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ELEMENTS OF METALLURGICAL ECONOLOGY

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ABSTRACT: A new branch of science called *econology* is being defined and shortly characterized as studying the *economics-ecology-energy* associations (3E or E^3 associations). In the future, the ternary must be transformed into *tehnology(T)-economy- energy-ecology*, so that the symbol of the econology shall be TE^3.
A new classification of the indexes is put up for approval:
→ Indexes, I_e, regarding the *extensive character* of the econological events; these indicators may be characterized as passive-meditative-observing, (*extensive* and *extensity* – antonym for *intensive* and *intensity*);
→ Indexes, I_i, regarding the *intensive character* of the econological events; these indicators may be characterized as dynamic-operative-active.
There are defined and characterised the following simple indexes:
- energetic extensity and energetic intensity of the gross domestic product;
- energetic extensity and energetic intensity of productivity (hourly production);
- extensity and intensity of material consumptions;
- extensity and intensity of pollutant emittance:
  - in metallurgical engineering;
  - in car area.

There are defined and characterised econological-aggregate indexes of 2E and TE levels. There are defined and characterised an aggregate index of 3E level (economy-energy-ecology). Special characteristics are assigned to the metallurgical industry.
KEYWORDS: metallurgical econology, extensity indexes, intensity indexes, econological-aggregate index

INTRODUCTION

The approach of the sustainable development concept can be based on two knowledge methodologies.

On one side, especially in the engineering area, specialization plays an important part. This in the reason why, for example, in metallurgy, the environment engineering is based more and more on a new subbranch of science called *ecometallurgy*. Its objective is the theoretical foundation of the knowledge and application of the technologies and techniques of improvement in the metallic material industry in agreement with the objectives of the durable development concept. Under the same terms, some other branches of knowledge can be brought forward: *environment economics* and *environment energetics*.

On the other side, in agreement with the globalization tendency, the inter (trans) disciplinary knowledge becomes more and more a necessity. This instrument allows the analysis of the *metallurgical process – industrial ecology – environment economics* associations as integralist - type modern methodology (*Nicolae A., ş.a., 2009*).

The above-mentioned have tunder lately into concern to explore (by study and research) the interdisciplinary area related to the *economics – ecology association* under optimization terms of *energetic requirements*. It is the area of the 3 E or, to underline the significance further, the area of E^3. This new field of scientific knowledge has been called *econology*. In the future, this ternary must be transformată into the *technology (T) – economy - energy-ecology* associations, so that the symbol of econology shall be TE^3. No special arguments are required to accept that econology deals, in particular cases, also with type 2E (or E^2) associations: economics – ecology, economics – energetics or ecology – energetics.

Econology came into being at the end of the XX[th] century. The etymology of the word is the resultant of a combination between the prefix *econo* (from *economics*) and the suffix *logy* (from *ecology*). Considering the above, it is difficult to briefly, but wholly define econology. The authors of the present article mean, by econology, the scientific branch of research - development – innovation and the discipline of study regarding the optimization of the pollution prevention and control strategies and of the natural resource consumption strategies under economic effectiveness and energetic requirement minimization terms. If econology approaches a certain sector of industrial activities, it may get specific forms as *metallurgical econology*. Considering the importance of the environmental conditions to the durable development of the society, for the metallurgical engineer, econology means knowledge with reference to associations in the field of environment economics – ecometallurgy – environment energetics – technological processes. In the metallurgical econology, the 3E correlations have to be studied as interdependences among the following functions:

- Energetic performance; it measures the minimization degree of the energetic consumptions;
- Ecological performance; it refers to the pollution level;
- Economic performance; it is a mixture of:
  - *financial performance* (minimisation of the fabrication costs of the product);
  - *production and productivity performance* (maximization of production, maximization of labour & facility productivity);
  - *quality performance* (social utility degree, whereby the product acquires competitiveness conditions).

From the metallurgical point of view, for the analysis and evaluation of the 3E correlations, it is required to define and use specific ecological indexes and indicators. We propose to classify them into two groups:

- *Extensity indexes* of the events (processes); there are indexes that refer to the size of the energetic consumptions or to the quantity of exhausted pollutants; because they can be derived by measurements or by calculations, they have a *passive* character *(of finding);* in this paper, they are denoted with I_e;
- *Intensity indexes* of the events (processes); there are indexes that refer to the economic performance; for the engineer that works in the industry of metallic materials, the performance of production and productivity has a special importance; because these indexes highlight the modalities of increasing the production and productivity in terms of decreased costs and increased quality, we consider they have a *dynamic* character *(of reforming, of intensification);* in this paper, they are denoted with I_i.

One of the basic principles of the metallurgical econology is: *the ecologic performance doesn't have to affect the economic performance*. In other words, the concerns regarding the minimisation of costs and increase of quality, production and productivity have priority. Therefore, we conclude that the econologic indexes must be predominantly from the category of intensity indexes.

DEFINITION AND CHARACTERISATION OF SOME SIMPLY INDEXES

Hereinafter, we are going to present some econologic indexes and indicators applicable in the industry of metallic materials.

THE EXTENSITY AND INTENSITY OF SPECIFIC MATERIAL CONSUMPTIONS. Currently, the specific consumption index is defined by the quantity of materials [tons of materials] consumed to produce one unit of metallurgical product [1 ton of metallic products]. Because it primarily refers to the quantity of consumed materials and not to the production of metallurgical goods (pig iron or steel), it should be the extensity index:

$$I_{e.m.c} = \left[\frac{\text{tons of materials}}{\text{1 ton of steel}}\right] \quad (1)$$

We propose to replace it with the index that measures the quantity of steel [tons of steel], produced when consuming one unit of materials. Because it primarily refers to the steel production under conditions of restricting the material consumption, it should be the intensity index:

$$I_{i.m.c} = \left[\frac{\text{tons of steel}}{\text{1 ton of materials}}\right] \quad (2)$$

THE ENERGETIC EXTENSITY AND INTENSITY OF THE *C* PRODUCTION AND *P* PRODUCTIVITY. Currently, the index that characterises the energy consumptions is defined by the *P* electric power [Mw] of the facility used to realise the *C* production [tons of steel] with the *p* productivity [tons of steel/h]. Because it refers to the energy consumptions (power) and not to the productivity or production, it should be the extensity index:

$$I_{e.e.p} = \left[\frac{h \cdot MW}{\text{1 ton of steel}}\right] \quad (3)$$

We propose to replace it with the index that measures the productivity we can get for one unit of power. Because it primarily shows the importance of the productivity, should be the intensity index:

$$I_{e.i.p} = \left[\frac{\text{tons of steel}}{h \cdot MW}\right] \quad (4)$$

The analysis of the above mentioned indexes shows that I_{ee} represents, in fact, the specific consumption of electric energy, in [MW·h/t. steel]. This means that the usually-used index called *specific consumption of energy* is an extensity index that has to be waived. It should be replaced with the intensity index $I_{i.e}$ [tons of steel/MW·h], which indicates the production to be obtained when consuming 1 MW·h.

THE EXTENSITY AND INTENSITY OF THE POLLUTANT EMISSIVITY OF THE METALLURGICAL FACILITIES. Currently, the index of the pollutant emissivity is defined by the quantity of pollutants [kg; m_N^3 pollutants] exhausted when producing one unit of metallurgical products [1 ton of steel]. Because it primarily refers to the quantity of pollutants and not to the metallurgical production, it should be the extensity index:

$$I_{e.e.p.m} = \left[\frac{kg; m_N^3 \text{ pollutant}}{1 \text{ ton of steel}}\right] \quad (5)$$

We propose to replace it with the index that measures the steel quantity that can be produced when restricting the pollutants to 1 kg; m_N^3. Because this index highlights the role of the steel production, it should be the intensity index:

$$I_{i.e.p.m} = \left[\frac{\text{tons of steel}}{1kg; m_N^3 \text{ pollutant}}\right] \quad (6)$$

THE EXTENSITY AND INTENSITY OF THE POLLUTANT EMISSIONS OF THE VEHICLES USED IN METALLURGY. Currently, the index is defined by the quantity of CO_2 exhausted when running 1 km distance. Because it refers to the quantity of pollutant without any information regarding the dynamic factor (number of kilometres), it should be the extensity index:

$$I_{e.e.p.v} = \left[\frac{gCO_2}{1km}\right] \quad (7)$$

We propose to replace it with the index that measures the number of kilometres afferent to an imposed quantity of CO_2. In this case, we refer to the intensity index:

$$I_{i.e.p.v} = \left[\frac{\text{number of kilometres}}{100\,g\,CO_2}\right] \quad (8)$$

The above information can be interpreted, for example, as follows:

- The furnace producing 0.8 tons of steel is more efficient than the furnace producing 0.7 tons, when the same quantity of materials (1 ton) is consumed;
- The vehicle that exhausts 100 g of CO_2 when running 1.2 km is more efficient than the vehicle that exhausts the same amount of CO_2 when running 0.9 km.

EXTENSITY AND INTENSITY OF THE ENERGETIC EVALUATION OF THE GROSS DOMESTIC PRODUCT (GDP). Currently, the energetic value of GDP is calculated by using an indicator that measures the energy consumption [GJ] required to obtain 1 unit of GDP:

$$\text{The current indicator used for the energetic evaluation of PIB} = \frac{[GJ]}{1\text{unity GDP}} \quad (9)$$

Defined by this formula, it is an extensity indicator, because it refers to the consumed quantity of energy and not to the PIB to be realised. We propose to replace it with the intensity indicator:

$$I_{i.e.GDP} = \frac{[\text{GDP units}]}{1GJ} \quad (10)$$

which measures the value of the PIB produced in a country by consuming an energy unit.

Table 1. Evaluation of the national energetic consumptions (Badea A., 2003)

Sr. no.	Country	Current situation		Proposed situation	
		Extensity index [GJ/1000USD]	Place in the rankings	Intensity index [USD/1 GJ]	Place in the rankings
1.	Austria	5.278	9	189.5	2
2.	France	7.076	6	142.0	5
3.	Italy	5.000	10	200.0	1
4.	Germany	6.700	7	149.0	4
5.	Spain	5.770	8	173.0	3
6.	Hungary	16.000	5	62.5	6
7.	Poland	18.450	4	54.2	7
8.	Czech Republic	23.000	3	43.5	8
9.	Romania	31.260	2	32.0	9
10.	Bulgaria	46.800	1	21.37	10

Table 2. Econologic indexes

Target	Defining relations	
	Extensity indexes (current solution)	Intensity indexes (proposed solution)
Specific consumption of materials	$\frac{\text{tons of materials}}{1\text{ton of steel}}$	$\frac{\text{tons of steel}}{1\text{ton of materials}}$
Energetic characterisation of the productivity	$\frac{h \cdot MW}{1\text{ton of steel}}$	$\frac{\text{tons of steel}}{h \cdot MW}$
The pollutant emissivity of the metallurgical facilities	$\frac{kg;\ m_N^3\text{pollutant}}{1\text{ton of steel}}$	$\frac{\text{tons of steel}}{1kg;\ m_N^3\text{pollutant}}$
The pollutant emissions of the vehicles	$\frac{gCO_2}{1km}$	$\frac{\text{number of kilometres}}{100\,g\,CO_2}$
The energetic characterisation of the gross domestic product	$\frac{GJ}{1\text{unity GDP}}$	$\frac{\text{PIB units}}{1GDP}$

Based on the above-mentioned things, the rankings of countries, according to the national energetic consumptions, are as follows (Table 1). The information about the econologic indexes is summarized in the table 2.

❖ AGGREGATE INDEXES OF 2E AND TE LEVELS

a) THE ECOLOGICAL-ENERGETIC INDEX, $I_{ecl.en.}$. It is a *2E level index*, which highlights the ecological-energetic correlation. In this paper, it is defined as the ratio between the required energy quantity, as input measure, and the CO_2 quantity emitted in the technological processes:

$$I_{ecl.en.} = \frac{[GJ]}{[1 ton CO_2]} \qquad (11)$$

The maximisation of this index implies, at the same energy requirement, the minimisation of the energy quantities (heat) obtained by burning materials that contain carbon substances. In this respect, we recommend to act as follows:

- to use the enthalpy of the secondary energetic resources;
- to extend the energy making processes (heat) based on hydrogen;
- to increase the share of the energy supplied by hydro and nuclear stations;
- to use renewable energy sources.

b) THE TECHNOLOGICAL-ECOLOGICAL INDEX, $I_{th.ecl.}$. It is an index used to analyse the influence of the technological factors on CO_2 constants. The $I_{th.ecl.}$ index is a *TE level index*. It is used to analyse the interdependence between the technological factors and the CO_2 conditions. For example, we can define two such indexes:

$$m_{CO_2} = f([\%Si]) \qquad (12)$$

$$m_{CO_2} = f(Pg) \qquad (13)$$

In the above expressions, [%Si] is the silicon percentage in the pig-iron made in the blast furnace, and Pg is the pressure at the loading aperture.

c) THE DEGREE OF COKE REPLACEMENT BY POWDERY COAL, η_{PC}. This index characterises the coke quantity that can be replaced by powdery coal (PC) at making iron in blast furnaces. It is measured in [t.coke/t.coal]. It is also a TE level index (technology-ecology), which characterises the technological role of the coke replacement by powdery coal in the modification of CO_2 quantities. It is also an intensity index, because it firstly refers to the *coke performance*, and secondly to the *coal performance*.

The ecological evaluation of the substitutes for coke and especially of the powdery coal (PC), can be realised by taking into account the comparision of the chemical reactions of the CO_2 emissions. Appealing to the concept of equivalent carbon, the CO_2 emission can be written as follows:

For coke:

$$C_k E_{C_k} + O_2 \rightarrow CO_2 \qquad (15)$$

For PC and coke:

$$\left[C_{PC} E_{CCP} + \left(C_k - \frac{C_{PC}}{\eta_{PC}}\right) E_{C_k}\right] + O_2 \rightarrow CO_2 \qquad (16)$$

In the above relations, C_k is the specific consumption of coke, in [t·coke/t·pig iron], C_{PC} is the specific consumption of coal [t·coal/t·pig iron], E_{C_k} is the equivalent in carbon of the coke [t·carbon/t·cocs], $E_{C_{PC}}$ is the equivalent in carbon of the PC [t·carbon/t·coal], and η_{PC} is the degree of substitution [t·coke/t·coal].

In making the coal replacement advantageous in terms of CO_2 emission, the following inequality should be satisfied:

$$C_{PC} E_{CCP} + (C_k - \eta_{PC} \cdot C_{PC}) E_{C_k} < C_k \cdot E_{C_k} \qquad (17)$$

When solving the inequality, we obtain the *maximum allowable value* of the substitution degree, in terms of CO_2 emission:

$$\eta_{PC} > \frac{E_{CPC}}{E_{C_K}} \qquad (18)$$

For instance, to replace the coke with 0.85 C with coal with 0.60% C, the process is allowed in terms of CO_2 emission if $\eta_{PC} > 0.70$.

d) THE FINANCIAL-ECOLOGICAL INDEX $I_{f.ecl.}$. It is a *2E level index*, which analyses the link between the savings to be realised through various technological processes and the quantity of CO_2. It can be expressed as follows:

$$I_{f.ecl.} = \frac{E_c}{1t.CO_2}, \quad \left[\frac{\frac{Euro}{t \cdot (pig\ iron)}}{1t \cdot CO_2} = \frac{Euro}{t(pig\ iron) \cdot t_{CO_2}}\right] \qquad (19)$$

where $E_c = (CF_1 - CF_2)$ is the saving [Euro] realised due to the difference between the production costs recorded in two different situations.

❖ AGGREGATE INDEX OF 3E LEVEL, FOR ECONOLOGICAL ANALYSES

The evaluation of the efficiency of the econological measures in the *ecology-economy-energy system* requires recourse to specific indexes of *3E level*.

The authors couldn't find this kind of indexes in the iron-steel industry. To define the indexes to be used in the engineering field, we should start from the information found in the economic literature (*Purica I., 2005*). So, for large scale systems (country, geographical area), there are defined indexes resulted from the multiplication of simpler indexes. For example, such index is recommendable:

$$I = \frac{1}{\frac{Energy}{PIB}} \cdot \frac{PIB}{Population} \cdot \frac{1}{CO_2\ emission}; \quad \left[\frac{PIB^2}{Energy \cdot Population \cdot CO_2\ emission}\right]$$

Analysing the above things, we found that the index trend was:

- ❖ inversely proportional to energy consumption;
- ❖ directly proportional to PIB;
- ❖ inversely proportional to the CO_2 emission.

Starting from this idea, we can define for the ecology-economy-energy correlation (e.e.e) an econological index whose trend is:

- ❖ inversely proportional to material price, p_{mat};
- ❖ directly proportional to calorific power, H_i;
- ❖ inversely proportional to carbon equivalent, E_c.

Therefore, we propose the following econological index:

$$I_{e.e.e} = \frac{1}{p_{mat}} \cdot H_i \cdot \frac{1}{E_c} \left[\frac{1}{\frac{Euro}{kg.mat.}} \cdot \frac{MJ}{kg.mat.} \cdot \frac{1}{\frac{kg.carbon}{kg.mat.}} = \frac{kg.mat.MJ}{Euro \cdot kg.carbon}\right] \quad (20)$$

Table 3. The values of the $I_{e.e.e}$ index.

Material	Price [Euro/kg]	H_i MJ/kg	E_c [kg,carbon/kg]	$I_{e.e.e.}\left[\frac{(kg.mat.)\cdot(MJ)}{(kg.carbon)\cdot(Euro)}\right]$
Coke	0.18	31.5	0.85	206.0
Natural gas (98% CH_4)	0.20	34.0	0.52	327.0
Fuel oil	0.22	42.0	0.87	220.0
Powdery coal	0.10	22.0	0.60	366.0

Applying the above mentioned things when replacing the coke with powdery coal at blast furnaces, and using the *estimative values used in Romania*, we obtain the results presented in Table 3.

❖ SOME CONCLUSION

- ❖ The metallurgical econology (application of the industrial econology) is a new field of knowledge to be researched and operationalised at the real conditions of the metallic materials industry.
- ❖ We propose and demonstrate the possibility to use the intensity indicators and indexes of events instead of the current ones, which characterise the extensity of events.
- ❖ Regarding the replacement of coke with powdery coal at blast furnaces, we can affirm that, from the econological point of view, all the materials proposed as coke replacements have a higher econological index.
- ❖ The recommended replacement materials are (in descending order):
  - powdery coal;
  - natural gas;
  - fuel oil.
- ❖ From E_c, combined with the other two parameters, we can deduce that, from the point of view of CO_2 emission, the partly replacement with PC is superior to the other two solutions.
- ❖ The above findings are supported by the results of other research areas. So, to improve the thermal performances of the blast furnace, we recommend the following materials (in descending order of importance): low-volatile coal, high-volatile coal, liquid fuel (fuel oil) and natural gases (*Peters K. H., 1995*).

❖ REFERENCES

[1.] NICOLAE A., BORŞ I., PREDESCU C., NICOALE M., ŞERBAN V., PREDESCU ANDRA, PREDESCU A., BERBECARU A. – (2009), *Metalurgical Econology* (În Romanian), Ed. Printech, Bucureşti.
[2.] BADEA, A. – (2003), Proc. *CNND*, Bucureşti.
[3.] PURICA, I. – (2005), Proc. *Sustainable development in Romania*, Ed. Expert, Bcureşti.
[4.] PETERS, K., H. – (1995), *Stahl und Eisen*, 115, p.4-29.