Environmental and Climate Technologies
2024, vol. 28, no. 1, pp. 1–11
https://doi.org/10.2478/rtuect-2024-0001
https://content.sciendo.com

Analysing Metal Melting Methods for Green Transformation of Scrap Metal: Case Study of Latvia using MCDA and SWOT Analysis

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Received 29.03.2023; accepted 09.10.2023

***Abstract* – Metal is one of the most widely used materials in the world. It was a crucial driving force in technological development since the industrial age and continues to push us forward to this day. As metal consumption grows, so does the amount of scrap metal generated. Proper utilization of this waste is crucial in mitigating the negative environmental impacts of the metalworking industry. The processing and use of raw materials is often associated with high resource consumption and high emissions. The utilisation of scrap metal instead of raw metal can lead to up to 10 times less electricity consumption and up to 30 times fewer CO_2 emissions. However, selecting the most suitable scrap metal processing technology is crucial, particularly in the case of the metal melting furnace which is the backbone of the industry. The efficiency of this process determines the environmental indicators for the entire scrap metal melting process. This paper conducts an analysis of 8 types of metal melting furnaces based on 11 environmental criteria. Furthermore, a SWOT analysis is conducted to evaluate the efficiency of the metal smelting process in Latvian metalworking enterprises and the potential for future expansion.**

***Keywords* – Emissions; industry; Latvia; metallurgy; MCDA; scrap metal; smelting; sustainability; SWOT; waste management.**

1. INTRODUCTION

Metal is one of the most widely used materials in the world. It is present in many areas of life, including construction, the production of household items, technology industries, etc. Metal has played an essential role in technological development since the beginning of the Industrial Age and continues to be a key material in modern times. The crude steel produced constantly grows and reaches 1.958 billion tons in 2021 [1], [2].

Given the rising demand for metals, it is unsurprising that the metals sector is facing the challenge of meeting the Paris Accords to keep global warming below two °C below pre-industrial levels. As indicated in [3], the steel sector is responsible for 7 % of direct CO_2 emissions. Investors in this sector demand active action from companies and count on the maximum possible decarbonization of the industry. Considering the benchmarks set by the agreement, it can be assumed that the pressure exerted on the industry will only increase [4].

One of the ways to reduce emissions in the metallurgy sector without losing quality at the same time can be the complete or partial replacement of pure metal in production with scrap

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metal. According to [2], the demand for this resource has been steadily growing over the past decade, reaching 503.5 million tons in 2021, when a year earlier demand was 473.2 million tons.

Scrap metal is obtained from discarded material that still has a monetary value and can be recycled. It can be divided into categories depending on the products it was recovered from – it can be obsolete scrap if the source was used and/or end-of-life products. Scrap can also be primary/new if the source is from a manufacturing process that generates scrap metal, shavings, etc. As follows from such a division, obsolete scrap metal requires cleaning and recovery before processing, while the new one can be used almost immediately without significant technical investments [5]–[7].

Scrap metal recycling involves recovering material to the extent required for the specific manufacturing process in which the scrap metal will be used. With a reasonably well-established process, the processing of scrap metal requires less investment of resources than the use of primary materials. This is an essential advantage as it avoids the disposal of materials in landfills (and thus avoids the loss of a resource), which in turn is an effective and sustainable strategy to reduce emissions [8], [9].

Scrap metal recycling is usually divided into ferrous metals and non-ferrous. Some iron content distinguishes ferrous metals, while non-ferrous scrap metal contains aluminium, lead, copper and other valuable metals. Recycling scrap metal allows extracting many components from already created alloys – copper, aluminium, brass, etc., without damage and using them to produce new valuable products [3], [10].

Proper disposal (recycling) of metal and scrap metal can help reduce emissions and CO_2. This can be achieved in the following ways:

1. The use of scrap metal in production requires less energy compared to the production of products from "raw metals". As stated in [3], producing new metals requires ten times more electricity and creates 30 times more CO_2 emissions than working with scrap metal. If done so, metallurgists can partially replace coal with electricity – and reduce the share of fossil fuels from 75 % (2020) to 22 % by 2050 (assuming CCUS plants are also used). They are assuming that by 2030, technologies already on the market will be able to provide up to 85 % reduction in emissions in the sector. This is possible, provided that the share of scrap metal in the steel industry reaches at least 46 % by 2050. Recycling metals saves commonly used materials such as aluminium. Its processing into a new product requires 5 % less energy than making this product from scratch. Using steel and tin to manufacture containers/cans can save 60 to 74 % of energy compared to production from raw materials [11].
2. Quality collection, sorting and processing of scrap metal can reduce emissions from transportation and waste management processes. The chemicals used in mining pollute the air, reduce soil quality, and often end up in groundwater. Simultaneously, ore mining processes require massive amounts of energy. Even though ores can only be mined in certain places worldwide, metal production is carried out everywhere. This means that the mined ore must be delivered to the plant, which is associated with emissions from transportation processes. Using scrap metal can not only conserve natural resources (which are not increasing in amount), reduce emissions from ore mining and improve the environmental performance of the sight but also significantly reduce emissions from international logistics [12].
3. Compared to primary metals, scrap metal requires significantly fewer resources, producing fewer emissions. Another advantage is reducing the burden on mining enterprises, as the need for iron ore and coal, the primary materials in metal production,

is reduced [3]. Each used ton of scrap metal avoids an average of 1.7 tons of CO_2 emissions and saves up to 1.4 tons of iron ore, up to 0.8 tons of coal and up to 0.3 tons of limestone [13]–[15].

Thus, proper scrap management can reduce CO_2 emissions, conserve resources and contribute to a sustainable and circular economy. In such a way, using scrap metal can be considered a "green transformation" of this material – it is no longer a waste but a valuable resource for widely utilized material production. According to [1], [16], in 2020, more than 20 % of steel was produced from scrap metal, but 70 % was still produced from raw metal. Most of the production relates to Blast Furnaces, designed to smelt iron ore and produce pig iron, which is then used to make steel. About 5 % of steel from raw metal was produced in electric furnaces (EAF). However, it should be noted that electric furnaces, unlike Blast furnaces, can fully work with scrap metal, significantly reducing dependence on raw metal.

1.1. Metalworking in Latvia

According to Eurostat data [17], the amount of scrap metal collected in Latvia increased over time. Unlike ferrous metal, non-ferrous metal is not growing so noticeably – over ten years, the increase was slightly less than 3 %. The increase in collected ferrous metal showed its maximum in 2018 – the increase was 23 % compared to 2010.

In 2008, the European Parliament issued a directive under which member states undertake to develop a waste collection and management system. One of the tasks is to develop and improve the separate collection of waste, including the separate collection of metal and scrap metal, as well as the availability of such a service throughout the country [18]. As follows from the Ministry of Environmental Protection and Regional Development report, although the Directive set a deadline of December 31, 2014, even for 2019, this task still needs to be completed. Another target – to prepare for recycling and recycle at least 50 % (by weight) of waste, including metal/scrap – was also not fully achieved. However, from the amount of metal collected for 2018, 71.38 % was recovered, and 71.34 % was recycled with a target of 50 % (by weight, for both indicators), which is a good result. However, it should be pointed out that this target only applies to packaging materials and not to total metal waste per se [19], [20].

As part of the measures taken to increase the amount of collected metal in the country, collection points for metal and scrap metal were created, contributing to an increase in the amount of collected ferrous metal from 2016. The increase in the number of scrap metal collection points in 2021 increased the production rate in the metalworking sector by 18 % compared to a year earlier [21], [22].

In 2017, MASOC (Association of Mechanical Engineering and Metalworking Industries of Latvia) launched a project aimed at strengthening the cluster of metalworking enterprises, increasing efficiency and developing sales markets, as well as close cooperation with the scientific sector and collaborating partners (suppliers and buyers) [23]. This project aims to strengthen the manufacturing sector, which means an increase in turnover, and cooperation with the scientific sector potentially means testing new technologies for the processing and processing of metal and scrap metal, which will also positively affect the productivity and environmental friendliness of the metalworking sector.

2. METHODOLOGY

The purpose of this work is to conduct an in-depth analysis of metal smelting furnaces based on the technologies available in Latvia, as well as to determine the potential for the country to move towards more environmentally friendly methods of scrap metal processing.

To achieve this goal, a combination of two methods was chosen – SWOT and Multi-Criteria Decision Analysis (MCDA). In this paper, MCDA includes 8 alternatives based on 11 natural sector indicators. In turn, the SWOT analysis includes an analysis of ten Latvian metalworking/smelting enterprises.

2.1. Multi-Criteria Decision Analysis

The first task is to carry out a Multi Criteria Decision Analysis of the currently used metal melting furnaces and determine the most efficient furnace in terms of environmental impact. In order to reduce differences between indicators (for example, the amount of carbon dioxide produced and electricity consumption), the method involves normalizing the available data for all considered alternatives (i.e., in this case, different types of metal melting furnaces). Thus, the alternatives are ordered depending on the indicators of the criteria [24].

In this work, the following impact criteria are used for analysis:

- Maximum capacity, t/d;
- SO_2 amount, year average, mg/m^3;
- CO_2, kg/t;
- Lead content in slag, %;
- Energy consumption, MWh/t;
- Oxygen, Nm^3/d;
- Gas, kWh/t;
- Amount of total lead production, t/year;
- Fuel consumption, kg/t;
- Amount of H_2SO_4, kg/t;
- Maximum temperature, °C/t.

The above indicators can be attributed to natural indicators and are based on open-access documents BAT (Best Available Technique) [25], technical descriptions of melting processes, as well as available literary sources [26]–[45]. The choice is justified by the fact that these indicators make it possible to compare scrap metal processing technologies from an environmental point of view.

If the process is well established, scrap metal recycling can have a positive impact on the environment, as well as be efficient and sustainable for the industry itself. The amount of lead in the slag is an essential indicator of processing efficiency. At the moment, lead slag is usually disposed of in landfills. As [46] indicates, considering the role of the metal industry in our lives, it can be assumed that the amount of space required for waste storage will only increase. Lead slag also contains toxic elements and compounds, creating environmental and human health risks.

The amount of carbon dioxide generated is directly related to the amount of energy consumed by the plant – gas, coal, coke and/or electricity. Modern metal-smelting furnaces consume significantly fewer fossil fuels than even half a century ago, and coal/coke is increasingly being replaced by more environmentally friendly fuels – gas and electricity. Increasingly, furnace fuel is supplied in pulverized form, improving combustion efficiency [47]. The maximum temperature in the furnace also depends on the amount of fuel supplied.

Insufficient temperature, or vice versa, its excess, can adversely affect either the metal melting quality or accelerate the furnaces' wear [48].

Thus, it is essential to consider the leading indicators of the metalworking industry, specifically the melting stage itself, and how effective this or that metal melting furnace is.

In this work, using the above indicators, the furnaces of the following type were studied:

- Flash smelting/QSL;
- Ausmet/ISASMELT furnace;
- Kaldo furnace;
- Kivcet furnace;
- Electric Arc furnace (EAF);
- Blast/Shaft furnace;
- Short Rotary furnace;
- Reverberator furnace.

It should be noted that the indicator values used in the study for each furnace are taken as an average of the sources found. More accurate values directly depend on the specific furnace and may vary depending on the conditions – the quality of the fuel, the quality of the metal being processed, the combustion conditions, etc. [49]–[51].

2.2. SWOT analysis

In order to determine the effectiveness, potential, and threats to the national metallurgy sector, a SWOT analysis (Strengths, Weaknesses, Opportunities, and Threats) was carried out in the work. SWOT is a method for identifying and formulating strategies for improving the performance of an enterprise, taking into account both external (opportunities and threats) and internal factors (weaknesses and strengths). Based on the analysis results, the enterprise can determine the development path, reduce the impact of potential threats, adapt to various factors and assign strategies for further work, development and/or behaviour in the context of the decision being made [52].

The SWOT analysis aims to determine the efficiency of 8 Latvian metallurgical enterprises. The analysis uses data provided by enterprises in reports for the State Environmental Service [53], as well as interviews with representatives of enterprises.

3. RESULTS

3.1. Multi-Criteria Decision Analysis

All values used in the multi-criteria analysis are referred to the production process and include either the consumption/emission per final product or amount of emission/waste in certain period of time. For the analysis the following indicator values were used.

Based on the values presented in Fig. 1, we find that the electric arc furnace (EAF) is the most efficient for the given values of the indicators. This result is consistent with the literature sources. This type of furnace is characterized by increased efficiency compared to the Blast furnace and the ability to use electricity generated from renewable energy sources, which reduces the total amount of emissions created from the entire process [54]–[57]. A significant advantage of EAF is the ability to work not only with raw metal but also with scrap metal, which in no way affects the quality of the final product. As indicated [58], compared to a Blast furnace, EAF can process up to 20 % more scrap metal, contributing to the sector's sustainability and circular economy.

TABLE 1. AVERAGE VALUES FOR THE ENVIRONMENTAL INDICATORS [25]–[45]

Type of furnace / Indicator	Flash smelting/QSL	Ausmelt/ Isasmelt	Kaldo	Kivcet	EAF	Blast/Shaft	Short Rotary	Reverberator
Maximum capacity, t/d	2200	1150	900	1800	600	13 000	3900	1000
SO_2 amount, year average, mg/m^3	700	850	400	400	90	100	350	560
CO_2, kg/t	1700	1318	1500	2730	850	1214	9000	3000*
Lead content in slag, %	5	1	3	2.5	1.5	3	4	5
Energy consumption, MWh/t	9	1.3	4.35	4.5	3	5.8	4.1	1.05
Oxygen, Nm^3/d	138 889	41 667	91 667	11 100	1528	2778	10 278	1778
Gas, kWh/t	275	1120	450	670	540	300	280	800
Amount of total lead production, t/year	135 000	120 000	145 000	130 000	148 000	110 000	16 000	110 000
Amount of H_2SO_4, kg/t	700	400	500	1100	670	0	390	830
Fuel consumption, kg/t	110	405	100	110	12	720	710	25
Maximum temperature, °C/t	1400	1370	1400	1400	1450	1400	1370	2000

Note: * $kgCO_2eq/t$

Using the data from Table 1 in the MCDA analysis, we get the following resulting picture:

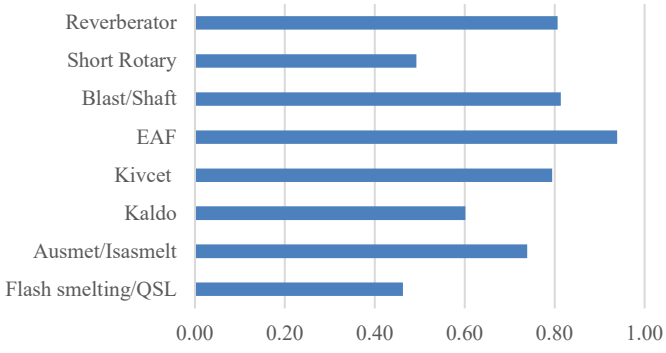


Fig. 1. Results of the MCDA analysis.

Next comes the Blast/Shaft furnace. This furnace consumes a significant amount of coal/coke, affecting CO_2 emissions. However, modern furnaces are equipped with technologies to reduce this amount. For example, the use of technologies for capturing, storing and/or utilization of carbon dioxide (CCUS), which can later be used to produce other valuable materials/products [59], or by using alternative fuels (the so-called bioreducers) – syngas, torrefied biogas, etc [60]. The advantage of Blast Furnace is its large capacity – the maximum load can hold up to 13,000 tons per day, allowing the production of a large amount of steel annually. Because the blast furnace can use low-quality ore as fuel, this furnace can be considered cost-effective [27].

In turn, the worst result compared to other observed furnaces was shown by the Flash smelting/QSL furnace. Although this process is characterized by a high degree of stability and productivity [61], at the moment, its performance is still inferior to more modern metallurgical furnaces, such as, for example, EAF. It should be noted that Ausmelt/Isasmelt furnaces also show excellent results. According to [26], [37], [43], [62], kilns of this type are especially remarkable for their high productivity and relatively low fuel costs. While Isasmelt stoves operate exclusively on solid fuels (coal, coke), Ausmelt can partially use electricity as fuel, significantly reducing the emissions created during fuel combustion. In the future, the Ausmelt process could eliminate the need for fossil fuels and become a greener technology [63].

3.2. SWOT analysis

Based on literary sources and descriptions of technological processes [53], [64]–[66] as well as on interviews with entrepreneurs, a SWOT analysis of Latvian metallurgical enterprises and the stage of melting of scrap metal in particular was carried out.

At the moment, nationwide metal processing enterprises rely on their strength and resources received from local sellers. The enterprises presented in the analysis are considered environmentally friendly. They use natural gas as fuel instead of coke (or the amount of coke is kept to a minimum, like in “Hidrolats”, “Evan Group” and “Fonekss Metals” companies). In this way, the amount of CO_2 emissions from the melting process can be significantly reduced. The enterprises have developed a system for attracting experts. The hiring of young specialists and students is stimulated to improve the skills of employees and develop new ways to improve the efficiency of the enterprise. Ways are also being considered to obtain funding from EU funds, which could contribute to the development of factories.

The results of the analysis are presented in Table 2.

Despite well-established supply chains and product distribution, businesses feel market instability due to political and economic influences. These fears force companies to reasonably assess all the risks associated with any changes – the expansion of production, modernization, etc. However, decisions of this kind carry with them the risks of another aspect – the environmental one. European Union directives require businesses to reduce emissions and use renewable energy sources. However, enterprises often cannot meet such requirements on their own. State financial assistance or temporary tax assistance could help enterprises develop, contributing to the sustainable production of goods with increased added value and the country's economy.

TABLE 2. RESULTS OF THE SWOT ANALYSIS OF THE LATVIAN METAL PROCESSING COMPANIES

Strength	**Weaknesses**
Good location of enterprises – reduction of logistics costs between the seller-buyer	Lack of skilled workers to operate and maintain complex equipment
Thanks to the replacement of obsolete equipment with more modern equipment nationwide, production can be considered efficient	Insufficient funding to purchase more efficient and sustainable equipment
Established and developed relationships with customers and the product sales market	Lack of available technologies for enterprise development. Stagnation of technological processes
Verified Suppliers	Work with material, the processing of which requires large energy investments and high capacities
Opportunity to use scrap instead of metal as a resource, contributing to the sustainability of the industry	At the moment there is no possibility to use alternative energy sources
Scrap metal delivery points, motivation of citizens to hand over scrap metal	Unstable financial growth, inability to predict long-term benefits
	Increasing demands on environmental "friendliness" of processes
	Undiversified energy supplier, dependence on one supplier
	Too small sales market

Opportunities	**Threats**
Opportunity to attract experts / working partners from other countries, thereby stimulating the development of the enterprise	Aging staff and lack of new skilled workers
Possibility to use foreign markets for sales/acquisition of products	An unstable economic and political environment, leading to instability in markets and established supply chains
Integrating new technologies that are more environmentally friendly, efficient and sustainable than those currently in use	Due to financial uncertainty, the impossibility of modernization and, as a result, the difficulty in meeting environmental requirements
The introduction of new technologies makes it possible to attract foreign investment	Instability of the political energy sector – there may be a need to change the energy supplier, which potentially entails increased financial costs
Installation of carbon dioxide capture systems, which will significantly reduce the amount of CO_2 emissions at the metal melting stage	Instability of the economic sector – the energy supplier can raise the price of energy, which leads to an increase in the price of the process and the final product
Attraction and use of alternative energy sources to improve the efficiency of the enterprise	Lack of funding and confidence in the stability of the enterprise
Cooperation with foreign enterprises in matters of technological and economic development	High raw material prices
The use of the latest melting furnaces allows to reduce the consumption of electricity without losing the efficiency of the process	The capture of sales markets by larger enterprises. The need to dump prices in order to obtain a sales market for products, which leads to a decrease in profits and illiquidity of the enterprise

The modernization of production can be a vital step for the enterprise, although it is associated with risk. Efficiency gains could attract additional funding to support production. New markets can bring additional profit and stability as various buyers will be obtained. However, the main threats to enterprises are in the energy sector. The enterprises use mainly electric furnaces, and the metal melting process is highly energy-consuming. An increase in the price of electricity can be a critical or even decisive step in the functioning of the enterprise [53]. Diversifying energy providers can add stability to the process as it no longer depends on one particular energy seller. Using alternative energy sources or already independent energy production will significantly secure both the melting process and the enterprise.

Because enterprises use fuels with a lower carbon footprint, it can be assumed that the country's energy sector will reduce CO_2 emissions. As follows from the data [53] and [67], metalworking enterprises considered in the analysis in 2021 produced 8 % less CO_2 emissions than a year earlier.

4. CONCLUSIONS

As part of this work, a metal smelting furnace was analysed to determine the most effective in terms of 11 natural indicators. The analysis was carried out using MCDA analysis, which showed that the most efficient furnace can be considered an electric arc furnace at the moment. The main advantage of EAF is the ability to work with a large amount of scrap metal and the relatively low amount of lead produced in the waste, low SO_2 and CO_2 emissions. Due to the ability to use electricity, this furnace is also characterized by low consumption of fossil fuels. Given the ability to use electricity generated from renewable energy sources, EAF can be considered the most environmentally friendly among those analysed in this paper.

The second task of the study was to carry out a SWOT analysis of metalworking enterprises in Latvia. The study showed that the main threats to the sector are the uncertainty and instability of the market, both internal and external. While businesses have and are still upgrading processes and installing more efficient furnaces, this can also be risky – new furnaces consume electricity, making the process environmentally friendly but highly dependent on electricity prices. Because the electricity supplier is not diversified, enterprises expose themselves to certain risks associated with the supply of this type of fuel. This problem may be another field for researching technologies and innovations, as energy consumption created from renewable energy sources and the diversification of suppliers will secure enterprises. The use of electric ovens by local businesses could be a significant advantage in the future as with the development of the industry and the shift away from fossil fuels (coal/coke), as well as the drastic change in markets due to political factors, coal/coke prices may increase, which will make the metal recycling process illiquid.

In conclusion, the sector needs cleaner and more efficient scrap metal processing and utilization technologies. In this regard, further research is needed on furnaces for processing this resource, including more criteria and research methods.

ACKNOWLEDGEMENT

This work has been supported by the European Social Fund within the Project No 8.2.2.0/20/I/008 “Strengthening of PhD students and academic personnel of Riga Technical University and BA School of Business and Finance in the strategic fields of specialization” of the Specific Objective 8.2.2 “To Strengthen Academic Staff of Higher Education Institutions in Strategic Specialization Areas” of the Operational Programme “Growth and Employment”.

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