Cañada, Asesor técnico para la contabilidad regional y cuentas satélite de la Dirección General de Economía, Estadística e Innovación Tecnológica de la Comunidad de Madrid
Blanca Simón, Profesora titular de Economía Aplicada de la Facultad de Economía y Empresa de la Universidad de Zaragoza
José Aixalá Pastó, Profesor titular de Economía Aplicada en la Facultad de Economía y Empresa de la Universidad de Zaragoza
Luis Pérez y Pérez, Investigador del Centro de Investigación y Tecnología Agroalimentaria (CITA) del Gobierno de Aragón
Jaime Sanaú Villarroya, Profesor titular de Economía Aplicada en la Facultad de Economía y Empresa de la Universidad de Zaragoza
Ángeles Cámara Sánchez, Profesora titular de la Universidad Rey Juan Carlos
Natalia Caldés Gómez, Investigadora en la Unidad de Análisis de Sistemas Energéticos del CIEMAT
Mónica Flores García, Profesora de Organización de Empresas en la Escuela de Ingeniería y Arquitectura de la Universidad de Zaragoza
Patricia Fuentes Saguar, Profesora Contratada-Doctora del Departamento de Economía de la Universidad Pablo de Olavide de Sevilla
Marta Santamaría Belda, Investigadora en la Unidad de Análisis de Sistemas Energéticos del CIEMAT
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Juan Antonio Vega, Catedrático de Universidad Departamento de Economía, Universidad de Extremadura

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Orkestra
INSTITUTO VASCO DE COMPETITIVIDAD
FUNDACIÓN DEUSTO

Mundaiz 50, E-20012, Donostia-San Sebastián
Tel.: 943 297 327. Fax: 943 279 323
comunicacion@orkestra.deusto.es
www.orkestra.deusto.es

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A PRODUCT ORIENTATED VIEW ON ENERGY USE

METHODOLOGY TO ESTIMATE ENERGY CONSERVATION POTENTIALS ALONG THE SUPPLY CHAINS OF PRODUCTS USING INPUT-OUTPUT ANALYSIS

Michael Hartner[1]

TU Wien

Institute of Energy Systems and Electrical Drives

Energy Economics Group

[1] Vienna University of Technology
Institute of Energy Systems and Electrical Drives
Energy Economics Group – EEG
Gusshausstrasse 25-29/370-3
A-1040 Wien
Tel: +43(0)-1-58801-370379
E-Mail: hartner@eeg.tuwien.ac.at

1. INTRODUCTION

In this paper a method to estimate energy conservation potentials on the basis of input output analyses will be discussed. When the energy requirement of countries, industries, households or individuals is analysed most studies refer to the direct energy consumption of those entities. Consequently these entities are analysed individually which ignores the linkages in between. In this research a different approach is used by estimating cross-boarder supply chains for goods and services. The energy requirement along the supply chains will be linked with energy intensities of industries to estimate the total energy requirement of final products. The focus is therefore on final products and the cumulative energy requirements to produce those products, which is in contrast to studies that focus on individual countries or industries. While this approach is widely used to calculate emission or energy footprints it is not common to estimate energy conservation potentials on aggregated level.

Such a perspective allows for analysing the supply chain of products and identifying efficiency potentials along those supply chains. Furthermore individual decisions and consumption patterns can be linked with the resulting energy requirement.

This paper also wants to shed light on the fact that conventional statistics only show a production based view that identifies energy needs for different economic sectors or entities individually without reporting embedded energy flows that arise from the interconnections of those entities. Those statistics do not show the cumulative energy requirement to produce products for final demand. The approach used in this paper allows for estimating the cumulative final energy requirement for product groups on aggregated level across national boarders using Extended Input-Output Analyses. The basic model itself will be presented in chapter 2. In chapter 3 some preliminary results for Austria will be shown to illustrate the findings that can be derived from such an approach. In Chapter 4 possibilities to evaluate the effects on the economic structure and the resulting energy requirement will be discussed.

This paper is supposed to be a working paper and does not aim at presenting robust empirical results. The focus here is on the methodology itself which should be subject to critical review.

2. ENERGY EXTENDED INPUT OUTPUT MODEL

Input Output models have been used to analyse economies since the basics have been developed by Wassily Leontief in the middle of the 20th century. While the focus of his work was on economics he also developed the basis for environmental extensions of IO models. By using additional data the model can be extended to provide insights into ecological impacts, external costs or material consumption of products on an aggregated level. Literature and applications of such models are diverse and abundant. A comprehensive description of the state of the art is given by Tukker et. al (2006) in their report on “Environmentally extended input-output tables and models for Europe” and in Minx (2010). Reinders, Vringer and Blok (2002) have conducted studies on the indirect energy requirements of households in the European Union concluding that the share of indirect requirements accounts to up to 60% of the total energy requirement for some countries. Rueda-Cantuche has contributed with his studies on multi-regional IO models and on aggregation of Input-Output tables, developing an IO table for EU-27 which is also used in this work. There are also numerous studies on carbon footprinting and carbon leakage using IO models. (Minx (2010), Peters (2010)). Robert A. Herendeen (1981, 1978), Manfred Lenzen (2000, 2003, 2007), Hertwich (1997), Peters (2006) and Suh (2004) have also published numerous articles on the issue and have contributed some further methodological

extensions and Hybrid LCA/IO approaches which will not be applied in this paper but will be used for further research on relevant products.
For Austria there have been two recent studies on embedded CO_2 emissions in the Austrian trade by Kratena (2010) and Bednar Friedl et. al. (2010). Both studies conclude that Austria is a net importer of embedded emissions, meaning that the emissions resulting from the production of goods and services consumed in Austria are higher than the emissions resulting from Austrian production processes. This is consistent with the findings that have been derived from the model that will be presented in this section. First the basic method of an energy extended IO table using energy intensities of sectors will be presented for a one-region case. Then the model will be extended to a two-region approach representing Austria and the rest of the world using an aggregated EU-27 table.

2.1 Basic Input-Output energy extension

In this section the basic Input-Output model formulation will be presented. The methodological background is mainly based on Miller and Blair (2009).

IO analyses on country level are based on symmetric IO tables that are derived from supply and use tables for goods and services by statistical agencies. In this model all tables are provided by Statistics Austria and Eurostat.

Output

Input

Industry	1	2	……	j	….	n	Total	Final demand	Total Use
1	z_{11}	z_{12}	…	z_{1j}	…	z_{1n}	$\sum_{j=1}^{n} z_{1j}$	y_1	X_1^{use}
2	z_{21}	z_{22}	…	z_{2j}	…	z_{1n}	$\sum_{j=1}^{n} z_{2j}$	y_2	X_2^{use}
…	…	…	…		…		…		…
i	z_{i1}	z_{i2}	…	z_{ij}		z_{in}	$\sum_{j=1}^{n} z_{ij}$	y_i	X_i^{use}
…	…	…	…	…	…	…	…	…	…
n	z_{n1}	z_{n2}	…	z_{nj}	…	z_{nn}	$\sum_{j=1}^{n} z_{nj}$	y_n	X_n^{use}
Total	$\sum_{i=1}^{n} z_{i1}$	$\sum_{i=1}^{n} z_{i2}$	…	$\sum_{i=1}^{n} z_{ij}$	…	$\sum_{i=1}^{n} z_{in}$	$\sum_{i=1}^{n}\sum_{j=1}^{n} z_{ij}$	$\sum_{i=1}^{n} y_i$	$\sum_{i=1}^{n} X_i^{use}$
Value added	v_1	v_2	…	v_j	…	v_n	$\sum_{j=1}^{n} v_j$		
Total supply	X_1^{supply}	X_2^{supply}	…	X_j^{supply}	…	X_n^{supply}	$\sum_{j=1}^{n} X_j^{supply}$		

Figure 2-1: General formulation of national Input-Output tables

Definition of variables

In a one-region case where all goods are produced and consumed within one region the economy can be described with the table provided in Figure 2-1. The economy exists of 1 to n industries. Each industry receives inputs from other industries which are quantified in the columns 1 to n. The inputs of the industry i can be described as a vector. Deliveries from one industry to other sectors can be found along the rows 1 to n. Note that all entries in the table are monetary values given in the domestic currency.

Inputs to one industry from other industries: $\boldsymbol{z}_j^{\text{in}} = \begin{bmatrix} z_{1j} \\ z_{2j} \\ \dots \\ z_{nj} \end{bmatrix}$

Outputs/deliveries from one industry to other industries: $\boldsymbol{z}_i^{out} = \begin{bmatrix} z_{i1} & z_{i2} & \dots & z_{\text{in}} \end{bmatrix}$

All those transactions are supposed to be intermediate goods that are needed by the industries to produce goods and services. In other words, the IO-table provides an aggregated supply chain for all industries indicated in the table. All entries of intermediate transactions constitute the Matrix **Z** which describes all interindustry sales and deliveries within the economy.

$$\boldsymbol{Z} = \begin{bmatrix} z_{1,1} & z_{1,2} & \dots & z_{1,n} \\ z_{2,1} & z_{2,2} & \dots & z_{2,n} \\ \dots & \dots & \dots & \dots \\ z_{n,1} & z_{n,2} & \dots & z_{n,n} \end{bmatrix}$$

In addition to interindustry sales final goods are delivered to final demand **Y**.

$$\boldsymbol{Y} = \begin{bmatrix} y_1 \\ y_2 \\ \dots \\ y_n \end{bmatrix}$$

Final demand can further be split up into private consumption **C**, government spending **G** and investments **I**, all vectors of the same size as **Y**.

$$\boldsymbol{Y} = \boldsymbol{C} + \boldsymbol{G} + \boldsymbol{I}$$

All sales to industries and final demand of an industry correspond to the total use of the industries output which corresponds to the row sum of an industry plus final demand.

$$\boldsymbol{X}_i^{\text{use}} = \sum_{j=1}^{n} z_{ij} + y_i$$

The sum of all sales corresponds to the total output **X** of the economy. Total output of the economy can also be derived by summing up all entries in the columns of matrix **Z** and adding the value added **V** by the industry which consists of wages and profits. This corresponds to the total use of inputs by an industry.

$$\boldsymbol{X}_j^{sup} = \sum_{i=1}^{n} z_{ij} + v_j$$

By definition the total use must equal total supply so total output can be derived from both relationships:

$$X = \sum_{i=1}^{n} X_i^{\text{use}} = \sum_{j=1}^{n} X_j^{sup}$$ and final demand equals total value added: $$\sum_{i=1}^{n} y_i = \sum_{j=1}^{n} v_j$$

Output as a function of final demand

The goal of the model is to estimate the energy inputs needed to deliver final products to final demand. Before we account for energy inputs the output of the economy has to be expressed as a function of final demand. This can be done by applying the Leontief-inverse which will be shown in this section.

Total output can be written as:

$$\boldsymbol{Zi} + \boldsymbol{Y} = \boldsymbol{X}$$

i represents a column vector of 1´s so **Zi** is equivalent to a vector of all row sums of **Z**. The equation indicates that total output of the economy equals the sum of all interindustry sales plus all deliveries to final demand. If we relate all inputs of one industry for its production of goods to the total output of the industry we find technical coefficients a_{ij} for the production of one unit of output.

$$a_{ij} = \frac{z_{ij}}{X_j}$$ or written as a matrix: $$\boldsymbol{A} = \begin{bmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{2,2} & \dots & a_{2n} \\ \dots & \dots & \dots & \dots \\ a_{n1} & a_{n2} & \dots & a_{nn} \end{bmatrix}$$

All a_{ij} can be interpreted as the (for the Austrian case) € worth of inputs from sector i to produce one € worth of output of sector j. The coefficients are also called direct input coefficients. Matrix ***A*** is also referred to as the direct requirement matrix or the technology of an economy and can be used to analyse the efficiency and technological change of economies. Note that the coefficients are assumed to be constant for all levels of output. By definition all a_{ij} show values between 0 and 1 and the column sums are less than 1.

With this relationship ***Z*** can be written as $\boldsymbol{Z} = \boldsymbol{A}\widehat{\boldsymbol{X}}$ where $\widehat{\boldsymbol{X}}$ is a diagonal matrix with total output of each industry as entries along the diagonal.

Consequently total output can be written as

$$\boldsymbol{AX} + \boldsymbol{Y} = \boldsymbol{X}$$

and

$$\boldsymbol{X} - \boldsymbol{AX} = \boldsymbol{Y}$$
$$(\boldsymbol{I} - \boldsymbol{A})\boldsymbol{X} = \boldsymbol{Y}$$
$$(\boldsymbol{I} - \boldsymbol{A})^{-1}\boldsymbol{Y} = \boldsymbol{X}$$

yields an expression that makes total output a function of the technical coefficients and final demand. ***I*** denotes the identity matrix of the same size as ***A***. Note that once the coefficients are determined total output is only a function of demand ***Y***. This is why Input-Output models are said to be demand driven. Of course demand is derived from the income received which depends on production and total output. This approach ignores this relationship and is therefore considered to be a rather static approach. However it provides a good description of the interrelations between industries for a certain level of output.
The inverse $(\boldsymbol{I} - \boldsymbol{A})^{-1}$ is known as the "Leontief inverse" and will be denoted as ***R***.

$$\boldsymbol{R} = (\boldsymbol{I} - \boldsymbol{A})^{-1} = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ r_{n1} & r_{n2} & \cdots & r_{nn} \end{bmatrix}$$

The Leontief inverse is also known as the total requirement matrix. The coefficients along the columns can be interpreted as the € worth of input of industry i to deliver goods worth one € to final demand. The entries along the diagonal can be interpreted as intraindustry deliveries (e.g. deliveries of engines to assembling plants in the car industry) while all other entries are interindustry inputs (e.g. deliveries from the metal industry to the car industry). The interpretation of the Leontief inverse gets clear when ***R*** is written as:[2]

$$(\boldsymbol{I} - \boldsymbol{A})^{-1} = \left(\boldsymbol{I} + \boldsymbol{A} + \boldsymbol{A}^2 + \boldsymbol{A}^3 + \ldots..\right)$$

and

$$\boldsymbol{X} = \left(\boldsymbol{I} + \boldsymbol{A} + \boldsymbol{A}^2 + \boldsymbol{A}^3 + \ldots..\right)\boldsymbol{Y}$$

The interpretation of this equation is as follows:

- To deliver one unit to final demand at least one unit has to be produced by the industry indicated by ***IY***.
- To produce this unit, inputs from other industries are needed, which is indicated by the technology coefficients in ***A*** →***AY***.
- To produce those intermediate inputs again inputs from other industries are needed indicated by $\boldsymbol{A^2Y}$.
- This goes on to infinity and the result is the total requirement of inputs from all industries to produce one unit of final output. Note that the contributions oft the elements in ***A*** get smaller for higher exponents and eventually approach zero as the coefficients in ***A*** are between 1 and 0.

Consequently the columns of ***R*** correspond to an aggregated supply chain[3] in which the monetary contributions of all industries to deliver one unit to final demand are indicated by the coefficients $\boldsymbol{r_{ij}}$.
Now, that an aggregated supply chain can be derived from IO tables the monetary data has to be linked with physical energy data to estimate the energy requirements along the supply chains.

2.2 ENERGY INPUT-OUTPUT ANALYSIS

In general there are two ways to derive energy use from IO analyses. Both approaches are described in detail by Miller and Blair (2009) and the method is called Energy Input-Output Analysis. While the first approach is a hybrid approach in the sense that all monetary entries in the IO table related to energy inputs are substituted by physical units (e.g. TJ, MWh…) while all other inputs are still represented by monetary units. The formulation of the requirement matrices can be derived in a similar matter as described in the previous section. The second approach uses energy intensities in the form of energy input per unit of total output (e.g. TJ/€, MWh/€…) to derive energy requirement coefficients.
While in terms of accuracy the hybrid method is more favourable, the data requirements are much higher and related to the data available for this study some further problems arise. For

[2] This is called the Power Series Approximation. For more details see Miller and Blair (2009) p. 31ff
[3] Of course the supply chain does not show the order in which the industries contribute to the production of a final product.

this study more than 20 energy carriers are used but the energy sectors in the IO table are rather uniform. This means that for implementing those energy carriers in a hybrid approach, the sectors have to be decomposed for which there is not enough data available at this stage. This is why the rather traditional approach of using energy intensities is used in this study. The two main limitations of this approach are that 1st the accuracy of the results depends on the unity of energy prices along the industries and 2nd the results are only accurate if the final demand for products is constant or growing uniformly meaning that the demand vector is a linear combination of the original demand vector used to derive the energy intensities.

Being aware of the limitations, the approach using energy intensities will be derived in the following section. Energy intensity here is defined as final energy demand per unit of output. This means that only the final energy demand and the own use of the industries will be included in the model. To derive primary energy use, conversion factors for the energy carriers have to be considered which will not be part of this paper. Also direct energy use of households is not part of the model. However the direct final energy use of households can be added as it is given as an extra value for each energy carrier in the data used from Statistic Austria.

The energy intensities used here are derived from:

$$\boldsymbol{e_j^t} = \frac{\boldsymbol{FE_j^t}}{\boldsymbol{X_j}}$$

e_j^t ....intensity of energy carrier t for sector j [kWh/€]

FE_j^t .... Use of final energy carrier t from sector j [kWh/year]

X_j ....Output of sector j [€/year]

By multiplying the Leontief inverse with a diagonal matrix with energy intensities of the industries on the diagonal we end up with a matrix containing total requirements ***RE*** of the energy carrier for the production of one unit for final demand. The columns contain the energy input along the supply chain of a product and the sum of the columns indicate the total inputs of one energy carrier to produce one unit of an industries products for final demand.

$$RE = \widehat{\boldsymbol{e}} \cdot (I - A)^{-1} = \begin{bmatrix} r_{11}e_1 & r_{12}e_1 & \cdots & r_{1n}e_1 \\ r_{21}e_2 & r_{22}e_2 & \cdots & r_{2n}e_2 \\ \cdots & \cdots & \cdots & \cdots \\ r_{n1}e_n & r_{n2}e_n & \cdots & r_{nn}e_n \end{bmatrix}$$

Together with the original equation for total output we get the total requirement of an energy carrier for the economy as a function of final demand.

$$\boldsymbol{E} = \widehat{\boldsymbol{e}} \cdot (\boldsymbol{I} - \boldsymbol{A})^{-1} \cdot \boldsymbol{Y}$$

Multiplying demand as a diagonal matrix yields a vector of total energy requirements for the consumption of products produced by all industries within one year.

$$\boldsymbol{E}_{pg} = \widehat{\boldsymbol{e}} \cdot (\boldsymbol{I} - \boldsymbol{A})^{-1} \cdot \widehat{\boldsymbol{Y}}$$

The Austrian IO table consists of 57 sectors and from additional data provided by Statistics Austria the demand of all 57 sectors for 23 final energy carriers could be derived. However, to account for the total energy requirement of a small economy like Austria, the imports of other countries must be considered. While the imports of energy carriers are reflected in the energy intensities of the industries, the energy requirement for the production of imported final goods and imported intermediate goods used to produce final goods in Austria is not included. The integration of imports and exports will be discussed in the next section.

2-Region Energy Input-Output model

There are basically two approaches to account for the energy requirement needed to produce imported goods to Austria. The most accurate approach is a Multi-Regional-Input-Output analysis where all imports are tracked back to the regions where they have been produced originally. Obviously the data requirement for such an analysis is very high. Additionally there are aggregation problems as the IO tables are not homogeneous meaning that the number of sectors varies from country to country and statistical agencies allocate and classify some economic activities differently. Additionally data on energy use is usually not available for all sectors, as the allocation of energy carriers in the IEA energy balances differs from what is needed to calculate energy intensities for all sectors. Although the GTAP data base would provide some of the necessary data, it provides less details as the data available for the Austrian energy use.

As the goal of this study is also to integrate data from process analyses, which will be discussed in the next chapter, the aggregation level of industries and energy inputs needed to be as low as possible which is why a 2-region approach was chosen. Instead of modelling each region individually only 2 regions – Austria and the rest of the world (ROW) are modelled. For the simulation of ROW an aggregated EU-27 Input-Output table was used. The table also consists of 57 industries and is considered to be consistent with the Austrian classification rules. This approach was also chosen by Kratena (2010) to assess the CO_2 emissions in Austrian trade flows.

All variables that relate to domestic activities will be denoted with the superscript *d,* activities taking place in the ROW will be denoted with *f*. Statistics Austria provides three tables. One contains only domestic interindustry transactions and demand for domestically produced final goods. From this table the technical coefficient matrix $\boldsymbol{A}^{d}$ and the vector of final demand for Austrian final goods $\boldsymbol{Y}^{d}$ consumed in Austria can be derived.[4] Additionally there is a table for imported goods which shows the Austrian matrix for imported intermediate goods $\boldsymbol{Z}^{dimp}$ and the vector for imported final products $\boldsymbol{Y}^{f}$. From $\boldsymbol{Z}^{dimp}$ the technological coefficient for imported intermediate goods $\boldsymbol{A}^{dimp}$ can be derived by:

$$a_{ij}^{dimp} = \frac{z_{ij}^{dimp}}{X_j^d} = A^{dimp}$$

The demand for Austrian final goods from ROW is given by the exports of Austria that are treated as a final demand component of the Austrian economy and is denoted as $\boldsymbol{Y}^{fimp}$. There is also the component of exported intermediate goods from Austria. The technology matrix of the foreign country $\boldsymbol{A}^{f}$ can be derived from the EU 27 table. Additionally the ROW uses imported intermediate goods from Austria for the production of final goods which is given by the technical coefficient matrix $\boldsymbol{A}^{fimp}$. However the contribution of Austria being a very small economy is marginal compared to the production of the rest of the world.[5] This is why this term will be ignored before energy intensities are introduced.
Including all matrices into one expression for the domestic country and the ROW yields the following equation for total output of both regions:

[4] Note that this vector excludes exports from Austria to other countries.
[5] For further discussion see Serrano and Dietzenbacher (2008)

$$\begin{bmatrix} X^d \\ X^f \end{bmatrix} = \begin{bmatrix} A^d & A^{fimp} \\ A^{dimp} & A^f \end{bmatrix} \cdot \begin{bmatrix} X^d \\ X^f \end{bmatrix} + \begin{bmatrix} Y^d & Y^{fimp} \\ Y^{dimp} & Y^f \end{bmatrix}$$

Assuming that the term $\boldsymbol{A^{fimp}}$ can be ignored because of its marginal contribution we get:

$$\begin{bmatrix} X^d \\ X^f \end{bmatrix} = \begin{bmatrix} A^d & 0 \\ A^{dimp} & A^f \end{bmatrix} \cdot \begin{bmatrix} X^d \\ X^f \end{bmatrix} + \begin{bmatrix} Y^d & Y^{fimp} \\ Y^{dimp} & Y^f \end{bmatrix}$$

Again the inverse can be calculated to make the outputs a function of the technology matrices and final demand of both regions. The invers is as follows:

$$\left(\begin{bmatrix} I & 0 \\ 0 & I \end{bmatrix} - \begin{bmatrix} A^d & 0 \\ A^{dimp} & A^f \end{bmatrix} \right)^{-1} = \begin{bmatrix} (I - A^d)^{-1} & 0 \\ A^{dimp} \cdot (I - A^d)^{-1} \cdot (I - A^f)^{-1} & (I - A^f) \end{bmatrix}$$

And the equation for the output of both nations is:

$$\begin{bmatrix} X^d \\ X^f \end{bmatrix} = \begin{bmatrix} (I - A^d)^{-1} & 0 \\ A^{dimp} \cdot (I - A^d)^{-1} \cdot (I - A^f)^{-1} & (I - A^f) \end{bmatrix} \cdot \begin{bmatrix} Y^d & Y^{fimp} \\ Y^{dimp} & Y^f \end{bmatrix}$$

By adding the energy intensity vectors of the domestic economy $\boldsymbol{e^d}$ and the rest of the world $\boldsymbol{e^f}$ total energy requirement in both regions and energy flows embedded in the trade between those regions can be calculated:

$$\begin{bmatrix} E^d \\ E^f \end{bmatrix} = \begin{bmatrix} \widehat{\boldsymbol{e}}^d (I - A^d)^{-1} & 0 \\ \widehat{\boldsymbol{e}}^f \cdot A^{dimp} \cdot (I - A^d)^{-1} \cdot (I - A^f)^{-1} & \widehat{\boldsymbol{e}}^f \cdot (I - A^f)^{-1} \end{bmatrix} \cdot \begin{bmatrix} Y^d & Y^{fimp} \\ Y^{dimp} & Y^f \end{bmatrix}$$

This formulation allows for tracking down energy flows along the supply chain even if the production of goods took place outside of the country.

Interpretation of the model

The terms in the partitioned Leontief inverse can be interpreted as follows:

$\widehat{\boldsymbol{e}}^d (I - A^d)^{-1}$ equals the term in the closed economy case and represents the total energy requirement coefficients of domestic production.

Likewise $e^f \cdot (I - A^f)^{-1}$ represents the total energy requirement coefficients of the ROW production.

$\widehat{\boldsymbol{e}}^f \cdot A^{dimp} \cdot (I - A^d)^{-1} \cdot (I - A^f)^{-1}$ represents total energy requirements of imported intermediate goods that are produced in the rest of the world and are used by domestic industries to produce domestic final goods.

The initial goal of this method was to determine the energy requirement for product groups consumed in Austria. This can be derived from:

$$E^d_{cons} = e^d \cdot (I - A^d)^{-1} \cdot Y^d + e^f \cdot A^{dimp} \cdot (I - A^d)^{-1} \cdot (I - A^f)^{-1} \cdot Y^d + e^f \cdot (I - A^f)^{-1} \cdot Y^{dimp}$$

E^d_{cons} stands for the energy requirement to satisfy the domestic demand for goods and services. The first term represents the energy requirement of domestic production to satisfy the demand for final goods produced in the domestic country. The second term represents the energy requirement for the production of intermediate goods in ROW needed to produce domestic final goods. The third term represents the energy requirement that arises from the

production of final goods produced in ROW and imported to the domestic country. Using the coefficients the transformation also provides an aggregated supply chain with corresponding energy requirements, which is of special interest for this study. The application of those supply chains will be discussed later. As shown before by multiplying the demand vectors $\boldsymbol{Y^d}$ and $\boldsymbol{Y^{dimp}}$ in the form of diagonal matrices the energy requirement can be calculated for each industry individually.
Although this is not the focus of this study we also want to show that of course part of the domestic energy requirement is induced by the production of final goods that are exported to ROW $\boldsymbol{Y^{dimp}}$. The exported embedded energy requirement resulting from Austrian production is denoted as $E^d_{\exp}$.[6]

$$E^d_{\exp} = \widehat{e}^d \cdot \left(I - A^d\right)^{-1} \cdot Y^{fimp}$$

From this the difference between the energy requirement for the production of domestic goods (production based view) and the energy requirement to satisfy the Austrian demand for goods and services (consumption based view) can be calculated as:

$$E_{balance} = e^d \cdot \left(I - A^d\right)^{-1} \cdot Y^{fimp} - e^f \cdot A^{dimp} \cdot \left(I - A^d\right)^{-1} \cdot \left(I - A^f\right)^{-1} \cdot Y^d - e^f \cdot \left(I - A^f\right) \cdot Y^{dimp}$$

If $\boldsymbol{E_{balance}}$ is positive the production based view as used in conventional energy statistics shows higher values than a consumption based approach. For European countries $\boldsymbol{E_{balance}}$ is typically negative indicating that most countries are net importers of embedded energy. Under the assumptions used in this study this is also the case in Austria.

The methodology described here is well known within Input-Output economists and has proven to be a helpful analytical framework for many research topics. The greatest shortcoming with respect to the assessment of the energy requirement of products is the relatively high aggregation level. The technical coefficients represent a mix of technologies and processes and not a single activity. Also the energy intensities are a result of different processes where one single process might be more energy intensive than others. The aggregated supply chains can therefore only be seen as rough estimations for the energy intensity of a product produced by the industry in question, even when the results of the model are sufficiently accurate as a whole. Before this shortcoming is addressed some results for an Austrian Energy Input-Output analysis will be shown in the next section.

3. Results of the IO Model for Austria

In this chapter some sample results for the empirical application of the model will be shown to illustrate some insights that can be gained from such an analysis. As stated before Input-Output tables from Austria and the EU-27 for the year 2007 have been used to set up a 2 region model. Both tables use the NACE 2digit classification which yields symmetric tables with 57 industries. The final demand function is split up into the components private consumption, government consumption, investments and exports. The final energy intensities for Austria have been derived from the “Energiegesamtrechnung”, which identifies total use of 23 final energy carriers for all 57 industries. Unfortunately this data was not available for the EU27 by the time of the calculations. For the time being Austrian energy intensities are used for EU27 production which leads to some inaccuracies in the calculation. The data for EU27 should be available soon as there is a project dedicated to harmonise data of EU members and will be implemented as soon as possible. So far the findings shown

[6] note that the total embedded energy of those products would also include the intermediate goods produced in ROW. Here only the part of the domestic energy requirement. To get the total embedded energy the term $e^f \cdot A^{dimp} \cdot \left(I - A^d\right)^{-1} \cdot \left(I - A^f\right)^{-1} \cdot Y^{fimp}$ has to be added.

should be seen as preliminary results that are subject to critical reflection. Direct energy use of households is not included in the calculation. Only the energy use of the 57 industry sectors is included in the analyse
is.

Energy flows between Austria and the rest of the world

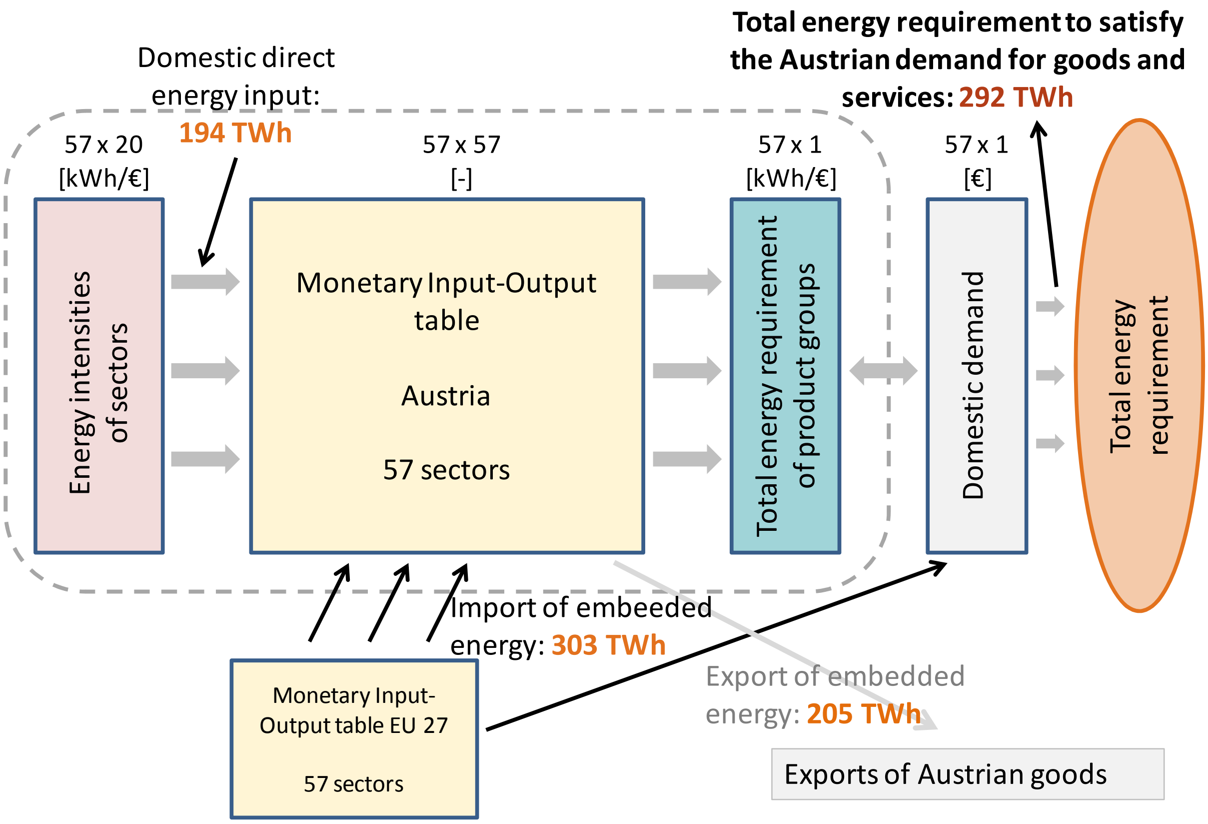

Figure 3-1: Energy flows embedded in Austrian imports and exports

Austria's economy is dependent on the import of intermediate and final goods to satisfy domestic demand for goods and services. The production value of imported intermediate goods amounts to about 29,5% of total production value of all intermediate goods and around 16% of final demand were satisfied by imported final goods. On the other hand around 37% of the final demand for Austrian final products results from exports to other countries.[7] Consequently there are substantial embedded energy flows related to the physical trade flows of goods and services. Figure 3-1 shows the flows of embedded final energy calculated by the model described in the previous section.

The results show, that Austria has a trade deficit of embedded energy in the sense that more embedded energy is imported than exported. Of the initial 194 TWh final energy used for the production of goods and services around 50% (97 TWh) are embedded in products to satisfy domestic demand. The other 50% is exported embedded energy to the rest of the world. On the other hand additional 303 TWh of embedded final energy enter the country in the form of imported intermediate and final products. Of those 303 TWh, 108 TWh are again embedded in exported products produced in Austria, which makes 205 TWh of total embedded final energy in Austrian exports. The rest is embedded in products to satisfy Austrian demand which results in a total energy requirement of 292 TWh in the year 2007. This is much higher

[7] Figures based on data from the Austrian IO table 2007

than the initial 194 TWh direct energy input. The embedded energy trade balance of Austria and the rest of the world is therefore -98 TWh, indicating that Austria is a net importer of embedded energy.[8] If the household final energy use in 2007 of around 109 TWh is considered, the total energy demand of Austria is around 33% higher from a consumption perspective than from the usual production perspective used in OECD energy balances and other statistics. This is consistent with the results estimated for CO_2 emissions in Bednar Friedl et. al. (2010) where emissions are estimated to be 38% higher from a consumption perspective compared to conventional emission inventories.

Composition of embedded final energy in Austria

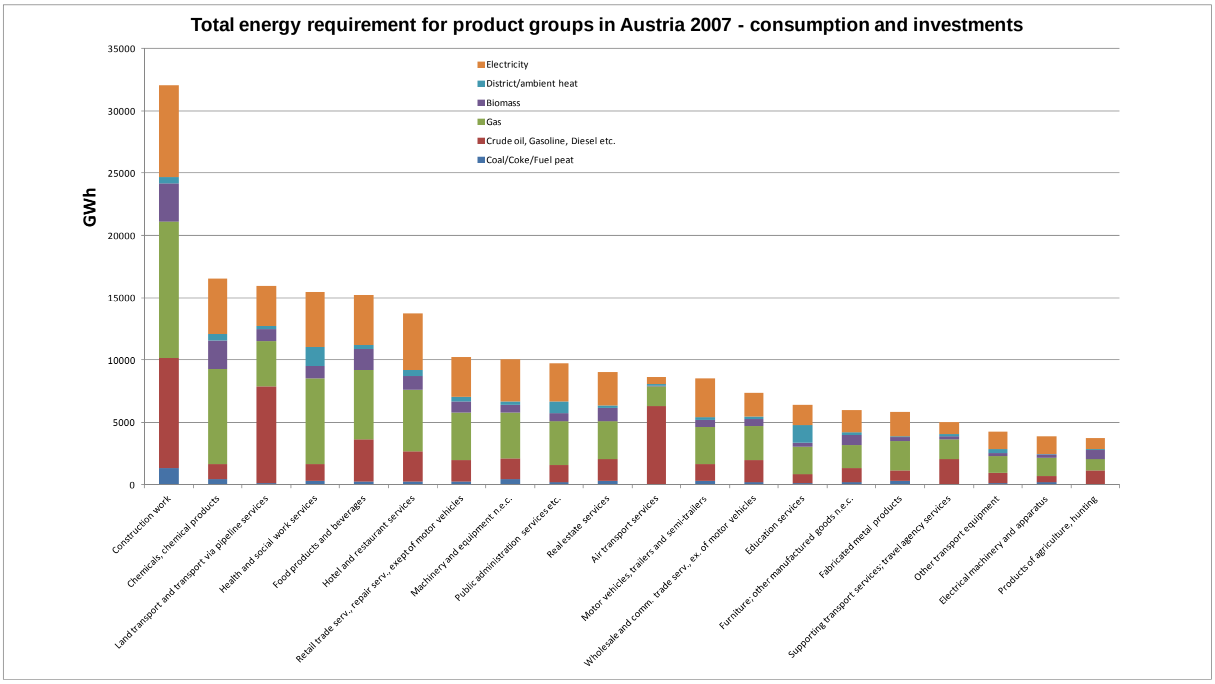

Figure 3-2 Total energy requirement for product groups in Austria 2007

The model allows identifying the energy requirement for the supply of each of the 57 product groups listed in the IO table. Figure 3-2 shows the energy demand for these products that were responsible for most of the final energy requirement to satisfy the demand for goods and services consumed and invested in Austria 2007 (energy sectors excluded). Construction work is the single product group that is responsible for the highest energy requirement resulting from inputs along the supply chain from the sectors *coke and refined petroleum products*, *other non-metallic mineral products*, *basic metals* and direct energy inputs from the sector *construction work* itself. Also chemicals and land transport services are responsible for a large share of total energy requirement which is not surprising. It is more surprising that Health and social work services show very high energy requirements, mainly resulting from the inputs *electrical energy, gas, steam and hot water* and *coke and refined petroleum products*. This might also result from the size of the sector. The aggregation level of the sectors and the classifications vary which also has to be considered in an analysis.

[8] Note that this can be derived from the difference between a consumption and production based view (194TWh-292TWh) or the balance of imports and exports of embedded energy (205TWh-303TWh)

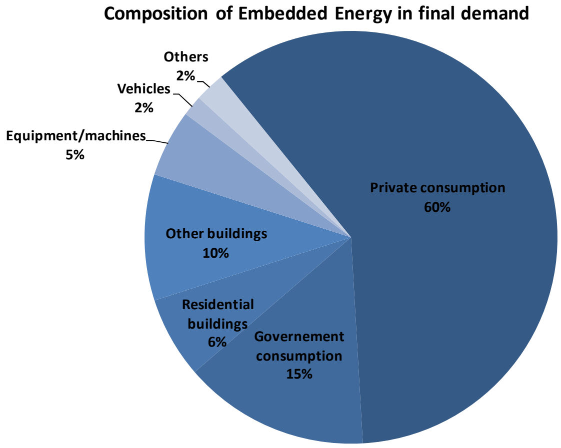

Figure 3-3 Composition of embedded final energy in final demand for Austria 2007

Figure 3-3 breaks down the embedded final energy into the components of final demand. Around 60% result from private consumption. Figure 3-4 splits up the embedded energy of private consumption into the most relevant product groups.

Government consumption accounts for 15% of total energy requirements. Here the product groups education services, health and social work services and public administration services are the most relevant ones. 16% of the energy requirement can be attributed to the investment in buildings. Most of this can be allocated to construction work. Investments in equipment and machines, vehicles and others account for the remaining 9% of total energy demand. It can be concluded that most of the energy demand results from private consumption and is distributed over different product groups. The majority of the energy requirement resulting from government spending can be tracked to three sectors only. The energy demand resulting from investments mainly consists of energy use along the supply chain of construction work.

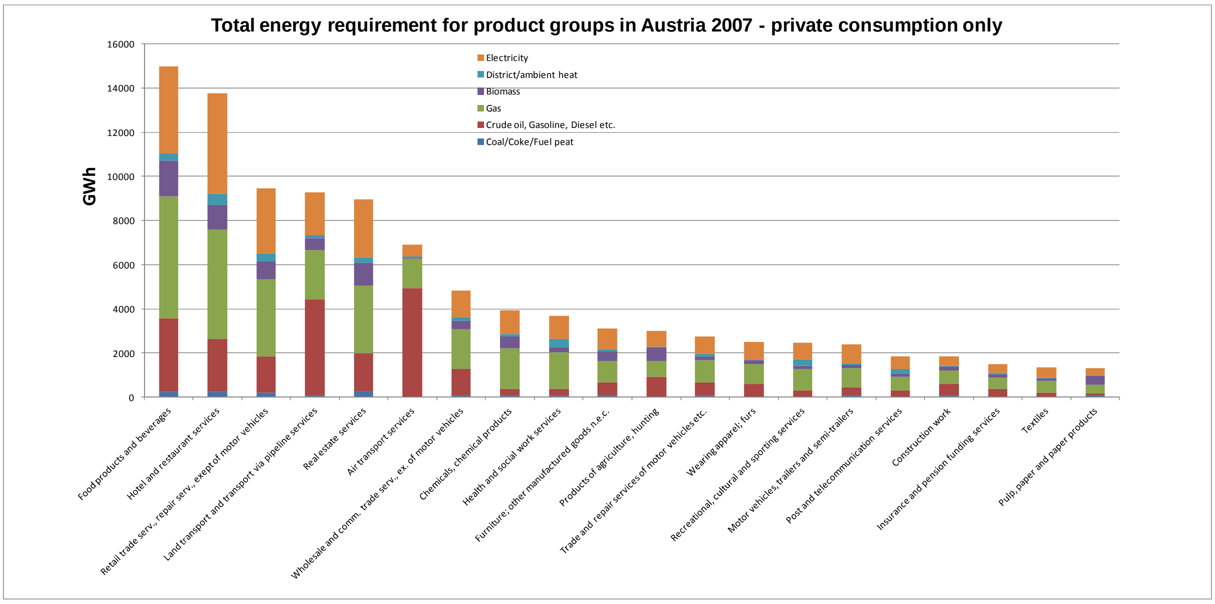

Figure 3-4: Energy requirement of private consumption for important product groups in Austria 2007

Detailed discussion on the results would be out of scope for this paper. Instead some further applications are shown to prepare for the actual goal of the modelling which is the integration of more detailed data for a single product into the Input-Output framework.

While the model proofs to be useful to track down the energy use to the demand for product groups, the aggregation level does not allow for analysing the supply chains to produce these products in detail, which is necessary to identify potentials to reduce the energy demand of these products. This can only be done on the level of process analyses for certain products. In the next section an approach to implement findings of process and life cycle analysis into the presented Input-Output framework will be discussed.

4. INTEGRATION OF PROCESS ANALYSES INTO THE IO-MODEL

The aggregation level of 57 product groups does not allow for investigating individual products. The technical coefficients in ***A*** and the energy intensity vectors ***e*** are determined by the technical processes within the sectors and the corresponding output weights of these processes. In other words, the coefficients represent a mix of supply chains of all products produced within a sector. The problem is, that each individual product within one sector has its own supply chain which might differ substantially from the average of the sector. This is why the findings of IO analyses cannot be directly used to analyse individual products. However the findings of process analyses can be combined with input output calculations. This method called Hybrid Input-Output analyses has been used to enhance the quality of Life-Cycle-Analysis. Here similar approach to estimate energy conservation potentials for Austria derived from findings in process analyses will be discussed. The method will be illustrated by using one sector and one product as an example. The demand for pulp and paper products of the sector insurance and pension funding will be analysed to estimate the total energy conservation potentials of measures concerning paper use in this sector.

4.1 INFORMATION FROM IO MODEL

The findings of the IO model serve as a starting point for the analyses.

Figure 4-1 shows the energy requirement for the production of services worth 1€ from the sector insurance and pension funding. This sector has been chosen because it illustrates the fact, that for some sectors the direct energy inputs9 are not always the best measure for total energy demand related to the production of goods and services for final demand. Total energy requirement for 1€ services is 0.32 kWh while the initial data for the energy intensity of the sector without considering the supply chain is only 0.016 kWh/€_total output. Direct energy inputs only account for 6% of total requirement. Most of the energy demand can be traced back to air transport services(17%) and pulp and paper products(15%). The bars on the left show contributions from other sectors. Those figures are derived from the Matrix RE. They correspond to the entries in column 45 which is the index for the insurance sector.

$$RE = \widehat{\boldsymbol{e}} \cdot \left(I - A\right)^{-1} = \begin{bmatrix} r_{11}e_1 & r_{12}e_1 & \dots & r_{1n}e_1 \\ r_{21}e_2 & r_{22}e_2 & \dots & r_{2n}e_2 \\ \dots & \dots & \dots & \dots \\ r_{n1}e_n & r_{n2}e_n & \dots & r_{nn}e_n \end{bmatrix}$$

$$RE_{45} = \begin{bmatrix} r_{1,45}e_1 \\ r_{2,45}e_2 \\ \dots \\ r_{57,45}e_{57} \end{bmatrix}$$

[9] For the case of insurance and pension funding the most important factors for direct energy use is electricity, cooling and heating

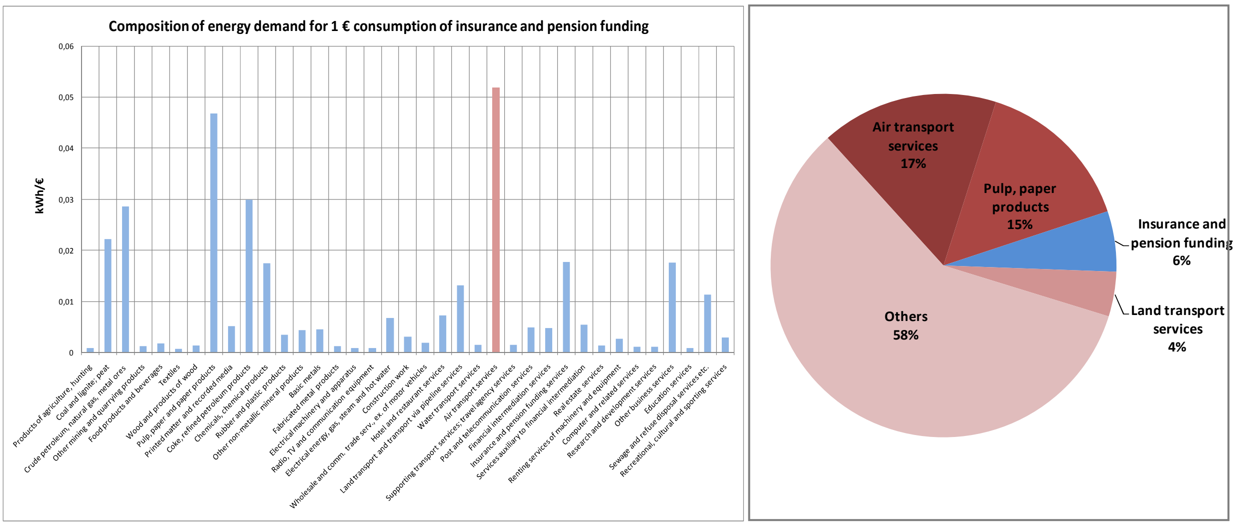

Figure 4-1: Composition of energy requirements for the insurance sector

Considering the supply chain of this sector one can conclude that there might be more potential to conserve energy looking at the intermediate inputs along the supply chain than considering the direct energy inputs of the sector itself. Here this approach will be illustrated by looking at the pulp and paper use of the sector. Note that the parameters used are just dummy values. The actual values are still to be estimated through further research. Here only the main principle shall be shown. The effect of two measures will be estimated using the IO model.

1) Reduction of energy use in the sector insurance and pension funding
2) Increased use of recycled paper in the sector

While the calculation of effects caused by measure 1 is straight forward, estimating effects of measure 2 requires detailed knowledge on the composition of the supply chain, the processes involved and the output weight of those processes. Again it should be stressed, that dummy variables are used that do not reflect the actual condition in the sector. Additionally it will be assumed that all changes in the structure only occur within the Austrian economy.[10]

4.2 Effect of paper use reduction in the insurance and pension funding sector

The input of paper products (sector 15) to the insurance and pension funding (sector 45) industry is given in the Matrix $\boldsymbol{Z}$ which contains all interindustry activities of the year 2007. $\boldsymbol{z}_{15,45}$=5,358 Mio€ which means that the insurance sector demanded around 5 million € worth of paper products to produce its services. This could be everything from office paper to brochures or envelopes. Now we suppose that certain measures could lead to a lower need for paper products in the sector. One could think of printing less emails, double sided print outs, increased online marketing instead of printed brochures. The actual potentials has to be estimated through investigations or literature studies. If we assume that the reduction potential is estimated to be 10% of the existing paper use, the total energy conservation potential can be estimated as follows.

$$z^{new}_{15,45} = z^{old}_{15,45} \cdot \left(1 - p_{15,45}\right)$$

[10] Theoretically, expanding the analyses to changes in the rest of the world can be done in the same manner. Also it should be noted that changes within the Austrian economy affects the foreign economies through changes in the structure of imported intermediate goods given by: $e^f \cdot A^{dimp} \cdot (I - A^d)^{-1} \cdot (I - A^f)^{-1} \cdot Y^d$

$z_{15,45}^{new}$ ……. new input of paper products to insurance sector (4,82 Mio€)
$z_{15,45}^{old}$ …….old input of paper products to insurance sector (5,358 Mio€)
$p_{15,45}$ …….reduction potential of paper products in the insurance sector (10%)

Those new input entries translate into a new technology coefficient $\boldsymbol{a_{15,45}}$, which again leads to a new Leontief inverse[11] The change in output also leads to changes in the energy demand of the whole economy. The following equation illustrates this relationship. Note that only one entry in the technology matrix has changed in $\boldsymbol{A^{new}}$ compared to $\boldsymbol{A^{old}}$.

$$\boldsymbol{E} = \widehat{\boldsymbol{e}} \cdot \left(\boldsymbol{I} - \boldsymbol{A}^{new}\right)^{-1} \cdot \boldsymbol{Y}$$

Here it should be noted, that the demand reduction of the insurance sector does not only affect the sector itself. Through the interdependence of the sectors all sectors are affected which is represented in the new Leontief inverse. Figure 4-2 illustrates this effect by plotting the changes in total requirement coefficients $\boldsymbol{r_{ij}}$ resulting from the reduction of a single technical coefficient $\boldsymbol{a_{15,45}}$. Note that a positive value in the figure indicates that the new coefficient is lower than the old one. The coefficients along column 45 $\boldsymbol{r_{i,45}}$ change because the insurance sector becomes more efficient. Lower requirement of paper also leads to lower requirement of other products related to paper production. For example also the coefficients $\boldsymbol{r_{36,45}}$ and $\boldsymbol{r_{39,45}}$, representing inputs from retail services and land transport services, are significantly lower than in the original $\boldsymbol{R}$ matrix. The changes in row 15 $\boldsymbol{r_{15,j}}$ represent lower demand for pulp and paper products from other sectors. This effect might seem wrong at first sight because demand for paper products of other sectors did not change. The explanation is that the lower coefficients are a result of the fact, that all other sectors demand inputs from the insurance sector. If the insurance sector reduces its need for paper products total paper demand of all other sectors that demand insurance services declines as well. This finding illustrates the complex linkages that arise when all inputs are attributed to the production of products for final demand.
To calculate the change in energy requirement the new total requirement matrix has to be connected with the energy intensities that stay unchanged to get the new energy requirement matrix ***RE*** and multiplied with the initial final demand vector. The total energy reduction consists of two main effects. First there is a reduction in domestic energy needs and second there is also an effect on imported intermediate goods because there are less imports needed to produce domestic products.

[11] $a_{15,45}^{old} = 8.97 \cdot 10^{-4}$
$a_{15,45}^{new} = 8.08 \cdot 10^{-4}$

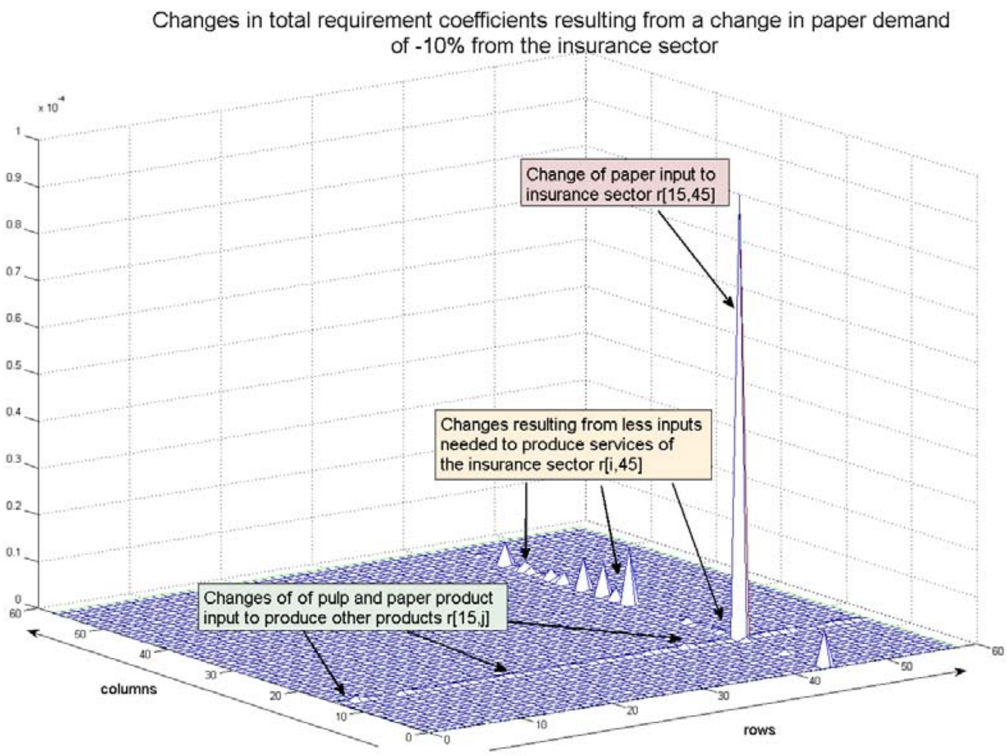

Figure 4-2 Changes in total requirement coefficients r_{ij}

In total the reduction of paper demand would lead to final energy savings of **2.25 GWh/year** for the whole economy. Domestic energy needs are reduced by 1.6 GWh and embedded energy in imported intermediate goods is reduced by 0.65 GWh. The reduction can be further split up into energy carriers which will not be done here. Once again it should be pointed out that only one coefficient has changed as a result of reduced need for an intermediate input of one sector. The effects are plausible and also the implementation into the IO model is straight forward. Of course the potential to reduce intermediate inputs has to be investigated. Furthermore the following question arises: If there were potentials for input reductions in the economy, why are they not realised already? However as research on energy efficiency has shown, there are potentials to conserve energy that could be economically exploited. So, one could argue that there are also potentials to reduce certain inputs. Identifying those potentials will be subject to further research. Here it has been shown, that IO analyses can serve as a tool to estimate the total impact of input reductions on the whole economy and on energy requirements.
In the next section the integration of products that are less energy intensive and that also lead to changes in the direct input structure will be discussed using the example of increased use of recycled office paper.

4.3 Effect of increased use of recycled paper in the insurance and pension funding sector

In this section the attempt to integrate results from process analyses will be illustrated. The assumptions here are very simplified and only the main principle of the approach shall be shown.

In a study conducted by IFU Heidelberg[12] the energy requirement for recycled copying paper and copying paper made of virgin fibre were analysed within a process analyses. The data

[12] see Gromke, Detzel 2006

used reflects German conditions. The conclusion was that primary energy demand was more than 50% less for recycled paper resulting from lower energy needs for transportation and for pulp production. The production of the paper itself was considered to be equal with respect to energy requirements for pulp made of virgin fibre and recycled paper. Here we want to integrate the effect of reduced energy demand in the pulp and paper industry assuming that the insurance industry was to satisfy all its paper demand with recycled paper. The effects of changes of transport requirements will not be considered here.
The assumptions are as follows:

- The insurance industry will increase the share of recycled paper from 20% to 100% of its total paper consumption.
- The supply chain for all types of paper used in the insurance industry is equal.
- The input structure of the pulp and paper industry changes from inputs of products of forestry (sector 2) and wood and products of wood (sector 14) to sector recovered secondary raw material (sector 31) so that total monetary input to the pulp and paper industry (sectors 15) stays constant. This is equivalent to the assumption that the price of recovered paper and virgin fibre out of wood is equal with respect to paper output.
- paper prices are assumed to be equal throughout all industries.
- Paper made of virgin fibre requires 25% more final energy than recycled paper in the pulp and paper industry. The energy intensity of all other industries does not change.

Again the relevant processes are represented in the technical coefficients that are given by the intermediate inputs related to total output of an industry. As Pan(2007) pointed out the coefficients can be seen as a mix of processes which can be described as:

$$a_{ij} = a_{ij}^0 \frac{X_j^0}{X_j^0 + X_j^n} + a_{ij}^n \frac{X_j^n}{X_j^0 + X_j^n}$$

$\boldsymbol{a^0}$ and $\boldsymbol{X^0}$represent the old process and the corresponding output produced and $\boldsymbol{a^n}$***,*** $\boldsymbol{X^n}$ represent new processes. This approach will be applied to estimate the change in the input structure of the relevant sectors. First the share of sales of pulp and paper products to the insurance sector has to be considered. This can be done by dividing the sales to sector 45 by the sum of sales to all sectors plus the sales to final demand, which is around 0.3%.

$$s_{15}^{45} = \frac{z_{15,45}}{\sum_{j=1}^{57} z_{15,j} + y_{15}} = 0.3\,\%$$

Assuming that all other sectors do not change their paper demand and assuming that 20% of those deliveries have already been recycled paper, only 0.24% of the paper production is affected. If we assume that the input structure of the pulp and paper industry changes by this percentage the result is that inputs worth of 1.09 Mio€ are shifted from the sectors 2 (forestry) and sector 14 (wood) towards the sector *secondary raw materials* (sector 31). This in turn results into new input coefficients. Even without considering the reduced energy demand of the pulp and paper industry this shift leads to savings of 0.5 GWh/year. This is because sector 31 is less energy intensive than sector 2 and 14.
Estimating the effect of the reduced energy intensity resulting from the increased production of recycling paper can be done by multiplying the new energy intensity with total sales of paper products to the insurance industry.

$$E_{15,45}^{old} = e^{old} \cdot Z_{15,45} = e^{recyc} \cdot Z_{15,45} \cdot p^{recyc} + e^{virg} \cdot Z_{15,45} \cdot \left(1 - p^{recyc}\right)$$

Assuming that the energy intensity to produce paper out of virgin fibre is 25% higher than for recycling paper and that the share of recycling paper used in the insurance sector grows from 20% to 100% the new intensity for deliveries to the insurance sector is $\boldsymbol{e^{recyc}}$.

$$e^{virg} = 1.25 \cdot e^{recyc}$$

$$e^{recyc} = \frac{e^{old}}{1,25 - 0.25 p^{recyc}}$$

$E^{old}_{15,\,45}$ …..direct energy requirement to deliver paper to insurance sector in base case [kWh]
e^{virg} ……..energy intensity to produce paper out of virgin fibre [kWh/€]
e^{recyc} …….energy intensity to produce recycling paper [kWh/€]
e^{old} ……...energy intensity in the base case [kWh/€]
$Z_{15,\,45}$ …...delivery of paper products to insurance sector
p^{recyc} …….share of recycling paper in the insurance sector

The savings in direct energy inputs to the pulp and paper industry are therefore given by:

$$\triangle E = e^{old} \cdot Z_{15,\,45} - e^{recyc} \cdot Z_{15,\,45}$$

This would result in savings of 10,9 GWh/year. Under these assumptions 11,4 GWh/year could be conserved if the insurance sector would increase its share of recycling paper from 20% to 100%. The main savings arise because of savings in direct energy use from the pulp and paper industry due to the fact that pulp production from collected waste paper is less energy intensive than production from virgin fibre. The changes in the input structure from forestry and wood products towards secondary raw materials only accounts for a small amount of the energy savings.

It should be noted that this is a very simplified implementation of results from process analyses. A lot of assumptions have been made to integrate those simplified results. To get robust empirical results, detailed data has to be collected and the assumptions have to be evaluated carefully. This will be further discussed in the upcoming research but is out of scope for this paper.

5. CONCLUSIONS

In this paper an approach towards estimating embedded final energy demand has been presented. It has been shown that energy flows on country level can be described using Input-Output analysis. Preliminary results have revealed that Austria is a net importer of final energy embedded in products and that total final energy requirements are 33% higher from a consumption perspective than in conventional statistics that use a production based view.

Tracking down energy flows to the demand of final products can be done on aggregated level. However the aggregation level of 57 products groups is too high to estimate effects on product level. Process analyses have to be used which are very data intensive and typically only account for the most important processes involved. The integration into Input-Output tables would be a way to combine the detailed findings of process analyses with additional aggregated data to estimate total effects on the economy. However, the integration requires making substantial assumption and calls for additional data on output shares and the classification of processes.

The approach presented here is a simplified version which can be used for crude estimations but cannot reflect the full complexity of the processes and supply chains involved in the production of goods and services. On the other hand the interconnections between industries can be illustrated which cannot be done with conventional process analyses.

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