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INTRA- AND EXTRA-EU TRADE IN RECYCLABLE METALS: OPPORTUNITIES FOR INDUSTRIAL SYMBIOSIS

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Abstract
Trade in recyclable metals within and outside the European Union borders is a key part of establishing patterns of circular economy and industrial symbiosis in the metalworking industry. Industrial symbiosis implies the creation of industrial synergies in areas that can utilize waste materials or by-products, and is particularly important in sectors of intensive mineral processing, as it reduces the amount of waste, the need for exploitation of primary raw materials (virgin materials), and the negative environmental impact. This paper examines the potential of European Union countries for creating industrial symbioses, based on an assessment of trade in recycled metals within the EU and with third countries. A multi-criteria analysis was employed, utilizing the MARCOS methodology to rank EU countries, thereby determining which countries have the most significant potential for recycling various types of metals and making synergies. Research on trade in recycled materials contributes to the promotion of circular and sustainable mechanisms, and the results can serve policy makers, industrial actors and researchers as a basis for investment planning, optimization of flows of secondary raw materials and development of regional centers of industrial symbiosis.

***Keywords**: industrial symbiosis, trade in recyclable metals, European Union*

1. INTRODUCTION

The economic progress we are experiencing nowadays is causing a significant increase in the required quantities of materials, especially metals. The OECD report estimates that by 2060, the need for metals will increase from 7 to 19 Gt per year. The use of such large quantities of metals in economic activities has significant environmental consequences, starting from the process of extracting materials through their use to disposal, which include greenhouse gas emissions, air pollution, land and water devastation, etc. Although there is a desire to increase efficiency and reduce the environmental impact per unit of product, due to the significant increase in global consumption, the environmental impact is actually growing. In addition to the large ecological footprint, there are also challenges related to the limited reserves of certain raw materials, especially scarce and strategic metals such as lithium, cobalt, rare earths, and indium. While some metals have relatively high recycling rates, some rare and precious metals, in addition to their low natural availability, also have extremely low recycling rates [1]. The importance of these minerals is reflected in the reliance of the energy transition on their extraction and use, as they are widely utilized in clean energy technologies, ranging from wind turbines and solar panels to electric vehicles.

Metal recycling represents one of the significant opportunities to overcome the problem and achieve sustainable resource use. Due to their physical and marketable properties, metals are among the most suitable materials for recycling. For decades, scrap metals have been used to produce new ferrous and non-ferrous metals, while retaining almost all of their functional properties. In terms of metal recycling, the potential is large. Existing data indicate that the proportion of steel waste used in steel production in the EU has been around 56% in recent years.

Of the total amount of copper waste produced in the EU, around 29% is lost due to inefficiency at the end of its life. Of the total amount of aluminum waste produced in the EU, 70% is collected and recycled annually [2]. Projections show that recycling will become increasingly competitive with the exploitation of primary raw materials, which will contribute to the recycling sector outpacing the growth of mining [3]. Metal recycling will be essential to achieve climate neutrality targets by 2050, especially in energy-intensive industries such as the metallurgical industry. Its role is clearly recognized in the European Green Deal and the Circular Economy Action Plan [2].

It is important to understand that the circular economy cannot be fully realized at the level of individual countries, but requires coordinated action at the European and global level. The trade in recyclable metals not only contributes to the development of the circular economy, but also represents a key mechanism for realizing industrial symbiosis (IS) - a concept in which waste or by-products of one industry become raw material for another [4]. Considering that IS assumes that surpluses from one production process are allocated where they are needed, through exchange of raw materials from recycling, enabling industries across different sectors to cooperate with each other. The secondary metals market enables IS regardless of geographical boundaries, thus encouraging more efficient use of resources at the regional and international level with direct benefits for the economy and the environment. For industrial symbiosis, it is necessary to harmonize the output and input of industries and to collect the necessary data on waste and recyclable materials and potential users of these resources and their needs.

The aim of this paper is to investigate the potential of industrial symbiosis and the role of recyclable metals in the transition to a circular economy, through the analysis of patterns of international trade in recycled materials. Special focus is on the identification of regional specialization in the processing of certain types of metals as well as on the assessment of the European Union's dependence on the import of secondary raw materials. This research provides a comprehensive overview of the EU market, enabling the identification of recycling metal flows, the recognition of key players, and the assessment of the potential for developing industrial symbiosis in the metal sector.

2. METHODS

The analysis is based on Eurostat data on Trade in recyclable raw materials, while a multi-criteria analysis using the MARCOS (Measurement Alternatives and Ranking according to Compromise Solution) methodology was applied as a methodological framework to identify similarities and group countries according to patterns of import and export of recyclable metals. The multi-criteria analysis approach for ranking countries has been used in numerous studies dealing with sustainability, energy efficiency and circular economy [5,6,7]. The MARCOS methodology was proposed by Stević et al. (2020) and is based on the comparison of alternatives and the determination of their positions in the ranking list based on the position in relation to the compromise solution. A compromise solution assumes the determination of the utility function in relation to the ideal and anti-ideal solution and their aggregation. The sequence of steps applied in order to obtain the final ranking of alternatives is presented in the work of [8].

3. RESULTS AND DISCUSSION

In order to carry out a comprehensive analysis, data were collected on intra- and extra-EU trade for the groups of ferrous, precious, non-ferrous (Cu, Al, Ni) and non-ferrous (other) metals. Then, through four ranking procedures, the EU countries were ranked according to criteria that represent values of trade in metals from waste or by-products, intended for further processing or recycling. The ranking results are presented graphically in Figure 1.

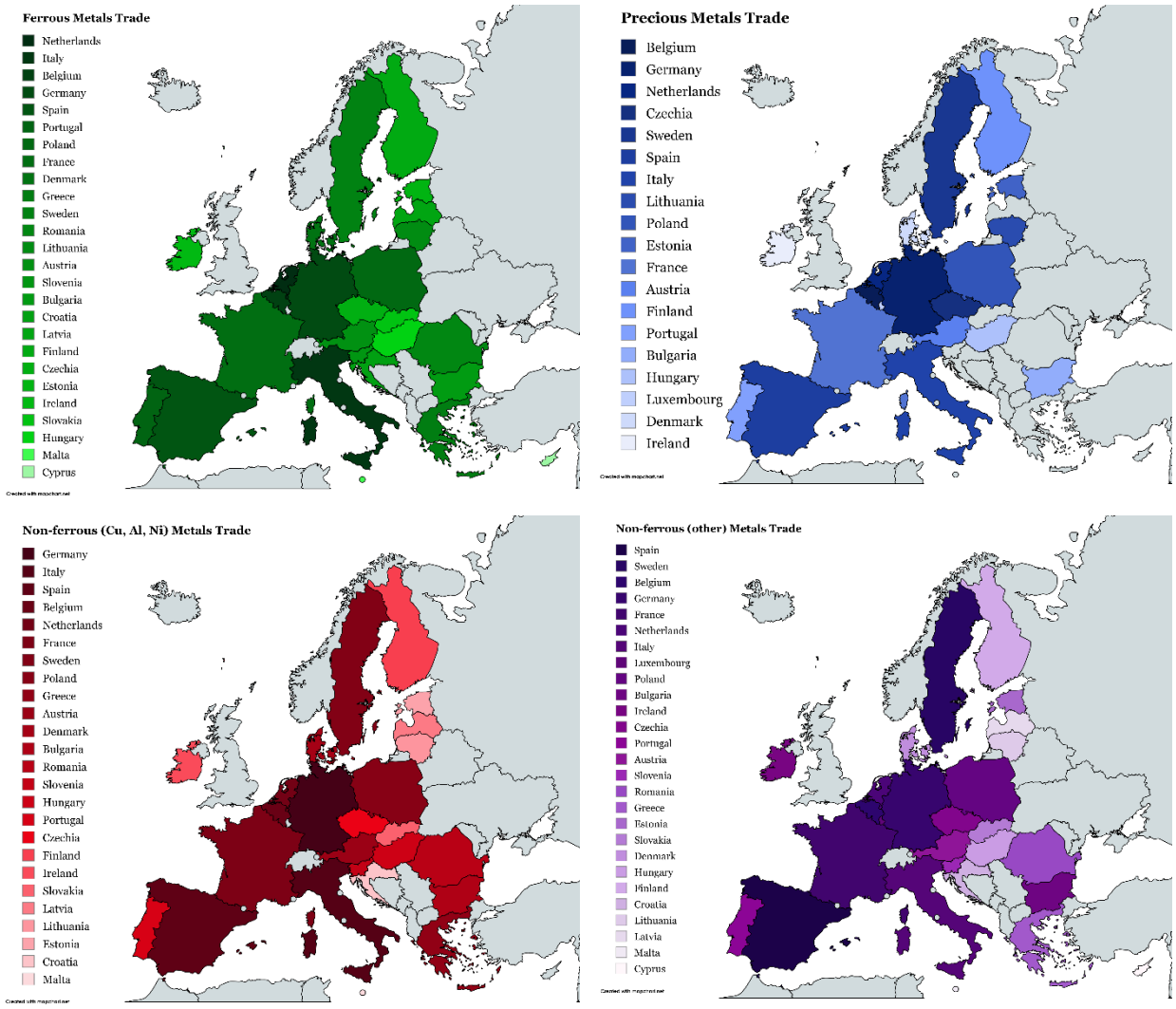

Figure 1. EU country rankings

The recycling of secondary metal raw materials represents a key step in the transition of the metal sector towards circular and sustainable practices. Among the leading countries in the trade of recyclable metals, Belgium and Germany stand out, followed by the Netherlands, Spain and Italy.

In the context of industrial symbiosis, the countries leading in the export of scrap metal usually have a developed infrastructure for collecting, sorting and transporting secondary raw materials, which makes them potential centers for the further development of these practices. Germany stands out in particular in the trade of non-ferrous metals (Cu, Al, Ni), while it also occupies a high position in the trade of precious metals. The German economy is characterized by robust industrial bases and strong environmental policies, as well as the largest number of Critical Raw Materials (CRM) recyclers in the EU [9]. The same applies to Belgium, which exhibits high levels of trade in recycled metals across all categories, and is particularly the leader in the import of precious metals. Belgium is already recognized as one of the leading centers of the metal recycling industry in Europe which is in accordance whit obtained results in this study [9].

The Netherlands is highly positioned in all rankings, although it does not have a particularly large domestic industrial base that produces metal scrap suitable for recycling. Its position is secured by high levels of trade in precious metals and significant exports of ferrous metals to countries outside the EU. Trade in secondary metal raw materials with third countries in the case of the Netherlands is largely based on its role as a transit and logistics hub, with much of the material passing through Dutch ports, even though it does not originate in the Netherlands itself.

On the other hand, the import of ferrous and non-ferrous metals (Cu, Al, Ni) is particularly important for the position of Italy, while the import of other non-ferrous metals is emphasized in Spain, which makes them suitable bases for establishing centers of industrial symbiosis. Countries such as Spain, Italy and Sweden are rapidly expanding capacity to switch to more environmentally friendly methods of steel production, thus increasing competition for high-quality scrap steel [10].

As expected, small countries with limited metal processing industries, such as Cyprus and Malta, are at the bottom of the rankings. The reason for this is the insufficient generation of metal waste, which reduces the need for large recycling facilities. In addition, since both countries are islands, the transport of scrap metal, as well as recycled material, is logistically more complex and expensive, which further limits their participation in the international trade in secondary metals.

Similarly, other EU countries that do not have a developed metal industry, nor industries that consume large amounts of metal, are lower on the rankings.

The positions of certain countries, such as Finland, Sweden and Austria, may seem surprising given their ecological tradition and developed recycling systems [11]. However, these very factors explain their relatively low volume of trade in secondary metals. These countries have developed domestic processing capacities, a high level of internal recycling and closed material flows, which means that most metal waste is processed and reused within national borders, without significant involvement in cross-border trade.

4. CONCLUSION

Research indicates that the EU's strong dependence on the rest of the world for metals is a significant issue, which is why various policies and interventions are being introduced to achieve a greater balance [12]. In recent years, the EU has established policies for trade in secondary metals, but it has also introduced restrictions on the level and prices of trade in certain types of these metals. However, the demand for metals is growing, as well as doubts about the effectiveness of some of the restrictive policies [13,14]. Therefore, recyclable metal scrap is treated as a valuable good in the EU, traded on international exchanges. Trading in recyclable metals does not hinder, but rather encourages, the establishment of a circular economy. The import of virgin raw materials into the EU has a significant negative impact on the environment and hinders the establishment of a circular economy, trade in raw materials from recycling does not have such consequences, but quite the opposite - the export of quality recycled metal from the EU can be key to achieving the goals of the European Union within the set goals of a sustainable economy.

Overall, the analysis of trade flows of recyclable metals among EU member states and towards third countries provides important insights into the availability of secondary raw materials and logistics capacities, which are key to planning and developing industrial symbiosis. Countries that combine a high level of import and export with a developed infrastructure for processing represent strategic points for strengthening the circular economy and reducing dependence on primary resources.

This research can serve as the basis for mapping the potential of industrial symbiosis in the metal sector, particularly at the international and European levels, and should be supplemented with data on quality, location, and local material flows.

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REFERENCES

[1] United Nations Environment Programme, Critical Transitions: Circularity, equity and responsibility in the quest for energy transition minerals, UNEP, Nairobi, 2024.
[2] European Recycling Industries' Confederation (EuRIC), EuRIC's position on free trade & metals circularity, 2021.
[3] OECD, Global Material Resources Outlook to 2060: Economic Drivers and Environmental Consequences, OECD Publishing, Paris, 2019.
[4] S. Jung, S. An, J. Park, S. Park, X. Bi, J. Ind. Ecol., (2025).
[5] J. Brodny, M. Tutak, Smart Cities, 6 (1) (2023) 339-367.
[6] V. Grybaitė, A. Burinskienė, Sustainability, 16 (21) (2023) 9582.
[7] E. Güler, Environ. Res. Commun., 7 (7) (2025) 075021.
[8] Ž. Stević, D. Pamučar, A. Puška, P. Chatterjee, Comput. Ind. Eng., 140 (2020) 106231.
[9] R. Mohan, "Critical Raw Materials Recycling: Key European Players and Capabilities," iimpcoll, 2024.
[10] Waste Transport Solutions, Metal waste vs. scrap: Exporting and recycling across Europe, Waste Transport Solutions, 2025.
[11] Alutrade, Which country recycles the most aluminium?, n.d.,
[12] T. Distefano, L. Lodi, M. Biggeri, J. Clean. Prod., 472 (2024) 143384.
[13] European Recycling Industries' Confederation (EuRIC), EuRIC Circular Metals Strategy, 2021.
[14] X. Zhou, H. Zhang, S. Zheng, W. Xing, Sustain. Prod. Consum., 33 (2022) 831-845.