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# Raw material depletion and scenario assessment in European Union – A circular economy approach

Florinda F. Martins[a,*], Hélio Castro[b]

[a] REQUIMTE/ISEP, Rua Dr. António Bernardino de Almeida, 431, 4249-015, Portugal
[b] ISEP, Rua Dr. António Bernardino de Almeida, 431, 4249-015, Portugal

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## Abstract

Nowadays the production systems are linear and the consumption patterns are essentially based on products with a short life cycle, which contribute to increase the demand for raw materials and environmental impacts. The Circular Economy (CE) is playing a major role among scholars and practitioners. Many aspects are now defining this new trending paradigm such as the roles of product development, transformation and remanufacturing/recycling, and/or management of waste, ensuring the economic and environmental benefits. The increasing demand causes instability of the prices and markets, and there is also the risk of supply rupture. This is very unsustainable and puts at risk countries' development. In this work we analyze and assess some EU critical raw material (CRM), considering existing global reserves and production. Correlation between several parameters was also analyzed. Under this assumption one scenario was considered to assess the depletion of two CRM. China is the main supplier in 15 out of 25 CRM considered in this analysis and its average percentage is 65%. Phosphate rock presents the highest value and antimony the lowest for depletion indicator. It was possible to conclude that no significant correlation was found between depletion, self-sufficiency and economic importance indicators.


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*Keywords:* Raw materials; Circular economy; Sustainability; European Union

## 1. Introduction

The production systems used are still linear and the consumption patterns are essentially based on products with a short life cycle. This production and consumption pattern provoke, high demand for raw materials, huge air emissions and waste rate generation, which contribute to resource depletion, pollution, climate change and other environmental impacts. Earth's resources are finite and as energy resources are also unevenly distributed. In this context it is important to guarantee that future generations will have enough resources to have a good quality of life. The Circular Economy (CE) is playing a major role among scholars and practitioners [1]. Many

* Corresponding author.
*E-mail addresses:* ffm@isep.ipp.pt (F.F. Martins), hcc@isep.ipp.pt (H. Castro).

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aspects are now defining this trending paradigm such as the roles of product development, transformation and remanufacturing/recycling, and/or management of waste, ensuring the economic benefits of the industrial activity [2]. They will also assure the environmental benefits such as the reduction of raw materials consumption and pollution. For example, in 2005, global economy through way 62% of all raw materials processed [3]. This fact shows how inefficient and unsustainable are the economies concerning resources' use. In addition, resource scarcity and a hyper-competitive market raise the awareness for a sustainable development [4]. Society, in general, and industries and consumers, in particular, are involved in the sustainable development and CE's policies establish incentives to foster favor behavior for sustainable approaches [5], however it is evidence that nowadays products' life cycle is getting shorter and the products' diversity is getting higher, leading towards a hyper production and consumption of products. These production and consumption practices generate a huge amount of products and therefore provoke high consumption of raw materials and energy especially, in more developed regions of the globe, such as European Union.

In the production perspective, many policies and practices were implemented, e.g., sustainable design, life thinking approach considering the products' life-cycle to minimize production system environmental impacts [6] and promoting inter-sectorial dynamics and cooperation to transform a certain industry's by-product or waste into a resource for a second industry [7]. CE will only be successfully implemented if there is a behavioral change. Social, environment and economic challenges emerge due to the peak amplitude provided by hyper production and consumption, and the need for a sustainable development, which will allow overcoming poverty trap, social vulnerability, supply risks, deregulated markets [5] and prices volatility. In this context it is important to ensure that future generations will have enough resources to have a good quality of life. CE is a key strategy to achieve Sustainable Development. The increasing demand causes instability of the prices and markets and there is also the risk of supply rupture. Therefore, EU is making a shift on this development pathway by implementing several strategies concerning raw materials such as the European Innovation Partnership on Raw Materials and the action plan for EC [8,9]. Concerning EU policy and strategy for raw materials (RM), the European Commission (EC) assumed and defined two integrated parts: (A) Raw Material Initiative [10], to adopt (1) a worldwide fair and sustainable supply of RM, (2) internal sustainable supply, and (3) stimulate the resource efficiency and supply of secondary raw material; and (B) The European Innovation Partnership on Raw Materials [11] as a platform to integrate all European stockholders (public and private) on innovative approaches for the future challenges related to raw materials. The implementation of EC is also the target of many studies from different stakeholders [12,13]. EU also developed studies to find the critical raw materials (CRM). These studies led to a list of CRMs that is being updated every 3 years, the first one was done in 2011 and the last in 2017 [14–16]. In this work we analyze and assess some EU CRM, considering existing global reserves and production. Correlation between several parameters was also analyzed as well as main providers. A scenario based on growth rate consumption was considered to assess raw material depletion.

## 2. Method

One of the 10 initiatives defined in The Raw Materials Initiative was the definition of the Critical raw materials [10]. The last revision of the list of CRMs was published in 2017 composed by 27 CRMs [16]. The raw materials were assessed considering criteria such as self-sufficiency (SS), economic importance (EI), supply risk (SR), End of life (EoL), etc. Table 1 presents the list of CRMs [16].

HREE (Heavy rare earths) and LREE (Light rare earths) are also CRM, however they are groups of chemicals elements, such as dysprosium, erbium, europium, etc. for the former and cerium, lanthanum, etc. for the later. Although CE is being implemented in EU country, demand for many CRMs is growing in several industries but the influence from recycling is largely insufficient to meet the demand [8]. The growth rate (GR) and depletion indicator of critical raw material (DI) were calculated according to Eqs. (1) and (2):

$$GR = \frac{World\ production\ present\ year\ (t) - World\ production\ previous\ year\ (t)}{World\ production\ previous\ year\ (t)} \quad (1)$$

$$DI = \frac{World\ reserves(t)}{Annually\ world\ production(\frac{t}{year})} \quad (2)$$

A normality test was used namely, the Shapiro–Wilk since the sample size is small, being more suitable this test. According to this test if the p value of the Shapiro–Wilk Test is greater than 0.05, the data is normal. Then a

**Table 1**. CRM Characterization.
*Source:* Data from [15,16].

| | SS (%) | EoL (%) | EI | Main supplier | Percentage |
|---|---|---|---|---|---|
| **Antimony** | 0 | 28 | 4.3 | China | 87% |
| **Baryte** | 0.2 | 1 | 2.9 | China | 44% |
| Beryllium | N/A | 0 | 3.9 | USA | 90% |
| Bismuth | 0 | 1 | 3.6 | China | 82% |
| **Borate** | 0 | 0 | 3.1 | Turkey | 38% |
| **Cobalt** | 0.68 | 0 | 5.7 | DRC | 64% |
| **Fluorspar** | 0.3 | 1 | 4.2 | China | 64% |
| Gallium | 0.66 | 0 | 3.2 | China | 73% |
| Germanium | 0.36 | 2 | 3.5 | China | 67% |
| Hafnium | 0.91 | 1 | 4.2 | France | 43% |
| **Helium** | 0.04 | 1 | 2.8 | USA | 73% |
| Indium | 1 | 0 | 3.1 | China | 56% |
| Magnesium | 0 | 9 | 7.1 | China | 87% |
| **Natural graphite** | 0.01 | 3 | 2.9 | China | 69% |
| Natural rubber | 0 | 1 | 5.4 | Thailand | 32% |
| Niobium | 0 | 0 | 4.8 | Brazil | 90% |
| **Platinum** | 0.01 | 10.5 | 4.9 | South Africa | 70% |
| **Palladium** | | | 5.6 | Russia | 46% |
| Phosphate rock | 0.12 | 17 | 5.1 | China | 44% |
| Phosphorus | 0 | 0 | 4.4 | China | 58% |
| Scandium | 0 | 0 | 3.7 | China | 66% |
| Silicon metal | 0.36 | 0 | 3.8 | China | 61% |
| **Tantalum** | 0 | 1 | 3.9 | Rwanda | 31% |
| **Tungsten** | 0.56 | 42 | 7.3 | China | 84% |
| **Vanadium** | 0.16 | 44 | 3.7 | China | 53% |

correlation analysis was performed. The Pearson correlation is more adequate when there is a normal distribution. When the data sets present significant deviation from a normal distribution the Spearman correlation is better. Significant correlation between variables exists when $p < 0.05$ in both methods. It was considered a future scenario in this study that was a Scenario based on constant growth rate of world production for each raw material, calculated from data from 2016 and 2017 [18].

## 3. Results

### *3.1. EU's suppliers analysis*

Fig. 1 resumes the analysis related to CMR suppliers done in this work. The frequency and average supply value was calculated for each country for the year 2017, and the results obtained shown in Fig. 1. China is the main

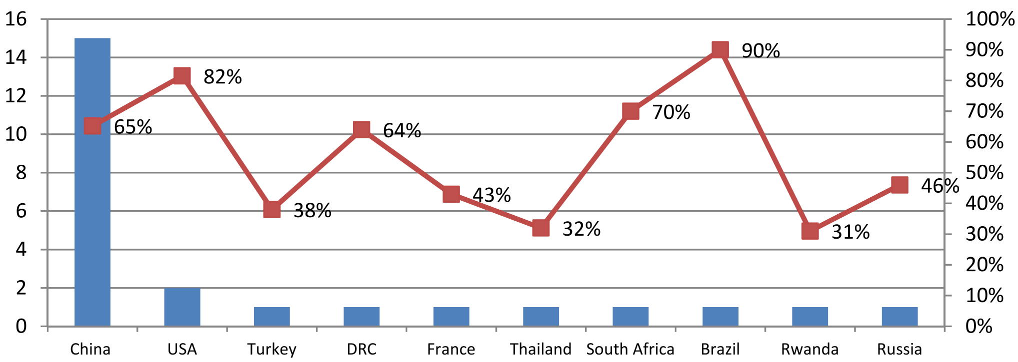


**Fig. 1.** CMR's suppliers' analysis.
*Source:* Data from [17].

supplier in 15 out of 25 CRM considered in this analysis (excluded HREE and LREE, Platinum and palladium considered separately) and its average percentage is 65%, the fourth highest value.

### 3.2. Depletion indicator

The values obtained for DI for the set of CRMs considered are presented in Fig. 2 and were calculated in this work, based on data from 2017. Phosphate rock presents the highest value and antimony the lowest.

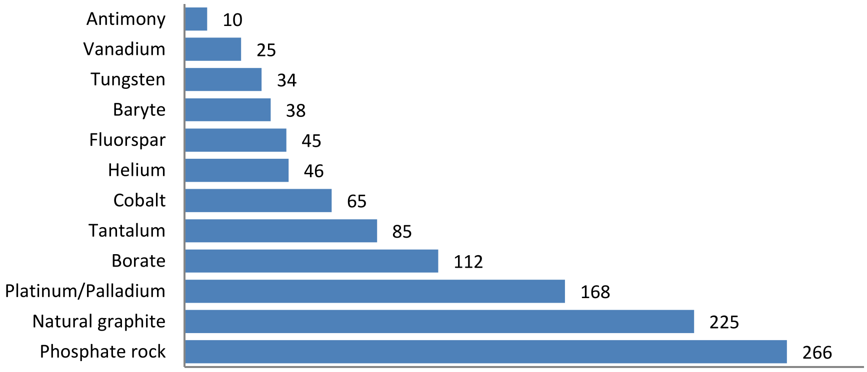


**Fig. 2.** Depletion indicator in years for the set of CMRs considered.
*Source:* Data from [18].

### 3.3. Correlation analysis

First a normality test was carried out. Since the number of countries is low the Shapiro–Wilk is more suitable. According to this test if the p value of the Shapiro–Wilk Test is greater than 0.05, the data is normal. So DI and SS data significantly deviate from a normal distribution (Table 2).

**Table 2**. Results of the normality tests.

| | Kolmogorov–Smirnov | | | Shapiro–Wilk | | |
|---|---|---|---|---|---|---|
| | Statistic | df | Sig. | Statistic | df | Sig. |
| DI | 0.216 | 12 | 0.129 | 0.842 | 12 | 0.029 |
| EI | 0.156 | 12 | .200* | 0.908 | 12 | 0.202 |
| SS | 0.227 | 12 | 0.090 | 0.777 | 12 | 0.005 |

Fig. 3 is the boxplot for the 3 indicators considered. There is one outlier in data set SS, which is more than 3 times the height of the box. Smaller boxes mean that the indicator varies less.

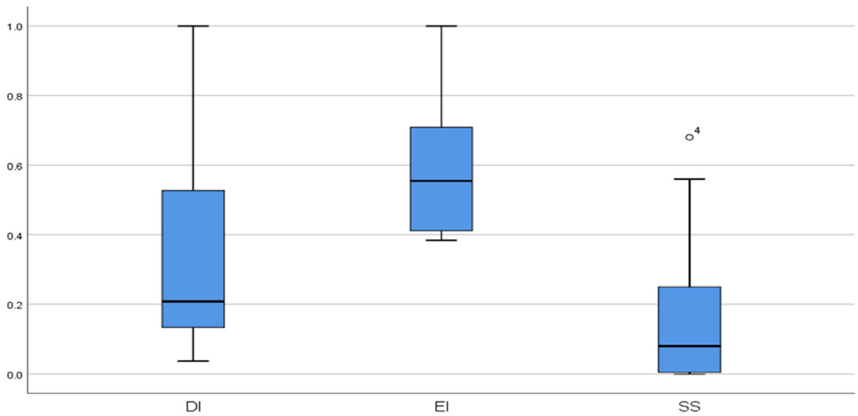


**Fig. 3.** BoxPlot for DI, EI and SS (normalized values).

Then a correlation analysis was performed. However since two of the three data sets present significant deviation from a normal distribution the Spearman correlation is better, so only the results for this test are presented. From the results from Table 3 is possible to conclude that no significant correlation was found (all values >0.05). The tests were carried out using SPSS 25.

**Table 3**. Correlation results.

| | | | DI | EI | SS |
|---|---|---|---|---|---|
| Spearman's rho | DI | Correlation coefficient | 1.000 | −0.039 | −0.265 |
| | | Sig. (2-tailed) | | 0.905 | 0.406 |
| | | N | 12 | 12 | 12 |
| | EI | Correlation coefficient | −0.039 | 1.000 | 0.359 |
| | | Sig. (2-tailed) | 0.905 | | 0.252 |
| | | N | 12 | 12 | 12 |
| | SS | Correlation coefficient | −0.265 | 0.359 | 1.000 |
| | | Sig. (2-tailed) | 0.406 | 0.252 | |
| | | N | 12 | 12 | 12 |

### *3.4. Future scenario assessment of two CRM*

In this section two CRM were analyzed considering the scenario mentioned in Section 2. Antimony will be completely depleted by 2025 and Fluorspar in 2052 Table 4.

**Table 4**. Future scenario for two CMR.

| | GR | Sc1 |
|---|---|---|
| Antimony | 1.4 | 2025 |
| Fluorspar | 1.2 | 2052 |

## 4. Conclusion

From this work it is possible to conclude that China is the main supplier in 15 out of 25 EU's CRM, which means that EU heavily depends on China exportations. The calculation of the depletion indicator shows that the range is very wide, from 266 years from phosphate rock to 10 years to Antimony. When the future scenario was considered taken in consideration the growth rate calculated with data from 2016 and 2017 Antimony will be completely depleted in 2025 (based on present proven reserves). It was possible to conclude that no significant correlation was found between depletion, self-sufficiency and economic importance indicators.

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