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CIRCULAR AND GREEN ECONOMY IN THE CASE OF WASTE MANAGEMENT THAT CONTAIN IRON

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Abstract: *In Romania, the transition process to a green and circular economy is proceeding slowly, as no concrete plan of measures based on the current situation has been achieved. Studying good practices in the implementation of the two concepts and developing viable models can generate benefits at both the national and global levels. Based on the study of the best practice models – the Danish model and the Hungarian model, respectively, but also on the principles underlying the two concepts, technologies have been proposed that can be implemented in a closed-loop stream, to recycle the waste with iron content. They require a minimum processing of the waste and by-products obtained: pellets, briquettes, and ferrous agglomerate can be used as secondary materials in steel processes. Qualitative and quantitative determinations of the own experimental approaches constitute future directions of the research.*
Key words: *green economy, circular economy, recycling, waste management, good-practice models.*

1. INTRODUCTION

Since the early 1990s, there has been an acute awareness that economic development is only to a lesser extent, in a relationship of interdependence with the activity of resource extraction, the main factor in increasing the level of environmental pollution. As a result, people have now become interested in the emergence, the way of implementation, and the benefits that the new concepts developed (circular economy, green economy, blue economy, sustainable development) generate. The main goals of the newly developed concepts include creating stability in policy implementation tools and forecasts, managing value and product planning chains, the engine of which is to increase activities related to innovation, technology, and better organization.

According to the definition given by the European Commission of the European Union, within a circular economy the value of products and materials is maintained for longer periods of time, waste, and the degree of depletion of resources are minimized, and when the product is found at the end of its life cycle, it is reused, generating additional value, generating multiple economic benefits (economic growth, generating new jobs for the population) and a major contribution to innovation processes [1].

The development of the concept of circular economy has been accelerated since the sixties, its emergence being influenced by theories based on the concepts of industrial ecology, performance-based economy, blue economy, Cradle-to-Cradle (the process of determining the directions for the use of materials is made according to their intrinsic value and useful life) [2].

In the literature, a multitude of definitions are given to the concept of circularity that are closely related to the efficiency of the use of natural resources throughout the entire life cycle of products and even after the transformation of waste into novel resources.

The Ellen MacArthur Foundation provided a comprehensive, internationally accepted, and widely circulated definition of the concept of circular economy, according to the following: A circular economy is a regenerative or restorative industrial system by intention and design; replaces the concept of renewable “end of life” with restoration, transition to the use of renewable sources, elimination of the use of

toxic chemicals, affecting reuse and aiming to eliminate waste through the superior design of materials, products and systems [3].

In the 2011 report by The United Nations Environment Programme (UNEP) entitled "Towards a Green Economy: Pathways to Sustainable Development and Eradication of Poverty", it was noted that the green economy is a concept interconnected with the concept of circular economy, since both concepts make direct reference to improving wellbeing and social equity, while at the same time having in the foreground the reduction of environmental risks and of the ecological deficit, as shown in Figure 1 [1].

The perspectives offered by the green and circular economy come in strengthening the known abrasion of sustainable development, the three concepts forming a unitary whole whose common denominator is to ensure the protection of the environment, increase the competitiveness, and productivity of resources. According to the European Commission, the scope of the green economy is defined by the following terms: innovation, resource efficiency, promotion of sustainable production and consumption models, prevention, and management of waste [1].

The role of the circular economy is to promote the reuse and recycling of materials and products, with recycled materials being cheaper than raw materials, thus reducing greenhouse gas emissions and reducing dependence on raw materials.

Due to the role played by the circular economy, it can be applied with guaranteed success in the field of recycling waste containing iron, the byproducts from recycling process become secondary raw materials in the processes of making cast iron and steel.

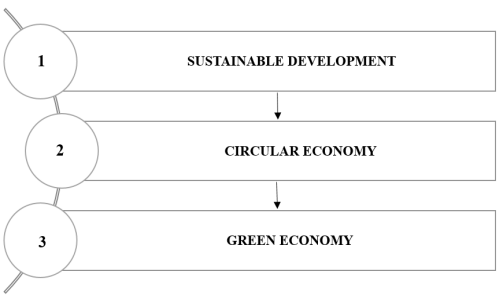

Fig. 1. Hierarchy of the three new concepts that underpin the EU resource efficiency strategy.

In the steel industry, the implementation of the circular global economy has started, which promotes the concept of zero waste, which aims at reducing the number of materials used in fabrication and encouraging the reuse and recycling of materials. The ecological concept applied to the management of waste that contains iron, involves the development of those types of closed-loop flows production in which no resource is disposed of and all materials are continuously reused, no hazardous waste or other products are discharged into the environment [4].

The action plan on the transition to a new economy aims to introduce circular economy principles at the level of each phase of the production chain - intrinsic value, and to stimulate the reintroduction of secondary raw materials represented by recycled waste into the economic circuit.

The research and studies carried out so far regarding the area of implementation of the circular and green economy, show that the two concepts concern any type of sector of activity and especially waste management.

There must be greater awareness and importance of waste prevention, recycling, and better waste management are essential to minimize material inputs (resources) and outputs (waste). At present, considering the accelerated mode of resource consumption, a situation of global interest, the transition from the linear economy model to the circular economy model needs to be made, and it is necessary to rethink the flow of production - consumption - elimination.

Because of this, the authors present in this paper the modalities of implementing this concept. Therefore, the potential is presented for the aspects caused by the implementation, respectively, the transition to a circular economy in Romania, considering the models and good practices existing in other countries.

The main aspects of these studies are identified as reducing the amount of iron-containing waste deposited in nature, as well as their recycling as a secondary material.

2. METHODOLOGIES

2.1. Study of good models of practice

In the paper, the methodology followed considered the highlighting of the beneficial aspects generated by the transition to a circular and green economy, presenting examples of good practices at the European level, practices that can be easily adapted and implemented in the national economic circuit. The emphasis was placed on the consequences generated by the adoption of the concept of a green and circular economy on the management of generated waste and on the recycling of waste with iron content, for which models of recovery processes have been proposed. The transition to a circular economy aims to promote those sustainable models of production and consumption that can be implemented within a society in constant search of novel resources, so necessary to support and grow the economy (Figure 2).

The approach proposed by the concept of circular economy envisages the saving of primary resources by introducing waste generated in the production streams that generated it.

The circular economy is seen as part of sustainable development (according to Figure 1) bringing to the fore the need to optimize the consumption of resources, to prevent waste of any kind, and to promote the concept of reuse.

In Figure 3 the three aspects of the circular economy are presented which are linked to the approach of the green economy, and as can be seen from waste management, the main subject of the work is among them. The concept of a circular economy concerns not only waste management, but all sectors of activity (production, consumption, food, manufacturing, etc.).

Waste management is a fundamental part of the circular economy approach, bringing into question the need to carry out an in-depth analysis of the life cycle of products, from the extraction of the necessary resources to the actual design and design phase of the product and ending with the realization of the finished product, which is to become a new resource for a given industry at the end of its life cycle (change status in waste).

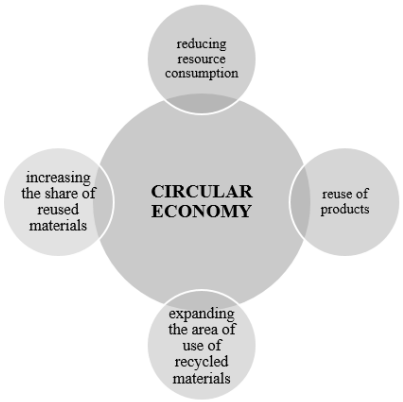

Fig. 2. The main aspects of the circular economy.

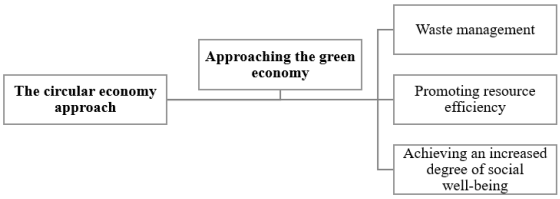

Fig. 3. The common aspects covered by the two approaches.

The Batumi Green Economy Initiative (BIG-E), which is a set of voluntary commitments made by interested countries and organizations to act in the green economy, should also be mentioned when considering the green economy (among the countries participating in this initiative are Romania and the Republic of Moldova). BIG-E contributes to the operationalization of the pan-European strategic framework for the greening of economics in the period 2016-2030 [5].

At the national level, initiatives have or have been developed with the purpose of promoting the green and circular economy in concrete cases, most of the projects have focused on how to manage waste. The paper will also contain a more precise presentation of these projects.

In Romania, supporting and implementing the concepts of green and circular economy requires supporting and developing projects and other initiatives in the field of technology and eco-design of products, increasing consumer awareness of the transformation of residues into new products as part of the circular economy [1].

To create a suitable circular economy model for the Romanian system, existing practices at the national, international, or European level must be considered and studied. Such practices are briefly described below:

- A highly regarded practice is the Danish model, whose development began in 1961 and was first implemented in the town of Kalundborg in Denmark. At the beginning, 11 public and private companies from Kalundborg were active in the Kalundborg symbiosis project and there are currently 13 partners with international vision. Global private companies in Kalundborg work with businesses and local authorities in all sectors and provide jobs to around 4,500 people [6]. Companies that cooperate under the Danish model in the city of Kalundborg are sending the waste resulting from their production process to other companies in the system, for which the waste is considered a valuable resource for their technological process. Among the resources exchanged / traded by companies that have participated in this cooperation process, there is steam, sludge, ash, or hot water [7]. This model has proposed a circular approach to production based on the principle of converting the residues generated by one organization into sources for another organization, which benefits both the environment and the economy [1]. The Kalundborg symbiosis is the first concrete example of a circular economy, which focuses on building collaborative connections between companies to reduce waste by facilitating resource reuse options within a functional and integrated system [1].
- Hungary also provides a model of good practice in the implementation of the circular economy where the objectives of the waste management project called Mecsek-Dráva, on the transition to a green, circular economy, consisted of achieving compliance with waste management, improving resource efficiency, reducing the amount of waste landfilled, reducing the cost of waste management activity, etc. [1]. The project was completed by opening a Pécs-Kökény Waste Management Center, whose role was to address the waste challenges of 313 municipalities. The project was funded by the Cohesion Fund and the European Investment Bank. Within the center, all waste is passed through a mechanical-biological treatment plant, with the right material for fuel generation being separated and used as energy. The organic matter in the waste is also disposed of and transferred to a composting plant [8]. Under this model, recyclable materials are recovered and used to generate raw materials for sale.

Among other countries that have developed and implemented good practice models in the field of recycling, management, and promotion of activities to optimize available resources through processes and technologies to recycle and transform waste into resources, are Finland (Kujala Waste Center, Lahti - main purpose of identifying solutions for the part of sludge, organic waste from stores and industry (use of ash resulting from industrial process)), Ireland (SMILE-Ireland), United Kingdom, according to a research conducted by the European Institute in Romania and called “Spos Strategy and Policy Studies 2018” [1].

In recent years, there is no doubt that more countries around the world have become familiar with the concepts of the circular and green economy, developing plans and initiatives in this regard. Therefore, several initiatives and projects carried out in Romania are presented below:

- Iasi zero waste RETRAGE – Circular Economy and Systemic Design in Romania - The aim was to implement sustainable production systems in which waste generated by one manufacturing process is integrated into other production processes, with the aim of making it easier to move towards the circular economy [1].
- Urban Wins Project - It aimed to establish a set of scientific planning tools

for the problem of waste management efficiency, which should be applied in any public institution in Europe [1].

Among the initiatives developed and implemented at national level regarding the circular economy, there are PlastiCircle (Improvement of the plastic packaging waste chain from a circular economy approach), CICERONE (Circular economy platform for European priorities a circular economy approach), the WeltPixel Initiative (envisaged the realization of a platform for retailers specialized in biodegradable products) etc. [1].

These initiatives that were developed at the national and local level prove the growing interest in the two concepts (circular and green economy) in all waste management domains.

2.2. Model for the application of circular and green economy concepts in the recycling and recovery of waste containing iron

Most of the waste with iron content comes from steelmaking and steel processing processes of steel, but also from the mining industry, where, after the extraction of ore deposits, its preparation occurs (ferrous concentrate from sideritic waste). As can be seen in Figure 4, waste from technological production streams of steel is found in the form of pieces or in powder form.

For a waste to be considered a new resource, it must meet certain end-of-waste (EoW) criteria. These criteria are laid down in the Waste Framework Directive 2008/98/EC and in the Waste Treatment Act no. 211/2011, which also introduced the end-of-waste concept (EoW).

According to the law in force, certain types of waste cease to be considered waste only when they have gone through recovery, recycling, and meeting the specified criteria. The criteria shall contain provisions relating to the allowed limit values for the various pollutants where appropriate, and to the potential effects that the waste may have on the environment when its waste status ends. The criteria contain provisions related to the limit values allowed for different pollutants, where appropriate, and to the potential effects that the waste may have on the environment when its waste status is over [9].

By initiating and promoting activities for the collection and recycling of ferrous waste, it contributes to the saving of global resources, protecting the environment, saving substantial amounts of energy, and generating an improvement in quality of life.

The recycling activity of iron containing waste is undoubtedly more economically efficient than the underground exploitation of iron ore and its preparation for the melting process. Through recycling, economic benefits are generated that should not be ignored, the recovery of waste with iron content having multiple directions of use, in Figure 5 are some such uses.

For some time, Romania and other countries around the world have been faced with the issue of disposing of industrial waste deposits, the solution being to apply the principles of the circular economy to minimize waste and limit environmental impact. A specific case of application of the Danish model could be the creation of an association between steel plants, cement production plants, and road and highway construction companies, the transfer of a type of waste from the steel industry is a necessary resource for the operation of the other two fields of activity.

As one of the main wastes generated by the steel industry, slag becomes a secondary raw material for the cement clinker manufacturing process and is also a cheap but sustainable material for the construction of roads and highways. Putting this Danish model into practice would, over time, lead to the final disposal of slag deposits, which are present in Romania. Implementing recycling process models would help prevent waste, protect the environment, and provide ways to reuse waste generated within the same generating companies.

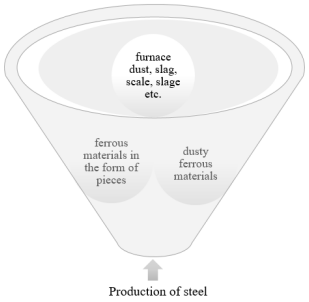

Fig. 4. Classification and examples of the main types of waste containing iron.

Such models (which will be tested under laboratory conditions and for which practical implementation methodologies will be established) are shown in Figures 6 (obtaining products from small and powdery ferrous waste) and 7 (technological process of steel manufacturing in an electric arc furnace or induction furnace, where waste containing iron can be used as secondary raw materials).

When these models are implemented in the steel industry, significant reductions in greenhouse gas emissions can be achieved.

By applying the basic principles of the circular economy (eco-design, keeping products and materials in a continuous cycle of use, regeneration of natural resources), which were the basis for the realization of the models of the recycling processes of waste with iron content, it will be possible to achieve more sustainable and innovative products.

At international and national level, the most used processes for the recovery of small and powdered waste (e.g., steel dust, blast furnace dust, scale, slurry from blast furnace agglomeration, etc.) are pelleting (resulting by-products called pellets), agglomeration (resulting ferrous agglomerate) and briquetting (resulting by-products called briquettes) as shown in Figure 6.

The palletization process applies only to iron-rich waste that has a fine grain (below 0.2mm) and is a method of transforming small material into larger material, so that the products obtained from the process can be used in the industrial steel and cast-iron production process after prior hardening [10].

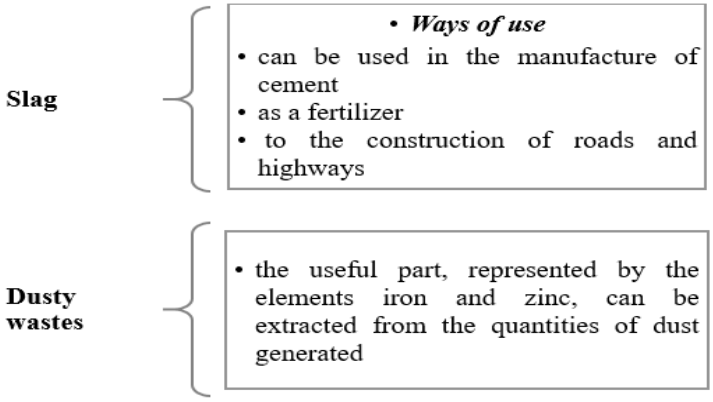

Fig. 5. The main uses of the residues generated by the steel manufacturing process.

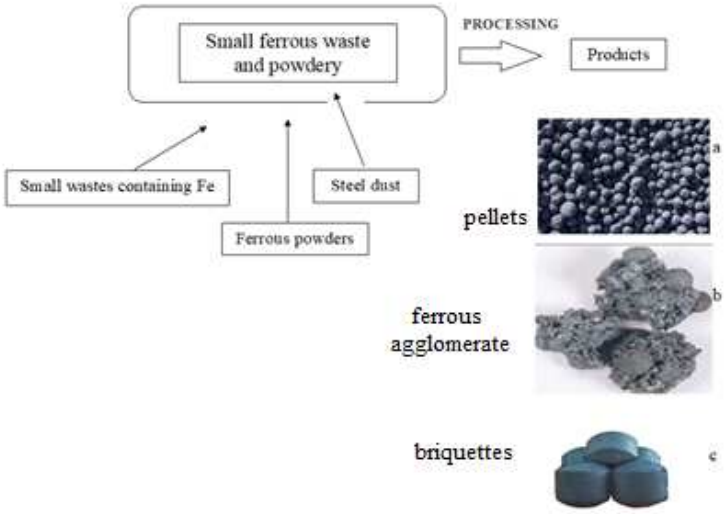

Fig. 6. Process for the recycling of ferrous and powder waste (realized by the author) [11].

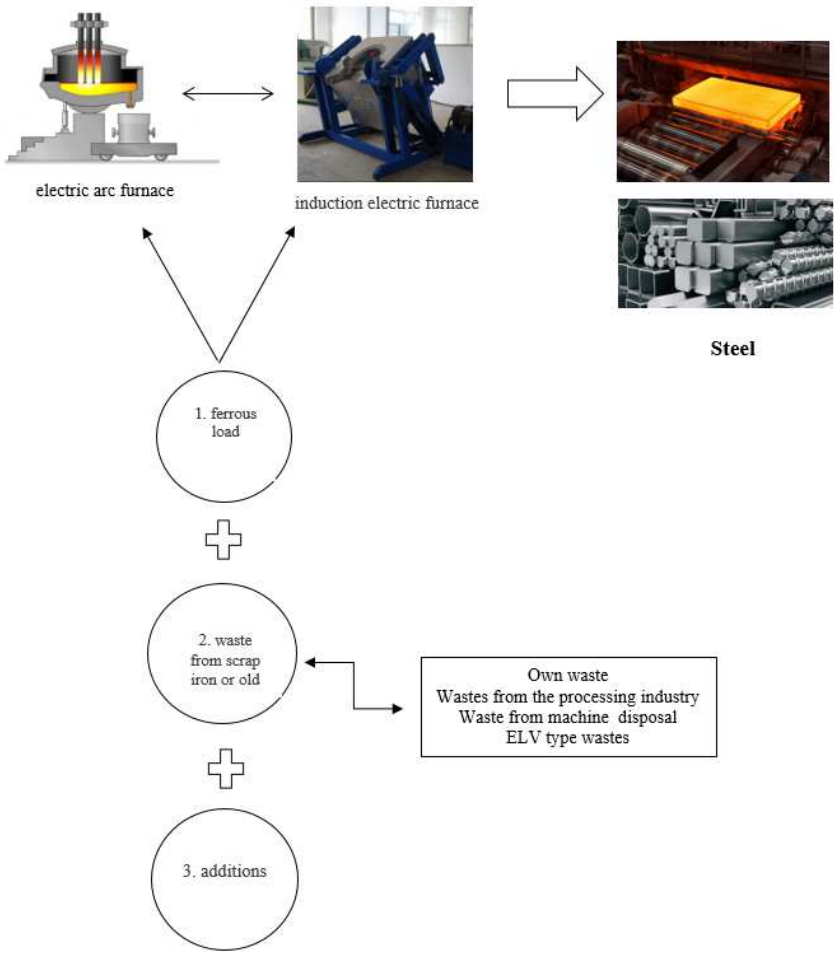

Fig. 7. Process for the recycling of ferrous waste (realized by the author) [11].

According to the specialized literature and some research carried out within the UPT (Politehnica University Timisoara), the process of pelleting powdered waste results in the formation of raw spheres due to the process of rolling the ground iron ore, respectively, of a

mechanical mixture from which bentonite (clay sedimentary rock that has a high-water absorption capacity) and a certain amount of water should not be missing [10].

Agglomeration is the most used recovery process, by means of which fine and small concentrates and ores (below 8mm, below 6mm and even below 3mm for metallurgical coke) are transformed into pieces by heating materials at elevated temperatures in special installations (in rotary furnaces, on the sintering tape or, in certain cases, in the sinter box) [10].

Briquetting is the operation by which small material with a grain size below 8mm (iron ore, ferrous waste) mixed with the binder is transformed into pieces by pressing with the help of specialized equipment (hydraulic presses) [10].

The waste, once processed in the form of pellets / briquettes / ferrous agglomerate, can be recovered in the process of development of ferrous alloys and, if they are also subjected to a reduction process, can be used in the load of the elaboration aggregates.

Hungary's model in which recyclable materials, in this case small and powdery waste with a high iron content, are recovered and used to generate raw materials for sale is easily suitable for the recycling process shown in Figure 6. The coproducts resulting from recycling (pellets /ferrous agglomerate / briquettes) can be put up for sale by recycling companies, the main buyer being the steel companies where these types of waste are only stored and not recovered.

According to the recycling process shown in Figure 7, steel can be manufactured both in the electric arc furnace and in the electric induction furnace, the load being formed in both cases from: Products obtained by processing small or powdery waste with high iron content (briquettes, metallized pellets, iron sponge, or self-founding agglomerate) + Waste from scrap metal or old cast iron (waste from the scrapping of machinery, wastes of end-of-life vehicle type ELV, own wastes such as scrap, etc.) + Additives to correct the chemical composition (ferroalloys, alloying elements etc.).

Based on the same purpose of identifying those solutions for the recovery of certain classes of waste on which the Finland model was based, the recycling process from Figure 7 presents a variant of integration and because of the disposal of waste resulting from industrial processes, of waste resulting from the scrapping of machinery, of waste of the type of end-of-life vehicles, etc. The use of this waste in the steel manufacturing process helps reduce the amount of energy consumed and reduce CO_2 emissions.

It is imperative that iron content waste be regarded as resources of important economic value in the manufacturing process of new products, because in this way the option of storage can be eliminated. Considering the potential generated by industrial landfills resulting from mining and metallurgy activities, located in the western part of the country (Hunedoara County in the Hunedoara and Călan localities, as well as in Caraș Severin County in Oţelul Roşu and Reșița, but also in Calarași) [12] it is more than obvious that the potential that can be exploited and transposed is more than obvious in the approach of the concept of cyclicity promoted by the circular economy.

Worldwide, according to WorldSteel, each steel production plant is also a recycling plant, with all steel production based on waste, up to 100% in the electric arc furnace (EAF) and up to 30% in the blast furnace (BF) route, the electric arc furnace (EAF) method of steel production can use exclusively recycled scrap metal [13, 14].

This aspect is also intended to be implemented in Romania to limit or even eliminate industrial waste deposits.

3. CONCLUSIONS

A circular economy aims to protect the added value of a product even when the product has reached the end of its life cycle and can continue to reuse the material productively and generate more value.

The circular economy proposes an approach to optimize the consumption of resources by identifying the best practices of prevention, recycling, reuse, and recirculation of by-products, which is so necessary in the field of waste management with iron content, especially in the development, design, or adaptation of

recycling / recovery processes. It is important to note that the concept of the circular economy is applicable to all sectors of activity with the capacity to achieve and determine new development opportunities. If these concepts envisage the development of new waste processing technologies with low environmental impact, the circular economy tends towards the green economy. Through the proposals made by the authors in this paper, closed-loop processing and recycling methods were identified of some waste with high iron content were identified, namely: pelletizing, briquetting, and agglomeration, and the resulting by-products (pellets, briquettes, or ferrous agglomerate) that could be used in the manufacture of cast iron or steel. The stages of implementing closed-loop flows in the technologies in real practice have not been defined yet, so they are considered future directions of research. In addition, between the technological proposals presented and the models of good practice, similarity and perfect matching were found in the field of waste containing iron.

It is considered that investment in infrastructure, research, and regional development could be directed towards easing the transition to a green and circular economy, and innovation is seen as the driving force for the implementation of the two concepts.

Furthermore, there have been considered future direction of research and development based on the following ideas:

1. The in-deep investigation of risks associated with the presented approach, and the occupational risks, too [14];
2. The extension of the investigation due to the university-industry collaboration contracts [15];
3. The development of an education, training program provided in a modern way (e.g., online as a complex e-learning solution) and that could support companies' behavior improvement in the filed of waste management [16, 17];
4. Considering issues of circular and green economy related to the transportation and storge processes of the waste containing iron, and thus, having a holistic perspective on the existing supply chain (modeling the green supply chain could be done similar with the research of [18]).

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Economia circulară și verde în managementul deșeurilor care conțin fier

În România, procesul de tranziție către o economie verde și circulară se desfășoară lent, deoarece nu s-a realizat un plan concret de măsuri, bazate pe situația actuală. Studiul bunelor practici privind punerea în aplicare a celor două concepte și dezvoltarea unor modele viabile pot genera beneficii atât la nivel național cât și mondial. Pe baza studiului modelelor de bune practici – modelul danez si respectiv modelul maghiar dar și a principiilor care stau la baza celor două concepte, au fost propuse tehnologii ce pot fi implementate în flux cu buclă închisă, în vederea reciclării deșeurilor cu conținut de fier. Acestea presupun o minimă procesare a deșeurilor iar subproduse obținute: pelete, brichete respectiv aglomerat pot fi utilizate ca materiale secundare în procese siderurgice. Determinările calitative și cantitative ale demersurilor experimentale proprii constituie viitoarele direcții ale cercetării.

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