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A MODEL FOR THE LINKAGE BETWEEN ECONOMY AND ENVIRONMENT

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1. On Methodology

Although it's not the whole story, in analytical terms the relationship between socio-economic system and environment can be described as a feed-back-loop or, less simplified, as a network of interrelations.

Steps of the feed-back-loop are:
Economic activities produce "goods" on one hand and deplete resources and release pollutants or "bads" on the other.
Pollutants are transmitted (or relocated) and end up as immissions, leading to environmental damage and quality decline.
Environmental quality decline causes (negative) feedbacks on the socio-economic system (partly measurable, e.g. avoidance costs, income losses...) (see UN-STATISTICAL OFFICE 1990, p. 57).
Depletion of resources, occupation of space (e.g. buildings, roads, hydroelectric power plants) and certain activities not primarily related to pollution (e.g. consolidation of farmland) more or less follow the same path.
As is seen clearly, many sciences are involved (economics, biology, chemistry, climatology, technical sciences...).

To find a chain of causation - activity->pollution->immission->damage->costs - often is hard work. An example for this difficulty was (and still is!) the debate on causes of forest dieback and their respective shares.

This paper deals with one step of the cycle only: the possibility of linking economic activities and pollution, demonstrated for the case of traffic.

"Pollution" marks a "crossing-the-border", matter-energy leaves technosphere and society (more or less) looses control. At this point environmentalists and economists meet. Economists learn the names of many substances that should not be released into environment any more, or at least should be reduced in amount. This is also one of the main points for measuring success in environmental policy.

To link economic activities and environmental loads (emissions) one needs to work on two fields of data.

• Economy must be represented by data easily and accurately gatherable **and** as near as possible to environmental impacts. The zero-growth-debate has shown that monetary aggregates (like GNP or turnover of branches or companies) are not an appropriate indicator for pressures on the environment which are connected with

the activities behind monetary figures. JÄNICKE ET AL (1989) tried to value the effects of structural change on environmental situation using indicators like cement production, steel consumption, freight transport and energy consumption (see also OECD 1991a, p. 58 f.).
For the purpose stated the conclusion is to use data with physical rather than monetary units. Similar to the approach of Jänicke et al we developed a concept called "economic-ecologic indicators" which will be presented later.

• Environmental loads can be represented by data about amounts of pollutants released (including waste deposited), data on land use and so on. As economic statistics as a rule don't contain output-data concerning "bads", pollution-concerned macro-data usually are based on special surveys or on estimations. In case of air pollution emission-factors are broadly used to estimate emissions. An emission-factor tells us the amount of certain emissions (in the form of a vector) going-with the use of a certain amount of input (e.g. input of energy by type of source and by type of equipment used) or the production of a certain amount of output. Such factors are usually derived from series of observations and, in general, not very accurate.

To link these two databases we use emission-factors. So we can link flows of material/energy through economy and/or goods and services produced by economy to quantities of emissions going-with these activities. Emission-factors were published by AHAMER 1989, ORTHOFER/URBAN 1989, LENZ/AKHLAGHI 1989 and BMWA 1990.

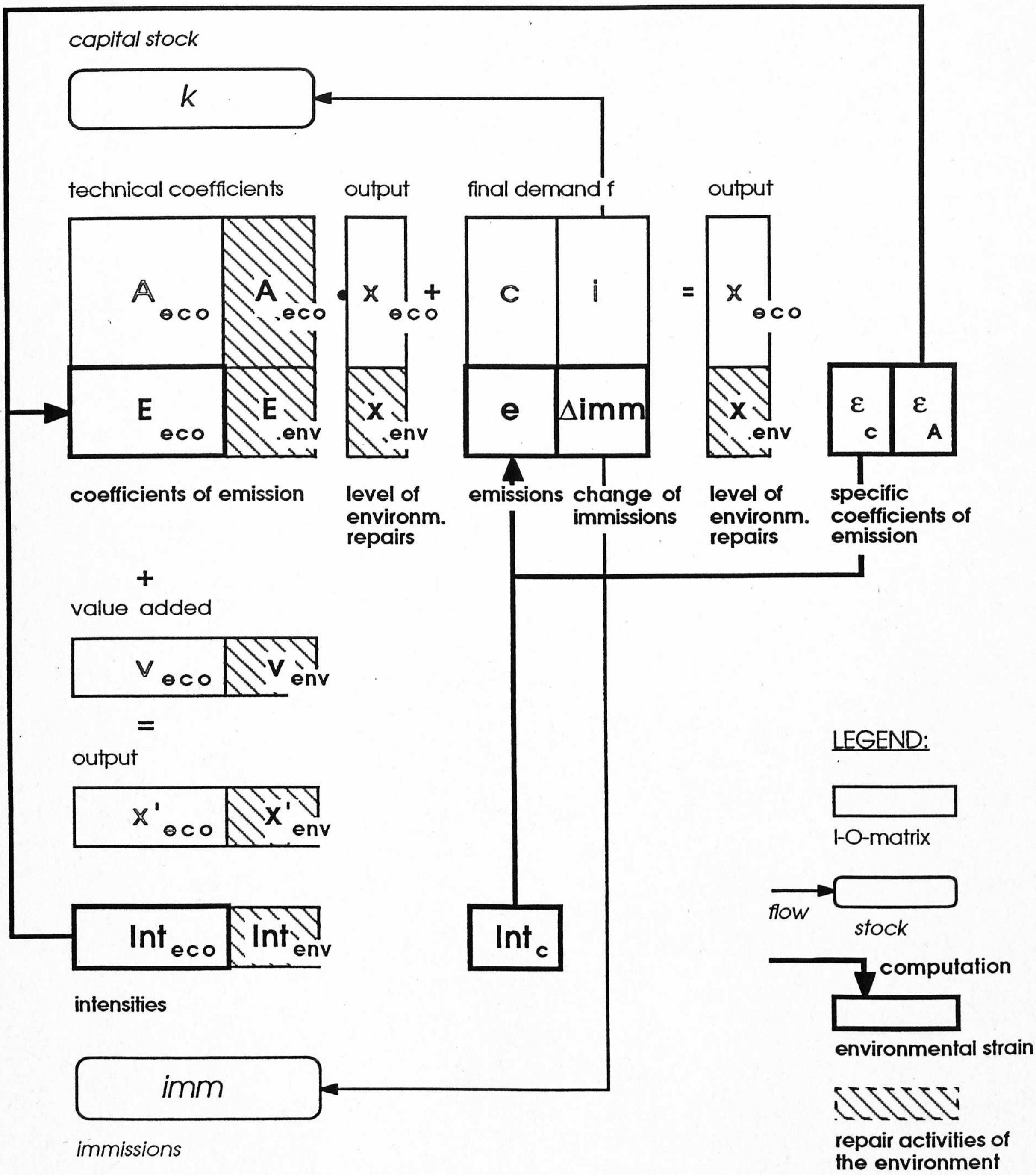
Doing this in the framework of an I/O-model, effects of structural changes forecasted or political steps planned on the emissions-situation can be valued (at least in principle).

From a practical point of view for data collection and building of the model a limited amount of manpower was needed (about one person-month).

2. The Model Used

The general model we start from is based on Leontief's extended input-output model where economic variables are combined with environmental indicators (LEONTIEF 1970; LEONTIEF 1973; DUCHIN 1990, 252-253). *Figure 1* shows the basic structure of the full model. The upper parts of the arrays shown in the upper half of the figure represent economic activities ($\mathbf{k}$, $\mathbf{g}_{eco}$, $\mathbf{c}$, $\mathbf{i}$, measured in currency units, and the coefficients of the matrices $\mathbf{A}_{eco}$ and $\mathbf{A}_{env}$), the lower part represents environmental variables ($\mathbf{e}$, $\Delta\mathbf{imm}$, $\mathbf{g}_{env}$, measured in physical units, and the coefficients of the matrices $\mathbf{E}_{eco}$ and $\mathbf{E}_{env}$). The right half of the matrix of technical coefficients ($\mathbf{A}_{env}$ and $\mathbf{E}_{env}$) is devoted to repair activities of the environment on a physical level of $\mathbf{g}_{env}$ (cleaning water, recycling etc.). Value added $\mathbf{w}_{env}$ is split correspondingly. The model is not restricted to comparative static but may be used to describe the dynamic process as well. Stocks are included in two ways, economic and environmental: fixed assets, $\mathbf{k}$, increased by net capital investment, are representing means of production

Figure 1: The Basic Structure of the Full Model



available; the level of immissions, **imm**, is changed by **Δimm**, the net pollutants set free to the environment. **imm** can also be interpreted as a potential of risks (e.g. in case of radioactive waste stored). In case of persistent substances (like heavy metals) a simple addition is performed. To describe the mechanism of reduction by itself or by natural processes (e.g. CO_2, most chemical compounds) lifetimes can be applied and depreciations can be made.

While we applied and connected the economic variables in the standard input-output way and continued to use both economic and environmental indicators we used **intensities** for the determination of environmental effects. Intensities represent a bundle of auxiliary variables as a measure of social activities which - if performed - will have effects to the environment in a very general meaning of the word. We introduced them to make it easier to compute particular **emission-factors** of pollutants.

Using emission-factors, the general formula for calculating the amount of emission is: specific emission-factor per base-unit times amount of base units.

Two effects are obvious, a technology-effect (changes of the emission-factor), and a growth-effect, which in case of disaggregation divides into a structural effect and a general growth effect.

Economic data (about base units used or produced) carry their specific error-ranges according to their origin. In general, data in physical units seem to be less accurate than monetary data.
For the specific emission-factors error-ranges usually are even higher. In case of standard technologies **and** steady operation modes **and** steady quality of inputs used or outputs produced, standard deviation usually is low (e.g. thermo-electric power plants). In case of high diversity of technology and/or quality of inputs/outputs and/or pulsed or unsteady operation modes standard deviation is high (eg. cars, single stoves). In such a case one has to combine a series of mean-values, each with its own error-ranges.

The idea behind the concept of "economic-ecological indicators" is very simple: We try to derive from economy-concerned data those best able to represent environmental loads. Such data are mainly mass-data about input or production, for example energy consumption, steel or cement production, also areas used for different purposes, waste produced and so on. These data, disaggregated by branches are **divided by turnover, value added, or number of employees**. By that way we get specific **intensities** of every branch.

In short, the intensities are (per unit of turnover, value added, or per employee):

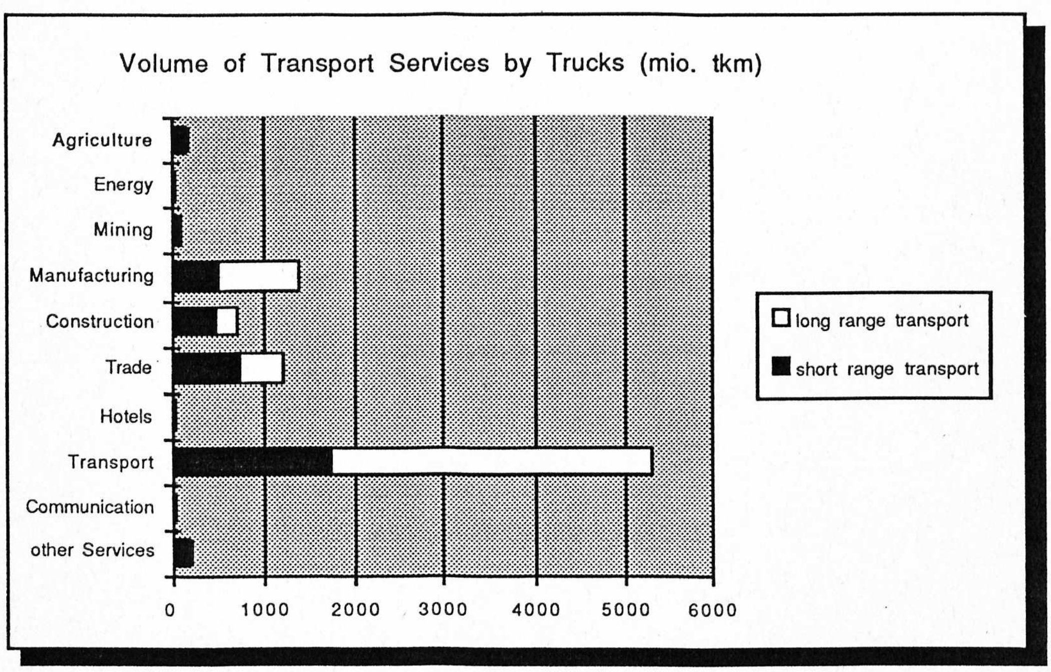
Energy-intensity:	net-energy used, summed up or disaggregated by groups of energy-sources (fossil, renewable, solar...) (see OECD 1991a, p. 54 f., OECD1991b, p. 225)
Transport-intensity:	ton-kilometers and person-kilometers consumed, summed up or disaggregated by type of vehicle used (car, tram, bus, rail, truck..) (see OECD 1990)
Matter-intensity:	net-tons-of-matter used (inputs minus products), summed up or disaggregated by class of material, (the concept of matter-intensity is similar to the concept of unit-value)
Packaging-intensity:	a special version of matter-intensity with regard to waste
Area-intensity:	square-meters occupied, summed up or disaggregated by type of use
Risk-intensity:	insurance premiums paid for certain purposes

The purpose of such a matrix (say, 40 branches with 30 indicators plus sub-indicators) is to measure relative environmental performance of each branch. Sets of pollution are loosely interlinked with these intensities, so from these data at least we can derive trends in environmental performance.

In Leontief's and Duchin's models usually the volume of pollution is directly determined by multiplying an economic output indicator by some emission factor. The disadvantage of this method is twofold: First, the emission factor must be known, second, a direct link between economic indicators and pollution is assumed implying that economic activity and pollution is proportionate which is not true in general. Because of the highly aggregated economic activities one factor usually represents not only one source of pollution but a spectrum of different sources and causes guided by different laws of behavior. This fact cannot be reflected by this method. Therefore we propose a different approach starting from polluting activities performed by society.

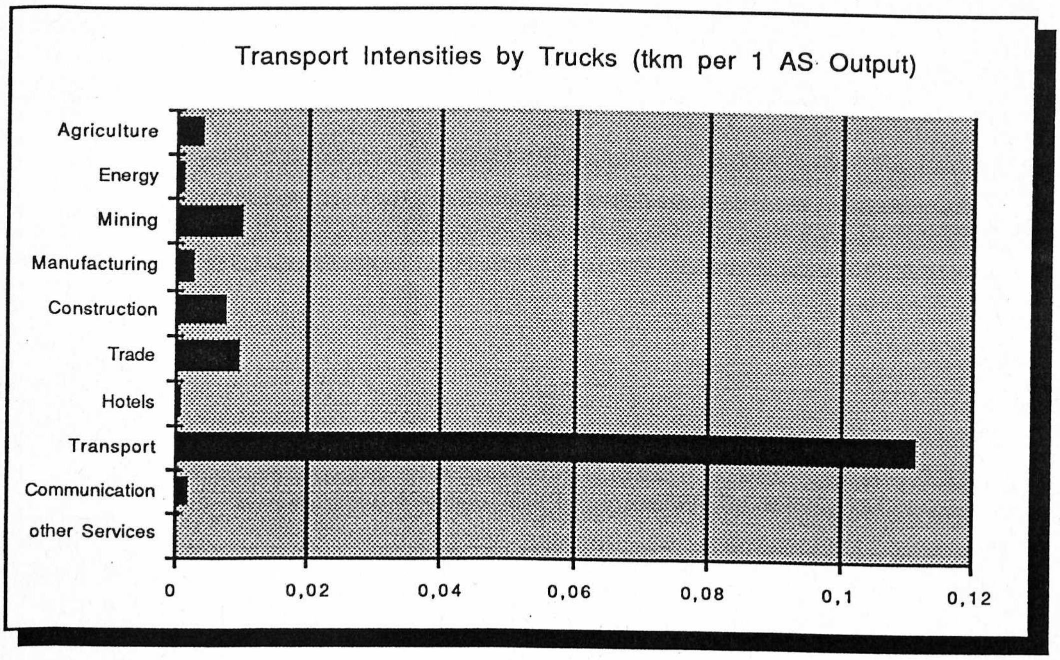
We will illustrate this approach by an example of societal activities, transportation. It is evident that transport activities can be measured by certain indicators like person-kilometers transported or ton-kilometers transported by different kinds of vehicles and range (railway, truck, bus, aeroplane, ship etc.). The volume of the Austrian company and commercial transport via trucks can be seen in *Figure 2*.

Figure 2: Volume of Transport Services by Trucks (mio. tkm)



For each branch and for total consumption transport activities can be measured (transport internal to the industry and company transport; transport industry; private car traffic etc.). The above intensities are defined as annual transport activities of a certain kind over an economic indicator, measuring the level of activity of a certain branch of production or consumption. In our example we use gross economic output or the level of total private consumption as denominators (see *Figure 3*).

Figure 3: Transport Intensities by Trucks (tkm per 1 AS output)



The intensities represent a useful instrument to reflect the fine-structure of a societal activity not only by "explaining" the content of economic activity within one industry but enabling us to create a link to pollution effects. Because it is rather easy to find pollution figures per ton-kilometer or per person-kilometer transported by kind of vehicle (see ε_C referring to consumption and ε_A referring to production in *Figure 1*) our approach enables us to construct factors of emission $\mathbf{E}_{eco}$ and $\mathbf{E}_{env}$ in a more detailed way which are more down to earth and can be interpreted by real activities of society than by an abstract concept of just dividing emissions by output.

3. The Method

In this chapter an application of the augmented input-output model is presented. As an example to illustrate the pros and cons of the above approach we study the economic and pollution effects of substituting long range commodity transport on roads by railway. This substitution implies a change in technology and a change in the specific emission factors. In the following we discuss the necessary steps.

3.1. Classifying Transport Activities

According to our goal of investigation total transport activities may be subdivided by the following criteria:

• 1. By the **supplier** of the service: Internal activities are organized by the companies themselves (company transport) and, economically speaking, are part of gross production of the specific industry. External activities are bought by companies on the market (commercial transport). Commercial transport constitutes a separate industry, company transport is distributed among all the other sectors of the economy.

- 2. By the **carrier**: Transport by trucks, by railroad and by others.
- 3. By the **type of transported entities**: Transport of persons, transport of commodities.
- 4. By the **range** of transport: Long range transport and short range transport.

Our overall goal is to study the effects of substituting long range (commodity) transport via trucks by (commercial) railroad transport.

Because in the input-output table data on total truck transport activities can be singled out only, we have to find out the share of long range services within this subgroup. Fortunately data on the amount of services split into long range and short range activities are available (measured in transported ton-kilometers). By means of a relative price, **r**, in terms of short range activities we can compute the volume of long range transport by trucks in million AS (**r** was assumed as 0.6).

$$x_l = x - x_s$$

$$x_s = p_s \cdot c_s$$

$$p_s = x / (c_s + r \cdot c_l)$$

$$p_l = r \cdot p_s$$

Thus the gross output for long range commodity transport is given by

$$x_l = x [1 - c_s / (c_s + r \cdot c_l)],$$

where

x is the gross output of the total truck transport sector,
x_s is the gross output of the short range truck transport sector
x_l is the gross output of the long range truck transport sector
c is the volume of services of the total truck transport sector,
c_s is the volume of services of the short range truck transport sector
c_l is the volume of services of the long range truck transport sector
p is the unit price for services of the total truck transport sector,
p_s is the unit price for services of the short range truck transport sector
p_l is the unit price for services of the long range truck transport sector
r is the relative price of long range transport compared to short range transport, $r = p_l / p_s$.

3.3. Shifting Company Transport to Commercial Transport

To illustrate the reallocation from company transport into commercial transport we use the following simplified input-output scheme.

Figure 4: Simplified Input-output Scheme before Reallocation

x_{11}	x_{12}		y_1	x_1
x_{21}	x_{22}		y_2	x_2
v_1	v_2			
x_1	x_2			

Let sector 1 represent an industry which applies company transport, and sector 2 the commercial transport industry. The volume of company transport of sector 1 is denoted by t_1 (in currency units). The respective values for intermediate inputs are denoted by t_{11} and t_{21}. These values have to be subtracted from the original intermediate inputs x_{11} and x_{21}, resp. The share of output, t_1, has to be added to the first element of the second row. It represents the market value of the former internal services produced by sector 1. Now this value has to be added to the output of sector 2. Accordingly an increase of the input elements of column 2 has to be performed. To check the correctness of this procedure one should compute the row of values added. The sum of the elements of this row remains invariant, as expected. While the GDP remains unchanged, the sum of output is increased by the amount of additional services which are now offered on the market.

Figure 5: Simplified Input-output Scheme after Reallocation

$x_{11}-t_{11}$	$x_{12}+t_{11}$		y_1	x_1
$x_{21}-t_{21}+t_1$	$x_{22}+t_{21}$		y_2	x_2+t_1
$v_1+t_{11}+t_{21}-t_1$	$v_2-t_{11}-t_{21}+t_1$			
x_1	x_2+t_1			

As a first step we transformed our original data in the way described above. Standardizing the resulting input values resulted in a matrix $\mathbf{A}_1$ of technical coefficients (see *Appendix*). They represent a situation where the internal long range commodity transport on trucks was reallocated to the transport sector. Its services were bought on the market at the actual price of long range services in the transport sector.

3.4. Defining Technology

The next step was to replace actual average technology in the transport sector by a technology where long range transport is done by railway instead of trucks completely.

The starting point of our substitution is the standard input-output model with the actual mix of different transportation technologies. This average standard technology we consider as our standard technology. In mathematical terms it is characterized by a column vector a_{st}. A more disaggregated version of our I-O table provides us with technology vectors for transport by railway, a_{rl} , and for road transport, a_{rd}. As we do not like to go into more details, we compute the technology vector which represents the residual categories of transport, a_{res}, which is just the technology used by transport other than railway or road, by the following formula

$$a_{res} = (a_{st} \cdot x_{st} - a_{rd} \cdot x_{rd} - a_{rl} \cdot x_{rl}) / x_{res},$$

where the aggregated gross product x_{st} is split into three parts:

$$x_{rd} + x_{rl} + x_{res} = x_{st}.$$

x_{res} actually includes the following categories (the figures in brackets refer to the number of the industry of the 175 x 175 version of the Austrian I-O table): tram and bus (128), taxi and other personal transport (129), auxiliary services for roads (131), lift transport (133), ship transport (134), air transport (135), services for airports (136), transport by pipelines (137), carrier services (138) and travel agencies (139).

The empirical values for the gross output and the technical coefficients are:

Kind of Technology	Average a_{st}	Road a_{rd}	Railway a_{rl}	Residual a_{res}
Industry:				
Agriculture	0,00100	0,00021	0,00164	0,00106
Energy	0,02163	0,00570	0,03799	0,02116
Mining	0,00257	0,00156	0,00405	0,00233
Manufacture	0,15615	0,26013	0,09727	0,13603
Construction	0,01268	0,00515	0,02093	0,01221
Trading	0,01921	0,03293	0,01023	0,01714
Hotels	0,03997	0,01756	0,00536	0,06721
Transport	0,08754	0,02126	0,08252	0,12098
Communication	0,00756	0,00468	0,00250	0,01136
Other Services	0,06934	0,08326	0,03477	0,07957
Output	x_{st}	x_{rd}	x_{rl}	x_{res}
(Billion AS)	47700	11431	11832	24437

To interpret this table it is necessary to give the definition of some sectors explicitly. The energy sector includes electric energy but excludes gasoline. The mining sector includes raw oil, gasoline is counted under the header of manufacturing industries. One can easily see that railways are using about seven times more (electric) energy per million AS gross output than truck transport, while transport by trucks needs nearly three times as much input from manufacturing industries than railway per unit of gross output.

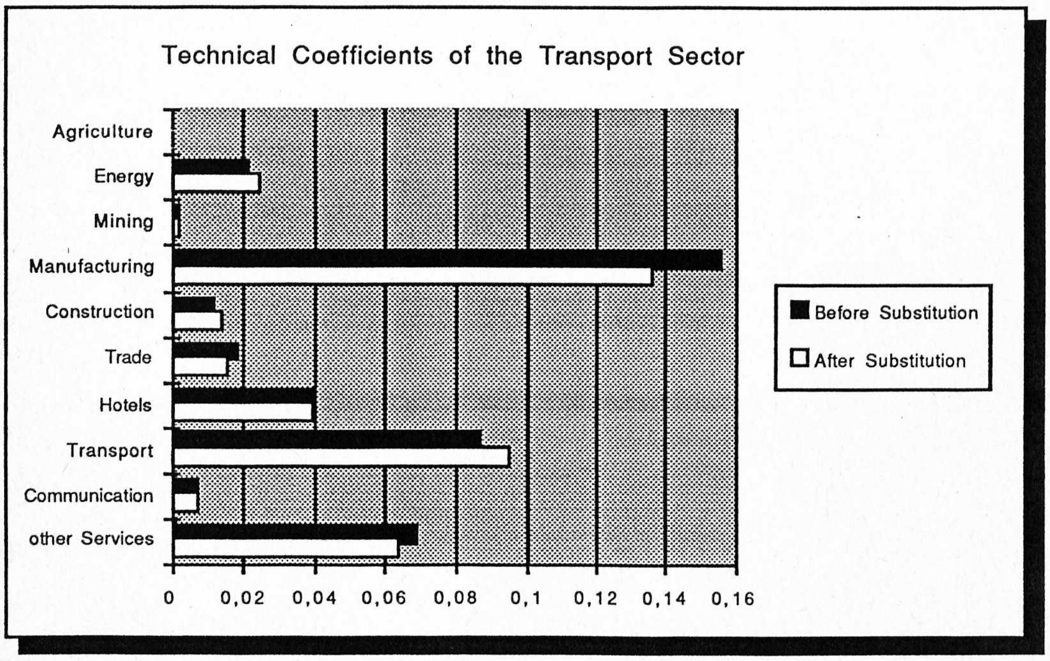
3.5. Changing Technical Coefficients

Under the assumption of constant final demand, **y**, we solve the I-O system for gross output, **x**, under changed technology. By changing technology we mean to replace the original technical coefficients of the transport sector by modified ones. In particular we have to determine a technology vector where long range transport via trucks is replaced by transport via railroad. By the above definition, the technology vector of the actual (standard) transport technology is composed as follows:

$$a_{st} = (a_{rd} \cdot x_{rd} + a_{rl} \cdot x_{rl} + a_{res} \cdot x_{res}) / x_{st}$$

Now we have to change the weights of the specific technologies. x_{rd} has to be corrected for its long range component. x_{rl} has to be increased by the revaluated amount of long range transport via trucks. This amount is a sum of the former long range component of company transport and the component of the above commercial transport, both revaluated at unit prices of railroad transport (see *Figure 6*).

Figure 6: Technical Coefficients of the Transport Sector before and after Substitution



As expected (electric) energy consumption of the new composed technology is increased, while input from manufacturing (because of reduced gasoline consumption) is decreased considerably.

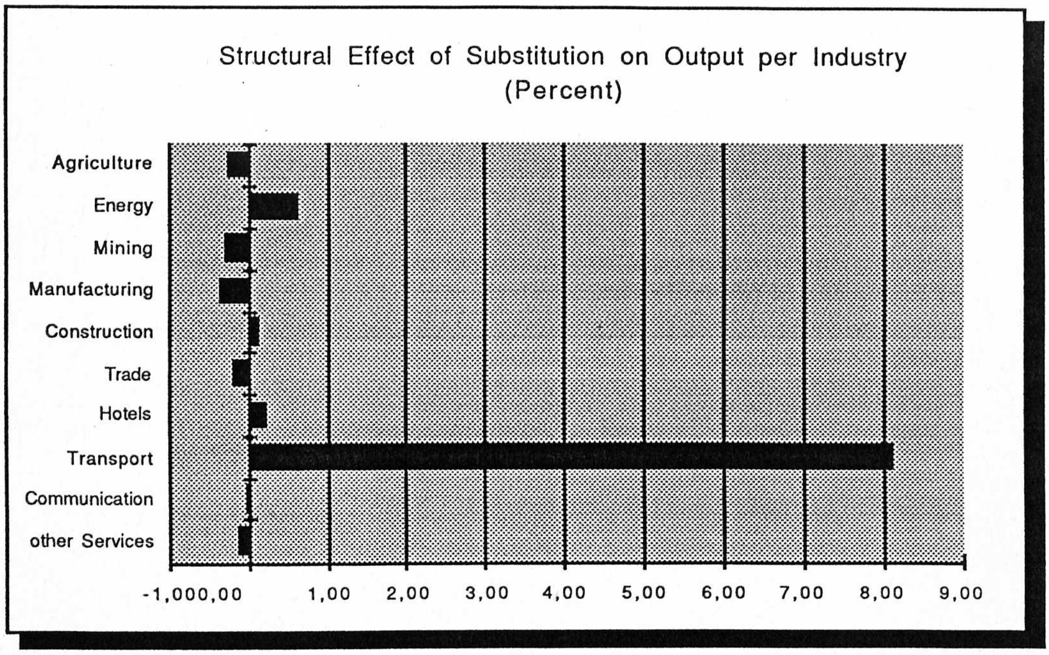
3.6. Determining the Substitution Effect on Gross Output

The output vector **x** now is a function of technology. It is the result of the pre-multiplication of the (constant) vector of final demand, **y**, by the Leontief inverse of $\mathbf{A}_2$, the matrix of changed technical coefficients:

$$\mathbf{x}_2 = [\,\mathbf{I} - \mathbf{A}_2\,]^{-1}\,\mathbf{y}.$$

The technological change results in a change in gross output (growth or structural effect of technological change, see *Figure 7*).

Figure 7: Structural Effect of Substitution on Output per Industry (Percent)



Obviously the gross product of the transport sector is increased most because of additional market activities of this sector. On the second rank is the increase in (electric) energy.

3.7. Determining Emission Factors

For the determination of emission factors we use specific emission vectors, ε_{rd} and ε_{rl}, answering the question: "What is the pollution output connected with a transport service for one ton-kilometer?". The following table shows our assumptions:

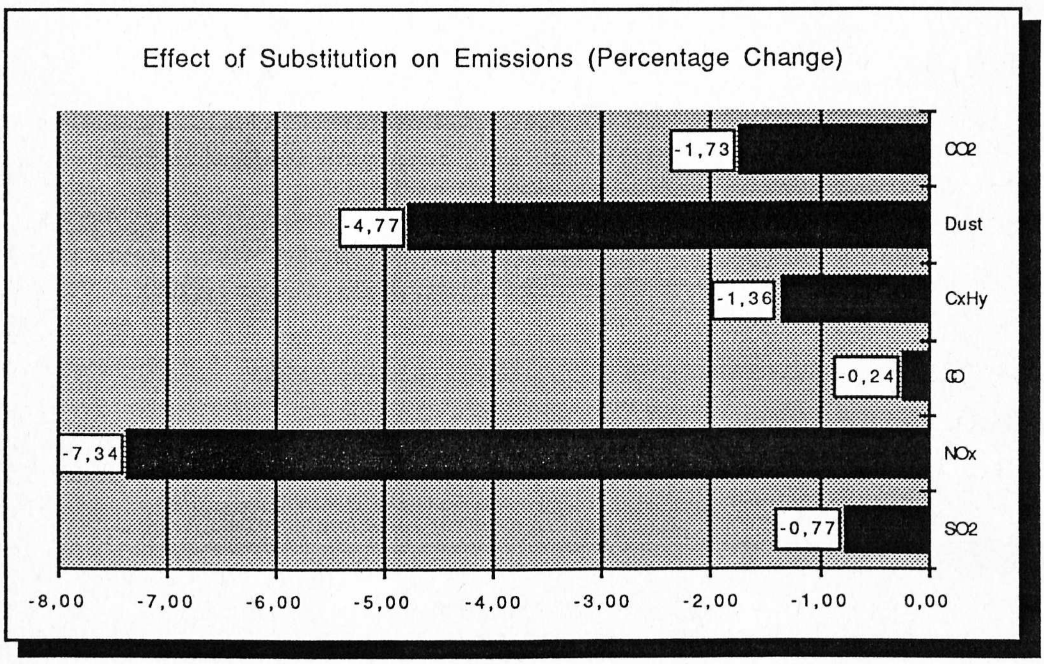
Pollutant (grammes per ton-km)	ε_{rd}	ε_{rl}
SO_2	0,172	*0,0077*
NO_x	3,088	*0,132*
CO	0,632	*0,058*
C_xH_y	0,510	*0,04*
Dust	0,283	*0,0216*
CO_2	197,391	*8,84*

Multiplication of the vectors by the annual amount of transport services (measured in ton kms) results in an estimate of the direct total pollution produced by road and railway transport respectively.

3.8. Determining the Substitution Effect on Pollution

To end up with the direct effect on pollution after a substitution of one technology by another has taken place we proceed in the following way:
a) we determine the amount of direct pollution of long range company road transport by industry;
b) we subtract this amount from total pollution;
c) we determine the amount of additional direct pollution by the increased railway transport;
d) we add this pollution to the above sum (the result of step b);
e) we determine new emission factors for the complete system, $\mathbf{E}_{econew}$.

Figure 8: Effect of Substitution on Emissions (Percentage Change)



Finally the direct effect on pollution by a change in technology has to be combined with the growth effect determined above. The matrix of total pollution, **P**, is given by

$$P = E_{econew} \, diag\{ [I - A_2]^{-1} y \},$$

where **diag(x)** means a diagonal matrix consisting of the vector **x** in the main diagonal. *Figure 8* shows the relative effects on total pollution.

The figure shows that without tangling the private car traffic a six percent reduction of NO_x emissions and a four percent reduction of particles likely due to the decreased emissions by diesel engines could be achieved. Although the railroad technology needs higher inputs from agriculture, energy, mining, construction and transport, thus resulting in higher activities (and emissions) of these sectors, the effect of the substitution as a whole overcompensates these increases in emissions.

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5. Appendix

Matrix of technical coefficients 1976:

Technical Coefficients	1	2	3	4	5	6	7	8	9	10
1 Agriculture	0,00897	0,00035	0,00270	0,08142	0,00106	0,00206	0,03240	0,00100	0,00008	0,00198
2 Energy	0,00995	0,27709	0,02492	0,01865	0,00599	0,01303	0,02966	0,02163	0,00450	0,01443
3 Mining	0,00213	0,09205	0,02243	0,04297	0,01694	0,00058	0,00166	0,00257	0,00051	0,00197
4 Manufacturing	0,22153	0,08776	0,19257	0,34423	0,29128	0,10213	0,29364	0,15615	0,05163	0,09411
5 Construction	0,00552	0,01336	0,00789	0,00450	0,02801	0,00489	0,02331	0,01268	0,00542	0,02934
6 Trade	0,03602	0,00933	0,01448	0,03661	0,03876	0,02897	0,04519	0,01921	0,00662	0,02152
7 Hotels	0,00124	0,00116	0,00334	0,00328	0,00355	0,00720	0,00074	0,03997	0,00549	0,00489
8 Transport	0,00982	0,01795	0,00460	0,01526	0,03762	0,00591	0,00662	0,08754	0,01938	0,01090
9 Communication	0,00533	0,00224	0,00402	0,00509	0,00394	0,01874	0,00476	0,00756	0,01394	0,00947
10 other Services	0,04493	0,04137	0,05649	0,05444	0,06011	0,11609	0,07608	0,06934	0,03697	0,14837

Final Demand, y, and gross output, x, 1976:

	y	x
1 Agriculture	10891	56098
2 Energy	12477	44373
3 Mining	-17496	11729
4 Manufacturing	230739	518427
5 Construction	76790	94141
6 Trade	89315	127892
7 Hotels	37225	43878
8 Transport	25955	47700
9 Communication	6416	15976
10 other Services	201548	308269

Source: ÖSTAT (Austrian Statistical Office)

Matrix of technical coefficients after shifting company transport to commercial transport:

Technical Coefficients	1	2	3	4	5	6	7	8	9	10
1 Agriculture	0,0090	0,0003	0,0027	0,0814	0,0011	0,0021	0,0324	0,0009	0,0001	0,0020
2 Energy	0,0099	0,2771	0,0244	0,0186	0,0059	0,0130	0,0297	0,0200	0,0045	0,0144
3 Mining	0,0021	0,0921	0,0223	0,0430	0,0169	0,0006	0,0017	0,0025	0,0005	0,0020
4 Manufacturing	0,2201	0,0875	0,1712	0,3436	0,2876	0,1005	0,2934	0,1666	0,0505	0,0937
5 Construction	0,0055	0,0134	0,0075	0,0045	0,0279	0,0049	0,0233	0,0119	0,0054	0,0293
6 Trade	0,0358	0,0093	0,0118	0,0365	0,0383	0,0288	0,0452	0,0206	0,0065	0,0215
7 Hotels	0,0011	0,0011	0,0019	0,0032	0,0033	0,0071	0,0007	0,0377	0,0054	0,0049
8 Transport	0,0151	0,0187	0,0850	0,0178	0,0514	0,0119	0,0074	0,0809	0,0238	0,0124
9 Communication	0,0053	0,0022	0,0036	0,0051	0,0039	0,0187	0,0048	0,0073	0,0139	0,0095
10 other Services	0,0445	0,0413	0,0497	0,0542	0,0589	0,1156	0,0760	0,0707	0,0366	0,1482

Emissions in 1987:

	Agriculture	Energy	Mining	Manufacturing	Construction	Trade	Hotels	Transport	Communication	other Services	private cars	residential
SO2 in 1000 t	9,7	25,0	8,0	44,4	2,2	5,3	4,0	1,9	0,0	7,1	0,7	11,0
NOx in 1000 t	13,6	14,4	5,7	33,7	5,3	8,4	1,5	49,3	0,2	4,3	69,1	6,0
CO in 1000 t	65,8	5,8	1,8	24,6	21,4	41,1	27,7	46,5	0,4	57,4	411,0	460,0
CxHy in 1000 t	12,9	1,2	0,5	5,8	3,9	7,3	3,3	19,6	0,1	7,4	63,5	48,0
Dust in 1000t	3,4	2,0	1,1	4,8	0,6	1,1	0,4	5,5	0,0	1,1	0,3	8,0
CO2 in Mio t	2,1	10,8	2,0	15,5	1,1	2,1	1,3	3,7	0,0	2,5	7,2	7,9

Source: BMWA (Federal Department of Economic Affairs): Energiebericht 1990; own calculations

Energy Consumption in 1987:

	Gasoline	Diesel
1 Agriculture	31,3	294,6
2 Energy	6,3	7,2
3 Mining	-10,2	94,2
4 Manufacturing	112,5	130,8
5 Construction	44,0	136,5
6 Trade	80,0	75,7
7 Hotels	9,7	3,8
8 Transport	89,4	712,3
9 Communication	5,7	7,3
10 other Services	40,0	49,0
11 Residential (residual)	2076,3	83,2

Source: ÖSTAT (Austrian Statistical Office): Statistische Nachrichten 1989, Vol. 8

Traffic Volumes in 1987 (on national territory):

	pkm (mio.)	tkm (mio.=
1 Agriculture	400	220
2 Energy	90	50
3 Mining	40	120
4 Manufacturing	1200	1430
5 Construction	470	730
6 Trade	820	1250
7 Hotels	220	40
8A Road Transport	---	5330
8B Railway	7570	10680
8C Other Transport	12020	---
9 Communication	40	30
10 other Services	900	240
11 Residential	58120	200

Source: ÖSTAT (Austrian Statistical Office): Verkehrsstatistik (Güterverkehr) 1984, 1987, 1988; own calculations