SUMMARY

From waste to resource: blast furnace slag used in the production of secondary zinc. Case study using Life Cycle Assessments

PhD Coordinator:

Prof. Univ. Dr. Ing. ALEXANDRU OZUNU

PhD Candidate:

Ing. VOICU-TEODOR MUICA

There is a special importance of zinc în the modern world. From its medicinal use, for the good development of organisms, to its use în industry, for its anticorrosive properties, zinc is part of the most used metals on the planet, along with iron, aluminum, and copper. In addition, zinc can be recycled economically and without loss of quality, which encourages finding new and new ways to recover it.

In the Europe of recent years, the concept of Circular Economy has been increasingly implemented - there are action programs adopted throughout the European Union, which largely aim at the so-called "closing the loop" of the life cycle of products. Therefore, the emphasis is on the reuse and recycling of waste, moreover on its transformation into raw materials for other processes.

A specific problem of waste management is the existence of large amounts of waste generated în the past, when the only way to manage it was storage. Such "historic" landfills have a significant impact on the environment and require feasible solutions în order to close them.

One such identified landfill is that of Sometra SA from Copșa Mică, Sibiu County, for which a new closure strategy is under debate, based on the principles of Circular Economy, respectively its closure by recycling the main category of landfilled waste: blast furnace slag with zinc content, using Waelz technology.

This doctoral thesis is built around this case study, and the main purpose of the paper is to analyze the life cycle impact of metallurgical zinc obtained by conventional method (from natural mining concentrates) compared to metallurgical zinc obtained from zinc oxides, at turn obtained by Waelz technology, having as raw material blast furnace slag. The study is of the Life Cycle Assessment type, according to the consistent method.

The first chapter, entitled "The state of research and technological applications for obtaining primary and secondary zinc from raw materials, alternative raw materials and waste", developed based on a complex literature analysis of zinc metallurgy. This chapter includes a brief history of zinc, aspects of

its importance today, and the current state of the industry. It also presents aspects of the technological processes applied to zinc, raw materials used in its production, but also the resulting waste and the impact of this industry on the environment. The continuation of the chapter describes the evolution of this industry and its inclusion in the concept of circular economy - a concept that is also analyzed in the chapter.

In Chapter 2, entitled “The current state of recovery / recycling of blast furnace slag from primary zinc metallurgy. The Sometra SA landfill”, various studies, projects and technological applications for the recovery of blast furnace slag resulting from primary zinc metallurgy are analyzed. The chapter also introduces the case study chosen for the doctoral thesis, namely the strategy and project proposed by Sometra SA for the closure by operation of its own slag industrial landfill. This chapter is largely based on specialized studies and information provided by the economic operator.

In Chapter 3, entitled ”Use of Waelz Technology to obtain secondary zinc from by-products and wastes containing zinc. Case study: ISP slag recycling through Waelz technology at Sometra SA”, the Waelz technology that was chosen by Sometra SA for recycling blast furnace slag resulting from the company's previous activities, namely obtaining zinc and primary lead through the pyrometallurgical process Imperial Smelting Process (ISP), is presented in detail.

Chapter 4, entitled “Life Cycle Assessment. Theoretical and practical considerations”, presents a short history and basic information on the Life Cycle Assessment tool. Also, the chapter defines all the details that will be used in the calculation of the Life Cycle Assessment and the comparison of future results.

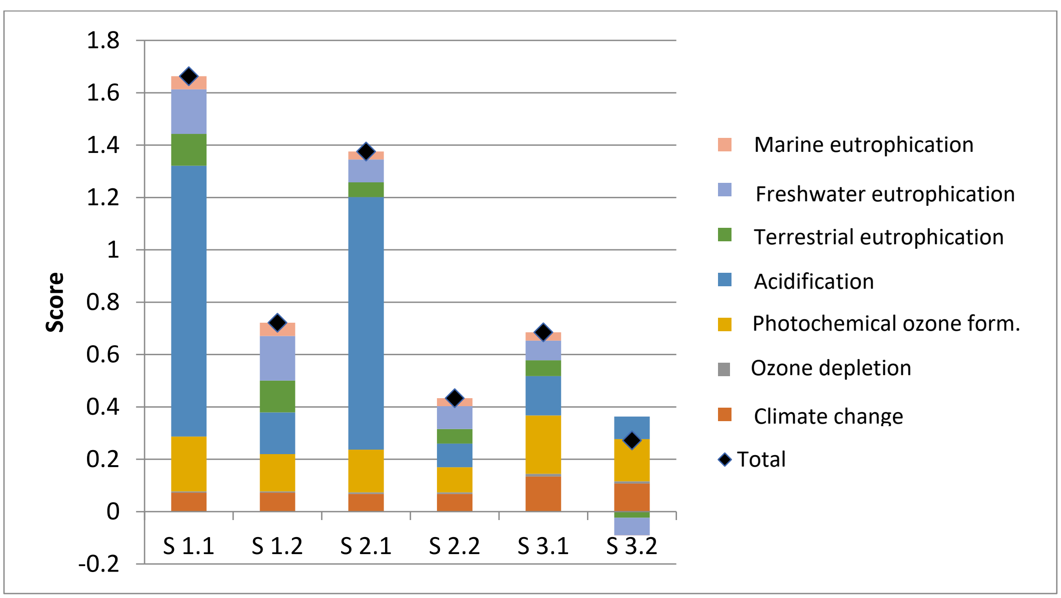
In Chapter 5, entitled “Description of the systems and scenarios evaluated. Life cycle inventory analysis ”, representing the first chapter of original research, presents the identified and studied systems, as well as their diagrams. These systems will be proposed for analysis and comparison, the main objective being to compare the obtaining of zinc from primary sources with the obtaining of zinc from zinc-containing waste. The following table shows the names of these scenarios:

Scenari0	Description
Scenario 1.1	Zinc from mining concentrates, ecoinvent, without SO_2 recovery
Scenario 1.2	Zinc from mining concentrates, ecoinvent, with SO_2 recovery
Scenario 2.1	Zinc from mining concentrates, custom, without SO_2 recovery
Scenario 2.2	Zinc from mining concentrates, custom, with SO_2 recovery
Scenario 3.1	Zinc from Waelz oxides, without material avoidance
Scenario 3.2	Zinc from Waelz oxides, with material avoidance

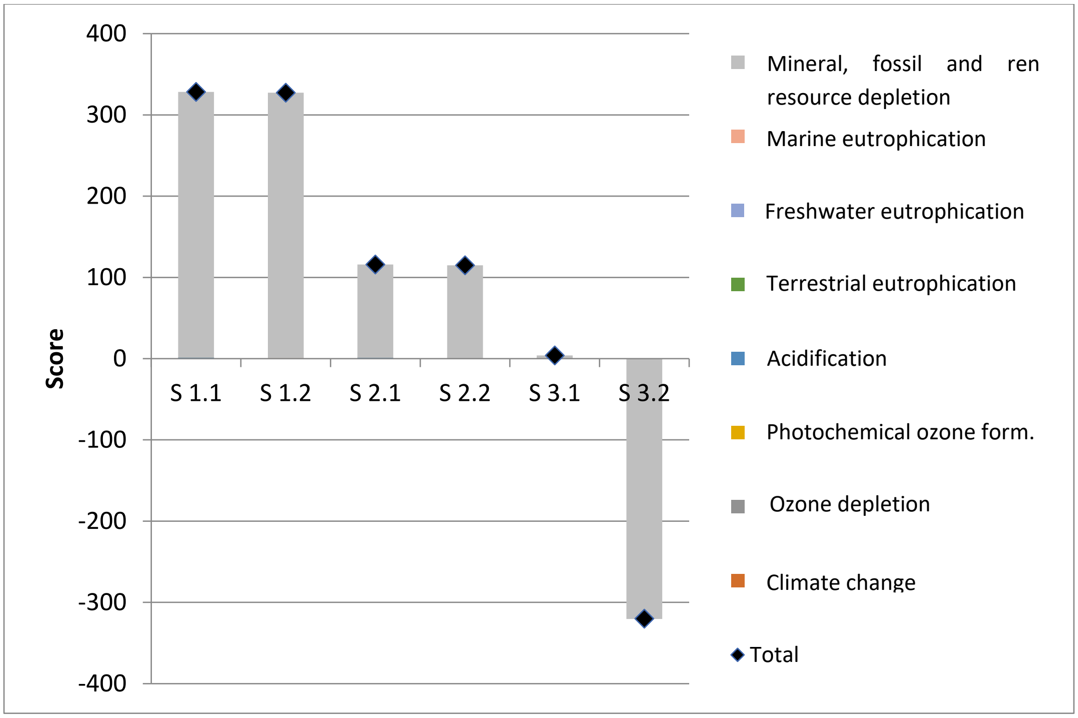
Chapter 6, entitled "Results of life cycle impact assessment", contains all the results of calculations on this topic, using special programs, culminating in a discussion section based on them. The final result for all the identified scenarios can be seen in the table below, according to the Single Score developed within the ILCD 2011 Midpoint+ method:

Impact category	S 1.1	S 1.2	S 2.1	S 2.2	S 3.1	S 3.2
Climate change	0.072448	0.072448	0.067295	0.067295	0.134213	0.103781
Ozone depletion	0.004937	0.004937	0.006311	0.006311	0.01018	0.008967
Photochemical ozone formation	0.209461	0.142378	0.162805	0.095722	0.223007	0.154251
Acidification	1.034455	0.159475	0.965298	0.090318	0.150196	0.079593
Terrestrial eutrophication	0.121555	0.121555	0.055916	0.055916	0.060666	-0.03199
Freshwater eutrophication	0.170312	0.170312	0.087476	0.087476	0.074713	-0.08176
Marine eutrophication	0.050247	0.050247	0.030306	0.030306	0.031729	-0.00406
Mineral, fossil and ren resource depletion	326.617	326.617	114.4704	114.4704	3.200306	-320.199
Total	**328.2804**	**327.3384**	**115.8458**	**114.9038**	**3.88501**	**-319.970**

For a more complete picture of the final results, the graph will be presented at the beginning the single score for all impact categories except "Mineral, fossil and ren resource depletion". This way of presentation was chosen because the score obtained by the latter category far exceeds the scores obtained by all the others, this fact can be observed in the following figures:



Final comparison, single score, excluding the category of resource depletion



The study is of the Life Cycle Assessment type, according to the consequential method. The general conclusion from the calculations and the comparative study between three elaborated scenarios and three variations of them is that, although în some respects it may seem that the alternative method is contraindicated, overall it brings many benefits to the environment, economy and population, and can be used as an example to follow where such materials are found.

Keywords: *zinc; circular economy; "historic" landfills; waste recycling; blast furnace slag; mining concentrates; Waelz oxides; zinc oxides; Waelz technology; life cycle assessment; life cycle impact assessment; system optimization;*

SCIENTIFIC CONTRIBUTIONS

Publications in ISI indexed journals:

- 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, pp. 1-17

- Muica, V.-T.; Ozunu, A.; Török, Z., 2021, ”New strategies and alternatives for closing historic industrial landfills. Case study: Copșa Mică”, Environmental Engineering and Management Journal, 20:8, pp. 1395-1403

Other publications

- Muica, V.-T., 2021 ”Life Cycle Impact Assessment of Zinc Production – Conventional Concentrates Versus Waelz Oxides Obtained From Slags. Case Study and Comparative Analysis”, 2021, în Mediul ca risc and urgență / Environment as Risk and Emergency, coord.: Burny, P.; Baciu, L.-C.; Botezan, C.S.; Petrescu, D.-C.; Vlad, G.

Oral presentations at specialized conferences:

- ELSEDIMA 2018 (Environmental Legislation, Safety Engineering and Disaster Management)
    - ”Modular closing by valorification of S.C. Sometra S.A. Industrial landfill, Copşa Mică, Sibiu county”. Held on 17 May2018
- ISUMADECIP 2020 (Institutului de Cercetări pentru Sustenabilitate and Managementul Dezastrelor bazat pe Calcul de Înaltă Performanță)
    - ” Circular economy – accountability of the industrial consumer. Case Study.” Held on 7 May 2020.
- SICHEM 2020 (International Chemical Engineering and Material Symposium)
    - ”Comparative life cycle impact assessment between the production of zinc from conventional concentrates versus waelz oxides obtained from slags”. Held on 17 September2020.
- ZASTR 2020 (Zilele Academiei de Științe Tehnice din România / Romanian Academy of Technical Sciences Days)
    - ” The use of blast furnace slag as an alternative raw material in the production of metallurgical zinc, in the context of the circular economy. Case study and comparative life cycle analysis.” Held on 27 November 2020

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