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The Presence of REM and CM in WEEE: Challenges for Recovery

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Abstract The fastest growing waste stream of WEEE is not only a threat to our environment, but is also creating a supply risk of certain rare earth metals (REM) and critical metals (CM). Hence WEEE are considered as "Urban mines", a source of highly valuable metals. Despite the fact that Directive 2012/19/EU encourages the prevention of WEEE by promoting re-use, recycling and other forms of recovery of such wastes, the recycling of these metals in WEEE is less than 1%. The insufficient data about the composition of REM and CM in EEE, the high recycling costs and the different motivations/interests of the stakeholders, including national authorities, non-profit companies and producers, are some of the main inhibitor factors. However, there is a growing interest in scientific community in sorting out the issues which leads to such a low recovery and in defining the challenges and possible benefits generated from recycling REM and CM. On this basis, this work highlights the characteristics of REM and CM in terms of their economic importance and their presence in EEE. Then, an overview of the supply risk of REM and CM and the challenges related to the recovery are provided, supported by countries examples.

Keywords: Rare Earth Metals (REM), Critical Metals (CM), WEEE recycling, Supply risks

1. Introduction

A metal is labeled as critical when there is a risk of its scarcity and its availability has simultaneously great economic and defensive importance for a country. The risk of supply may derive from political and economic conditions of the producing countries, difficulties in substitution and low recycling rates. Specifically, REM are 95% of global and 97% of European Union REs market in 2010 (European Commission, 2010). Dearth of REMs does not only affect large economic value added industries, but not characterized as rare referring to their mineral depletion, but since their extraction through economically-feasible and environmentally-sound manner is troublesome taking into account both their low concentrations and also their attachment to other minerals. The rare earth element (REE) group consists of 17 chemical elements that are characterized by similar properties. Both REM and CM are found in a great number of applications. Miniaturization of electronics, empowerment of telecommunication, boost to renewable energy and improvement in medical and defense technologies are made possible due to these so called "technology metals". Today, nearly 95% of REEs are produced in China (USGS, 2010). As nearly 40% of the world's rare earth oxides (REOs) reserves are located in China (USGS, 2014), it may be easily predicted that China will remain a dominant REMs supplier globally. This arises a great concern to have a reliable, sustainable, and legitimate access to these critical metals. Recycling, substitution, and resource efficiency are the remedies against risk of supply providing an alternative to primary production, which is not only strategic but also sustainable.

2. The economic importance of REM and CM and European dependency

Reliable and unhindered access to REMs is crucial for a country's economy. REMs market, which is the youngest goods market, is quite unpredictable. In the past the balance of demand and supply in the world market of REMs followed a wavy trajectory that started with extremely high prices between 2008 and 2011 and a dramatic 70% fall afterwards (Charalampides *et al.*, 2015). China was controlling

also many defense products and industry. As a result, whoever controls the supply side have the power to manipulate the economics of the developed countries. In

2015 and 2016, China's share in RE market decreased to 85.27% and 83.60%, respectively. Other top RE production countries are Australia, Russia, India, Brazil and Thailand (Fig. 1).

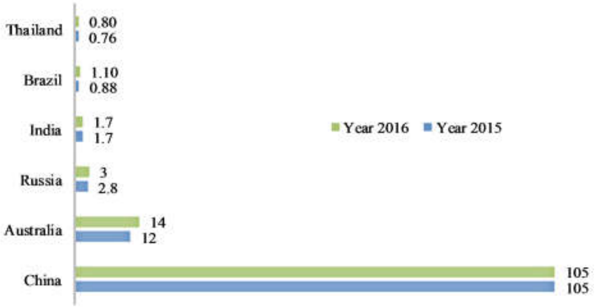

Fig. 1. Top countries in RE mine production (in 10^3 metric tons), (Investing News Network, 2016)

Prices of REMs are influenced by many internal and external factors. Internal issues may be the imbalance between demand and supply, the market trends, the customary assumptions etc. These factors have a short-time influence on prices, whereas external factors like economic growth of producing countries, policies and legislations, geopolitical situation, natural disaster etc. tend to induce long-term influence on prices. Variation in prices of selected rare earth oxides (REOs) are shown in Fig. 2, indicating the price difference between year 2012 and 2016

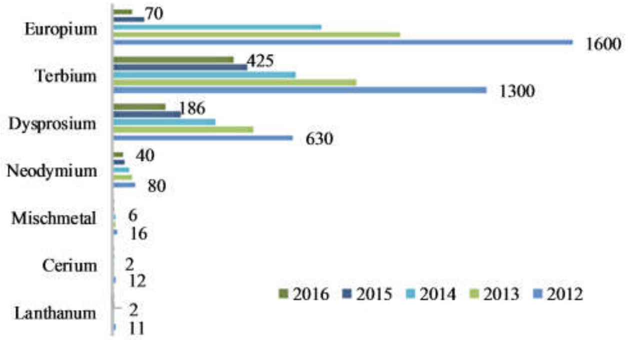

Fig. 2. Evaluation of price of selected REOs (in USD/kg), (USGS Minerals Information, 2017)

Although the RE industry is currently in the maturity phase which means slowdown in the demand of RE raw material, at the same time the use of REMs in green products like hybrid cars, wind mills, fuel cells and many other hi-tech industrial and consumer products are highly favored in Europe, predicting a considerable increase in demand of REMs in future.

3. REM and CM use in EEE

In order to focus on the secondary production of REMs and CMs, it is needed to consider their common uses and find where these metals are mostly located. The use of REMs/CMs in EEE is too numerous to list, but the major uses include ultra-strong magnets for electric motors, advanced batteries, and phosphors for fluorescent lighting and display panels. The major end uses of light rare earth (LRE) and heavy rare earth (HRE) are listed in Table 1. It is clear that EEE has introduced a significant use of REMs and CMs required for manufacturing techniques.

4. The risk of supply - Challenges for REM and CM recovery

Despite the high prices of REM and CM, a respective increase in their production has not yet been recorded. In fact, REM and CM are not the main products of mining operations, but "by-products" occurred through the extraction of abundant base metals (Bakas *et al*., 2014). In parallel, the production of REM and CM from secondary resources, such as via recycling processes, remains very low due to the missing incentives with the focus mostly concentrated in other valuable materials. On this basis, the supply-demand interaction is not well-balanced. Taking into account that these metals are neither the main product in mining (primary production), nor in recycling or other activities (secondary production), REM and CM are almost "predestined" for the risk of supply. Therefore, the metal criticality is closely related to significant strategic/ technical or economic issues (Chanceler *et al*., 2016) and not derived from the limited ore deposits (Bakas *et al*., 2014). This phenomenon is called structural or technical scarcity.

The present work is totally oriented in the secondary production of REM and CM located in WEEE, which should be encouraged to bring both economic and environmental benefits in the frame of circular economy (Bakas *et al*., 2016). The share of worldwide mine or refinery production of REM and CM consumed in the manufacturing of EEE has recently sparked great interest among the scientific community. Chanceler *et al*., (2016) have reported concerns about the low concentrations located in the products and highlighted the gaps in the life cycle including the short useful time of products, then the insufficient collection of WEEE and the troublesome treatment chain. As a matter of fact, the insufficient infrastructures, the complex structure of this waste stream, the low concentrations of REM and CM used for highly specialized applications, the difficulties in scrap-metal recovery, the uncertainties of sales data, the illegal export, as well as the adverse technical and economic

Table 1. Selected end uses of REEs in EEE (DOI, U.S. Geological Survey, Circular 930-N)

LRE	Major end uses	HRE	Major end uses
Lanthanum	hybrid engines, Phosphors	Terbium	permanent magnets , Phosphors
Lutetium	catalysts in petroleum refining	Dysprosium	permanent magnets, hybrid engines
Praseodymium	magnets	Gadolinium	Magnets
Neodymium	auto catalyst, hard drives in laptops, headphones, hybrid engines	Yttrium	red color, fluorescent lamps, Phosphors
Samarium	magnets	Holmium	glass coloring, lasers
Cerium	auto catalyst, Phosphors	Thulium	medical x-ray units,
Europium	red color for television and computer screens, phosphorus		

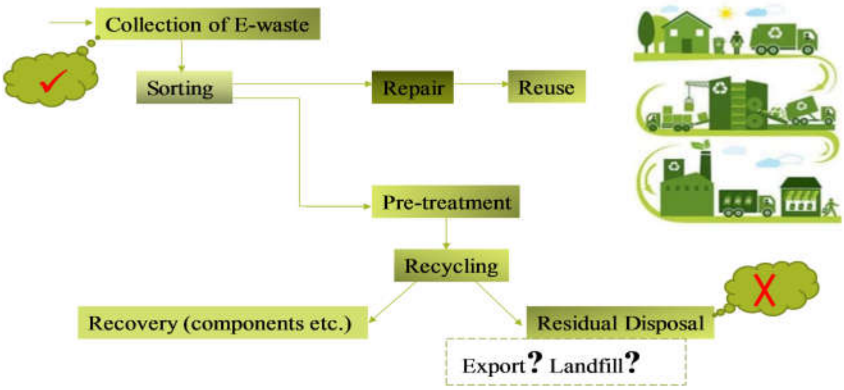

Fig. 3. WEEE management procedures

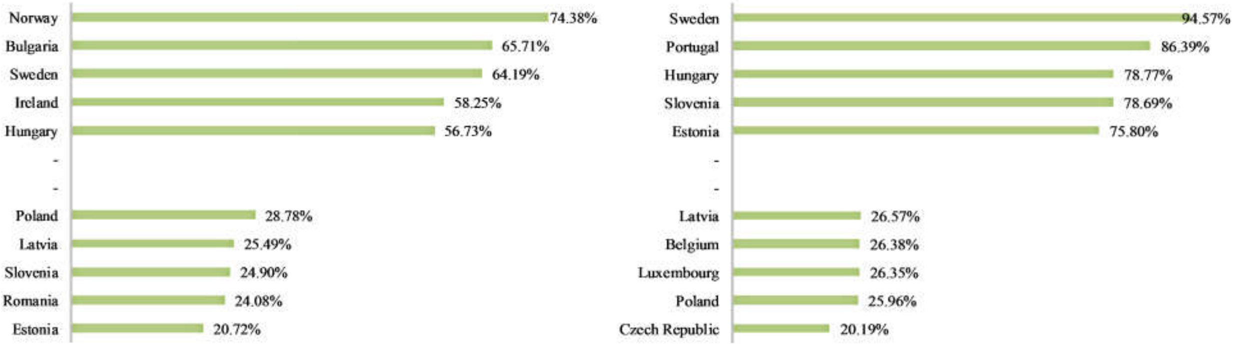

Fig. 4. EU countries with highest and lowest collection rate of large household appliances (left) and IT and Telecommunication Equipment (right), (Eurostat, updated till Mar 2017)

limitations are the boundary conditions due to which only minor fractions of REM and CM are recycled (Binnemans *et al*., 2013). In spite of the aforementioned limitations, the recovery of REM and CM can offer significant reduction of CO_2 emissions which are typically produced during the mining and refinery (Bakas *et al*., 2016; Hobohm *et al*., 2016; Cucchiella *et al*., 2015) and also reduction of REM and CM criticality (Savvilotidou *et al*., 2017; Hobohm *et al*., 2016). However, the recycling rate of REM and CM is less than 1 % (Binnemans *et al*., 2013). Therefore, the question is: what should be done to improve this recycling rate?

5. Current situation of collection systems

EU governments have developed strategies and policies associated to critical raw materials in order to introduce the sustainable production, use and recycling of REM and CM. The core points needed optimization are (a) the technological development and innovation (e.g. sustainable supply, boosting recycling technologies), (b) the "raw materials diplomacy" (strong relations among countries, partnerships, stakeholders), (c) the higher education and training (to promote cooperation of professionals with scientific community), (d) the substitution of critical metals by less critical metals. No doubt the perspective for an efficient use of REM and CM including the mining operations, the refining, recycling and substitution generates great challenges (Chanceler *et al.*, 2009). Focusing on WEEE recycling, there are three fundamental steps: collection, pre-processing and end-processing (Marra *et al.*, 2015). Fig. 3 illustrates the WEEE management step by step.

To maximize the recovery quantities of REM and CM, it is better to start from the onset of the problem. According Binnemans *et al.*, (2013) and Hobohm *et al.*, (2016), the inefficient collection (Ylä-Mella *et al.*, 2014) is one of the main reasons for the low recycling rate. Directive on WEEE has established collection level of 65 % wt. of the equipment placed on the market (POM) as an average of the three preceding years. Notably, in 2012 the WEEE collection rate was less than 50%, while the average for the entire EU had reached only 38% (Król *et al.*, 2016). The attitude of consumers (cultural-national-social habits), the storage of WEEE in households, and the weak national take-back systems may play a key role which explains this low rate.

Collection of WEEE in Europe

According to Eurostat (2017), among 28 member countries, the collection rate of WEEE varies significantly. Fig. 4 presents the EU countries with highest and lowest collection rate for large household appliances (left) and IT and Telecommunication Equipment (right). Based on literature, Scandinavian territories have managed high collection rates by achieving well-developed systems for waste handling and treatment (Baxter *et al.*, 2016). This is also confirmed in Fig. 4, since Norway has the highest collection rate of large household appliances of approximately 74.38%. Regarding IT and Telecommunications equipment, 5 countries can achieve collection rate higher than 75%. However, there are also 5 countries reaching rate lower than 30%.

Looking forward to deal with the future criticality risks, some recommendations and potential solutions should be introduced among which (1) technological innovation, (2) strong legislation, (3) improvement of the data quality and (4) new initiatives are the most important. To the author's best knowledge, prior to any attempt, responsibilities should be addressed to the closely associated parties, as mentioned in Fig. 5.

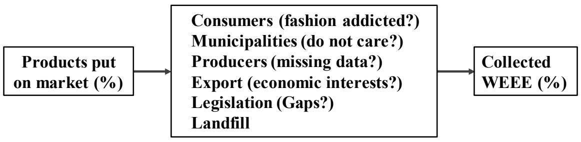

Fig. 5. Parties with responsibility in WEEE collection

It is crucially important to determine the real percentage of products put on market, and then to identify the losses driving to low collection rates. In Fig. 6, the data presented are related to the annual amount of products put on market and the respective collection rate from 2006 to 2014. It is revealed that the collection rate has been increasing, but not enough.

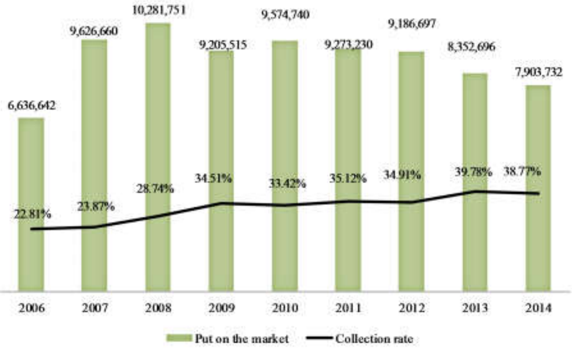

Fig. 6. Amount of EEE put on the market (in tonnes) and Collection rate in EU (Eurostat, updated till Mar 2017)

With respect to higher collection rates, among the promising perspectives recommended to member states is to provide attractive incentives for critical metals-rich product groups collection. In specific terms, although legislation addresses WEEE as a uniform waste stream, if product groups with high concentrations of critical metals are promoted for separate collection, the smelters would probably benefit from the economic aspects, as well as from the simpler processing of such a sub-stream (Moss *et al.*, 2011).

6. Conclusions

Nowadays, rare earth metals and critical metals are used in a wide range of electronic products. With this, the supply risk of these metals will significantly increase considering the growing demand for more advanced technologies, as well as the shorter lifespan of EEE in the market. To compensate the supply of these metals, WEEE can act as a secondary resource of REMs and CMs. This has already been acknowledged through numerous research calls released by the EU within the Horizon 2020 program. However, despite this fact, there are still several aspects of WEEE recycling left unaddressed; the most important of which is the inefficient collection of WEEE. To make sure that WEEE could be a part of the solution to the risk of supply of REMs and CMs, sustainable management of these wastes should be given significant attention. This can be done by improving practices dealing with the production and waste management stages. This calls for more complete and stricter WEEE legislations and the formulation of corresponding policies and regulations. Economic incentives for bringing WEEE into the circular economy should be developed and promoted. Moreover, if material recovery will be targeted, it is important that this is already considered in the design and manufacturing processes of EEE. Green design, cost-effective, and environmentally friendly production concepts should be introduced into EEE industry to meet the terms of the legislations. As a final point, public awareness regarding environmental protection should also be advocated. It is time that universities, governments, organizations, and companies work together to change the outlook of the public on the end-of-life EEE.

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