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Article

Vectors of sustainable development and global knowledge in the metallic materials industry in Romania

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Abstract: As a 21st century trend, sustainability has encompassed the entire world economy, including industry. Today the concept of "Industry 4.0" is known, resulting from advances in ICT (information and communication technologies). In recent years, companies in the metal materials industry have also implemented strategies and technologies belonging to the Industry 4.0 concept. The main purpose of the manuscript is to identify the key issues in the evolution of the development of the metal materials industry. The transition to a higher level of its evolution is based on two vectors, namely: the ecological paradigm, as a vector of in-depth knowledge, and sustainable material, as a vector that ensures sustainability in the areas of convergence of systems in the spheres of life and social consciousness. The systems that have an impact on the sustainable development of the metallic materials industry, through the interactions between them, are: the technological system, the social system and the natural-ecological system. Global knowledge requires the use of all inter and multidisciplinary knowledge, which ultimately contributes to the definition and characterization of new intersystem scientific branches: Ecometallurgy, Metallurgical Economics, Metallurgical Ecosociology and Sustainable Materials Engineering. The paper is considered a research study based on elements such as: literary foundations, using databases such as Web of Science (WoS), Scopus, Google Scholar, sustainable universal principles and legislative parameters.

Keywords: sustainable development; ecometallurgy; metallurgical econology; metallurgical ecosociology; sustainable materials engineering

1. Introduction

Today, changes and influences, produced by science in social life, are closely related to a new process of remarkable conceptual progress. In recent years, companies in the metal materials industry have also implemented strategies and technologies belonging to the Industry 4.0 concept.

Industry 4.0 is understood as a fourth industrial revolution, and is a consequence of the advances in ICT (information and communication technologies) being implemented in industry. The changes in the metal materials industry are focused on production, information technology and environmental protection. So, we can talk about Sustainable Industry 4.0, which leads to the formation of new value chains, changes in business models and the reorganization of service and work processes. This concept is based on key pillars which result from continuous advances in new technologies, such as the Internet of Things, cloud computing, Big Data, modeling and simulation, autonomous systems AS), augmented reality (AR), additive manufacture (AM) and cyber security [1].

The Sustainable Industry 4.0 concept has been gaining increasing interest among scientists and practitioners in recent years [1].

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Currently, the authors of many scientific articles draw attention to the lack of recognition of both positive and negative effects on sustainable development and therefore undertake research on Sustainable Industry 4.0.

With the industrial revolutions, many changes took place in the environment, which later led to constant crises or even endangering survival. Because of these, people realized that they began to face various problems, which led them to work hard to improve the situation. The urgency of global environmental protection and sustainability development is more obvious and the global interest in efforts to address sustainability challenges through education is growing steadily. Accordingly, education is a key enabler of sustainable development. The Education in Sustainable Development forms part of Target 4.7 of Sustainable Development Goal 4, which by 2030, aims to ensure that people acquire the knowledge and skills needed to meet the needs using a balanced and integrated approach to the economic, social and environmental dimensions of sustainable development and is understood as an important means to achieve all the other Sustainable Development Goals [2]. However, all the SDGs contribute to the achievement of Goal 4 [2].

Thus, the progress of science in social life is supported by a *sustainable development model*. Generally speaking, the concept of sustainable development can be interpreted in different ways, but the best known is "Sustainable development refers to the development that meets the needs of the present without compromising the ability of future generations to meet their own needs". The general definition emphasizes that industrial companies should reduce their negative impact on future generations [3]. In this context, the metallic materials industry is under pressure due to the large environmental footprint in the production process. The efforts are being made today to develop more energy efficient technologies, with low environmental impact and socially acceptable [4].

Each part of the metallurgical process has a different magnitude of environmental risk during its execution. There is a notable disassembly between what every unit in this sector promotes as the main and most important parts of their management (ecologic programs, sustainability, environmental responsibility, etc.) [5].

As a result, there is a need to create a sustainability development model that includes these different perspectives, which should be based on the legal, social and operational duties of the metallurgical units [5].

Studies have shown that organizational/individual behavioral factors play important roles in sustainable development, such as technical risk, lack of the manager's influence, and top management commitment [3]. Research also shows that there are a number of sustainable development dilemmas that managerial factors in enterprises face, such as the lower controllability of operations, cultural differences among the top managers, and inefficient communication systems, processes and policies established between retailers and suppliers [3]. It was found that, management efficiency mainly depends on the operational level, focusing on the implementation of the sustainability practices among different operational functions [3].

In essence, the concept is an approach to development, which strives to balance different and often competing needs, with a growing awareness [6] in technological system, the social system and the natural-ecological system.

In this way, the conceptual progress of science in social life represents the process, defined by the evolutionary and adaptive transformations, within the mega system eco – socio – economic – technological, resulting in conditions of *interaction and inter-conditioning* between its components: the natural-ecological system, also called *foundation system*, the social system, the economic system and the technological system, which are also known as *parasitic systems* [6-9].

The design of a *new model of sustainable development*, regarding *the changes and influences of science in social life* should propose qualitative and quantitative improvements in *the design, dissemination* and *operationalization* of new knowledge (figure 1). Certain targets become mandatory, as follows:

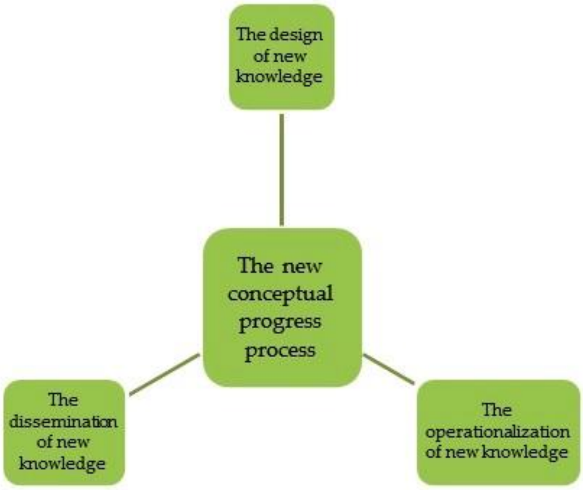

Figure 1. The new model of sustainable development, based on the changes and influences of science in social life

- The use of *multi* and *interdisciplinary integration tools*, so that the new model should provide the theoretical framework for understanding adaptive and evolutionary transformations, i.e. designing new methodological and managerial tools;
- Achieving *the integration of sectorial knowledge*, provided by a wide range of disciplines, in order to understand the mega system integration events;
- The permanent reactivation of human thinking which, compared to the technique development, cannot come immediately and consecutively after the development of material life.

Lately, such goals are accomplished based on new concepts, known as *global knowledge* and *global thinking* [9, 10].

2. Theoretical Basis

The bibliographic research was carried out in two fields:

- *Sustainability*, as the main lever in the evolution of the development, at a higher level, of the metallic materials industry. The time interval of the analyzed period is 2000–2021;
- *Sustainable Industry 4.0*, as a concept for the development of the metal materials industry, through the use of advances in ICT, *new global knowledge* and the latest and most advanced techniques and technologies with low impact on the environment. The time interval of the analyzed period is 2011–2022.

Based on the literature available, using databases such as Web of Science (WoS), Scopus, Google Scholar, sustainable universal principles and legislative parameters, we conducted a literary study, which led to theoretical assumptions about a sustainable evolution of metallurgical companies to increase efficiency with low impact on the environment. Prior literature did not emphasize the importance of the conditions of interaction and inter-conditioning of the need to build new knowledge and innovative skills, together with their dissemination and implementation in the process of training community members from field of metallic materials industry. In recent years, metallurgical engineering companies have been facing external sustainability pressures, including ecological and environmental protection by reducing emissions, laws and institutions, beneficiary requirements, competitive pressure and technical improvement; and internal sustainability pressures, including human resource management, cost reduction and improved operational efficiency [3].

From an the external perspective of metallurgical companies development, the researchers showed that the support policies and mandatory policies, issued by the government provide an institutional guarantee and constraint for the implementation of sustainable development goals, are important institutional mechanisms [3] for sustainable development of the metal industry. An important guarantee for companies in the metal materials industry shows that for a remarkable conceptual progress, the interactions and inter-conditioning of the components within the mega eco – socio - economic – technological system must be optimized.

3. Results of Bibliometric Analysis

Based on bibliometric analysis, the researchers found that under the conditions of super development of the information society, by shifting it to a peak stage represented by the knowledge society, it becomes necessary to operate with new conceptual categories that characterize the qualitative leap to a knowledge level superior to the existing one. This makes it mandatory to use and operationalize certain tools, such as: *the global knowledge* and *the ecological paradigm*.

3.1. The global knowledge

The global knowledge for the material engineer means to build new knowledge and innovative competencies, on the one hand, and their dissemination and implementation through the process of training and improving the community members, on the other hand, considering that:

- The interactions and inter-conditionings occurring *the convergence areas* of the four systems of the mega system eco-socio-economic-technological should be studied in-depth, using *the postulate of the interdependence of parts* and *the priorities of the whole in relation to these parts* [14];
- It is necessary to *minimize the negative inter-conditionings* between the technological system (producer of metal materials and metallurgical services) and the other systems;
- The natural-ecological system must be supported to be able to perform its two fundamental functions (resource provider for the other systems and processing or storage basin for the polluting secondary materials);
- The mega system eco-socio-economic-technological investigation is a matter that is based on specialization, disciplinarity, interdisciplinarity and transdisciplinarity;
- The possibility to generate new ideas by the specialist who collaborates interdisciplinary to increase the value of the initial information becomes greatly necessary [15];
- The global knowledge pattern shall match with the magnitude of *the durable (sustainable) knowledge*;
- *The dissemination of new knowledge* must have a multisystem nature;
- The metallurgical engineer must shift from the *gogglewise* knowledge to the fanwise knowledge [16];
- The metalworking engineer must contribute to the development and expansion of *technological know-how and technological knowledge*.

3.2. The eco-socio-technological paradigm

The ecological paradigm, as a vector of in-depth knowledge, is considered a form of superior paradigm, which is understood as a constellation of beliefs, values and methods within which the community members ask questions and find answers on durable development and global knowledge about materials engineering. Within such a framework, the engineering event is investigated, identified, characterized and made available based on methodological principles, methods and tools that highlight *the priority importance of the natural-ecological system* as a foundation system. More specifically, this means that the technological processes and the resulting materials must go through *a circular active anti-entropic life cycle* (provision of resources → manufacture → use → reintegration of secondary materials using 3R technologies (recirculation, recycling and regeneration) → disposal of residues) [17].

The operationalization of the eco-socio-technological paradigm is acting over two aspects:

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- It replaces the current *techno-technologist paradigms*, which are *conventional paradigms;*

- It predicts *a global-type paradigm* that can be called *"durable development paradigm"*.

As will be seen below, the use of ecological paradigm leads to important changes in the knowledge of materials engineering.

The application of the eco-socio-technological paradigm enables:

- The systemic approach, in which the eco-socio-technological paradigm mega system is appreciated on the basis of interactions of the ecological, economic, social and technological components, so that the impact of one component affects the system as a whole;

- The contingency approach, which states that the objectives can be solved taking into account either the connections intra-system or between them and the elements of the external environment; in such a framework, it becomes possible to know the methodological tools to characterize *the human activated dichotomy - the environment condition* [18].

3.3. The new materials

The advanced material, according to the ecological paradigm, is *the material that goes fully through a negentropic life cycle*.

According to the techno-technologist paradigm, the advanced material is the material that meets the rigours imposed by the advanced (top) industries. Based on this paradigm, *the nuclear materials*, for example, are advanced materials. According to the ecological paradigm, this function is ***not*** fulfilled, because they do not go through a negentropic life cycle, the nuclear waste being just disposed and not re-used.

The high-performance material, according to the ecological paradigm, is *the material which, going through an anti-entropic life cycle, ensures a maximum degree of recovery to the primary substance (intrinsic substance or native substance)*.

The primary substance is a necessary notion, because the cost-benefit analysis provides costs only for extraction, preparation, transport and handling, but not for the intrinsic value of the raw materials given by the content of the useful substance (e.g. the value of the main petroleum hydrocarbon).

According to the techno-technologist paradigm, the efficient material is the material whose use characteristics reach maximum values. Judging by this paradigm, the nuclear materials are efficient materials. According to the ecological paradigm, this function is not fulfilled, since the nuclear residues, which still contain the primary substance, cannot be re-used.

3.4. Scientific branches of global knowledge in the metal materials engineering

The inter-, trans- and multisystem activities (actions) have recently become subjects for new scientific branches, the subject of which are areas of inter- or multidisciplinary convergence. Thus, the investigations on ecology-economics inter-conditionings (ECOL-ECON correlations) have led to the foundation of some disciplines, such as *Natural Resources Economics* or *Environmental Economics*. Lately, this correlation has been supplemented by *the energy factor*, which characterizes a new sphere of knowledge: ecology-economics-energy correlations (ECOL-ECON-ENERG correlations, or 3E correlations, or E^3 correlations). This area has become the object of study for a new discipline, called *Econology*. In the same vein, there are more numerous and more important concerns regarding the inter-conditionings between ecology and sociology (ECOL-SOC correlations), which became an object of knowledge for a new discipline, called *Environmental Sociology* or *General Ecosociology* [19].

4. Discussion

In the spirit of scientific research, more and more specialists are currently participating in the extension of durable development knowledge implementation area.

It is also the case of metal materials engineers who, in their capacity as distinguished members of the technological system, have launched *Research-Development-Innovation* to the market, *new branches of science in terms of global knowledge*.

The Ecometallurgy *is the scientific branch whose objective is the theoretical substantiation of the knowledge and application of the improvement technologies and techniques in the metal materials industry, in accordance with the rigours of the sustainable development concept* [20].

The emergence of this scientific branch is due to certain causes, such as:

- The necessity of transition from specialized industrial branches (metallurgy and environmental engineering) providing conventional materials and services to branches producing efficient and advanced materials, as well as ecomaterials and sociomaterials;
- In case of eco-metallurgy, there are training conditions based on multi- and interdisciplinary knowledge;
- The Eco-metallurgy becomes a field adaptable to the rigours imposed by two systems: the natural-ecological system and the technological system;
- This discipline brings the metallurgist closer to nature, a modern trend of the sustainable development;
- The Eco-metalurgy enables the dissemination and knowledge of the rigours convergently imposed by the natural-ecological system and the technological system.

The Metallurgical Econology is *the scientific branch dealing with the optimization of pollution prevention and control policies and the specific consumptions of natural capital in conditions of economic efficiency and minimization of energy needs in the metal materials industry* [15].

The launch of metallurgical econology is imposed by the importance of the economic system in the operationalization of *the economic magnitude* of the concept of sustainable development. This means solving a complex made of two main segments [21]:

- Streamlining of metallurgical product manufacture processes (the economic system and the technological system);
- Optimization of specific consumptions of natural capital, under conditions of pollution prevention and control (the natural-ecological system and the technological system).

The Metallurgical Ecosociology is the branch of science that approaches the engineering ways of optimizing the socio-environmental interactions and correlations existing in the metallurgy field. It deals with the ways, modalities and possibilities through which *the engineering actions (activities) interrelate with the sociological restrictions*. The attention focuses on the scientific branch whose *main knowledge objective is to optimize the impact of industrial policies, technologies and equipment on the quality of life, mainly through the quality of the metallurgical environment* [22].

The Sustainable Materials Engineering has emerged as a result of the fact that in the domain of defining, characterizing and designing new ways of evolving in the field of materials it is felt the need for *a qualitative leap to a level of knowledge superior to the existing one* [23].

There are currently many papers that deal with studies on materials. Their analysis leads to conclusions that confirm the previous finding. Therefore:

- The materials are a restricted and sectoral subject, with a particular aim to achieve [24];
- Almost all situations are focused on *the use phase of the life cycle* [25];
- The material is not regarded as an industrial lever that can influence the interactions and inter-conditionings occurring in the convergence zones of the systems [26];
- The material is not analyzed and evaluated as a tool to help ensure the sustainability and durability of the systems.

The authors believe that overcoming such dysfunctions as above can be done by moving to another level of approaching the materials. In other words, it is believed that the sphere of human activity has started to depend on a new generation (class) of materials that become a subject of knowledge under two names:

- *Durable materials* (a name adopted and adapted in Romanian from the French name *durables matteriaux*), or

- *Sustainable materials* (a name adopted and adapted in Romanian from the English name *sustainable materials*).

Starting from the above names, we propose the following definitions for the notion of durable material:

The durable material (**sustainable material**) is *the material considered to be the major vector that ensures the sustainability and durability in the convergence zones of the three systems, in general, and between the technological system and the natural-ecological system, in particular*.

The durable material (sustainable material) is *the material which, going through all the phases of the circular active life cycle, contributes to solving the rigours, restrictions, conformances and specifications imposed by the need to achieve the system performance in all three systems*.

The durable material (sustainable material) is *the material which simultaneously performs the functions of efficient material, advanced material, eco-material and sociomaterial*.

Given that the authors of this paper are metallurgical engineers, *the main heroes* of this paper are, in general, the durable metal materials and, in particular, *the steel*, which will continue in the next decades to be the foundation of the economic and social development. The authors are approaching and treating these materials as characters considered to be trustworthy life partners. The steel is a sociomaterial not only because the living standards are based on it, but also because it undergoes a real social life. Thus, it is a diligent learner because it is learning and operationalizing high-level scientific knowledge, it occupies the position of service provider, has a modern attitude in relation to the media, sustains the collective work, cultivates public relations, taking into account the emotional state from other spheres, behaves like a young practitioner of industrial fitness, is a flexible and adaptable partner, stubborn in the positive sense of the word. The steel can display such qualities as it uses modern ways, means and tools of technological and social evolution represented by *durable technologies and equipment*. The home (the family) in which the steel lives is *the durable metallurgy*, an industrial branch able to put its shoulder to the wheel for reaching the economic and social optimum in our country.

5. Conclusions

The article confirms the thesis that the evolution in the metal materials industry is based on three new concepts:

- *The durable (sustainable) development;*
- *The global knowledge;*
- *The eco-socio-technological paradigm*.

The interaction between the technological system (represented in this paper by Metallurgy) and the natural-ecological system must be optimized in the following directions:

- Ensuring the durability and sustainability of the natural-ecological system in its dual quality: natural resource provider and collection basin for the pollutant secondary materials;
- Using the multidisciplinary and interdisciplinary integration knowledge to study the interactions of the technological system, the natural-ecological system and the social system.

In a context like the one above, new scientific branches of durable development and global knowledge become important, as Ecometallurgy, Metallurgical Econology, Metallurgical Ecosociology and Sustainable Materials Engineering, defined and briefly described in this paper.

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