Environmental Engineering and Management Journal August 2021, Vol. 20, No. 8, 1395-1403
http://www.eemj.icpm.tuiasi.ro/; http://www.eemj.eu

"Gheorghe Asachi" Technical University of Iasi, Romania

NEW STRATEGIES AND ALTERNATIVES FOR CLOSING HISTORIC INDUSTRIAL LANDFILLS. CASE STUDY: COPȘA MICĂ

Voicu-Teodor Muica[1], Alexandru Ozunu[1,2]*, Zoltàn Török[1]

[1]*Faculty of Environmental Science and Engineering, Research Institute for Sustainability and Disaster Management Based on High Performance Computing, Babeș-Bolyai University, Cluj-Napoca, Romania*
[2]*University of the Free State, DIMTEC, Bloemfontein, South Africa*

Abstract

Continuous global economic development, necessary to ensure a high standard of living and comfort of human society, has produced and continues to produce enormous pressures on the environment. This was done through consumption of natural raw materials with the risk of depletion, emissions to all environmental factors (water, air, soil) with detrimental consequences on vegetation, fauna, climate change, human health and, last but not least, by massive waste generation. For this reason, the European Union has embarked on an extensive process of changing its policy in the field of environment and economy, based on the principles of the new concept of "Circular Economy". These principles can also be applied to existing historical industrial landfills, which can become important sources of alternative raw materials. One such case is the historical industrial waste landfill of Sometra SA from Copșa Mică, Sibiu County. This paper presents a comparison of three different possible methods for closing the landfill, of which an optimum Closure Project which combines both the legislation in force on waste storage and the legislation in force on waste management is chosen. The presented methods are chosen based on expert analysis by relevant authorities and all interested parties, bearing in mind legislative limitations, requirements as well as economic and social issues. The method selected ultimately brings the most benefits, both in an environmental and economic capacity. In conclusion, we can state that the chosen method could be used as a prime example of the closure of a historical industrial landfill.

Keywords: alternative raw materials, Circular Economy, historical industrial landfill, industrial waste, integrated waste management

Received: April, 2021; Revised final: June, 2021; Accepted: July, 2020; Published in final edited form: August, 2021

1. Introduction

The tendency of permanent growth of the economic-social development and the disposition of perfected technical and technological means, lead to the consumption of immense quantities of natural resources, exploiting more and more intensely the environmental factors and modifying the nature in fast rhythm, especially in developing countries and emerging economies (Dagiliūtė, 2018). In this chain, the waste generation from human activities are a topical issue due to the quantities generated, representing a potential danger to the environment and human health (Fortuna et al., 2011). In this context, in the last decade, it has been necessary to re-evaluate waste management options, in order to drastically reduce the amount of waste generated and increasing the degree of capitalization and playback in their economic circuit (Bartolacci et al., 2017; Franco-Garcia et al., 2019).

The complex field of waste is currently divided into two main groups, namely newly generated waste and historical waste, produced from human activities over the past decades.

For the first group, the need for the transition to a circular economy has recently been defined in the

* Author to whom all correspondence should be addressed: e-mail: alexandru.ozunu@gmail.com; alexandru.ozunu@ubbcluj.ro

European Union, in which the value of products, materials and resources should be maintained in the economy for as long as possible. Waste generation is minimized and the transformation of waste resources to secondary raw materials represent loop closure systems which promote a circular economy (Fig. 1)m(Andersen, 2007; Ghisellini et al., 2016).

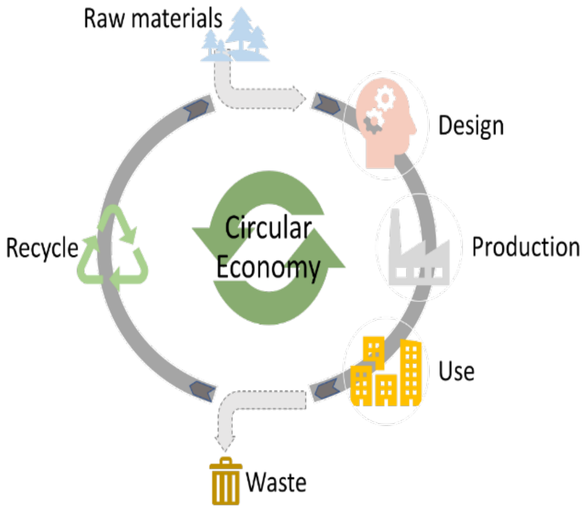

Fig. 1. Circular Economy loop (own work)

The Action Plan for the Circular Economy, adopted by the European Union in December 2015, emphasizes the need to transition to a life-cycle based "Circular Economy" in which the reuse of resources is as high as possible and the generation of waste reaches close to zero (EC, 2018a). The 7th Environment Action Program (EC Decision, 2013) sets binding environmental targets for the European Union and its Member States to achieve by 2020, followed by the European response to the "2030 Agenda" (CE, 2017). There are a total of 17 objectives established in the 2030 Agenda, with the goal of ending poverty, protecting the planet, ensuring human rights and guarantee prosperity for all. The European response to them was, among others, the transition towards a Circular Economy.

A very important mechanism in the implementation of new European waste management policies is the Waste Directive 2008/98 / EC (EC Directive, 2008) which sets out the hierarchy to be followed for waste management and prevention, namely (Fig. 2):

a) Prevention;
b) Preparation for reuse;
c) Recycling;
d) Recovery operations, for example energy recovery;
e) Disposal.

Other important amendments and additions to Directive 2008/98 / EC on waste are:

– Clear definition of waste and by-products;
– Adding a mechanism to clarify when a waste ceases to be waste ("end of waste");
– Clarification of the definitions of certain waste management operations;
– Introduction of new tools in waste management, such as life cycle analysis.

The second group in the field of waste is represented by historical waste. These have been generated over the past decades by human activities, in very large quantities and in various categories (hazardous or non-hazardous industrial waste, construction material waste, municipal waste, tailings dumps from mining operations, etc.). The current quantities of such historical waste are huge, and it is understandable that this was generated in accordance with the principles of the linear economy practiced in the past according to the "take-make-dispose-pattern", a model based on the exclusive consumption of natural raw materials and easily accessible and cheap energy (Fig. 3).

The generation of waste in the past has inevitably led to the establishment and development over time of large landfills, representing the main and easiest method of disposal of waste generated. Most often, these landfills have been established without taking special measures to protect environmental qualities (water, air, soil) becoming, in many cases, real ecological bombs with a significant impact on the environment and human health.

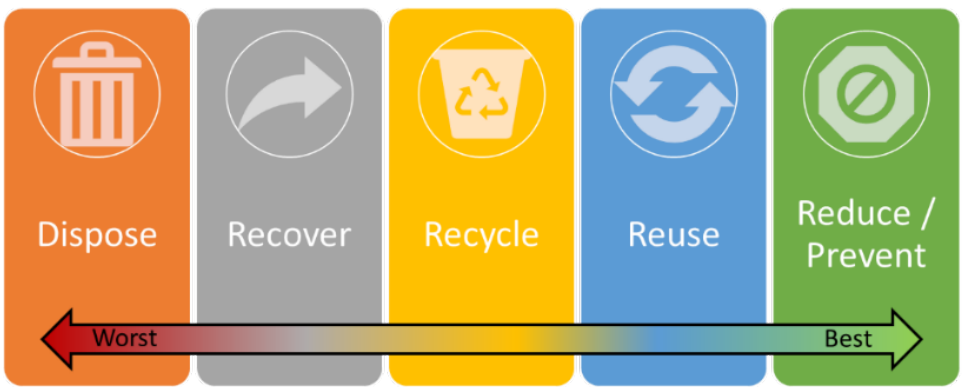

Fig. 2. Hierarchy of waste according to Directive 2008/98/EC on waste (after European Directive, 2008)

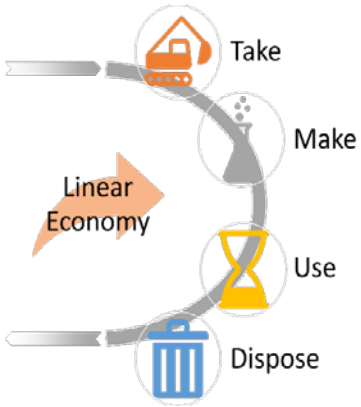

Fig. 3. Linear economy model (own work)

Therefore, at present, on a European level, the existence of these historical deposits is a special problem, exacerbated over time, their management raising very complex issues which require complex actions at local and central level in collaboration with central authorities and civil society, government representatives and last but not least in collaboration between states within the European Union (Stehlik, 2009). The stated priority direction for solving this problem is the development and execution in the shortest possible time of closure projects. As a rule, these projects provide for the encapsulation (surface closure) of these deposits and their follow-up (monitoring) after closure. The method can ensure a relatively short execution time of the closure process but, at the same time, raises many questions about sustainability, economic feasibility and even feasibility over time regarding environmental protection.

Moreover, a multitude of wastes currently deposited on these historic industrial landfills can certainly become alternative raw materials, can be recycled and reintroduced into economic circuits, in full accordance with the new principles of the circular economy. New strategies and methods for closing the large historical landfills are beginning to emerge, combining both the specific requirements for closure and active participation in the construction of the loop, the circular economy. One such case is represented by the company Sometra SA from Copşa Mică, Sibiu County, which is in the process of developing a project to close its own historical industrial waste landfill by recycling and fully recovering the categories of landfilled waste.

2. Scope and objective

The development of new principles at the European Union level on waste management, grouped in the concept of "Circular Economy" and the creation of legislative mechanisms necessary for the implementation of this policy have created the premises for developing new strategies for closing existing historic landfills (EC, 2015). The novelty of these new strategies is that for the closure of such landfills not only the specific requirements of the legislation on the closure of landfills can be applied, but a combination of this legislation with the new waste legislation. In this context, the application of the Waste Hierarchy provided for in the Waste Directive 2008/98 / EC. In general, the application of the principles contained in the Circular Economy (EC Directive, 2008) should also be mandatory for many historical industrial landfills, as long as there are feasible techniques from an economic, social and environmental point of view. Many of these deposits can be important sources of alternative raw materials, and this should take precedence over the method of encapsulating the landfill as is. For example, the most common use of slags is in road construction and soil structures (Havanagi et al., 2012; Prasad and Ramana, 2016; Vegas et al., 2008) or using it as filler in the production of bricks (Quijorna et al., 2012; Quijorna et al., 2011) or other materials (Abba et al., 2017; Pasetto and Baldo, 2011; Sorlini et al., 2004).

The scope of this paper is to present three identified methods of closing the historical landfill, each with its own advantages and disadvantages:

- Method 1: Closing of the landfill as is
- Method 2: The phased closure of the landfill
- Method 3. Closure of the landfill by emptying it and full recovery of the waste

The main objective is to be able to select the most suitable method for implementation, as resulted from expert analysis on environmental, technical and economic levels with appropriate authorities and stakeholders.

3. Case study: the industrial waste landfill of Sometra SA

In Romania, the European approach to waste generation and management was necessary in the stages preceding the country's accession to the European Union and, after accession, to comply with the obligations assumed by the accession treaty, respectively the obligations assumed in the accession treaty's Chapter 22, “Environment”. A particular problem in this context was the existence of a large number of non-compliant landfills, a heavy legacy of the communist era before 1990, an era based strictly on the principle of linear economy, generating very large quantities of waste for which, the simplest method of disposal was storage on land without special arrangements necessary to protect environmental factors. A first necessary action was the cessation of storage activities on all existing non-compliant landfills, an action carried out by Government Decision no. 349/2005 on waste storage (RG, 2005). At the same time, through the treaty of accession to the European Union, Romania has assumed the obligation to close a number of 68 landfills (municipal and industrial). Failure to comply with this obligation by 2017 led to the introduction by the European Commission against Romania of Case C-301/17, motivated by “Failure of a Member State to fulfill its obligations - 2005 Act of Accession - Obligations of the acceding States - Environment - Directive 1999/31 / EC - Article 14 (b) - Landfills - Closure of sites (EU Treaty, 2005) which have not been authorized to operate a landfill - Closure and post-treatment procedure” (EC Directive, 1999). In turn, the European Court issued the following Decision on this question: " Given the fact that it did not comply with the obligation of taking all necessary measures to close the 68 landfills as soon as possible according to article 7(g) and article 13 in Directive 1999/31/EC regarding landfills, Romania did not fulfil its obligations resulting from article 14 (b) and 13 of the Directive 1999/31” (EC, 2018b).

The Sometra SA industrial waste landfill (GPS Coordinates: 46°07'06.0"N 24°13'04.4"E) is included in the 68 landfills covered by Case C-301/17 (Fig. 4). Sometra SA was established as an economic unit (under the name Sonemin) in 1939-1940 for the production of zinc from local ores. Over time, the company, under the new name of IMMN (Metallurgical Enterprise of Non-Ferrous Metals), owned by the Romanian State, has known a continuous development of productive capacities, having in its activity profile the processing of Zn and Pb mining concentrates by pyrometallurgical processes (using the technology of Imperial Smelting Processes) and the production of non-ferrous metals and their alloys: zinc, lead, antimony, cadmium, bismuth, as well as sulfuric acid. After 1990, the plant received the name of Sometra SA, and since 1998 it has been privatized, the majority share being acquired by Mitilyneos Holdings in Greece. Until 2009 (the year of the cessation of the main production processes), the company was the only producer in the country of refined zinc and lead.

The 70-year activity of the company resulted in industrial waste from technological processes, waste from maintenance and repair works, and waste from demolition.

All these categories of waste have been stored, since the establishment of the plant, on a plot of land belonging to the company, located at the western limit of the industrial platform. The chosen surface did not undergo special arrangements, as there was no specific legislation for deposits at that time, considering sufficient the geomorphology of the soil and subsoil in the area, more precisely the natural barrier of the waterproofing layer (clay layer). Moreover, the storage was carried out uncontrolled, mixing different categories of waste: inert, non-hazardous, and hazardous. Thus, a heterogeneous and non-compliant landfill of different categories of waste was initiated and developed, which operated until December 31, 2006, when, according to the legal provisions, the storage activity stopped.

After the cessation of the storage activity, following some complex analyzes and technical studies and extensive discussions with the environmental and local authorities, the necessary directions for closing the deposit were outlined.

Fig. 4. Satellite view of the slag deposit. Source: Google Earth

Thus, within the framework of an execution project regulated by an environmental agreement, the operation works of the industrial landfill necessary for the closure of this dump were established by mutual agreement. These works, regulated for the period 2010 - 2017 by Environmental Agreement no. 10/2010 issued by APM Sibiu, had the below activities:

- Sorting and separating hazardous and non-hazardous waste and recycling them entirely in the existing production capacities on the platform, a work considered a priority, completed since 2010.
- Works for the operation of the dump with the aim of withdrawing it from the nearby river, with the establishment of a safety corridor between it and the body of the deposit, work considered a priority, completed since 2012.
- Works for the operation-exploitation of the dump for the sorting and separation of the different categories of non-hazardous waste stored, aiming at their preparation for reuse / recovery - work completed in 2017.

Maximum recovery of the quantities of non-hazardous waste sorted on the industrial landfill - action carried out in 2017 in a proportion of about 10% of the total sorted waste.The year 2017 represented both the expiration date for the Environmental Agreement no. 10/2010 but at the same time the year in which it was put on the roll by the European Commission of Case C-301/17 against Romania (EC, 2018b). In this context, the environmental authorities in law required the initiation and development of an execution project for the closure of the economically viable Sometra SA industrial landfill and the protection of the environment, achievable in a reasonable period of time. For this, in the first phase it was necessary a new assessment of the industrial dump, at the level of 2017, action carried out by elaborating an Environmental Balance of level I and II, carried out by expert analysts based on an extensive geotechnical study carried out in the field by SGS of Canada (Societe Generale de Surveillance). According to these studies, the situation of the Sometra SA industrial landfill is as follows:

1. The surface of the Sometra SA industrial landfill: 190.022 m^2
2. The volume of the Sometra SA industrial landfill: 1.344.000 m^3
3. Total mass of stored materials: 2.688.000 tons
4. Quantities by categories of waste deposited on the Sometra SA industrial landfill:

Having these data at its disposal, the Institute of Energy Studies and Designs SA from Bucharest elaborated a Feasibility Study, which included a technical, economic and environmental protection analysis of three methods for the closure of the industrial dump, respectively:

- **Method 1:** Closing the industrial landfill in it's current shape and size, through encapsulation
- **Method 2:** Continuation and completion of in situ and ex situ recovery of all existing waste on the industrial landfill, followed by remediation and greening of land after disposal of the landfill
- **Method 3:** An alternative of method no. 2, but through which the waste is relocated for recovery inside the industrial platform, on existing waterproofed platforms, with the main purpose of shortening the time of dismantling the industrial landfill and subsequent remediation and greening of the land.

4. Analysis of methods

Method 1. Closing in situ of the industrial landfill in its current shape and dimensions, in accordance with Ord. 757/2004 for the approval of the Technical Regulation on waste storage (MEWM, 2004), which would involve artificial waterproofing (insulating) of both the base layer of the landfill and its surface coverage, in compliance with the specific technical rules for a landfill (non-hazardous or hazardous). From the beginning, however, given the current characteristics of the landfill (area, quantities of waste stored), the provisions of the Technical Regulation can be applied only partially, respectively a surface coverage, therefore this closure cannot be considered sustainable and it cannot ensure the protection of all environmental factors. In addition to these aspects, the closure option has a number of other disadvantages resulting from the current waste legislation:

- Disposal of waste by final disposal is the least desirable step on the waste hierarchy, according to Directive 2008/98 / EC on waste (EC Directive, 2008) transposed into Romanian legislation by Law 211/2011 (RP, 2011).
- The solution of disposing of waste by final disposal is in contradiction with the principles of the Circular Economy which obliges the operator to recycle waste, as long as there are feasible technical and technological possibilities in this regard, without endangering the environment and human health (Lacy and Rutqvit, 2015).
- The environmental benefits of this solution are small compared to the technical and financial efforts applied.

Method 2. The phased closure of the landfill by the exploitation and full recovery of the existing waste in the landfill, followed by the remediation and greening of the land after the closure of the landfill. A separate study comparing different site remediation methods shall be performed closer to the date of closure. According to the studies carried out and the experience of Sometra SA accumulated in the period 2014 - 2017 within the works of exploitation of the industrial dump, this represents, at present, a potential source of alternative raw materials, for all categories of existing deposited waste:

- Crude ferrous and non-ferrous waste to specific processing industries.

• Pyrite ash in the cement industry, as a valuable addition to the raw material, due to its rich iron content.

• Construction materials (concrete, bricks) to specific processing industries or used as fillers.

• For blast furnace slag (which represents about 78% of the industrial landfill) recycling in Waelz kilns with Waelz oxides and Waelz clinker results in finished products that are raw materials for a number of other industries.

• The use of waste as raw materials in other processes is in line with the recommendations for a Circular Economy (Ferronato et al., 2019).

Waelz technology is an old but still relevant technology in Europe for the production of secondary zinc from waste and by-products containing zinc. This technology, included in the Best Available Techniques for Obtaining Secondary Zinc (IPPC, 2001), is owned by Sometra SA and operated until 1990 on the platform in two production capacities (Waelz furnaces) for recycling its own waste from zinc refining. One of these production capacities (Waelz furnace) was rehabilitated and put back into operation in 2014, in order to test the processing (recycling) of blast furnace slag from the industrial landfill, waste that has an average zinc content of 7-8 %. The operation of the installation in the period 2014 - 2017 demonstrated the following aspects:

• The blast furnace slag can be successfully recycled by applying Waelz technology

• By applying Waelz technology, from a material currently considered a waste (blast furnace slag) a main product is obtained (Waelz oxides) as well as a by-product (Waelz clinker), products with market demand, without generating other industrial waste. This is a prime concern for the Circular Economy (Puntillo et al., 2020).

• Waelz technology, at the technical level of current installations, does not generate industrial wastewater and emissions into the atmosphere are within the emissions provided by the best available techniques, without creating an impact on its environment or public health.

• However, the existing Waelz plant at Sometra is an installation with a low processing capacity (approx. 35.000 tons of slag / year), compared to the total amount of slag in the industrial dump (approx. 2.100.000 tons). As such, in parallel, in accordance with the Business Plan of Sometra SA in the short, medium and long term, a process of regulating and implementing extensive technological investment is in the works. This will provide for the construction and commissioning of two new Waelz furnace capacities, with the aim of increasing the processing capacity of blast furnace slag stored on the industrial landfill. Under these conditions, it is estimated the completion of the recovery of all categories of waste existing on the industrial landfill in about 13 years

For more detailed material fractions please see Table 1. The exact recovery potential of each of these materials are hard to assess, except the main component – blast furnace slag. Based on actual figures received from Sometra SA, the below quantities have been processed by the existing Waelz plant (Table 2).

The closure solution proposed by this method has multiple advantages:

• Closure of the warehouse, its closure and removal from the list of deposits constituting case C301/17.

Table 1. Contents of the slag deposit (Ocon Ecorisc SRL, 2008)

Furnace slags (Tons)		2.100 million	**78.13%**
Pyrite ash (Tons)		300	**11.16%**
Waelz clinker	***(Tons)***	150	**5.58%**
Powder and ash from gas purification	***(Tons)***	5	**0.19%**
Building materials	***(Tons)***	100	**3.72%**
Slurry (blue powder)	***(Tons)***	7	**0.26%**
Ferrous and non-ferrous wastes	***(Tons)***	25	**0.93%**
Other	***(Tons)***	1	**0.04%**
Total (Tons)		2.688 million	**100%**

Table 2. Quantity of blast furnace slag processed, as received from Sometra SA

Year	***2014 (6 months)***	***2015***	***2016***	***2017 (3 months)***
Quantity (tons)	13.745	28.265	17.300	4.472

• Full recovery of all existing waste in landfill, which is in line with the principles of the circular economy, waste hierarchy and sustainable development (Geissdoerfer et al., 2017).

• Eliminate the current ways of affecting the quality of environmental factors by emptying the landfill. This eliminates the impact on surface water, groundwater and soil / subsoil quality, as well as eliminating the currently significant visual impact.

• The proposed project takes into account and combines the provisions of two European Directives: Directive 1999/31 / EC on the landfill of waste (transposed into Romanian law by GD no. 349/2005 on landfill) and Directive 2008/98 / EC of the European Parliament and of the Council from 19.11.2008 on waste (transposed into Romanian legislation by Law 211/2011 on waste regime).

• The proposed project will provide new jobs and economic sustainability in the area.

The only disadvantage of this new strategy can be considered the completion deadline of all closure works, estimated at about 15 years. To considerably shorten this execution time, an alternative of this project was developed.

Method 3. Closure of the landfill by emptying it and full recovery of the waste. This solution is an alternative to method 2. In order to speed up the closure of the warehouse, respectively the completion target of the works being estimated at 5 years, solutions were sought in order not to depend on the existing capitalization capacities. In this context, the new version of the project provides:

- Preparation for reuse of blast furnace slag (ISP slag) stored on the industrial landfill of Sometra SA by advanced sieving.
- Transport of the raw material for Waelz ovens and its relocation on the existing waterproof platforms designated for this purpose, inside the industrial platform of Sometra SA.
- Capitalization of pyrite ash based on existing contracts, as before, according to a schedule that falls within the proposed period of 5 years for the closure of the site
- Recovery of inert materials (construction materials, sand, iron, rubber - about 443,000 tons), based on existing contracts, as before, according to a calendar that falls within the 5-year period proposed for the closure of the site.
- After clearing, the deposit - transformed into free land - is assessed (based on the historical influence) and establish what additional measures for decontaminating the soil need to be performed. The relevant authorities will determine (based on specialized studies) whether the soil and groundwater have an acceptable quality (taking into account the mandatory downward trend of pollution in the future) for the environment and public health or whether decontamination work is required. Until then, the land will be covered with a layer of topsoil from authorized sources.
- As stated before, the same as for Method 2, the full recovery of waste in the landfill is in line with the principles of the Circular Economy, waste hierarchy and sustainable development (Geissdoerfer et al., 2017).

The proposed Method 3 allows a relatively quick closure of the store, but higher costs in the holder. Another impediment in the implementation of this alternative is given by the status of the blast furnace slag, after its relocation inside the industrial platform. In order to prevent some restrictions regarding the temporary storage of blast furnace slag for recovery (internal recycling through Waelz technology), Sometra SA requested the termination of the waste status for this, in accordance with the provisions of art. 6 of Directive 2008/98 / EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives, article transposed into Law 211/2011 on waste management.

The argumentation of Sometra SA for this purpose, included in a “Report of the study for the evaluation of the social, economic impact and effects on the environment”, is based on the fulfillment of the conditions established by art. 6 for termination of waste status (EC Directive, 2008):

a) The substance or object is commonly used for specific purposes;

b) there is a market or demand for the substance or object in question;

c) the substance or object meets the technical requirements for the fulfillment of specific purposes and complies with the laws and regulations applicable to the products; and

d) The use of the substance or object will not produce harmful effects on the environment of the population's health. The criteria shall also include limit values for pollutants, if necessary, and take into account any possible adverse effects on the environment of the substance or product concerned.

The procedure of implementing the full project is ongoing and in discussion with the Ministry of Environment. It is to be noted that the Circular Economy encourages the transformation of wastes into resources and raw materials, thus closing an economic loop (Puntillo et al., 2020).

Further studies on the environmental impact of this proposed method are ongoing. A new study published by the authors (Muica et al., 2021) compares the overall environmental impact of producing zinc conventionally from mining concentrates versus using Waelz oxides as raw material, which are produced from the existing blast furnace slag. Using the consequential Life Cycle Assessment method and impact categories in line with the recommendations of (Santero and Hendry, 2016) for the metal industry and the European ILCD methodology as recommended by (Hauschild et al., 2011) in a European context. The conclusion is that the impact on the environment is significantly less when using Waelz oxides obtained from the existing slags as primary material, rather than using conventional ores.

5. Discussions

In the case study presented, the operator Sometra SA understood the obligation stipulated by the legislation to close its own industrial waste landfill, and at the same time acknowledged the obligation to identify and implement its own methods of recycling/recovery of landfilled waste. As such, it identified three possible methods of dealing with the existing landfill.

The first method consisting on in situ closing and encapsulating the landfill as-is, is not suitable from an environmental point of view, as extensive remediation procedures cannot be implemented. Also, there is no economic advantage in using this method, the only advantage would be the speed at which this method can be implemented.

The second method, already tested using a small-scale Waelz installation, presents multiple advantages, in both an environmental and economic aspect. All these advantages are shared with the third method, as below. The one major disadvantage of this second method is the very long time frame in which the landfill would be completely closed.

The third method builds upon the second, in the sense that all the landfilled blast furnace slag is first transported on the industrial site itself, thus allowing a far more efficient operation of the Waelz process. In addition, the building of new Waelz furnaces along with the rapid emptying on the landfill area allow the shortening of the project to reasonable time frames as opposed to Method 2 where all the waste remains on the landfill itself.

Based on the third method, Sometra SA has developed a Closure Project that combines the two requirements, presenting a series of major advantages:

• Total recycling / recovery of existing waste categories in the landfill. According to the project, this action is carried out in a proportion of 80% internally, by processing the existing blast furnace slag in ovens using Waelz technology. This technology, widely used in Europe and worldwide for the production of secondary zinc, is owned by SC Sometra SA. To increase processing capacity, major investment works are being implemented which provide for the construction and commissioning in the next two years of two new Waelz ovens that will be able to process the entire existing amount of blast furnace slag (approx. 2.5000.000 tons) in 10 years. The products obtained (Waelz oxides and Waelz clinker) are valuable raw materials for a number of other industries. Following the technological chain of Waelz oxides obtained (from which metal zinc is subsequently obtained by pyrometallurgical processes), the calculations show that the recycling by Waelz technology of approx. 2,500,000 tons of blast furnace slag leads to the saving of approx. 700,000 tons of natural mining concentrates to finally obtain the same amounts of metallic zinc.

• The total recycling/recovery of the categories of waste existing in the landfill practically leads to the abolition of the landfill. The related land area will be greened and restored in the economic circuit.

• The positive effects on environmental factors (water, air, soil) by implementing this strategy are obviously more contoured and easier to follow compared to a closure of the warehouse to its current form by encapsulation. By applying the new strategy, the landscape impact produced at the current storage time is completely eliminated.

• Other benefits of economic sustainability in the area and the creation of new jobs are not to be overlooked.

• The whole process helps diminish the total environmental impact of zinc production by avoiding the use of conventional ores.

6. Conclusions

As a first step, there were three identified methods of closing the landfill:

• Method 1: Closing of the landfill as is

• Method 2: The phased closure of the landfill

• Method 3. Closure of the landfill by emptying it and full recovery of the waste

After a careful analysis from the authorities and stakeholders, the third method was considered as optimal from both an environmental and economic point of view.

Based on this the Closure Project has been created and its application, with the agreement and support of environmental authorities in law, is in accordance with three important directives: Directive 1999/31/ EC on the disposal of waste and Directive 2008/98/EC on waste, and the principles of the Circular Economy model of transforming wastes to resources.

The present work lays the foundation for further research in the field of historic industrial landfills closures through the recovery of selected waste groups which can be transformed into raw materials for other processes. By identifying Method 3 and using Waelz technology to recover zinc from blast furnace slags, this study based on Sometra SA’s landfill is the first at a European level.

Furthermore, recent studies based on the Life Cycle Assessment method support the use of this project regarding overall environmental impact, further emphasizing its suitability.

The success of the proposed project can be an example at a national and European level, for closing a historic landfill with industrial waste, to be preferred wherever similar conditions are met.

References

Abba A., Sorlini S., Collivignarelli M., (2017), *Research Experiences on the Reuse of Industrial Waste for Concrete Productio*n, Proceedings of the MATECWeb Conference, Sibiu, Romania.

Andersen M., (2007), An introductory note on the environmental economics of the circular economy, *Sustainable Science*, **2**, 133-140.

Bartolacci F., Del Gobbo R., Paolini A., Soverchia M., (2017), Waste management companies towards circular economy: What impacts on production costs?, *Environmental Engineering and Management Journal*, **16**, 1789-1796.

Dagiliūtė R., (2018), (Un)sustainable consumption and some policies behind: Lithuanian case, *Environmental Engineering and Management Journal*, **17**, 1439-1448.

EC, (2018a), Report on Critical Raw Materials and the Circular Economy, European Commission, Brussels, On line at: https://op.europa.eu/en/publication-detail/-/publication/d1be1b43-e18f-11e8-b690-01aa75ed71a1/language-en/format-PDF/source-80004733

EC, (2018b), Case C-301/17-Failure of a Member State to fulfil obligations-2005 Act of Accession-Obligations of the accession States-Environment-Directive 1999/31/EC-Article 14(b)-Operation of landfill sites-Closure of sites which have not been granted a permit to operate a landfill-Closure and after-care procedures, European Commission, Brussels, On line at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A62017CJ0301.

EC, (2015), Closing the loop - An EU action plan for the Circular Economy, European Commission, Brussels, On line at: http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52015DC0614

EC Directive, (1999), Council Directive 1999/31/EC of 26 April 1999 on the landfill of waste, *Official Journal of the European Communities*, 182/1, 26.04.1999, Brussels.

CE, (2017), EU Response to the 2030 Agenda for Sustainable Development—A Sustainable European Future, Council of the European Union, Brussels, On line at: https://www.consilium.europa.eu/media/23989/st10370-en17.pdf

IPPC, (2001), Reference Document on Best Available Techniques in the Non Ferrous Metals Industries, European IPPC Bureau - Joint Research Centre (European Commission), Luxembourg, On line at: https://op.europa.eu/en/publication-detail/-/publication/c0bc6046-651c-11e7-b2f2-01aa75ed71a1

EC Directive, (2008), Directive 2008/98/EC on waste (Waste Framework Directive), *Official Journal of the European Union*, L312, 22.11.2008, Brussels.

EC Decision, (2013), Decision No 1386/2013/EU of the European Parliament and of the Council of 20 November 2013 on a General Union Environment Action Programme to 2020 'Living well, within the limits of our planet', *Official Journal of the European Union*, L 354/171, 20.11.2013, Brussels.

EU Treaty, (2005), Treaty concerning the accession of the Republic of Bulgaria and Romania to the European Union, Act of Accession and its Annexes, On line at: https://ec.europa.eu/neighbourhood-enlargement/sites/near/files/archives/pdf/enlargement_process/future_prospects/negotiations/eu10_bulgaria_romania/act_of_accession_bulgaria_romania_en.pdf.

Ferronato N., Rada E.C., Portillo M.A.G., Cioca L.I., Ragazzi M., Torretta V., (2019), *Journal of Environmental Management*, **230**, 366-378

Fortuna M.E., Simion I.M., Gavrilescu M., (2011), Sustainability in environmental remediation, *Environmental Engineering and Management Journal*, **10**, 1988-1996

Franco-Garcia M.-L., Carpio-Aguilar J.C., Bressers H., (2019), *Towards Zero Waste, Circular Economy Boost: Waste to Resources*, International Publishing, http://doi.org/10.1007/978-3-319-92931-6_1.

Geissdoerfer M., Savaget P., Bocken N., Hultnik E., (2017), The Circular Economy- a new sustainability paradigm?, *Journal of Cleaner Production*, **143**, 757-768.

Ghisellini P., Cialani C., Ulgiati S., (2016), A review on circular economy: the expected transition to a balanced interplay of environmental and economic systems, *Journal of Cleaner Production*, **114**, 11-32.

Hauschild M., Goedkoop M., Guinee J.H.R., Huijbregts M., Jolliet O., Margni M., de Schryver A., (2011), *Recommendations for Life Cycle Impact Assessment in the European Context Based on Existing Environmental Impact Assessment Models and Factors (International Reference Life Cycle Data System—ILCD Handbook)*, Publications Office of the European Union, ILCD Handbook, Luxembourg, http://doi.org/10.2788/33030.

Havanagi V., Anil S., Arora V.K., Mathur S., (2012), Waste Materials for construction of roads embankment and pavement layers, *International Journal of Environmental Research*, **1**, 51-59.

Lacy P., Rutqvit J., (2015), *Waste to Wealth: The Circular Economy Advantage*, Palgrave Macmillan, Hampshire

MEWM, (2004), Order no. 757 of November 26, 2004 for the approval of the technical norm regarding the waste storage, Ministry of the Environment and Waters Management, On line at: http://www.mmediu.ro/beta/wp-content/uploads/2012/05/2012-05-17_ordin_757_2004.pdf

Muica V.-T., Ozunu A., Török Z., (2021), Comparative life cycle impact assessment between the productions of zinc from conventional concentrates versus Waelz oxides obtained from slags, *Sustainability*, **13**, 580, https://doi.org/10.3390/su13020580

Ocon Ecorisc SRL (2008), *Technical Project for the Closure of the Sometra SA Industrial Dump*, Turda, Romania.

Pasetto M., Baldo N., (2011), Mix design and performance analysis of asphalt concretes with electric arc furnace slag, *Construction and Building Materials*, **25**, 3458-3468

Prasad P., Ramana G.V., (2016), Imperial smelting furnace (zinc) slag as a structural fill in reinforced soil structures, *Geotextiles and Geomembranes*, **44**, 406-428.

Puntillo P., Gulluscio C., Huisingh D., Veltri S., (2020), Reevaluating waste as a resource under a circular economy approach from a system perspective: Findings from a case study, *Business Strategy and the Environment*, **30**, 968-984

Quijorna N., Coza A., Andresa A., Cheeseman C., (2012), Recycling of Waelz slag and waste foundry sand in red clay bricks, *Resources, Conservation and Recycling*, **65**, 1-10.

Quijorna N., San Miguel G., Andrés A., (2011), Incorporation of Waelz slag into commercial ceramic bricks: a practical example of industrial ecology, *Industrial Engineering Chemistry Research*, **50**, 5806-5814.

RG, (2005), Decision no. 349 of April 21, 2005 on waste storage, Romanian Government, *Official Monitor*, **394**

RP, (2011), Law No. 211 of November 15, 2011 on the waste regime, *Romanian Official Monitor*, Part I, no. 757 of 12 November 2012.

Sorlini S., Collivignarelli M., Plizzari G., Foglie M., (2004), *Reuse of Waelz Slag as Recycled Aggregate for Structural Concrete*, Conference Proceedings on Use of Recycled Materials in Buildings and Structures, RILEM, Barcelona, Spain, 1086-1094.

Santero N., Hendry J., (2016), Harmonization of LCA methodologies for the metal and mining industry, *International Journal of Life Cycle Assessment*, **21**, 1543-1553

Stehlik P., (2009), Efficient waste processing and waste to energy: challenge for the future, *Clean Technologies and Environmental Policy*, **11**, 7-9.

Vegas I., Ibañez J., San José J., Urzelai A., (2008), Construction demolition wastes, Waelz slag and MSWI bottom ash: a comparative technical analysis as material for road construction, *Waste Management*, **28**, 565-574.