International Input-Output Association

Fourteenth International Conference on Input-Output Techniques
October 10-15, 2002, Montréal, Canada

ECOLIO – an ECOLogical Input-Output model for economic purposes and ecological usage

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The paper is based on parts of the author's doctoral thesis (SCHAFFER, 2002).

1 Introduction

When monetary input-output tables are used exclusively for economic purposes or when input-output tables – formed by a single physical indicator – are applied for ecological usage, there arise no major methodological problems. The complications begin when monetary and physical cycles are combined or interchangeably applied. This paper deals specifically with these problems.

The model ECOLIO considers nature as intermediate sector that provides resources and absorption services as monetarized inputs for the conventional intermediate sectors. For this purpose the user can set the evaluation of ecological flows[1] within exogenous elaborated price corridors for several resources and pollutants. It is assumed that the consumption of natural

[1] The ecological flows are taken from the Physical Input-Output Table (PIOT) for Germany (STAHMER et al., 1997).

services is 'free of charge' for the industries. Hence the presented approach interprets the evaluated physical flows of sector 'Nature' as natural subsidies.

However, input-output tables generally present subsidies with a negative sign and since 'Nature' is considered as intermediate sector, negative input-coefficients occur in the A-matrix. Subsequently backward output multipliers decline in dependence on the quantitative consumption of physical flows and on the evaluation set by the user. The more natural services are absorbed (and the higher these are evaluated) the bigger are the multiplier decreases. Eventually the explicit consideration of ecological flows within the intermediate quadrant enables the user to identify (more) sustainable[2] multipliers.

Within the frame of the model the mentioned backward multipliers determine, besides backward spreads and forward multipliers and spreads, key sector indices. Thus the pricing of natural services finally results in a modification of key sector indices for the ecological extension. Consequently a comparative analysis of key sector indices for 58 intermediate sectors for the German economy in 1990[3] with and without the integration of natural services can be performed.

Having in mind the growing awareness of ecological problems, ECOLIO could provide valuable input for regional economics and policies in Germany. If instead of the conventional approach the suggested ecological approach is applied, the tradeoff between additional sectoral output on the one hand and more intensive usage of natural services on the other hand becomes more transparent. The obvious occurrence of the opportunity costs for natural usage could particularly support a sensitivity analysis performed by the user.

2 The conventional approach within the frame of ECOLIO

Starting basis of the ecological extension is the conventional calculation of multipliers and key sector indices for 58 sectors of the German economy, which is outlined in this chapter. The elaboration of key sector indices follows methodologies suggested particularly by WEST (1998) and the DIW[4] (1974, 1995).

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[2] Since 'sustainability' or 'sustainable development' can be interpreted in various ways, it should be mentioned that sustainable development is - for this study - considered to be a development, that satisfies the needs of the present without risking, that future generations cannot satisfy their needs anymore. This definition is in line with the definition of sustainability set by the Brundtlandt Report in 1987.

[3] As soon as the next PIOT will be published (already announced), the data can be included into the analysis.

[4] DIW: German Institute for Economic Research

The analytical part starts with the generation of input coefficient Matrix A (with the elements a_{ij}[5]). Via the Leontief inverse matrix (I-A)$^{-1}$ (with the elements b_{ij}) normalized output multipliers form the backward linkages L_j:

$$L_j = \frac{n \sum_{i=1}^{n} b_{ij}}{\sum_{j=1}^{n} \sum_{i=1}^{n} b_{ij}}$$

If L_j > 1 the stimulus induced via an additional unit of sector j's final demand yields an over average multiplier effect. Vice versa an under average effect can be expected for L_j < 1.

It is of further interest whether the multiplier effect focuses on the own sector, or whether the stimulus is spread widely. The coefficient of variation (CV) provides information about this backward spread:

$$CV_j = \frac{\sqrt{\frac{1}{n-1} \sum_{i=1}^{n} (b_{ij} - \frac{1}{n} \sum_{i=1}^{n} b_{ij})^2}}{\frac{1}{n} \sum_{i=1}^{n} b_{ij}}$$

Due to a better comparison CV_j is normalized and labeled V_j :

$$V_j = \frac{nCV_j}{\sum_{j=1}^{n} CV_j}$$

If the additional demand in sector j yields above average backward spreads, i. e. several other sectors would benefit from the initial investment, V_j will be relatively small (V_j<1). Vice versa, high V_j (>1) indicate a high share of self-contributions.

Besides the demand driven backward linkages and spreads, the elaboration of key sector indices includes supply driven forward effects. Based on the output coefficient Matrix $\overline{A}$ (with the elements $\overline{a}_{ij}$[6]) forward linkages $\overline{L}_i$ and spreads $\overline{CV}_i$ / $\overline{V}_i$ are – via the Ghosh inverse matrix (I-$\overline{A}$)$^{-1}$ (with the elements $\overline{b}_{ij}$) - determined equivalently to the backward linkages and spreads:

[5] with $a_{ij} = \frac{x_{ij}}{x_j}$

[6] with $\overline{a}_{ij} = \frac{x_{ij}}{x_i}$

$$\overline{L}_i = \frac{n\sum_{j=1}^{n}\overline{b}_{ij}}{\sum_{i=1}^{n}\sum_{j=1}^{n}\overline{b}_{ij}}; \qquad \overline{CV}_i = \frac{\sqrt{\frac{1}{n-1}\sum_{j=1}^{n}(\overline{b}_{ij} - \frac{1}{n}\sum_{j=1}^{n}\overline{b}_{ij})^2}}{\frac{1}{n}\sum_{j=1}^{n}\overline{b}_{ij}}; \qquad \overline{V}_i = \frac{n\overline{CV}_i}{\sum_{i=1}^{n}\overline{CV}_i}$$

”The forward linkages are now defined in terms of input multipliers, which measure the effect on total output of all sectors associated with a unit change in the primary inputs of sector i” (WEST, 1998, p. 4).

Accounting backward and forward effects, key sector indices can be elaborated. Therefore ECOLIO defines first the product matrix M (element by element multiplication):

$$M = L_j \bullet \overline{L}_i$$

The second step is to include the spread indices into the analysis. ”Noting that the mean of the spread indices is unity, an adjusted set of indices symmetric to the original set about unity can be constructed by” (WEST, 1998, p. 5):

$$U_j = 2i - V_j \quad \text{and} \quad \overline{U}_i = 2i - \overline{V}_i$$

where i is an n-element column vector of ones.

Since low values for V and $\overline{V}$ respectively show wide spread effects for the regional economies the assumed goal of regional policies is to get large values for U and $\overline{U}$ and therefore to maximize the spread product index (element by element multiplication):

$$S = U_j \bullet \overline{U}_i$$

Finally, the key sector indices vector can be given by (element by element multiplication):

$$key = M \bullet S$$

It is important to keep in mind that the backward and forward multipliers are independent from the absolute sectoral flows. However, if key sectors are elaborated the significance of the absolute sectoral output cannot be neglected. Hence a weighting factor w is introduced. The weighted key sector index is defined as follows:

$$key_j(w) = w_j * key_j$$

where the weighting factor w_j is defined as normalized share of sectoral input of the total input.

Taking into account backward income and forward investment multipliers and spreads, the conventional part of ECOLIO enables the user to calculate specific key sector indices as well. However, these do not change within the ecological analysis and therefore remain unconsidered in this paper.

3 Physical flows and their integration into the model

Physical input-output tables in Germany

In 1997 the German Office of Statistics presented the first detailed Physical Input-Output Table (PIOT) for West Germany based on data of the year 1990. Though the published table delivers very detailed information about the material flows STAHMER, one of the authors, points out that it seems appropriate to focus on sectoral usage of natural resources and the generation of pollution, rather than trying to draw a complete picture. Table 1 provides the simplified structure of a PIOT. All entries are measured in tons. In modern economies more than 90% of the physical flows are related to natural resources as input and emissions as output respectively (STRASSERT, 1997).

Table 1: Structured breakdown of the German PIOT, flows in tons

into from	Sector 1 – n	Intermediate Output	Nature	Final Demand	Total Output
Sector 1 - n	goods (<10% of total physical flows)		emissions, non-recyclable waste	goods	
Intermediate Input					
Nature	Resources				
'Primary Input'	emissions, nonre-cyclable waste				
Total Input					

The German Office of Statistics publishes physical input-output tables for 59 branches, including a sector 'External Environmental Protection'. This sector covers in particular 'Sewage for Treatment' and 'Waste for Disposal'. While these activities are already incorporated into the monetary tables, flows from and into nature such as solid energy resources, minerals, natural water and various kind of gases or sewage are exclusively taken into account by the physical tables.

The critical point of the physical analysis is that inputs and outputs are either of physical or of intellectual nature. And while on the one hand the additional data clearly improve the ecological part of the research, they do on the other hand neglect the intellectual or immaterial inputs and outputs. If it is true, that "all history - as well as all current experience - points to the fact that it is man, not nature, who provides the primary resource: that the key factor of all economic development comes out of the mind of man" (SCHUMACHER, 1993, p. 60) important information is missing in the physical tables.

One possibility to overcome this problem is the 'parallel-accounting' approach followed by the German Office of Statistics, where Social National Accounting (SNA) and ecological accounting are elaborated simultaneously and connected by an environmental satellite system. The other possibility is to monetarize natural usage and to include nature as emancipated partner within the framework of the SNA.

From physical to monetary flows

"The difficulty of taking into account qualitative aspects of material flows is a severe disadvantage of physical accounting. Poisonous and innocuous materials are 'valued' only by their weights, but not according to their impacts, e.g. on living beings. Such analysis has to be made in a second step, using suitable weighting schemes" (STAHMER, 2001, p. 127). The monetary evaluation of the material flows could be considered as one appropriate weighting scheme. However, the evaluation of natural services in monetary terms is discussed vividly. Though these discussions often start and unfortunately also result in polarizing points of views neither monetarization nor the strict physical analysis should be considered as the superior way to follow the path of sustainability. Sometimes it can be dangerous and even perverse to monetarize external (environmental) effects, while in other cases differentiated toxicity factors may not be sufficient to cause a reversal in political and economic thinking and acting.

Several studies have been published in the field of ecological economics that deal with the evaluation of ecological flows and the results serve as exogenous inputs for this model (see table 5). But before practically evaluating one ton of carbon or sulphur dioxide (etc.), some principal problems need to be addressed that occur when physical flows are transferred into monetary ones within ECOLIO.

Compared to the physical tables provided by the national office of statistics, the physical part of ECOLIO includes **nature as an intermediate sector**. Thus the first quadrant incorporates resources and emissions. (No data are available for the quantities from ‘Nature’ to ‘Nature’).

Table 2: Physical part of ECOLIO (structure)

PIOT	Agriculture, manu-facturing, services	Nature	Sum	Final Demand	Total Output
Agriculture, manu-facturing, services	Goods (<10% of total physical flows)	Goods, emissions, non-recyclable waste		Goods	
Nature	Resources	No flows		Resources	
Sum					
'Primary Input'	No flows	Emissions, non-recyclable waste			
Total input					

The consideration of a sector ‘Nature’ within the intermediate quadrant clearly distinguishes this approach from other methodologies. While FRERICHS sees the role of nature as supplier of primary inputs[7] STRASSERT (1997, p.3) and DALY (1994, p. 3) emphasize the analogy of the consumption of natural resources and the production of pollutants with the principle of imports and exports.

The PIOT of the German Office of Statistics, places the usage of resources as primary input on the incoming side of the SNA, while the emissions are located as category of the final demand on the expenditure side. The location within the primary input and the final demand quadrant respectively makes perfect sense as long as only physical flows are considered.

COSTANZA et al. (1997, p. 253) point out that "the services of the ecological systems and the natural capital stocks that produce them are critical to the functioning of the Earth's life-support system. They contribute to human welfare, both directly and indirectly and therefore represent part of the total economic value of the planet". On the one hand the expression 'total economic value' may suggest a classification of natural input as category of value added, and therefore as primary input. On the other hand the consideration of ecological systems as 'services' shows the close linkage to already monetarized disposal services and, concerning natural resources, to the supplier of raw materials. Thus, with regard to the transformation of physical into monetary terms, nature can alternatively be considered as intermediate sector.

While natural resources are obviously inputs for the industrial production, emissions are physical industrial output. But with the translation into monetary terms the absorption of pollution serves as input for the industrial production.

Figure 1 shows the direction of the circulation in physical terms and the monetary disposition of nature.

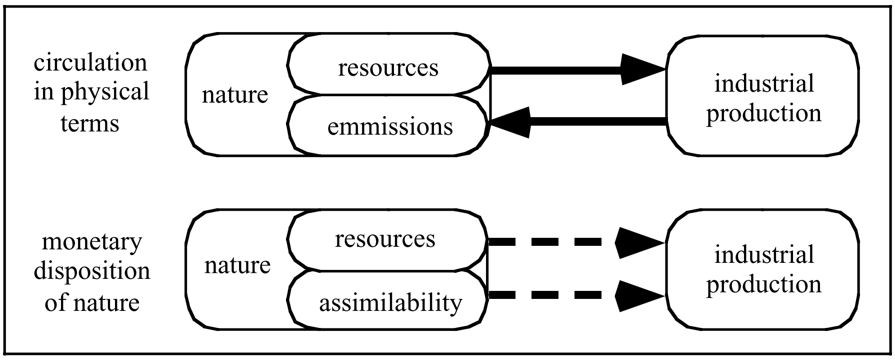

Figure 1: Monetary disposition of sector 'Nature'

This procedure is oriented at already internalized pollutants as 'sewage for treatment' or 'waste for disposal'. Aggregated to the sector 'external environmental protection' these activities are considered differently within the official physical and the monetary input-output tables (see table 3).

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[7] "Stellung des Umweltsektors als Lieferant primärer Inputs" see FRERICHS, 1976, p. 154

Table 3: Structure of intermediate quadrant German PIOT and MIOT respectively

PIOT (flows in tons)	Agriculture, manufacturing, services	External environmental services	Units
Agriculture, manufacturing, services	Goods	Goods / Sewage for treatment, waste for disposal	Tons
External environmental services	Goods	Goods / Sewage for treatment, waste for disposal	Tons
MIOT (flows in EURO)	Agriculture, manufacturing, services	External environmental services	Units
Agriculture, manufacturing, services	Goods and services	Goods and services	€
External environmental services	Disposal services	Disposal services	€

Considering the physical flows 'sewage for treatment' and 'waste for disposal' are classified as output of the production process. However, the monetary output delivered from agriculture, manufacturing or services towards the external environmental services, is limited to the valuable output such as capital goods and transport or banking services. The physical units of the polluted output vanish. Only the costs for the disposal services are included. These costs are regarded as intermediate inputs.

The ECOLIO approach for not yet internalized natural usage is similar. Emissions produced by the industry and absorbed by the nature are considered as absorption or disposal services (output of sector nature), and therefore as intermediate input for the production processes. Hence (the provision of) resources as well as (the absorption of) emissions are listed in the row 'Nature' of the monetary part of the input-output table applied by the model (see Table 4).

Table 4: Monetary part of ECOLIO (structure)

Flows in €	Agriculture, manufacturing, services	Nature	Sum	Final Demand	Total Output
Agriculture, manufacturing, services	Goods, services	Goods, services		Goods, services	
Nature	Resources, disposal services	No flows		Resources, disposal services	
Sum					
'Primary Input'	No flows	No flows			
Total input					

The column of sector ‘Nature’ shows monetarized industrial output that is used by 'Nature' to produce its output. Due to the transfer of physical into monetary units only the 'goods' but not the so-called 'bads' (e.g. emissions) appear in the column[8].

Within the frame of the market system, the behavior of the economic actors is not of an altruistic nature. Efforts to install environmental protection measures are either driven by legislation or by the market (e.g. nature friendly decisions provide a green image, ecological taxation). Since the traditional monetary input-output tables already enclose all operational environmental costs for the enforced measures the industries are not expected to provide any monetary goods to the production of the newly introduced sector ’Nature’[9]. E.g. old steel products, that are recycled are part of the market process and cannot be considered again. With the exception of 6500 tons (0.001% of total flows), this assumption is consistent with the PIOT provided by the German office of statistics. According to the official statistics roundabout 6500 tons construction waste per year are used for the renaturization of soft coal mines. It is assumed, that the existing costs e.g. for transport are included in the ordinary tables and that the additional value of this waste for generating natural resources is zero. Consequently the assumption leads to zeros in the intermediate part of the corresponding column 'Nature' for the monetary table (see also next chapter, table 6).

The efforts to generate ecologically more appropriate multipliers include the (at least) partial internalization of the environmental costs. But since market prices do not exist for these inputs, the evaluation of nature becomes inescapable for the transfer from physical to monetary flows. Table 5 provides – based on a literature review - price corridors for diverse categories of resources and emissions listed in the PIOT. Since imputed market values for changes in environmental quality "are now much more robust than several decades ago" (DARMSTADTER, 2000, p. 13) these corridors shall give a good idea of ecological evalution based mainly on Willingness to accept (WTA) and Willingness to pay (WTP) concepts.

Though market values may indeed be 'more robust' than several years ago, monetarizing environmental flows still causes various problems. With regard to the natural resources market prices - if existing at all - rather reflect costs for the exhaustion than the degree of scarcity. Considering pollutants the complex and often non-linear correlations of different emissions make it difficult to determine the 'correct' price of a specific category. Dynamic models could solve the problem by generating prices endogenous within a given set of assumptions and taking into account future emission targets that have to be fulfilled. Though it is planned to embed ECOLIO into a dynamic environment, the current character of the model is of static nature. Therefore the user of the model can set the prices within the exogenous given price corridors. Thus the user can perform a detailed sensitivity analysis despite the missing of dynamic features.

[8] As already mentioned emissions are only considered as necessity to provide absorption services by nature, which is taken into account as industrial input rather than industrial output.

[9] Though exceptions prove as ever the rule, altruistic ecological efforts are neglectable up to now. Additionally it is hardly possible to separate altruistic and opportunistic endeavours.

Table 5: Suggested price corridors for resources and pollutants in €/t

Resources[10]	Min	Reference	Suggest[11]	Reference	Max	Reference
Coal[12]	0	IWW[13]	5	IWW	32	IWW
Crude oil, Gas	0	IWW	4	IWW	26	IWW
Stones, clay, sand	0	IWW	0	IWW	0.5	IWW
Natural water[14]	0.02	IWW	0.25	IWW	0.60	VILL[15]
Cooling water	0	IWW	0	IWW	0.03	IWW
Pollutants						
Directly derived sewage	0	IWW	0.08	KAI[16]	0.10	IWW
Carbon monoxide CO	0.50	IWW	6	BVWP[17]	15	BLEIJ[18]
Carbon dioxide CO_2	4	UIC[19]	20	UIC	50	UIC[20]
Di-Nitrogen Oxide N_2O[21]	440	TOL[22]	750	TOL	1250	TOL
Nitrogen oxides NO_x	750	BLEIJ	1200	BVWP	4200	BLEIJ
Methane CH_4	30	TOL	45	TOL	70	TOL
Sulphur dioxide[23] SO_2	500	BVWP	3000	ZEW[24]	3200	BLEIJ
Volatile Organic Compounds	500	BLEIJ	4000	BLEIJ	6000	BLEIJ

10 It is important to emphasize that the evaluation of energy resources is based on the their scarcity only. The different emissions resulting from the combustion processes of coal, crude oil or gas are not considered at this point, but are taken into account separately below. The evaluation of the scarcity of energy resources is oriented at the costs for alternative energy production (e.g. windparcs, solar power). The maximum evaluation of natural water is based on the costs of desalinization. Transport costs are neglected.

11 The suggested price is not necessarily an average evaluation, but rather a price close to the prices recommended by the majority or the result of own estimations

12 The PIOT 1990 does not split up energy resources in further detail. However, the sectoral data provide sufficient information to split up coal and crude oil / crude gas. A further disaggregation into (different types of) hard and brown coal is not possible. Though the study could indeed benefit by a more detailed classification of energy resources,

13 IWW: The estimations have been elaborated at the Institute for Economic Policy Research, University Karlsruhe (IWW) and follow methodologies outlined e.g. by HOHMEYER (1992, p. 10)

14 Water that is taken directly from nature (e.g. groundwater).

15 VILL: de VILLIERS, 2000, p. 419

16 KAI: KAISER, 1990, p. 294

17 BVWP: German ‘Bundesverkehrswegeplan‘ BVWP, 1992

18 BLEIJ: BLEIJENBERG et al. (1994)

19 UIC: UIC Report 2000 (Editor: INFRAS and IWW, 2000)

20 The UIC report points to a conservative estimate between 8 and 280 DM/ton and an illustrative restricted price range from 40 to 100 DM/ton (INFRAS/IWW 2000, table 122, p. 209).

21 Often referred to as Laughing Gas

22 TOL, DOWNING, 2000

23 As a consequence of poor data availability the also important pollutant sulphur trioxide is not considered here.

24 Emission targets for sulphur dioxide have been elaborated in the 'Protocol of Oslo' in 1994 (KOSCHEL et al., 1998, p. 168ff) According to a study by ZEW, this target can be fulfilled by the distribution of SO_2-certificates. The appropriate price for the right to pollute 1 ton sulphur dioxid should be 6000 DM (KOSCHEL et al., 1998, p. 225ff, p. 296)

A critical point is, that though the value of resources is not yet considered in the monetary tables, the pertinent costs for the extraction and the usage of these resources are already included. If finally the value of the natural output is calculated within the input-output framework, these costs should be separated and added to the sector 'Nature'. Thus the subsidies would become smaller. Unfortunately the empirical efforts would be too high for the expected benefits.

4 The elaboration of ecologically more appropriate key sector indices

The monetarization of services provided by nature does not imply that industry will in fact bear the ecological costs. But if natural consumption is monetarized and if further on industry is not willing to balance the ecological account, sector ‘Nature’ (that aggregates the diverse resource contributions and emission absorbtions) provides payments in kind of environmental services. These payments[25] are considered to have the character of natural subsidies and appear with a negative sign in the intermediate matrix. To illustrate the following procedure an exemplary 4x4 sector economy plus sector ‘Nature’ is given below.

Table 6: Exemplary ecological input-output table applied within 'ECOLIO’ (in 1000 €)

Sector	1	2	3	4	**Nature**	Sum 1	Final Demand	Total Output
1	20	15	12	17	**0**	64	46	110
2	18	25	17	15	**0**	75	60	135
3	16	13	22	18	**0**	69	51	120
4	14	16	20	28	**0**	78	62	140
Nature	**-20**	**-5**	**-10**	**-5**	**0**	**-40**	**0**	**-40**
Sum 2	48	64	61	73	**0**	246	219	465
Net Value Added	35	56	37	53	**0**	181		
Depreciation	7	10	12	9	**0**	38		
Ecomarge	**20**	**5**	**10**	**5**	**-40**	**0**		
Total Input	110	135	120	140	-40	465		

At first the application of natural subsidies leads to decreasing sectoral outputs, which can be interpreted as a current overestimation of the gross production value. It can be argued that so far consumed but not paid natural contribution must be subtracted from the industrial production as well as it is done with governmental transfers.

On the other hand the careful incorporation of the ecological approach into the traditional SNA is a main aim of ECOLIO and (hypothetical) decreasing sectoral outputs (and

[25] Hypothetical payments depend on the physical quantities and the chosen prices for each category of naturla services.

subsequent significant changes of the input coefficients a_{ij} caused by declining outputs x_j and constant intermediate flows x_{ij}) would not fulfill this criteria.

To ensure the comparability with the traditional approach, the supposed natural subsidies are equalized via a row called 'Ecomarge' in the primary input quadrant. Though the main purpose of 'Ecomarge' is of technical character, it could also be interpreted as kind of supposed ecological depreciation. The sectoral natural depreciation corresponds to the inputs delivered by nature in the intermediate quadrant. The total natural depreciation corresponds to the total exhaustion of the natural capital stock[26], which is listed in the cell 'Ecomarge (row) / Nature (column)'. The negative sign reflects the loss of natural capital.

Following the conventional Leontief approach, high output multipliers partly result from an intensive but 'gratis' usage of natural capital. Considering ecological services as natural subsidies will cause smaller and therefore ecologically more appropriate output multipliers. Relatively intensive (direct and indirect) natural usage results in strongly declining multipliers. Vice versa nature friendly production is 'rewarded' by rather small decreases. However, once the natural subsidies have been accounted adequately, this ecological concept follows the general reasoning of preferring relatively high output multipliers[27]. Consequently (more) sustainable key sector indices can be calculated in line with the methodology applied for the conventional technique in section 2.

Backward linkages and spread effects

In order to allow a comparative analysis the calculation of linkage, spread and finally key sector indices is based on the conventional approach described in section 2. Basic changes occur particularly for the calculation of the output multiplier.

From the economic point of view the existence of natural subsidies and the assignment within the intermediate quadrant is one alternative among various possibilities. However, mathematically the negative x_{ij} and especially the negative coefficients a_{ij} (i=n+1, j=1,..., n) have to be scrutinized closely. With regard to the appearance of negative a_{ij} the Leontief inverse cannot be calculated reasonably without the following assumptions:

A1 $\quad a_{ij} \geq 0,\quad$ i,j = 1...n (former intermediate sectors)

A2 $\quad a_{ij} \leq 0,\quad$ i = n+1 (Nature), j = 1...n

A3 $\quad a_{ij} = 0,\quad$ i = 1...n, j = n+1 (Nature)

[26] Natural capital is defined as the value of energy resources and fresh water reservoirs and of the capability to absorb further industrial emissions.

[27] In contrast to this concept, ECOLIO offers the alternative calculation mode ‘eco2’. According to 'eco2' sectors with high output multipliers often follow the characteristics of 'The German Throughput Economy' (criticized by STRASSERT, 1998), whereas branches with similar income effects and relatively small output multipliers fulfill the criteria of a sustainable development in a more appropriate way (see also outlook).

The first assumption describes the condition for the ordinary intermediate relationships, which do not include the sector 'Nature'.

Monetarized output of sector ‘Nature’ is negative or zero, i.e. the production value of sector j is decreased by the estimated value of natural services absorbed by sector j (assumption A2).

Assumption A3 shows that the production process does not provide additional inputs for the production of natural resources, i.e. all potential industrial inputs are already included within the ordinary monetary tables.

Since natural services are incorporated in monetary terms into the intermediate quadrant, the approach directly affects the core of the input-output analysis. With regard to the exemplary economy, presented by table 6, the model determines A-matrices without and including natural services.

Conventional A - matrix	$j=1$	$j=2$	$j=3$	$j=4$
$i=1$	0.18	0.11	0.10	0.12
$i=2$	0.16	0.19	0.14	0.11
$i=3$	0.15	0.10	0.18	0.13
$i=4$	0.13	0.12	0.17	0.20

Extended A - matrix	$j=1$	$j=2$	$j=3$	$j=4$	*Nature*
$i=1$	0.18	0.11	0.10	0.12	0
$i=2$	0.16	0.19	0.14	0.11	0
$i=3$	0.15	0.10	0.18	0.13	0
$i=4$	0.13	0.12	0.17	0.20	0
Nature	–0.18	–0.04	–0.08	–0.04	0

Starting from the A-matrix the Leontief inverse matrix $(I-A)^{-1}$ can be calculated. Due to the assumptions A1, A2 and A3 the calculation including sector ‘Nature’ does not interfere with the (conventional) interindustrial part. A comparison of the Leontief inverse according to the conventional A-Matrix and the extended version shows equal b_{ij} for the four industrial sectors. However, significant changes occur for the output multipliers, represented by the last row 'sum'.

Conventional Inverse	$j=1$	$j=2$	$j=3$	$j=4$
$i=1$	1.37	0.26	0.27	0.29
$i=2$	0.38	1.36	0.34	0.30
$i=3$	0.34	0.25	1.37	0.31
$i=4$	0.35	0.30	0.38	1.40
sum	2.43	2.17	2.37	2.29

Extended Inverse	$j=1$	$j=2$	$j=3$	$j=4$	*Nature*
$i=1$	1.37	0.26	0.27	0.29	0
$i=2$	0.38	1.36	0.34	0.30	0
$i=3$	0.34	0.25	1.37	0.31	0
$i=4$	0.35	0.30	0.38	1.40	0
Nature	–0.30	–0.13	–0.19	–0.14	1
sum	2.13	2.04	2.18	2.15	1

According to the conventional approach, i.e. without considering 'Nature' as intermediate sector the output multiplier for sector 1 equals 2.43 €. Including sector 'Nature' one € additional final demand for sector 1, which is – in this example – supposed to use nature capital intensively[28], results in a total effect of 2.13 € (including initial €).

[28] $|a_{Nature,1}| \; > \; |a_{Nature,j}|$ for j = 2,3,4

Since all sectors are supposed to use natural capital, the first general effect of the applied methodology is the generation of decreasing output multipliers for any sector. However, the magnitude, which depends on the intensity of natural usage, differs significantly. Hence the second more specific effect is a reassignment of the sectoral ordering. According to the traditional approach sector 1 shows the highest multiplier for the examplary economy, followed by sector 3, sector 4 and finally sector 2. Including 'Nature' sector 3 takes the lead, followed by sector 4, sector 1 and sector 2. Thus, if regional policy-makers include output multiplier into their decision making process, the ecological approach could influence the outcomes significantly all the more since the model enables the user to apply different prices for each category of natural resources and pollutants and to observe the effects on the multipliers simultaneously.

Based on the modified inverse the ecological linkage index L_j^{eco} can be derived[29]:

$$L_j^{eco} = \frac{n \sum_{i=1}^{n+1} b_{ij}}{\sum_{j=1}^{n} \sum_{i=1}^{n+1} b_{ij}} \quad (\mathrm{j} = 1,...,\mathrm{n} \ \text{ and } \mathrm{i} = 1,...,\mathrm{n} + 1)$$

The next step is the derivation of the ecological oriented coefficient of variation CV_j^{eco} and the normalized version V_j^{eco} as indicators for backward spread effects.

$$CV_j^{eco} = \frac{\sqrt{\frac{1}{n} \sum_{i=1}^{n+1} (b_{ij} - \frac{1}{n+1} \sum_{i=1}^{n+1} b_{ij})^2}}{\frac{1}{n+1} \sum_{i=1}^{n+1} b_{ij}} \qquad V_j^{eco} = \frac{n * CV_j^{eco}}{\sum_{j=1}^{n} CV_j^{eco}}$$

Forward linkages and spreads

The forward multipliers show the direct and indirect effects for the economy, if the primary inputs of the considered sector in- or decrease. Since sector ‘Nature’ does not absorb any goods (but only ‘bads’) by the industrial sectors, the forward linkages for sector 1 to 4 remain constant (zeros in column of sector ‘Nature’). Contrary the industrial sectors absorb natural services intensively, what should cause significant forward multipliers for sector 'Nature'.

Equivalently to the approach applied in section 2 the output coefficients $\bar{a}_{ij}$ are calculated. Since intermediate and total output show a negative sign (see table 6) $\bar{a}_{Nature,j}$ is positive.

According to WEST (1998, p. 4) increasing intermediate outputs of sector i may alleviate a bottleneck for the production of sector j. Following this interpretation the high forward

[29] Notice that the ecologically appropriate backward and forward linkages and spreads include any services supplied by nature and absorbed by the industries (i=1,..., n+1), but that, due to the zeros in the intermediate column of sector ‘Nature‘, neither linkages nor spreads have been calculated for sector ‘Nature‘ (j=1, ..., n).

multiplier for sector 'Nature' shows the over average relevance of natural inputs to alleviate bottlenecks. Indeed industrial production has exploded in the last decades, last but not least at the cost of nature. Eventually ECOLIO determines ecological forward linkages $\overline{L}_i^{eco}$ and spreads $\overline{CV}_i^{eco}$ / $\overline{V}_i^{eco}$.

$$\overline{L}_i^{eco} = \frac{n+1\sum_{j=1}^{n}\overline{b}_{ij}}{\sum_{i=1}^{n+1}\sum_{j=1}^{n}\overline{b}_{ij}} \qquad \overline{CV}_i^{eco} = \frac{\sqrt{\frac{1}{n-1}\sum_{j=1}^{n}(\overline{b}_{ij}-\frac{1}{n}\sum_{j=1}^{n}\overline{b}_{ij})^2}}{\frac{1}{n}\sum_{j=1}^{n}\overline{b}_{ij}} \qquad \overline{V}_i^{eco} = \frac{(n+1)\cdot\overline{CV}_i^{eco}}{\sum_{i=1}^{n+1}\overline{CV}_i^{eco}}$$

Identification of ecologically more appropriate key sectors

After the incorporation of natural usage in monetary terms, the definition of key sectors follows the traditional way of thinking. A key sector is still defined as sector with high linkage indices and high spread effects. However, the incorporation of nature into the analysis leads to smaller backward multipliers for nature-intensive producing sectors. Hence the ordering of key sector indices may change. If regional policy includes key sector indices into the decision making process, the applied strategies can be scrutinized more closely with regard to the natural consumption. The first step towards ecologically based key sectors is the elaboration of an ecological backward and forward linkage product matrix as:

$$M^{eco} = L_j^{eco} \bullet \overline{L}_i^{eco}$$

In line with the traditional approach large elements of M identify sectors with high backward as well as high forward linkages. Second ecological spread indices are introduced analogue to the conventional analysis. Again U_j^{eco} and $\overline{U}_i^{eco}$ are calculated first (see section 2):

$$U_j^{eco} = 2i - V_j^{eco}$$
$$\overline{U}_i^{eco} = 2i - \overline{V}_i^{eco}$$

where i is an n-element column vector of ones.

Since large values for U^{eco} and $\overline{U}^{eco}$ identify wide spread effects for the regional economies the goal is to maximize the spread product index S^{eco}:

$$S^{eco} = U_j^{eco} \bullet \overline{U}_i^{eco}$$

The last step is the elaboration of the key sector index vector:

$$key^{eco} = M^{eco} \bullet S^{eco}$$

Though the elements cannot be interpreted as multipliers, the general decline of the ecological indices versus the traditional results reflects the intensive usage of the natural capital stock. With a simple normalization process the mean could be set to 1 again.

Still the weighted concept is an appropriate alternative. However, the weighting factors are slightly modified. The sectoral inputs are considered without 'Ecomarge'. Thus weighting factors get smaller for (in absolute terms) nature intensive production:

$$w_j = \frac{n * (x_j - Ecom\arg e)}{x}$$

and finally the weighted ecological key sector indices

$$key^{eco}(w) = w_j^{eco} * key^{eco}.$$

Model results for the German economy

The model offers the calculation of conventional key sector indices for 1986, 88, 90 (West-Germany) and 1991, 93 and 95 (Unified Germany). Due to the data availability the ecological part of ECOLIO focuses the region of former West-Germany and the year 1990. Though the German Office of Statistics planned to publish a physical input-output table for 1995 in autumn 2001, the release of new data has been adjourned until summer 2002. As soon as new data are available ECOLIO could be ‘fed’ with the new physical flows[30] and would generate results for the unified Germany of 1995.

According to the above described approach the Leontief output multiplier will decline for any sector that consumes nature. But since, dependent on the intensity of natural usage, the decreases vary significantly the ranking of the sectoral multipliers including natural services differs significantly from the conventional ordering without the consideration of nature. Consequently the key sector indices, which are partly determined by the output multipliers, will be modified by the natural evaluation as well. Potential environmental spread effects may intensify the ecological influence for the identification of ecological key sector indices. The normalization process may even lead to higher key sector indices for nature friendly sectors.

Smallest effects can be expected for the weighted analysis. Though sectors, which do not (only) absorb natural resources and services intensively per output unit, but do (also) consume nature in high absolute terms will be 'punished' by a decreasing weighting factor, the rather significant differences of absolute monetary terms will still dominate the identification of weighted key sectors.

[30] In fact the implementation of new data can be done easily. However, it should be noted that the new PIOT for 1995 will be based on the new classification of 1995 and the results will not be comparable with the data of 1990. However, the German office of statistics is also planning to publish yearly MIOT for 1991 to 1999 based on the 95 classification and 95 prices including the relevant environmental flows. This indeed will add to the attractivity of 'ecolio'.

Table 7 gives an overview of sectors that have shown relatively high weighted key sector indices (mean is 1) as well as over average income effects[31] for the conventional approach considering the period from 1986 to 1993[32]. For comparison the table lists weighted key sector indices according to the conventional approach and according to the ecological approach, assuming the maximum prices for the disposal of pollutants[33].

Table 7: Weighted key sector indices without and including sector 'Nature' in 1990

Sector	Chemistry*	Ferrous metals	Food	Electronics
Weighted key sector index without 'Nature'	2.80	2.12	1.75	1.56
Weighted key sector index including 'Nature' (max. prices)	2.81	1.91	1.77	1.65
Δ	+0.01	-0.21	+0.02	+0.09
Sector	Energy supply	Mechanical engineering	Road transport	Road vehicles
Weighted key sector index without 'Nature'	1.55	1.43	1.43	1.35
Weighted key sector index including 'Nature' (max. prices)	0.59	1.50	1.35	1.40
Δ	-0.96	+0.07	-0.08	+0.05

* The German classification of sectors separates Chemistry and the production of chemical pulp.

While the decreases of key sector indices for 'Energy supply', 'Ferrous metals' and 'Road transport' can be expected when particularly pollutants are considered, the sectors 'Chemistry' and 'Food' are hardly affected by the natural evaluation. This does not mean that no emissions occurred but that pollution is at average level. Due to under-average pollution, indices increase for the branches 'Electronics', 'Mechanical engineering' and 'Road vehicles'.

Finally the following four screenshots give an overview of the results as they are presented by ECOLIO. While the screenshots 1 and 3 show the Leontief multipliers and weighted key sector indices for sectors 1 to 20[34] without pricing natural services, screenshots 2 and 4 provide the changes (Delta-M(ultiplier) / Delta-K(ey index)[35]) for the same sectors, if, as assumed above, maximum prices for the disposal of emissions are applied[36]. Considering the changes the light grey (for colored copies: yellow) bars mark decreases of multipliers or indices and the dark ones (blue) increases.

[31] Income effects have not been discussed here but are included in the model. They are based on income coefficients and the Leontief inverse matrix.

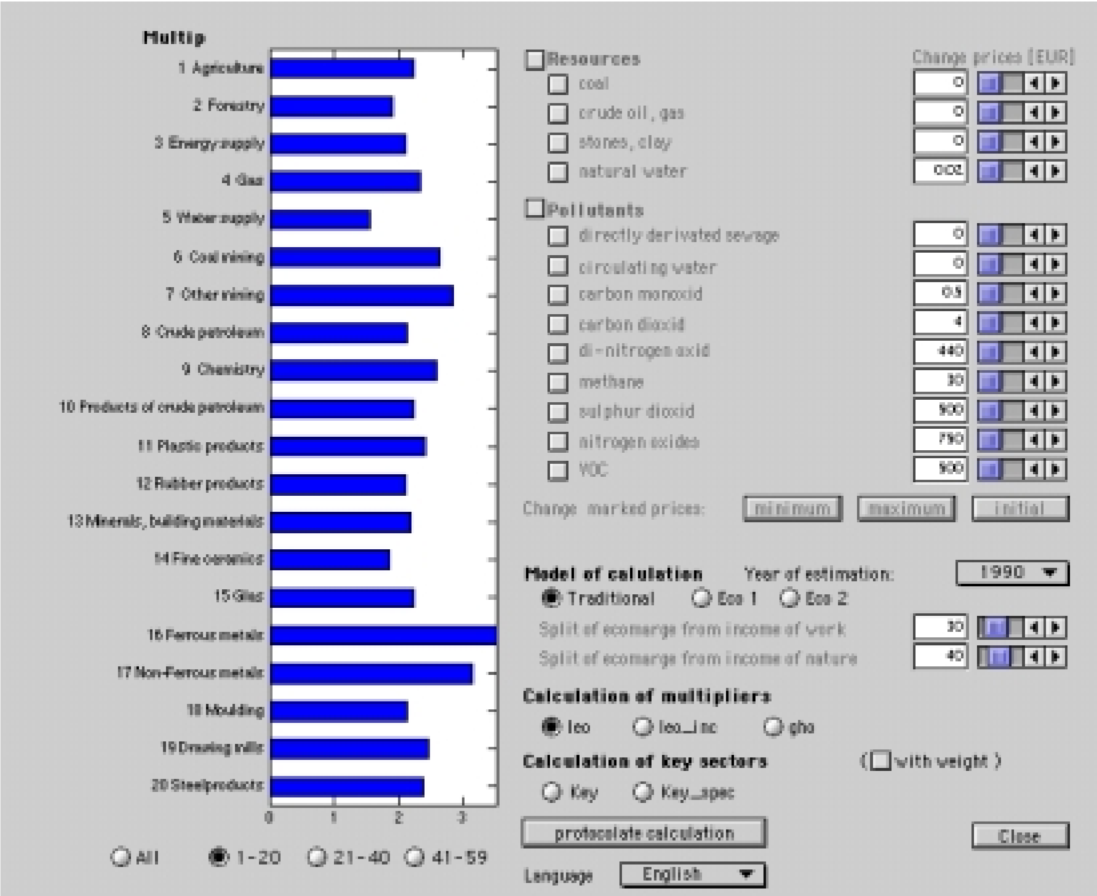
[32] The I-O table for 1995 is based on a new sectoral classification, which makes comparative analysis difficult.

[33] Natural resources and cooling water are included with minimum ecological prices.

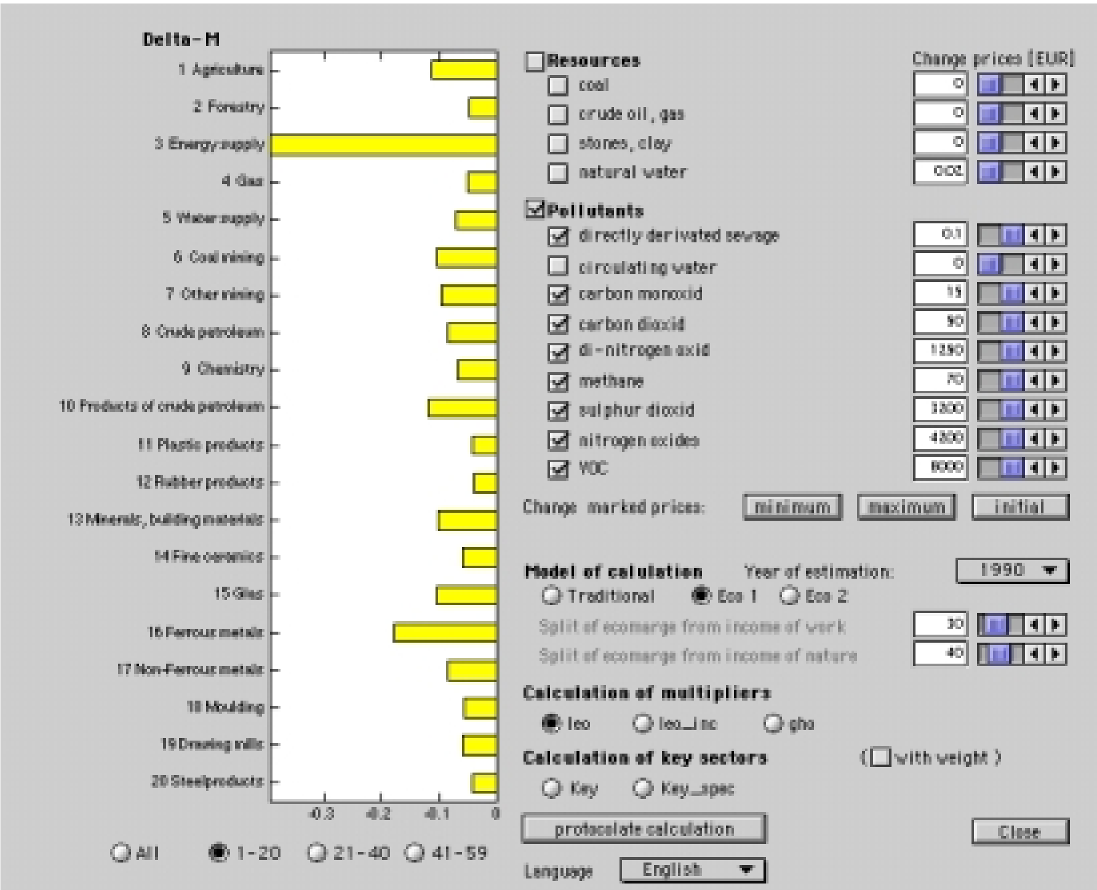
[34] To improve the clarity, the sectors are split into three groups.

[35] A Delta-M of –0.4 for sector i, points to a decrease of sector i's multiplier caused by increased natural prices.

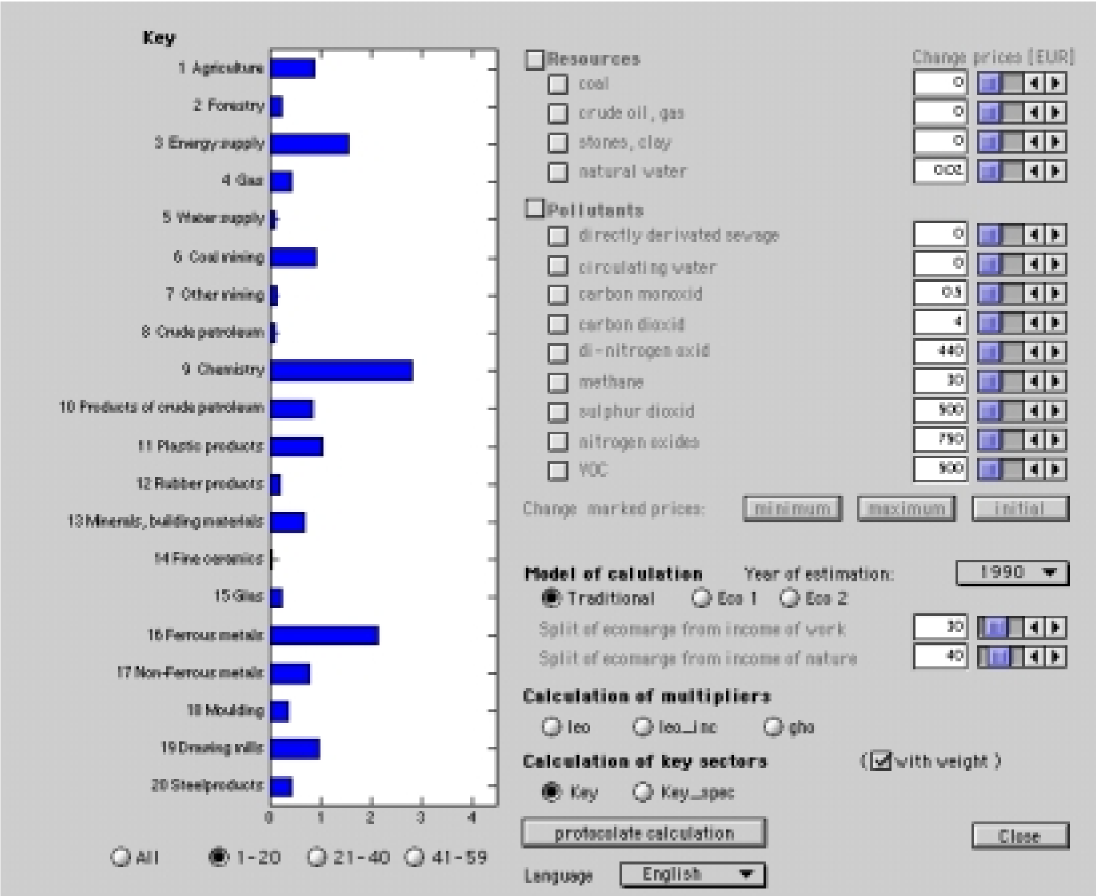
[36] The user can easily set the prices for the emissions (and the resources) separately within the suggested corridor.



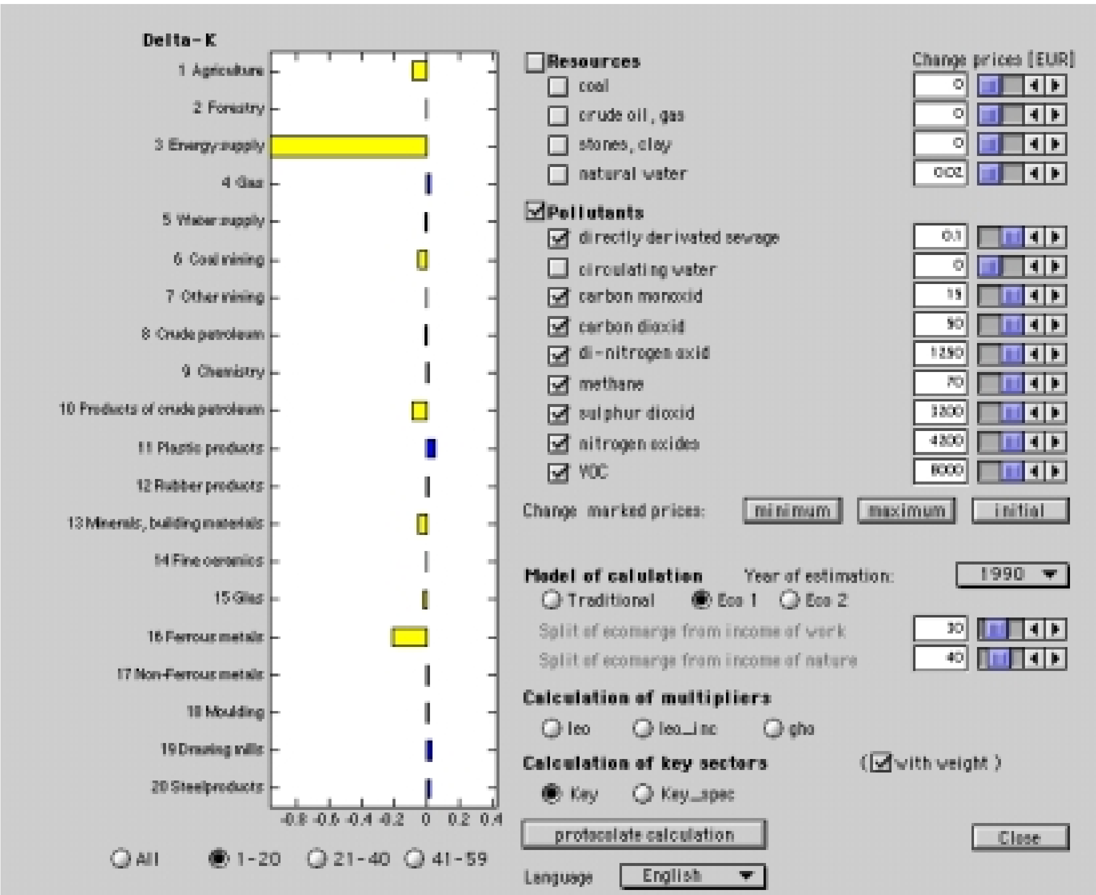
Screenshot 1: Mode: traditional, parameter: Leontief multiplier, sector 1-20



Screenshot 2: Mode: eco1, parameter: changes of Leontief multipliers caused by natural pricing



Screenshot 3: Mode: traditional, parameter: key sector indices, weighted, sector 1-20



Screenshot 4: Mode: eco1, parameter: changes of weighted indices caused by natural pricing

5 Conclusions and outlook

Conclusions

Main purpose of the outlined methodology is the integration of natural services into the analytical part of an input-output model. The presented model enables the user to evaluate several categories of resources and pollutants within exogenous determined price corridors. Once monetarized the diverse natural services are aggregated to one common sector 'Nature' that is introduced as intermediate sector. This sector does not include any flows of the conventional Monetary Input-Output Tables (MIOT) for Germany, but is based exclusively on additional information about ecological flows provided from the official German Physical Input-Output Table (PIOT).

Both, provision of resources and the absorption of emissions, are considered as inputs for the conventional sectors. Since industry does absorb these inputs without paying for them, natural services can be interpreted as natural subsidies. Thus the flows in the row of sector 'Nature' show a negative sign. According to the PIOT no goods (but only 'bads') are delivered from the conventional sectors to their natural environment[37]. Therefore the column of sector 'Nature' shows zeros. Due to these zeros Leontief multipliers and key sector indices can be calculated in line with the conventional rules.

The usage of natural capital results in declining output multipliers. The more resources are consumed and the more emissions are produced the more significant decrease the multipliers. Since the output multipliers partly determine the key sector indices, the ordering of key sector indices can be modified via the evaluation of natural services. Consequently the model enables the user to perform an ecologically driven sensitivity analysis.

Outlook

Prior goal of the outlined ecological approach has been to identify sustainable regional key sectors in line with the traditional methodology. A second variant offered by ECOLIO assumes that in contrast to the described variant, consumption of nature capital is not free of charge any longer. When emissions are produced, companies have to buy certificates in an adequate quantity from sector 'Nature' (represented e.g. by public authorities). This leads to positive valued intermediate natural services. Subsequently resource intensive production would tend to result in higher output multipliers for the analyzed sector. Main idea of this alternative approach is therefore to reconsider the concept of multipliers or at least the interpretation of these from the sustainable point of view.

Assuming an additional unit of final demand results for two sectors i=1,2 in similar spread effects the application of the traditional methodology would consider the sector with the higher output multiplier as more important for the regional development. This may be true for

[37] Note that natural protection is already included in the conventional MIOT.

under-developing regions, where the prior goal of the regional policy is to settle a strong interindustrial base as core for further development. But while high output multipliers could be seen as important stimulus for developing regions to stabilize their still fragile economic base, the focus in highly developed regions is different. In this case high output multipliers serve merely as indicator for a relatively material and/or nature intensive 'throughput production' without any guarantee of growing welfare. Thus the dependence of modern economies on material intensive but not material productive sectors can with regard to the idea of a sustainable development be doubted convincingly. Sectors with high shares of primary inputs, in particular of high wages and salaries should be regarded at least as important - though these sectors often show relatively low output multipliers. Regarding e.g. several sectors with similar income multipliers, the sectors generating the smaller output multipliers can therefore not considered to be less important. Figure 2 shows output mulitpliers and income effects (derived from the Leontief inverse) for selected sectors.

Contrary a strategy that leads to less production and equal household incomes saves natural resources and should rather be preferred over strategies favoring sectors with higher output multipliers. Considering figure 2, the output multiplier for the production of road vehicles is clearly bigger than the multiplier for sector 'Electronics'. Consequently ECOLIO concludes, within the frame of the alternative ecological approach, a higher material throughput for this sector. Since both branches show similar direct and indirect income effects the model would finally classify 'Electronics' the more sustainable sector.

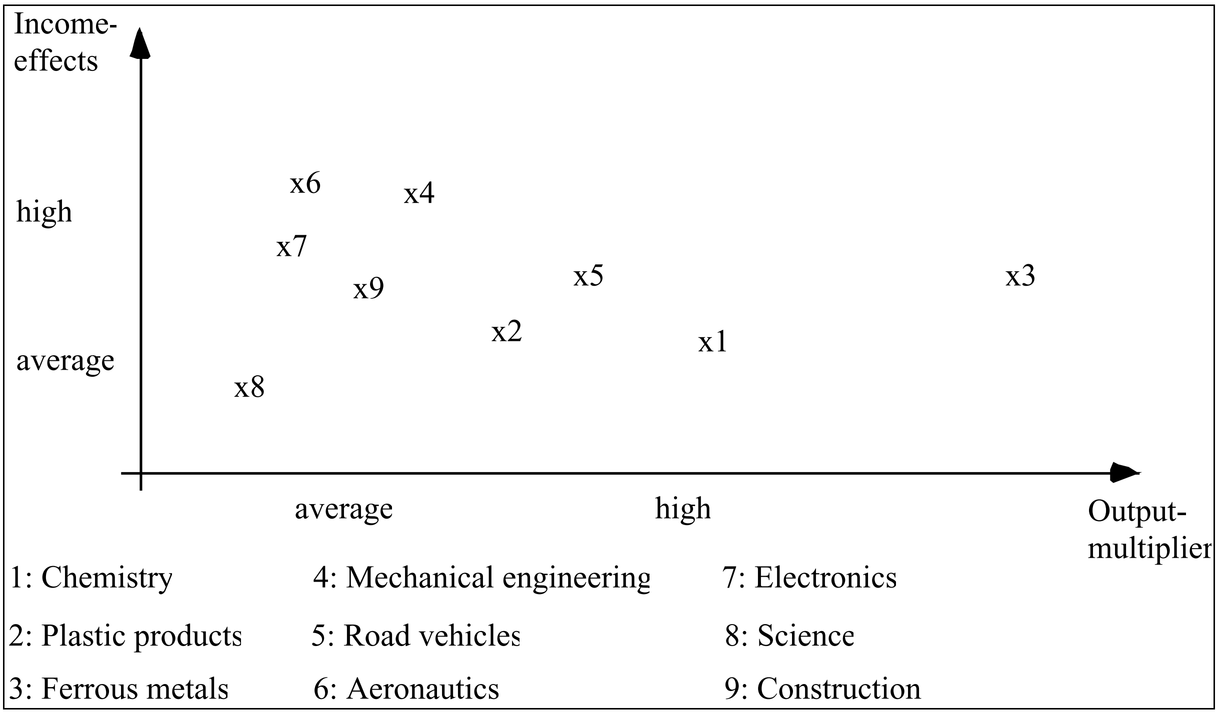


Figure 2: Output multiplier and income effects for selected sectors in1990

When, in line with the assumption of this approach, companies have to pay for natural services, production processes will change rapidly. If e.g. certificates for the right to emit sulphur dioxid have to be purchased, substitution processes from sulphur rich to sulphur poor energy resources and / or innovative technologies for sulphur poor combustion can be expected. Since these processes are accompanied by changing input coefficents, current research with ECOLIO focuses on this problem.

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