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Iterative Method to Evaluate the Ecological Cost of Imported Goods[#]

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Abstract

Ecological cost indices can be defined as the cumulative consumption of non-renewable exergy connected with the fabrication of particular products. This cumulative consumption should comprise the additional exergy consumption of non-renewable resources resulting from the necessity of compensating the deleterious effects of the rejection of waste products to the environment. Ecological cost indices can be calculated by means of the system of linear balance equations of ecological cost. Indices calculated in this way, within the regional system, take into account the ecological cost indices of imported raw materials and imported semi-finished products. It is difficult to build up a set of balance equations to determine the indices of imported goods.

In this paper the author proposes an iterative method of evaluating the ecological cost of imported goods. The results of sample calculations are also presented.

Key words: exergy, ecological cost, natural resources, environmental losses, cumulative exergy consumption.

1. Introduction

The ecological cost connected with the fabrication of particular products should result from the depletion of non-renewable natural resources (Szargut 1986, 1997, 1997; Szargut and Ziębik, 1998). This depletion is caused by consumption appearing in each link of the chain of the production processes leading to this final product. Additionally the ecological cost should also comprise the consumption of non-renewable resources resulting from the necessity of compensating the losses caused by the emission of harmful substances to the environment. Using exergy as a measure of the quality of natural resources (Szargut, 1987; Szargut et al., 1988), the ecological cost index can be defined as the cumulative exergy consumption of non-renewable natural resources connected with the production of some particular product and the additional cumulative exergy consumption connected with prevention and compensation of environmental losses. The idea of ecological cost is presented in *Figure 1*. The thermodynamic evaluation of environmental losses and natural resources has also been considered in (Frangopoulos 1992; Sciubba 1998).

The depletion of non-renewable resources is dangerous for the future existence of mankind. The ecological criterion (minimization of cumulative exergy consumption of natural resources) should be as important as the economical one.

The ecological cost indices can be determined by means of solving the set of linear ecological cost balance equations (Stanek 1998; Szargut 1995, 1997, 1999; Szargut and Ziębik 1998). Some of these equations include the ecological cost of imported goods. If the balance boundary comprises the national management, the ecological cost indices of imported goods present additional unknowns. The author proposes an iterative method of determining the ecological cost of imported goods. Results of sample calculation, obtained by means of this method, are also presented. A comparison of the results obtained by means of the iterative method

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and the simplified method (Stanek 1998; Szargut and Stanek 1998; Szargut and Ziębik 1998) used so far have also been included.

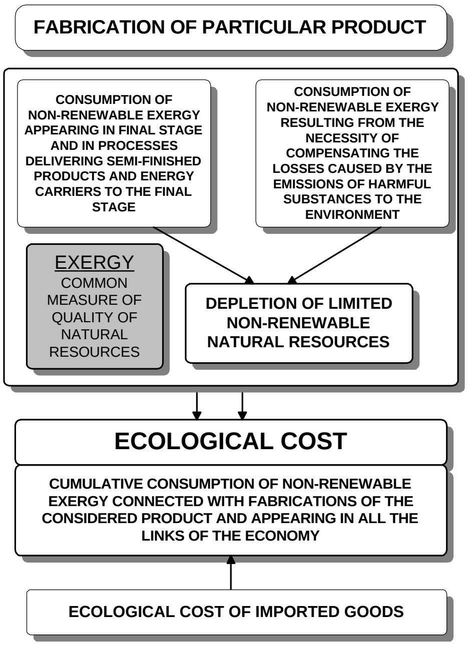

Figure 1. The idea of ecological cost calculation

In accurate calculations the set of balance equations should comprise all the branches of national management. Because of troubles with building up and solving such a set of equations, only strongly connected branches are taken into consideration.

2. Balance Equations of the Ecological Cost

Based on the idea of ecological cost calculation presented in *Figure 1*, the input-output ecological cost balance equation for the j-th branch (Szargut 1995, 1997, 1999; Szargut and Ziębik 1998) takes the form:

$$\rho_j + \sum_i \left(f_{ij} - a_{ij}\right)\rho_i - \sum_r a_{rj}\rho_r = \\ = \sum_s b_{sj} + \sum_k p_{kj}\zeta_k \qquad (1)$$

The structure of the ecological cost balance equation (Eq. 1) is explained in *Figure 2.*

In general, the ecological cost balance equation for branch "j" includes:

- ecological cost of domestic energy carriers and semi-finished products,
- ecological cost of imported goods,
- direct exergy consumption of non-renewable natural resources (ecological cost of natural resources),
- ecological cost of by-products. The by-production of goods that replace other useful products (e.g. coke oven gas replaces natural gas in ironwork furnaces) results in the decrease of the ecological cost of main products "j".

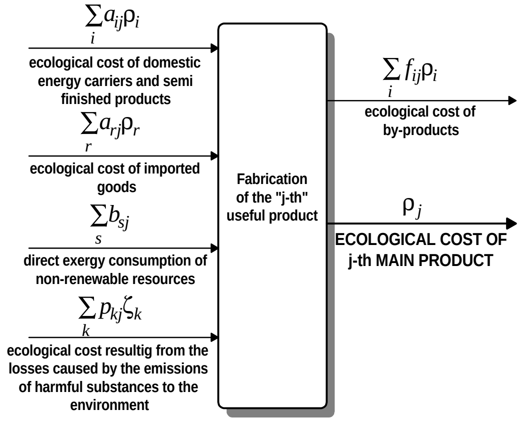

Figure 2. Structure of ecological cost balance equation

Each balance equation (1) includes the element ζ_k – the cumulative exergy consumption of non-renewable resources due to the emission of a unit of k-th waste product (indices of harmful impact). These indices, determining the additional consumption resulting from the necessity of prevention and compensation of the losses caused by the emission of harmful substances to the natural environment, should be determined for all the branches of life in which the losses appear, such as industry, health, agriculture, buildings. Because of the lack of data, the determination of these indices in this way is very difficult. It was proposed (Szargut 1997, 1999) that the index ζ_k of harmful impact (based on the monetary determination of noxious effects of emissions) could be calculated from the following formula:

$$\zeta_k = \frac{B w_k}{GDP + \sum_k P_k w_k} \qquad (2)$$

In the present work the emission of main harmful substances (NO_X, SO_2, dust) was taken into account. The indices ζ_k were calculated based on data for 1997 (GUS 1998, 2000).

The annual exergy consumption of domestic non-renewable natural resources in Poland contains the exergy of hard coal (hc), lignite (l), natural gas (ng), crude oil (co), sulphur (s) and copper (c).

$$B = B_{hc} + B_l + B_{ng} + B_{co} + B_s + B_c$$

In 1997 it was:

$$B = 4455 \cdot 10^9 \, MJ/a$$

The quantities appearing in Eq. 2 are as follows:

$GDP=143.1\cdot10^9$ US$/a, w_{SO2}=1500 US$/Mg, w_{NOX}=1500 US$/Mg, w_d=310 US$/Mg, P_{NOX}= $1114\cdot10^3$ Mg/a, P_{SO2}=$2181\cdot10^3$ Mg/a, P_d=$1130\cdot10^3$ Mg/a (GUS 1998, 2000).

Introducing indices presented above into Eq. 2, the following values of the ζ_k have been obtained:

ζ_{SO2} = 45 MJ/kg,
ζ_{NOx} = 45 MJ/kg,
ζ_d = 9.3 MJ/kg.

3. Ecological Cost of Imported Goods – An Iterative Method

The ecological cost indices can be calculated on a global or regional scale. In the first case the whole interregional exchange appears within the balance boundary. In this case it is not necessity to introduce the ecological cost of imported goods into the balance equation set.

If the balance boundary comprises the national management (regional balance boundary), the ecological cost indices of imported goods represent the additional unknowns. Thus, to solve the set of equations (1), some knowledge of the ecological cost indices of imported goods is necessary.

The depletion of non-renewable natural resources burdening the monetary unit spending for imported goods appears within the balance boundary. The ecological cost of imported goods can be replaced by the equivalent ecological cost of exported goods (Szargut 1987, 1997, 1999). It can be assumed (Szargut 1987, 1999) that the ecological cost of imported goods per unit of monetary value is the same as that burdening the exported goods. Thus, the ecological cost of imported goods is not dependent on the country they come from but results from the amount of consumption of the domestic non-renewable resources per monetary unit of imported goods.

The index ρ_r of the ecological cost of r-th imported goods can be expressed as:

$$\rho_r = \rho_m D_r \tag{3}$$

The index of the ecological cost of exported goods per monetary unit ρ_m is calculated from the following formula:

$$\rho_m = \frac{\sum_i S_i \rho_i}{\sum_i S_i D_i} \tag{4}$$

Eq. 4. comprises only exported products.

Introducing Eq. 4 into Eq. 3, the ecological cost of imported goods can be expressed as:

$$\rho_r = \frac{\sum_i S_i \rho_i}{\sum_i S_i D_i} D_r \tag{5}$$

To determine the index of ecological cost of imported goods we have to know the values of the indices of ecological cost of the exported goods resulting from the main set of Eq. 1. On the other hand, the knowledge of the indices of imported goods is necessary to solve the main set of balance, Eq. 1. The problem can be solved using an iterative method.

The algorithm of determination of the ecological cost indices of imported goods is presented in *Figure 3*.

In the first iteration step it can be assumed (Stanek 1998; Szargut and Stanek 1998; Stanek and Ziębik 1999) that the index ρ_m of the ecological cost of exported goods per monetary unit is the same as the average ecological cost of the Gross Domestic Product (GDP). The average ecological cost of GDP is equal to the annual consumption of exergy of non-renewable resources per monetary unit of GDP. Based on this assumption the indices of the ecological cost of imported goods are expressed as follows (simplified method):

$$\rho_r = \rho_m D_r = \frac{B}{GDP} D_r \tag{6}$$

After the first determination of the index ρ_m we can, as the next step, calculate the values of the indices of ecological cost of domestic products ρ_i from the main equation set (1). Some of them belong to the exported goods. Knowing the values of ρ_i of exported goods we can correct (using Eq. 4) the value of ρ_m - the ecological cost of the exported goods per monetary unit, then (using Eq. 5) we can correct the values of the ecological cost of imported goods and return to solve the main equation set (1).

In each iterative step the main equation set is solved and after that the ecological cost of the exported goods per monetary unit ρ_m is corrected and the new value of the ecological cost of imported goods indices ρ_r is calculated from Eq. 5.

The iterative step is stopped when the difference between the values of ρ_m from the current and previous step is less than ε. If there is a balance equation for branches without any consumption of imported goods and without connections of feedback character with other branches from the main equation set, such a balance equation can be solved outside the main equation set (outside the iterative slope).

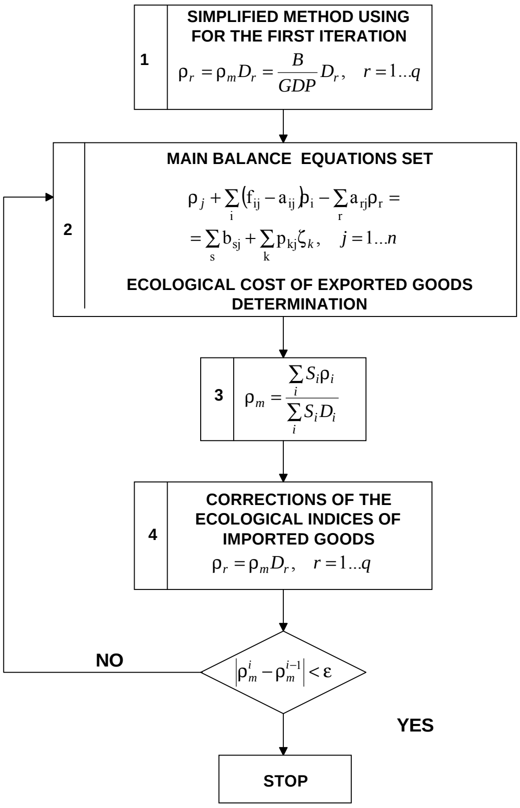

Figure 3. Algorithm of determination of the ecological cost of imported goods

4. Sample Calculations

The algorithm discussed in this paper has been applied for a sample calculation. The statistical data for 1997 were taken into account (GUS 1998, 2000). Dominant positions of Polish export have been applied. Goods produced in similar technologies have been grouped. TABLE I presents the main structure of our export. TABLE I includes information about the amount and monetary value of each group of domestic exported goods.

The production of exported goods presented in TABLE I is connected with the consumption of other products and semi-finished products. All of them should be introduced into the equation set (1). The following branches are strongly connected with the production of exported goods presented in TABLE I:

TABLE I. DATA CONCERNING THE STRUCTURE OF DOMESTIC EXPORTED GOODS (GUS 1998, 2000)

Branch number	Name of the exported product	Amount per year	Monetary value per year US$/a
1	2	3	4
5	Coke, kg	$3234 \cdot 10^6$	$273 \cdot 10^6$
9	Coal, kg	$29.5 \cdot 10^9$	$1124.5 \cdot 10^6$
16, 17	Semi-finished metallurgical products, kg	$1124 \cdot 10^6$	$243.3 \cdot 10^6$
19	Sulphur, kg	$1127.4 \cdot 10^6$	$48.5 \cdot 10^6$
21	Copper, kg	$361.6 \cdot 10^6$	$346 \cdot 10^6$
22	Cement, kg	$2827 \cdot 10^6$	$113.8 \cdot 10^6$
24	Metallurgical products, kg	$2935 \cdot 10^6$	$1128 \cdot 10^6$
25	Aluminum, kg	$111.9 \cdot 10^6$	$302.7 \cdot 10^6$
26	Machines and devices, $	$1268.6 \cdot 10^6$	$1268.6 \cdot 10^6$
27	Agricultural products (meat), kg	$444.8 \cdot 10^6$	$643 \cdot 10^6$
28	Agricultural prod. (plants), kg	$979.2 \cdot 10^6$	$647.3 \cdot 10^6$

1- high quality hard coal,
2- iron ore (imported),
3- domestic natural gas, 3r -imported natural gas
4- electric energy,
5- coke and metallurgical coke,
6- sinter,
7- pig iron,
8- blast,
9- energy coal,
10- oxygen
11- electrode
12- lime,
13- technological steam,
14- converter steel,
15- electric steel,
16- metallurgical semi-finished products (conventional technology),
17- metallurgical semi-finished products (continuous casting),
18- brown coal,
19- sulphur,
20- copper ore,
21- copper
22- cement
23- imported crude oil,
24- metallurgical products,
25- aluminum
26- machinery and devices
27- agricultural products (meat),
28- agricultural products (plant),
29- wood and products from wood,
30- zinc.

For each of theses products separate balance equations of ecological cost are introduced into the main equation set (1). Imported goods appearing in the main equation set are: natural gas, fuel oil, iron ore.

In (Stanek 1998; Stanek and Ziebik 1999) the whole equation set of balances has been presented. In the present paper, because of the size of the main equation set, only sample balance equations from the main equation set (1) are presented:

Branch 5 – production of **coke**

$$\rho_5 - a_{15}\rho_1 - a_{45}\rho_4 = \sum_k p_{5k}\zeta_k + (a_{35} - f_{35})\rho_{3r} \quad (7)$$

where:

$a_{1\,5}$=1.6 kg/kg; $a_{4\,5}$=0.0958 MJ/kg;

$a_{3\,5}$=0.00458 kmol/kg; $f_{3\,5}$=0.0112 kmol/kg;

$P_{5\,SO2}$=0.000129 kg/kg; $P_{5\,NOX}$=0.000473 kg/kg;

P_d=0.000613 kg/kg.

In the process of coke production coke-oven gas is produced as a by-product; coke batteries are also fired with coke-oven gas. The consumption of coke-oven gas and the amount of by-produced coke-oven gas are expressed by the equivalent consumption of natural gas a_{35} and the amount of substituted imported natural gas by coke-oven gas f_{35}. It has been assumed that the substitution ratio of coke oven gas by natural gas is

$\nu_{cg\text{-}ng}$=0.5 kmol/kmol.

Branch 9 – **energy coal**

$$(1 - a_{99})\rho_9 - \chi_3 a_{39}\rho_3 - a_{49}\rho_4 - a_{79}\rho_7 = b_9 + (1-\chi_3)a_{39}\rho_{3r} + \sum_k p_{9k}\zeta_k \quad (8)$$

where:

$a_{9\,9}$=0.0058 kg/kg; χ_3=0.42;

$a_{3\,9}$=0.000041 kmol/kg; $a_{4\,9}$=0.175 MJ/kg;

$a_{7\,9}$=0.004 kg/kg; b_9=26.2 MJ/kg;

P_{SO2}= P_{NOX}=P_d=0.0001 kg/kg,

χ_3 denotes the fraction of domestic natural gas in total consumption of natural gas.

Branch 14 – **converter steel**

$$\rho_{14} - a_{414}\rho_4 - a_{714}\rho_7 - a_{1014}\rho_{10} - a_{1314}\rho_{13} = \sum_k p_{14k}\zeta_k \quad (9)$$

where:

$a_{4\ 14}$ =0.216 MJ/kg; $a_{7\ 14}$=0.85 kg/kg (the rest is scrap-iron); $a_{10\ 14}$=0.0024 kmol/kg;

$a_{13\ 14}$=0.427 kg/kg.

Branch 17 – iron metallurgy **semi-products** (continuous casting)

$$\rho_{17} - \chi_{317}a_{317}\rho_3 - a_{417}\rho_4 - a_{417}\rho_4 - a_{517}\rho_5 + -(1-\chi_{es})a_{s17}\rho_{14} - \chi_{es}a_{s17}\rho_{15} = (1-\chi_{317})a_{317}\rho_{3r} + \sum_k p_{1k}\zeta_k \quad (10)$$

where:

$\chi_{3\ 17}$=0.42; $a_{4\ 17}$=0.252 MJ/kg; $a_{5\ 17}$=0.006 kg/kg; χ_{es}=0.0; $a_{s\ 17}$=1.12 kg/kg;

$P_{17\ SO2}$=$4\cdot10^{-6}$ kg/kg; $P_{17\ NOX}$=$2\cdot10^{-5}$; P_d=$2\cdot10^{-5}$;

$\chi_{3\ 17}$ – fraction of domestic natural gas in the total consumption;

χ_{es} – fraction of electric steel in the total consumption of steel for the production of semi-finished metallurgical products;

$a_{s\ 17}$ – specific consumption of steel for metallurgical semi-finished products.

Branch 26 – **machinery and devices**

$$\rho_{26} - \chi_3 a_{326}\rho_3 - a_{426}\rho_4 - a_{726}\rho_7 + -a_{926}\rho_9 - \chi_{sel}a_{s26}\rho_{15} - (1-\chi_{sel})a_{s26}\rho_{14} + -\chi_{COS}a_{sem}\rho_{17} - (1-\chi_{COS})a_{sem}\rho_{16} + -a_{2126}\rho_{21} - a_{2426}\rho_{24} - a_{2526}\rho_{25} - a_{526}\rho_5 = (1-\chi_3)a_{326}\rho_{3r} + a_{2326}\rho_{23r} + \sum_k p_{26k}\zeta_k \quad (11)$$

where:

$a_{7\,26}$=0.0081 kg/US\$; $a_{s\,26}$=0.0023 kg/US\$;

a_{sem}=0.0051 kg/US\$; $a_{24\,26}$=0.06 kg/US\$;

$a_{25\ 26}$=0.0014 kg/US\$; $a_{30\ 26}$=0.00057 kg/US\$;

$a_{21\,26}$=0.001 kg/US\$; $a_{9\,26}$=0.14 kg/US\$;

$a_{3\ 26}$=0.00053 kmol/US\$; $a_{4\ 26}$=1.32 MJ/US\$;

$a_{5\,26}$=0.004 kg/US\$; $a_{23\,26}$=0.00664 kg/US\$;

$\chi_{s\ el}$ denotes the fraction of electric steel in total steel consumption in branch 26, χ_{COS} denotes the fraction of semi finished products from continuous casting in total semi-products consumption in branch 26.

The data for the main equation set (1) were taken from (Jędrzejowski 1987; Kozioł and Knapik 1997; Stanek 1998; GUS 1998, 2000).

4.1 Results of sample calculations

To calculate the index of ρ_m in the first iteration the following statistical data (GUS 1998, 2000) were introduced:

B =4455 PJ/a,

(GDP)= $143.1\cdot10^9$ US\$/a,

The value of ρ_m in the first step of iteration is:

ρ_m =31.13 MJ/US$.

For the structure of the domestic export presented in TABLE I sample calculations have been carried out.

TABLE II presents the ecological cost of domestic exported goods (for each iteration) calculated using an iterative method described in point 4.

TABLE II. ECOLOGICAL COST OF EXPORTED GOODS*), MJ/KG

Branch	I **Iteration step**			
	0	**1**	**2**	**3**
5	**49.61**	45.85	45.77	**45.77**
9	**27.10**	27.13	27.13	**27.13**
16	**39.34**	44.54	44.64	**44.64**
17	**35.18**	38.95	39.07	**39.02**
19	**24.59**	24.60	24.60	**24.60**
21	**369.48**	366.97	366.92	**366.92**
22	**6.95**	5.96	5.96	**5.96**
24	**49.42**	56.10	56.23	**56.23**
25	**249.36**	249.62	249.63	**249.63**
26 *)	**13.00**	13.09	13.92	**13.92**
27	**13.92**	25.26	25.48	**25.48**
28	**5.59**	10.19	10.27	**10.27**

*)ecological cost of exported machinery and devices (branch 26) is expressed in MJ/US$.

TABLE III presents the results of calculations (for each iteration) of the index ρ_m - ecological cost of the exported goods per monetary and the ecological cost indices of imported natural gas and energy oil.

The number of branches in TABLE II corresponds to the list below TABLE I.

TABLE III. ECOLOGICAL COST OF IMPORTED GOODS

Iterative step	Ecolo-gical cost per moneta ry unit	imported oil (23 r)		imported natural gas (3 r)	
	ρ_m	ρ_{23r}	$\frac{\rho_{23r}}{b_{23}}$	ρ_{3r}	$\frac{\rho_{3r}}{b_3}$
	MJ/$	MJ/kg	MJ/MJ	MJ/kmol	MJ/MJ
0	**31.13**	**6.85**	**0.15**	**95.89**	**0.12**
1	218.1	47.9	1.05	671.7	0.84
2	221.7	48.7	1.06	682.8	0.85
3	221.8	48.8	1.07	683.0	0.85
4	**221.8**	**48.8**	**1.07**	**683.0**	**0.85**

The first row of TABLE III presents the results of calculations (using simplified method – Eq. 6) of the index ρ_m of imported goods per monetary unit and ecological cost indices of imported oil and natural gas. In the next rows the results obtained by using the iterative method are presented.

There are significant differences between the results of the initial iteration step "0" and the results obtained by the iterative method. In the simplified method it has been assumed that the structure of our export is quite similar to the structure of domestic production. The differences result from the fact that the structure of our export (TABLE I) dominates products with a rather high ecological cost.

Calculations carried out by means of the iterative method proved that the simplified method could be used only in a specific case – if there are no significant differences between the ecological cost of gross domestic products and the ecological cost of national export. The greatest differences in the results of calculations of ecological cost indices appear in branches with a relatively high consumption of imported goods. The increase in the value of the index ρ_m in a specific case causes a decrease of the value of the ecological cost index, for example in the case of coke production (branch 5). In this branch we have a relative high by-production of coke oven gas which replaces imported natural gas.

In the case of natural gas the ecological cost of imported natural gas is smaller than that of domestic one. The ratio of the ecological cost of imported natural gas to its specific exergy is less than one. It indicates that the consumption of imported natural gas is more favorable from the point of view of the depletion of domestic natural resources.

TABLE IV presents the index of the structure of ecological cost of domestic export (ρ_E).

TABLE IV. INDICES OF THE STRUCTURE OF DOMESTIC EXPORT

Branch i	$\rho_E = \frac{S_i \rho_i}{(SD)_i}$, MJ/$
5 – Coke	542.6
9 – Energy coal	711.8
16, 17 – Metallurgical semi-finished products	195.6
19 – Sulphur	571.9
21 – Copper	383.5
22 – Cement	148.1
24 – Metallurgical products	146.1
25 – Aluminum	92.5
26 – Machinery and devices	13.9
27 – Meat products	17.5
28 – Plant products	15.5

The index ρ_E represents the total ecological cost of a particular branch per monetary value of this branch. Assuming that all the export is based only on one branch, the index of structure ρ_E expresses the ecological cost of monetary unit of export based only on considered branch. Using the index ρ_E we can investigate the influence of the ecological cost of each group of products upon the ecological cost of exported and imported goods. The ecological cost of exported goods decreases along with the degree of product transformation. From the point of view of minimization of the depletion of non-renewable natural resources, the export should be based on the products with low value of index ρ_E. The highly transformed and agricultural products are characterized by low value of the index ρ_E. For example (TABLE IV) ρ_E=13.9 MJ/$ for machinery and devices and ρ_E=15.5 MJ/$ for plant agricultural products. Simultaneously the export of low transformed (coke - ρ_E=542.6 MJ/$) and raw materials (energy coal - ρ_E=711.8) should be reduced. The structure of export has significant influence on the ecological cost of imported goods.

TABLE V presents the influence of the structure of export upon the ecological cost of monetary unit of imported goods and ecological cost of imported gas.

Taking into account the structure of export (variant 2 in TABLE V), the ratio of ecological cost of imported natural gas per its chemical exergy is about 0.85; for the structure of export similar to GDP (variant 1) this ratio is about 0.12. It results from the fact that the structure of domestic export dominates products of rather high ecological cost.

TABLE V: ECOLOGICAL COST OF MONETARY UNIT OF IMPORTED GOODS AND IMPORTED NATURAL GAS

Variant of structure	ρ_m MJ/US $	ρ_{3r} MJ/kmol	$\frac{\rho_{3r}}{b_3}$
1. Structure of export similar to the structure of GDP	31.1	95.9	0.12
2. Structure of export corresponding with TABLE I	221.8	683.1	0.85
3. Export based on raw materials (coal)	711.8	2192.3	2.7
4. Export based on highly transformed goods (machinery and devices)	13.9	42.8	0.05
5. Export based on agricultural products	16.6	51.1	0.06

Variant 3 from TABLE V shows the unfavorable influence of export of raw material upon ecological cost of imported goods. In variants 4 and 5 the ratio of ecological cost per chemical exergy of imported natural gas is equal 0.05 and 0.06. Variants 4 and 5 show the positive influence of highly transformed goods and agricultural goods in structure of export upon the ecological cost of imported goods.

5. Final Remarks

The algorithm to determine the ecological cost using the exergy method has been developed using an iterative method of determination of the ecological cost of imported goods.

The iterative method is based on the assumption that the ecological cost per monetary unit of imported goods is the same as the ecological cost per monetary unit of exported goods.

Sample calculations based on statistical data of 1997 show that there are significant differences between the value of the ecological cost of imported goods resulting from the simplified method and from an iterative method. It is caused by the differences between the structures of export and domestic production. Thus, the results of sample calculations proved that the simplified method could be used only in some specific cases.

The calculations of ecological cost of imported natural gas for several variants of the structure of domestic export have been carried out. These calculations show the influence of the structure of export upon the ecological cost of imported goods.

Nomenclature

- a_{ij}, f_{ij} coefficient of the consumption and by-production of i-th product per unit of j-th major product
- b_{sj} exergy of s-th non-renewable natural resource immediately consumed in the process under consideration per unit of j-th product, MJ/kg, MJ/kmol
- B annual exergy consumption of non-renewable natural resources, MJ/a
- D_i, D_r monetary value of the i-th domestic and r-th imported product, US$/kg, US$/kmol
- GDP annual gross domestic product, US$/a
- P_k annual production of the k-th aggressive component of waste products rejected to the environment in the considered region, Mg/a
- p_{jk} amount of k-th aggressive component of waste products rejected to the environment per unit of j-th product, kg/kg, kg/kmol

S_i	annual amount of i-th exported good, kg/a, US$/a
w_k	monetary coefficient of ecological damages per unit of the k-th aggressive waste product, MJ/Mg
ε	condition of the end of iterative slope
ζ_k	cumulative exergy consumption of non-renewable resources due to the emission of unit of the k-th waste product, MJ/kg
ρ_j, ρ_r	specific ecological cost of the j-th product or imported r-th good, MJ/kg, MJ/kmol
ρ_m	ecological cost of the exported products, per monetary unit, MJ/US$
d	dust
r	imported goods

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