SPECIFIC KNOWLEDGE REGARDING THE SUSTAINABLE AND DURABLE DEVELOPMENT OF ECOTECHNOLOGICAL COMPLEXES

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This paper presents new knowledge on the role of the technological system (represented by the metallurgical industry) in the sustainable development of ecotechnological complexes, by consolidating a conceptual model of development, produced in the form of adaptive transformation cycles (MD-ATC). The results of research and investigations (methodologically conducted with notions of global knowledge and ecotechnological paradigm) refer to the assessment of ecotechnological impact based on a certain environment entropization degree, based on industrial metabolism on the ecotechnological sustainability of the natural ecological system.

Keywords: sustainable development, adaptive transformation cycles, ecotehnological impact, environment entropization, ecotechnological sustainability

1. Introduction

The requisite industrial activities in the economic sustainable development process are directly reshaping the Earth’s environmental system. The contradiction between industrial development and ecological environment pressure has been becoming progressively severe [1]. The services provided by ecosystems are benefits that nature provides to people, and are community or ecosystem-wide, or even landscape-wide attributes [2].

Nowadays, we say that **the eco-socio-economical-technological megasystem (E.S.E.T.-M.S.)** is the actual form of knowing *the human existence*

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sphere. This is defined the result of intra- and inter-system interconditioning involving four systems: *the natural-ecological system, the social system, the economic system* (E.S.) and *the technological system.* In this paper, the political system is not included, but it is considered that the sustainability of a product in a system is not a final state but a process that could be continuously improved, in agreement with European Parliament regarding the life cycle analyses and insurance of competitive products fabrication [1].

In this paper, the technological system is represented by *the metallic materials industry* (M.M.I.) or *the metallurgical industry* (Met. I.). Lifecycle of a material consists of the key sequences given by two fundamental events: reintegration of secondary materials (waste) using 3R technologies (recirculation, recycling, regeneration) and disposal of the secondary materials (waste) in the environment [3].

The development means the transformation and evolution of the eco-socio-economical-technological megasystem towards higher levels of scientific knowledge and technological achievements. The desirable characteristics for the level of sustainability indicators have to include: simple to calculate, useful for decision making, and robust in indicating progress toward sustainability [4].

The evolutionary transformations become necessary following the pressures exerted by the control parameters on the systems.

The control parameters (C.P.) are forces or factors that can induce transformations into the system. By the place of occurrence, they are: *endogenous C.P.* and *exogenous C.P.* By the effect produced, they are: *stabilizing C.P.* and *destabilizing C.P.* The latter are also called *disturbing C.P.*

In the last decades of the last century, the need to move to *a new development model (N.D.M.)* appeared and became operational [5].

According to this model, the development and, implicitly, the evolution, are occurring in the form of *adaptive transformation cycles* (MD-ATC – model of development by adaptive transformation cycles) [6-8]. Such a cycle consists of four phases (stages): r, K, Ω and α. The cycle shape and the names of the phases are given in Fig. 1.

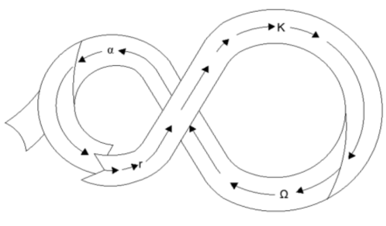

Fig.1. Schematic representation of the sequence of phases in a complete development cycle: r – growth phase; K – accumulation phase; Ω – release phase; α – restructuring phase [5].

System potential is concerned with the range of options available for future responses of the system; in ecosystems this can mean an accumulation of nutrients, resources, biomass, and diversity that provide abroad range of options for the future behaviour of the system in response to change [5].

For the model of development by adaptive transformation cycles, there are several definitions similar in substance. One of the models is shown below as an example.

The durable (sustainable) development *is the model that ensures the capacity of the systems to create and preserve their adaptation and sustainability potential within the socio-ecological complexes* [6].

As can be seen in the above definition, *the durability and sustainability – fundamental system features* – are not analysed separately.

From the above-mentioned things, it turns out that a thorough research on the role of technological system in the development of the eco-socio-economical-technological megasystem is required.

2. Materials and Methods

The materials used for the research were documentary and informative materials whose processing led to the acquisition of *new knowledge*.

The main **methodological tools** were:

a) *The global knowledge*, based on interdisciplinarity, which becomes mandatory for the study of interconditioning systems, enables the transition from *goggle wise knowledge to fanwise knowledge* [9].

Complex adaptive systems arise when systems are non-isolated [4].

b) *The ecotechnological paradigm*, which considers that the natural-ecological system has a major importance in the interactions between the technological system and the natural-ecological system; it is a superior form of the current conventional technical-technological paradigm used in the technological system; in this context, the natural-ecological system is considered *the foundation system*, because it has two essential functions [11]:

- Natural resource (N.R.) provider for the technological system, and
- Deposit for the polluting residues generated by the technological system.

At the same time, the technological system is considered a parasitic system [13].

3. Results and discussions

The ecotechnological complexes, E.T.C., are a set of structures whose development depends on the interactions between the technological system and the natural-ecological system.

According to the model of development by adaptive transformation cycles, the development of **the technological system,** (the totality of technologies and techniques operationalized for obtaining material goods), and **the natural-ecological system** or **environment** (living spaces, natural resources basin, and deposit for the collection of polluting residues) occurs in the form of cycles of adaptive transformations [12].

The factors influencing the interactions between the technological system and the natural-ecological system, *(T.S. ↔ N.E.S.)* are:

- *human activities, H_a*: preparation of natural resources, manufacture, use, reintegration of residues through 3R technologies (recirculation, recycling, regeneration), residues disposal in the environment;

- *natural resources, N.R.*, used in the ecotechnological complexes;

- *technology (Tech)*, as source of the rules established to conduct the technological process;

- *industrial results, I.R.*, represented by the metallic materials;

- *ecotechnological impact, E.T.I.*, as sum of the negative effects of interconditioning, *(T.S. ↔ N.E.S.)* on the environment quality.

The human activities, the technologies, impacts and natural resources are not topics to be explored in this paper. The following information is required for industrial results (metallic materials).

3.1. Utilitarian aptitude of materials

The materials used in the manufacturing stages of **the technological system** and those used in **the social system** undergo transformations that cause changes in *the utilitarian aptitude of the materials*. This topic will be further discussed (Fig. 2).

The primary materials, p.m., are the object of the activities carried out in the technological system. Their utility is given by *the technological properties of the materials*, which concern, first of all, the chemical composition and structure. At high values, the materials are declared *technically efficient materials*. If the materials are subjected to multiple processing, they are also considered *technological advanced materials*.

Adaptive reuse has been defined as finding new suitable uses for a material in the same system or in another [13].

The useful materials, u.m., are the materials that, in the social system, satisfy the social needs. According to the law of unity and conflict of opposites, two contradictory processes occur in the social system: use and degradation (transformation of primary materials into secondary materials).

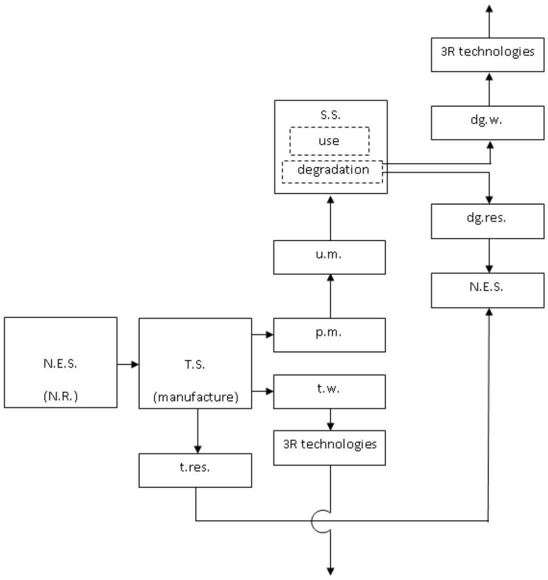

Fig.2. Transformations of materials in the technological system (T.S.), social system (S.S.), and natural-ecological system (N.E.S.)

The useful materials, u.m., are the materials that, in the social system, satisfy the social needs. According to the law of unity and conflict of opposites, two contradictory processes occur in the social system: use and degradation (transformation of primary materials into secondary materials).

In this case, the utility of materials is given by *the use properties* and *the degradation properties*. At their optimal values, the materials acquire the quality of *socio-materials*.

The above information refers to *the social utility* of materials.

The secondary materials, s.m., are the materials that, following the technical processing and use, are going to accompany the primary and useful materials. Adaptive reuse has been defined as finding new suitable uses for a material in the same system or in another [13]. There are two situations in this regard:

- *the wastes, r.w.*, are secondary materials with *reintegration potential* through the 3R technologies;

- *the residues, res.*, are secondary materials deposited in the environment, which have a negative impact on it.

In short, **the pollutants** are the residues that, when deposited in **the natural-ecological system** has a negative impact on *the environmental factors* (water, air, soil, fauna, flora, buildings, and people).

In this case, the utility of materials is measured by *the ecological properties*. At their optimal values, the materials have the quality of *eco-materials* and multi-resource recycling across various ecosystems through ecological linkage, interaction, and intercorrelation construct a huge recycling process [14].

The above information refers to *the ecological utility* of materials.

The secondary materials can be also classified according to other criteria:

• Based on the technological manufacturing process, there are:
  - *Technological waste (t.w.)*;
  - *Technological residues (t.res.)*.

• Based on the degradation occurred in the social system, there are:
  - *Degradation waste (dg.w.)*;
  - *Degradation residues (dg.res.)*.

Minimizing the resource consumption and minimizing the amount of manufacturing waste are also certain technological programmes of great importance [15].

3.2. Defining the new development model with application in the ecotechnological complexes

The industrial metabolism represents the concept that analyses *the flows (exchanges)* of materials and energy in **the ecotechnological complexes** [16]. It accounts for the exchange components in an integrated manner, based on the balance sheets drawn-up in accordance with the law on conservation of materials and energy [17].

In the ecotechnological complexes there are two categories of *essential exchanges of materials and energy*. For reasons related to the systematization of knowledge and pragmatic engineering needs, we propose the imaginary division of the natural-ecological system into two zones (Fig. 3).

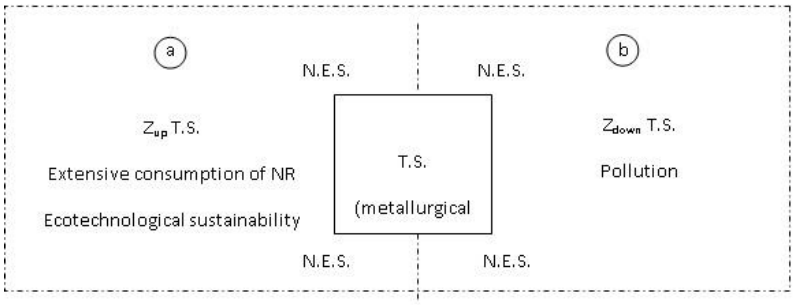

Fig.2. Zones of the natural-ecological system (N.E.S.) versus extensive consumption and pollution

The zone located upstream of the technological system (Z_{up} T.S.).

In this area, the vectors of material and energy exchanges are the natural resources consumed by the technological system. In this zone, the technological system exerts on the natural-ecological system destabilizing pressures generated by *the disturbing control parameter* called *extensive consumption of natural resources*, caused by two causes mentioned below.

Imposing technological of consumption

This paper is not approaching the subject of *irrational consumption*. The high consumption in metallurgy is justified by technological restrictions (rigors). It is given a very important example. The manufacture of pig-iron in blast furnaces is based on the process:

$$\begin{array}{c} \qquad\qquad\qquad\qquad CO_2 \\ \qquad\qquad\qquad\qquad \uparrow \\ (FeO)_{ore} + C_{coke} \leftrightarrow FeO + CO \\ \qquad\qquad\quad \uparrow \\ \qquad\qquad\quad \text{coal} \\ \qquad\qquad\quad \text{(N.R.)} \end{array}$$

The consumption of coke [t_{coke} / $t_{pig\text{-}iron}$] cannot fall below the limit imposed by the chemical equilibrium of the above reaction.

Technological depreciation of the natural resources

This is reflected by the increased content of *residual elements* (Cu, Sn, Cd, Hg, Pb, As) in some sources causing technological disadvantages worsening the steel quality and ecological disadvantages due to the heavy metal pollution. Another issue is the size depreciation, being known that some technologies impose dimensional limits for certain natural resources and the decrease in the useful metal contents in ores.

To counteract the negative impacts of extensive consumption, the natural-ecological system must provide a fundamental system feature called *ecotechnological sustainability (S)*. It is assessed through the system variable called *support capacity*, which measures the natural-ecological system ability to create, sustain and maintain certain levers of the technological system supply with natural resources.

The zone located downstream of the technological system (Z_{down} T.S.).

In this area, the vectors of material and energy exchanges are the pollutants produced by the technological system and deposited into the natural-ecological system. In this zone, the technological system exerts on the natural-ecological system destabilizing pressures generated by the disturbing control parameter called *pollution*. To counteract the negative impacts of pollution, the natural-ecological system must have a fundamental system feature called *ecotechnological durability (D)*. It is assessed by the system variable called *system resilience*, which measures the structures resistance to the transformations given by shock and unpredictable stresses [18, 19]. The model of development by adaptive transformation cycles considers the system resilience as a complex variable, which is targeting the system potentials for growth, accumulation, release and reorganisation (Fig. 1).

Based on the above, we propose the definition given below for the new development model (N.D.M.) of ecotechnological complexes.

The sustainable and durable development (S.D.D.) *is the development model based on which the natural-ecological system can absorb the negative impacts caused by extensive consumption of natural resources and pollution*.

3.3. Unconventional method for analysing the technological system development

It is about *the intra-system development* of the technological system. In this case, the interactions occur among the structures of the system (constructive elements, energy sources, metal melts, metallurgical slag, process gases, etc.).

We propose the analysis of the technological system development to be made based on *the law of transformation of quantitative accumulations into qualitative leaps*.

According to the above-mentioned law*, the development* is the result of the leap from a qualitative level to a higher qualitative level, supported by the accumulations developed in the lower level.

There are two categories of leaps:

The shock-type qualitative leap (St.Q.L.) represents *a sudden transition* from one quality to another one (this is the case of *industrial revolutions*). Such a leap can be considered a destabilizing control parameter. The metallurgical revolutions took place over long periods of time (even centuries). Here are some examples: the transition from the Bronze Age to the Iron Age; manufacture of pig-iron using coke in blast furnaces; steel-making in oxygen converters combined with continuous casting of steel; manufacture of high-performance and advanced materials.

The slow qualitative leap (S.Q.L.) is the leap caused by *slow and continuous accumulations over time*. Such a leap is considered a stabilizing control parameter.

The scientific and technological progress provides knowledge for quantitative accumulations in both situations.

The specific contribution of the progress ⟦(value of contribution)/(leap duration)⟧ makes the difference between the two leaps.

The history of metallurgical civilization shows that, in most cases, the development of this industry occurred through slow leaps, i.e. under the action of stabilizing control parameters.

3.4. Analysis of the development of ecotechnological complexes according to the environment entropisation

An important goal of the development projects is to know the ecotechnological impact, E.T.I., on the environment. In this paper, we propose to assess it based on *the environment entropization degree (E.E.D.)*.

$$E.T.I. = f\,(E.E.D.), \tag{1}$$

In order to make this proposal operational, it is necessary the items of material and energy balances to be expressed by *an all-encompassing equivalent*. It is mentioned that, in order to *absolutely quantify* the items of an ecological balance, the biologists had used an energy notion called emergy [16]. In support of the above, it is considered that:

- According to Einstein's equation, the matter and energy are equivalent;

- The idea that the monetary administration can lead to a more accurate assessment and evaluation of *the growth and development* must be tempered; the energy is the actual *driving force* for the economy; the money is just *its surrogate* [20, 21].

Consequently, we proposed that, at integrative scale, the definition of impacts to be also given by *energy equivalence*. The proposed energies are the entropy and negentropy, as fundamental items of certain *(neg)entropic balances*, based on which an important ecotechnological impact is defined, called *environment entropization*.

The environment entropization is, in short, the major ecotechnological impact represented by the growth of the entropic basin of the natural-ecological system following the human activities, based on interactions (T.S. ↔ N.E.S.).

The human activity causes sustainable and durable development transformations which, in turn, are causing:

- Decrease of the ordering degree (increase of the chaos degree) of matter (substance) in the system;
- Increase of the ordering degree (decrease of the chaos degree) of matter (substance) in the system.

For a start, some information from general scientific culture is used.

The entropy (S) is the thermodynamic parameter used to measure the amount of disorder in a system. The increase of the degree of disorder is given by the increase of entropy (S), calculated with the expression:

$$\Delta S = \frac{\Delta Q}{T}\ , \ \ [J/K] \tag{2}$$

The negentropy (nS) or **anti-entropy (aS)** is the parameter used to measure the ordering degree of the matter. The increase of the ordering degree is given by the increase of negentropy, calculated with the expression:

$$\Delta nS = -\frac{\Delta Q}{T}, \ [J/K] \tag{3}$$

The entropy and negentropy are two forms of *conservable energy* (stored inside the material). According to the first law of thermodynamics, the transformation from one form to another one $(|S| \Leftrightarrow |nS|)$ is made in such a way that their sum in absolute values remains constant, i.e.:

$$(|S| \Leftrightarrow |nS|) = ct \tag{4}$$

This means that the increase of one of them causes the decrease of the other one in equivalent values, and vice versa; i.e. the increase in negentropy in a specific area (temporal or spatial), caused by *the ordering and improvement* of the systems and materials, may have the effect of increasing the entropy in another area [22].

The concomitant existence of negentropy and entropy inside the contour of a system, as two contradictory but complementary forms of energy, could be likened to *the yin-yang structure* described by the philosophy and metaphysics of ancient China. According to them, *the light side (yin)* coexists in a system with *the dark side (yang)*, which can be converted into one another [13].

(Neg)entropic characterization of materials

From the (neg)entropic point of view, in a preliminary evaluation, the materials can be characterized as such (Fig. 4):

• *Natural resources (N.R.)*, which have a certain ordering degree of the matter; therefore, they are materials carrying a certain level of negentropy $nS_{N.R}$, considered predominantly *negentropic materials*, or *yin materials*.

• *Primary materials (p.m.)*, which are negentropy deposits at a higher level than the N.R., due to the over-ordering of the matter caused by the technological process (t.p.); it can be said that *the technology itself appears as a specific stock of negentropy*; *the negentropy created by a technological process* is $nS_{t.p.}$; the useful materials are considered *predominantly negentropic materials* or *yin materials*; at the advanced processing of materials from technological phase 1 to phase 2, its negentropy increases with $\Delta nS_{1;2}$; at the same *time the newly added value* increases with $\Delta V_{1;2}$; for S.E. it is recommended to use the expression:

$$\Delta V_{1;2} = f(\Delta nS_{1;2}) \tag{5}$$

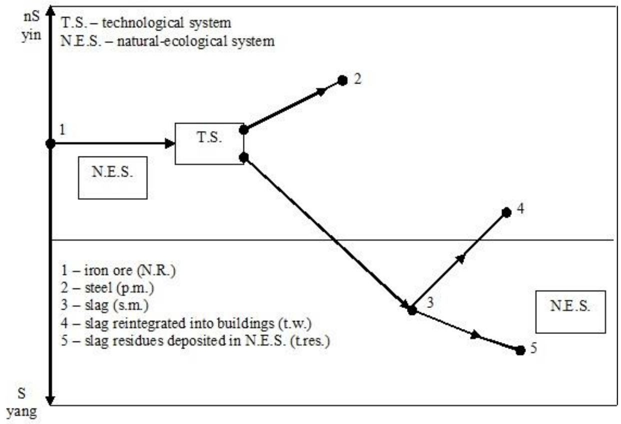

Fig 4. (Neg)entropic transformations in a steelmaking flow

The secondary materials (s.m.) fall into two categories:

- *Technological waste, t.w.* and *degradation waste, dg.w.*; these materials regain through 3R technologies a reordering of the matter, due to which they carry the negentropy of returnable waste $nS_{r.w.}$; they are considered *predominantly negentropic materials* or *yin materials*;
- *Technological residues, t.res.* and *degradation residues, deg.res.*; they are degraded (disordered) materials, and that's why they carry entropy S_{res}; they are considered *predominantly entropic materials* or *yang materials*.

Calculation of the environment entropization degree (E.E.D.)

For the calculation of the environment entropization degree, *a (neg)entropic balance* is drawn up taking into account the two antagonistic impacts given by the human activities:

• *Negentropic intake* in the natural-ecological system:

$$|\Delta nS| = |nS_{t.p.}| + |nS_{r.w.}| \quad (6)$$

• *The entropic intake* in the natural-ecological system, consisting of:

- Disposal of polluting residues which are carrying entropy S_{res};

- Consuming N.R., whose initial negentropy $nS_{N.R.}$ turns into entropy ($-nS_{N.R.}$) at the resource dislocation from the natural-ecological system. This means:

$$\Delta S = (-nS_{N.R.}) + S_{res.} \quad (7)$$

As in any balance sheet, there should be equality between the two components (as absolute values). In reality, however, the laws of thermodynamics and the history of civilization show that there is an inequality, because *the objective and irrevocable phenomenon of environment entropization* occurs in the natural-ecological system due to some causes, such as:

- Changing the negentropy ↔ entropy balance in the favour of the latter, due to the consumption of environmental resources, carriers of natural negentropy; *the yang phenomenon replaces the yin phenomenon*;

- Increase of the natural entropy deposit, caused by the supplement brought by the entropy of residues (pollutants) deposited in the environment;

- The use of natural resources, as well as the reintegration through 3R technologies, are both processes whose yields have subunit values, i.e. they are processes that inevitably produce *new entropy-carrier residues*;

- The heat released from the technological installations turns into *irretrievable entropy* [21-23].

The above means:

$$\left[\left(-nS_{N.R.}\right)+S_{res.}\right]>\left[\left|nS_{t.p.}\right|+\left|nS_{r.w.}\right|\right] \tag{8}$$

In this paper, the above relation is called *the inequality of environment entropization*.

The environment entropization degree is:

$$\mathrm{E.E.D.}=\left[\left(-\mathrm{nS_{N.R.}}\right)+\mathrm{S_{res.}}\right]-\left[\left|\mathrm{nS_{t.p.}}\right|+\left|\mathrm{nS_{r.w.}}\right|\right] \tag{9}$$

4. Conclusions

The model of development through adaptive transformation cycles (MD-ATC), known as durable (sustainable) development, must be strengthened with new knowledge regarding the role of the technological system in the development of ecotechnological complexes. In the above context, the operationalization of new concepts and methods through development projects becomes necessary, i.e.: resource consumption extensity; ecotechnological sustainability; industrial pollution; ecotechnological durability; sustainable and durable development; application of the laws regarding the unity and conflict of opposites, transformation of the quantitative accumulations into qualitative leaps; irreversible environment entropization.

The ecotechnological complexes development projects should start from the following some essential principles as the one listed above.

The essence of the sustainable and durable development is *the synergy (sustainability + durability).*

The extensive consumption of natural resources and the pollution are two disturbing control parameters (T.S. → N.E.S.), which cause negative impacts expressed by *the depletion of resources* and, respectively, *the decrease of environmental quality*.

The principle of the technological system destroys the technological system repairs; meaning that, based on the intrasystem development, the technological system must and can reduce the negative impacts.

The natural-ecological system ability to absorb the impacts through *negative feedback* must be taken into consideration. According to the model of development through adaptive transformation cycles, the development cycles of the technological system must be correlated with the development cycles of the natural-ecological system.

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