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Efficient Use of Critical Raw Materials for Optimal Resource Management in EU Countries

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Abstract: The European Commission has established a Critical Raw Materials List (CRM) for the European Union (EU), which is subject to regular review and updating. CRMs are needed in many key industries such as automotive, steel, aerospace, renewable energy, etc. To address this issue, we studied publicly available data from databases developed by the EU for monitoring the progress of individual countries in key areas for the development of society. The paper analyzes indicators of import reliance, net additions to stock, domestic material consumption (DMC), resource productivity, and circular material use rate. Prospective products and technologies, in electromobility, digitalization, Industry 4.0, and energy transformation, are changing and increasing the demand for raw materials. The aim of this article is to look at the ways forward in order to use critical raw materials as efficiently as possible while at the same time ensuring the optimal economy of the countries. From the sources and databases of data available for the EU, we analyzed a number of variables and suggested options for future developments in the efficient use of critical raw materials. We defined what we believed to be the optimal management means in relation to critical raw materials and worked backwards to find a path to efficient use of critical raw materials.

Keywords: raw material; critical raw material; resources; gross domestic product; SAS JMP software

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1. Introduction

Energy security (ES) is a highly topical issue globally, on the level of the EU, as well as in Slovakia. ES has become not only a phenomenon of the 21st century but also one of the greatest challenges of environmental policy. The effects of climate change appear all around the world, but its various adverse effects apply to socio-economic and natural systems in Slovakia as well, increasing in scale and requiring active solutions. The concept of energy security is relatively novel. It was first implemented into the theory by the Copenhagen School in the early 1990s. In practical applications, there are many definitions of energy security.

Several types of industries depend on the ordinary supply of raw materials in terms of the combination of the domestic extraction of resources, import, and recycling. The European Union defined 27 critical raw materials, some of which are available in Slovakia as well. The extractive industry is intertwined with other industries as well [1,2]. Hence, extractive activities generally generate, on average, four times more indirect job opportunities compared to direct job opportunities in the respective regions [3]. Therefore, sustainable growth in the future relies on raw materials from the local extracting activities since only such extraction allows us to reduce the carbon footprint of transport. Planning utilizes mineral raw materials so that the needs of the society and the economy are fulfilled while also limiting the impact of extraction and processing on the environment, as well as on people living in the environment [4,5].

CRMs are a crucial topic for the EU economy. The present paper deals with the efficient use of CRMs. We analyzed data from the Eurostat database in the SAS JMP software. The compared data were analyzed in the period from 1988 to 2020.

We evaluated and analyzed indicators of consumption and the reliance of the EU on raw materials supply (metals, non-metallic materials, biomass, and fossil fuels). We examined the reliance of EU countries on metal materials since they also include several CRMs. Using other indicators, we attempted to analyze the consumption and potential future trends of consumption, considering that these two variables reveal the potential reliance of the EU on raw materials in the near future.

The materials' consumption per capita and the domestic material consumption on the one hand and the resource utilization rate on the other allow us to understand the future consumption and to set out goals for the future consumption and materials use. Fortunately, the resource utilization rate is higher and has a rising tendency due to the implementation of a circular economy and the increasing pressure of the EU on the environmental aspects of the industry.

The aim of this paper is to assess the consumerist model of behavior in the EU member states based on various indicators in terms of the consumption of mineral raw materials and the utilization rate of materials. The behavior and consumption of critical raw materials were analyzed based on a set of selected indicators.

2. Literature Research

Many authors define energy security as the availability of sufficient supplies for available prices, although they admit that different countries interpret this term in different ways [6–8].

Energy security in Slovakia is defined as a reliable supply of energy and securing approach to energy resources and fuels in sufficient amounts and quality for acceptable prices. The integrated national energy and climate plan of Slovakia and its section dedicated to the energy security mention renewable resources and lignite as the main contemporary domestic resources [9]. Once the support of electricity production from domestic coal ends after 2023, we expect a significant decrease in the mining of lignite. The decarbonization of the Slovak economy will come with increased expenses, which is why its implementation will require the sensitive and gradual replacement of high-emission resources with accessible and cost-efficient low-emission resources [10]. A similar approach to energy is adopted by other coal regions of the EU as well, which are currently on their way through the transformation process or have already completed it (such as the Limburg province in the Netherlands or Lusatia in Germany). The aim is to take advantage of the tradition of the region in the field of energy and to support activities and measures in the transformation process focusing on sustainable, low-carbon energy, as well as measures aiming to reduce the demand for energy in the forms of energy-efficiency projects in various fields and to implement smart energy solutions [11,12].

The transition to a competitive, low-carbon economy means that the EU should prepare to reduce its internal emissions by 80% until 2050, compared to the rates from 1990. The analysis of various scenarios suggests that in terms of cost-efficiency, by 2030, the EU should ideally reduce internal emissions by 40% compared to the rates from 1990 and by 2040, they should aim for 60% reductions. It is believed that once more cost-efficient technologies become available, the efforts will become more intense [13–15].

The EU plan for green transformation is presented in the Fit for 55 package. As a part of the European Green Deal, the EU set out a binding goal to become climate-neutral by 2050 by means of the European Climate Law [16,17]. This means that the contemporary greenhouse gas emissions levels have to decrease substantially over the following decades. To further enhance its ambitions for 2030, the EU has also set out an interim goal toward climate neutrality: to reduce its emissions by at least 55% by 2030. The EU is currently working on the revision of its legislation in the fields of climate, energy and transport as a part of the Fit for 55 package, with the aim to consolidate the applicable regulations with their ambitions for 2030 and 2050 [18].

In the context of raw materials, access to resources and sustainability are the key factors for the resilience of the EU. Achieving resource security requires measures for the diversification of the supply of both primary and secondary resources, for reducing the reliance on resources, for more efficient use and improving the circularity of the resources, including the sustainable design of products. This applies to all raw materials, including basic metals, industrial mineral raw materials, aggregates, and biotic materials, but it is even more necessary in the case of raw materials that are critical for the EU. Securing supplies of raw materials, particularly those determined as critical, is essential for the development of the strategic industrial sector in the EU [19].

Furthermore, there are also new strategies and policies which raise the importance of minerals at the EU level, including the European Green Deal, Industrial Strategy for Europe, EU Regulation on the establishment of a framework to facilitate sustainable investment, and the EU Recovery plan for Europe, but also at a worldwide level, such as the United Nations (UN) Sustainable Development Goals. Since they are an all-inclusive set of policy initiatives dedicated to the energy transition, circular economy, and resource efficiency, they are applied to the management of minerals in order to enable climate neutrality by 2050 [3,16].

The Commission re-evaluates the list of critical raw materials of the EU on a three-year basis. The first list was published in 2011 and updated in 2014 and 2017. The re-evaluation is based on data from recent history and shows how criticality has evolved [20]. The 2020 re-evaluation is based on the same methodology as in 2017 and uses the average for the latest, complete 5-year period for the EU without the United Kingdom (EU-27). It examined 83 materials (5 more than in 2017) and observed (in greater detail than in previous assessments) where criticality appears in the value chain: extraction and processing [21–23]. The criticality of the EU is determined based on two main parameters: economic importance and supply risk. Economic importance focuses on the allocation of raw materials to end-uses based on their industrial applications. Supply risk focuses on the concentration of global production of primary raw materials and sourcing to the EU on the national level, the governance of supplier countries including environmental aspects, the contribution of recycling (i.e., secondary raw materials), substitution, EU import reliance, and trade restrictions in third countries [24].

Compared to the 14 materials in 2011, 20 materials in 2014, and 27 materials in 2017, the 2020 EU list includes 30 materials. A total of 26 materials stay on the list, with bauxite, lithium, titanium, and strontium being added to the list for the first time [25]. Table 1 shows the structure of critical raw materials in the EU.

Table 1. 2020 Structure of Critical Raw Materials (new as compared to 2017 in bold) [25].

Antimony	**Gallium**	**Natural Rubber**	**Tungsten**
Baryte	Germanium	Niobium	Vanadium
Beryllium	Hafnium	Platinum Group Metals	Bauxite
Bismuth	Heavy Rare Earth Elements	Phosphate rock	Lithium
Borate	Light Rare Earth Elements	Phosphorus	Titanium
Cobalt	Indium	Scandium	Strontium
Fluorspar	Magnesium	Silicon metal	
Coking coal	Natural Graphite	Tantalum	

The updated 2020 list of Critical Raw Materials states that for electric vehicle batteries and energy storage, the EU would need up to 18 times more lithium and 5 times more cobalt in 2030 and almost 60 times more lithium and 15 times more cobalt in 2050 [23]. The OECD

(Organization for Economic Co-operation and Development) predicts that global use of minerals will increase by more than double, from 79 billion tons in 2011 to 167 billion tons in 2060. Better recycling, resource efficiency, improved product design, and new materials will help to reduce mineral and metal consumption per capita, but mining of primary resources will still play a vital role in the future when building sustainable societies [26].

The supply of several critical raw materials is substantially concentrated. For example, the EU sources 98% of its rare earth elements (REE) from China, Turkey provides 98% of the EU's supply of borate, and South Africa is the source of 71% of the EU's needs for platinum and an even higher share of the platinum group metals iridium, rhodium, and ruthenium. As to the supply of hafnium and strontium, the EU relies on a single EU company. Comparing the current supply to the whole EU economy, the EU would need up to 18 times more lithium and 5 times more cobalt in 2030 and almost 60 times more lithium and 15 times more cobalt in 2050 for electric vehicle batteries and energy storage. Unless the increase in demand is addressed, it may lead to supply issues. By 2050, the demand for rare earth used in permanent magnets, e.g., for electric vehicles or digital technologies, could be 10 times higher. This should be resolved in the context of growing global demand for raw materials due to population growth, industrialization, decarbonization of transport, energy systems, and other industrial sectors, increasing demand from developing countries, and new technological uses [3,12,27]. The World Bank forecasts that demand for metals and minerals will increase steeply with climate-related ambitions [28,29].

Virtually all scientific papers agree that CRM use is a very topical issue, considering the unfavorable political–economic development in the world and the unstable pricing conditions of mineral raw materials and commodities on the global markets, which means that it is essential to address it in the context of application. The European Union has been extracting, processing, and producing raw materials over the course of its whole existence. Many European mining sites boast modern and optimized mining technologies and resource-efficient production, and yet, the import dependency for many raw materials sourced outside the EU has rapidly increased over the last decades [13,20,27,30]. With the Raw Materials Initiative, which was launched in 2008 and consolidated in 2011 [10,20], the EU made steps to secure the global competitiveness of the manufacturing industries and accelerate the transition to a sustainable and resource-efficient society. The Raw Materials Initiative has the following aims: (i) to ensure a fair and sustainable supply of raw materials from global markets; (ii) to promote a sustainable supply of raw materials within the EU; and (iii) to improve resource efficiency and the supply of "secondary raw materials" by means of recycling [24].

CRMs are one of the main topics for the EU economy. However, the concept of criticality is highly dynamic, which is why the list of CRMs is reviewed on a 3-year basis. The most recent list [8,17] representing the economic importance and associated supply risk is provided in Table 1 and demonstrates that 30 elements or groups of elements are in the critical area as compared to the 14 materials in 2011, 20 materials in 2014 [9], and 27 materials in 2017 [21,22].

3. Materials and Methods

To address this issue, we studied publicly available data from databases developed by the European Union for monitoring the progress of individual countries in the key areas of development for society. The ambition was to assess the contemporary state of raw material management from the perspective of their availability today and in the future, using the above-mentioned sources of information.

After defining critical raw materials, this paper analyzes indicators (described below), which, on the one hand, define the contemporary state of reliance of countries on raw materials and, on the other hand, demonstrate the effort of the individual countries to resolve this situation.

The indicators include:

- the reliance of countries on material imports;

- net additions to stock;
- domestic material consumption DMC;
- resource productivity;
- circular material use rate.

The data were collected by continuously noting the published values of selected variables from the portal at https://ec.europa.eu/eurostat/data/database (accessed on 2 February 2022) for all years and member states available. The collected data were sorted out and modified in a database created in the sheet editor MS Excel based on the requirements of the statistical software JMP; the modified data were transferred into the software and analyzed. Table 2 shows the collected data that present the results of 5 indicators for the period of 1990–2020. The final database comprises 13,053 pieces of data, with each indicator defined for a specific EU member state and a specific year.

Table 2. Structure of the collected data.

Name of the Indicator	Number of Data	Reported Period
Resource productivity	742	2000–2020
Domestic material consumption	832	1990–2020
Circular material use rate	340	2004–2020
Import reliance of countries	4329	1990–2020
Net additions to stock	6810	1990–2020
Total	13,053	1990–2020

Reliance of countries on material imports. This set of data provides the percentage of the ratio of imports (IMP) to direct material inputs (DMI). The term "reliance on material imports" determines the extent to which an economy relies on imports to satisfy its material needs. The reliance on material imports cannot be a negative value or higher than 100%. The values equal to 100% suggest that no domestic extraction took place during the reference year.

We continued with the analysis of indicators of metal ores and non-metallic materials. Next, we analyzed the net additions to stock, which determine the "physical growth of the economy". Materials in the form of structures, infrastructure, and durable goods, such as vehicles, industrial machinery, or domestic appliances, are added to the material stocks of the economy every year (gross additions), and old materials are discarded from the stocks when structures are demolished and durable goods are destroyed (disposal). The approximate value of NAS can be calculated by the following formula:

$$\text{NAS} = \text{DMC-DPO} + \text{BI (input-output)}.$$

To explore the trend of the behavior of EU countries, we analyzed domestic material consumption. DMC indicates the total amount of material actually used on the domestic market by residential units. The DMC of an economy can be calculated as the direct material input minus physical export:

$$\text{DMC} = \text{DMI-EXP}.$$

In general, the DMC of countries is additive. However, this characteristic does not apply to the EW-MFA set of data from Eurostat due to the method of calculating physical trade for the aggregate economy of the EU (see point 18.5 of the metadata).

During the studies, analysis, and the subsequent need to see the consequences, we also focused on the Resource productivity (Env_ac_rp). This data set provides the ratio of the gross domestic product (GDP) and the domestic material consumption (DMC) in various measuring units (see also item 4 of the metadata). The term "Resource productivity" refers to an indicator of the GDP created per a unit of resources used by an economy. It is usually a macro-economic concept, which may be presented along with labor or capital productivity.

The data set "Resource productivity" (Env_ac_rp) employs various units depending on what type of GDP (contemporary price or volume) was used for calculating the ratio:

- "Euro per kilogram" (GDP in normal prices), which is supposed to be used for the analysis of a single country at a single point in time (for a specific year);
- "PPS per kilogram" (GDP in normal prices expressed in purchasing power standards). Purchasing power standards are artificial "currency" units, which remove the differences in the purchasing power, thus eliminating the differences between the price levels in the individual countries, and are used for making comparisons between countries at a single point in time;
- "Chain-linked volumes in EUR per kg from 2015" (GDP in chain-linked volumes normalized to prices from 2015). The volume data show the development of aggregates without inflation; it is used for the comparison of a single country over time (several years);
- "Index, 2000 = 100" (based on the GDP in chain-linked volumes normalized to prices in 2000).

Circular economy and the implementation of the related tasks is a great challenge in modern times. This is why we could not omit the indicator of the circular material use rate. All indicators were processed by software and statistical methods.

4. Results

The first indicator analyzed was reliance on material imports. The visual result is available in Figure 1. Figure 1 illustrates the reliance on the import of raw materials for the EU countries, per individual country. The countries are also reliant on certain types of raw materials. Countries rely the most on metal ores, including critical raw materials, see Table 1. The second substantial category reliant on imports is traditional fossil energy materials.

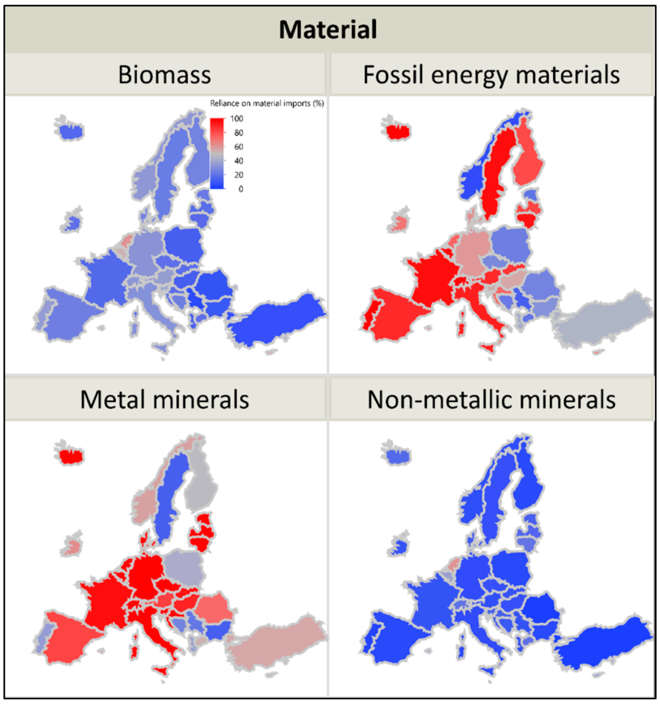

Figure 1. Cartographer-dependence on material imports (%) by type of material.

The results will concentrate mostly on metal ores, and other materials will only be used for the sake of clarification. Critical raw materials are utilized, especially in the chemical, metallurgic, textile, electrical engineering, and heavy industries.

Import reliance results from the combination of non-existent deposits in a region and the high consumption of the material. Nowadays, it also depends on what materials are trendy in technology and what materials are preferred in the individual industries. The reliance on their import is present in all EU countries. Figure 2 shows the consumption of metal ores in EU countries over time.

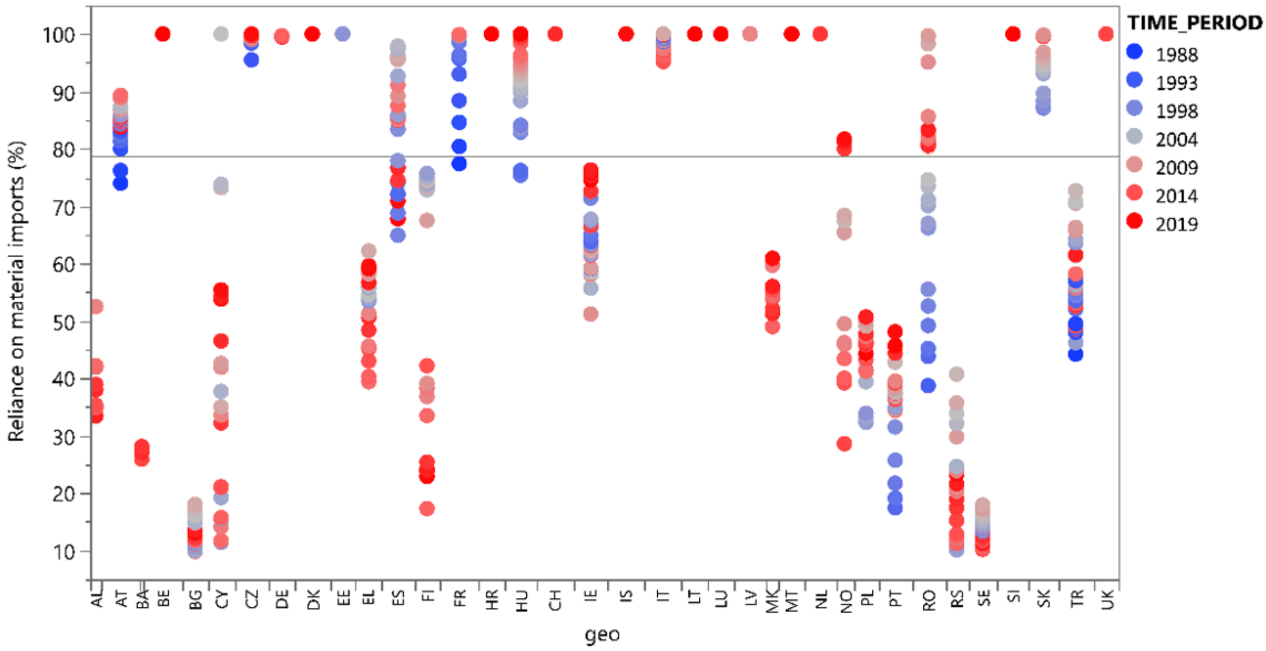

Figure 2. Dependence on metal ore imports (%) in EU countries for the years 1988–2019.

The chart of correlation between the metal ore consumption and time indicates an increasing trend. None of the EU countries is reducing its consumption. The maximum consumption of countries such as Latvia, Luxembourg, Lithuania, Slovakia, Germany, and Denmark was in 2019.

Until then, metals do not exhibit any consumption in these countries. This is possibly due to implementing new technology into a certain industry or a new technological trend, the changing structure of the industry, and the development of industries depending on critical raw materials, such as metal ores in this case. The source material does not provide data before this period, meaning they are not available.

If we look at non-metallic materials and their correlation for the EU countries, there is a considerably more balanced trend of consumption over time. This is due to the traditional processing method and the use of these materials in the industry and the economy, see Figure 3.

Nowadays, EU countries are reporting an increase in the consumption of both metallic and non-metallic materials. This is caused by the growth of the EU economy, the living standard of people in EU countries, and the resulting increase in the consumption of materials and goods.

This assumption may be supported by the analysis of net additions to stock, which indicate the physical growth of the economy, see Figure 4.

Figure 4 shows the observed period from 1988 to 2018, with significant differences in the developmental trend of the individual member states. Finland and Sweden have the most striking growth. In the case of Iceland, this indicator exhibits a significant decrease. The average increment for the EU is approximately 11 units. The substantial variability in values proves the differences in the levels of economies of the individual countries, which may also have an impact on the use of raw materials.

Countries should aim to reduce their domestic material consumption and increase their resource productivity and circular use of materials in the spirit of resource efficiency. The effort to reduce domestic material consumption puts more pressure on implementing new technologies with the maximum use of raw materials.

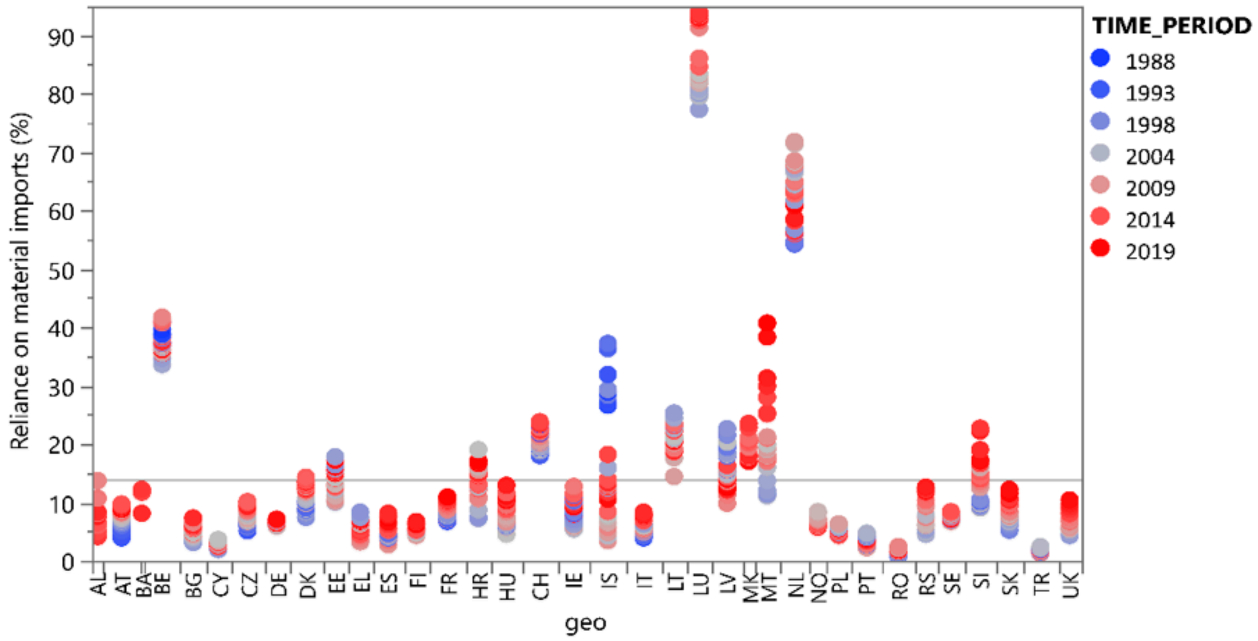

Figure 3. Dependence on non-metallic materials imports (%) in EU countries for the years 1988–2019.

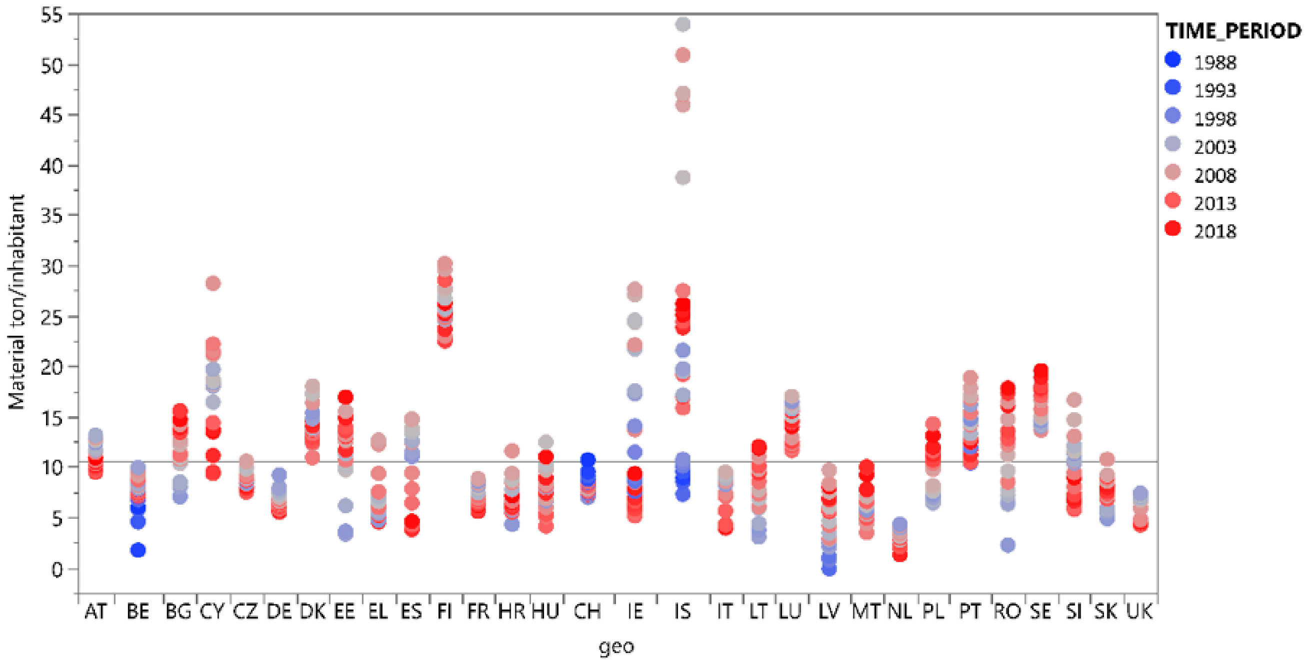

Figure 4. Net additions to stocks comparison countries, 1988–2018.

Domestic material consumption indicates the total amount of material actually used on the domestic market by residential areas, see Figure 5. The consumption rates of the individual countries range from 3.5–60 t/per capita, which is a rather wide range. The mean value for the EU is 17 t/per capita. Most states successfully reduce their consumption, which is positive, but the results equally show that there are also countries with the opposite trend, including EE, SE, RO, BG, LT, and NO.

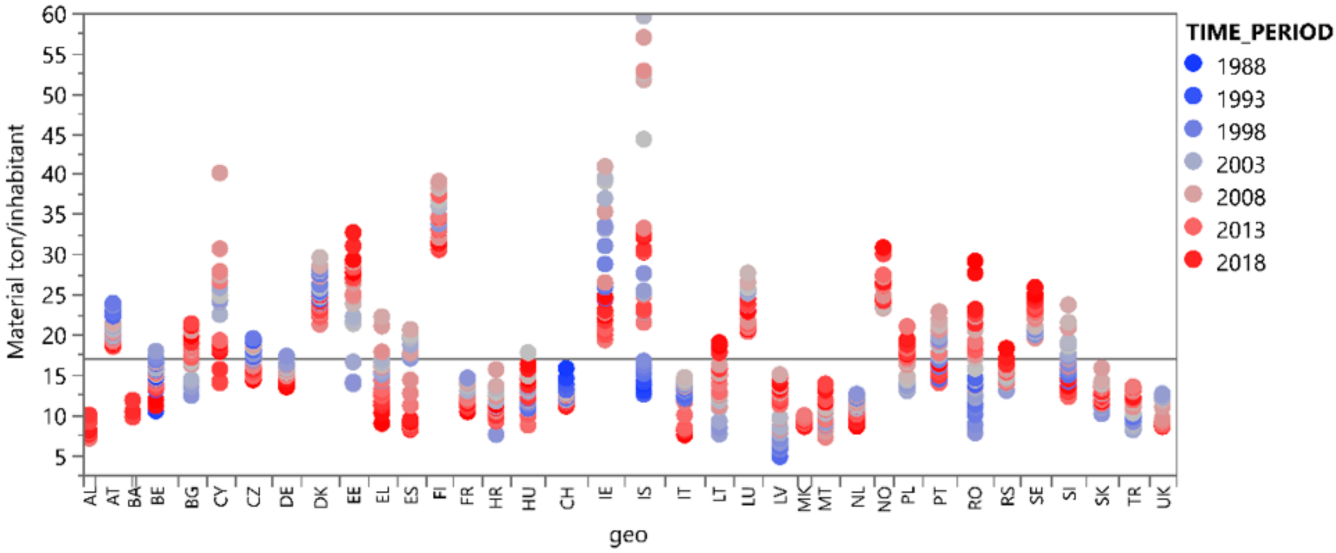

Figure 5. Domestic material consumption in EU countries in the years 1988–2018.

A possible solution for the efficient use of critical raw materials could be to decrease consumption and use as much as possible. These indicators illustrate the possibility of the efficient use of resources, including critical raw materials.

Using as much as possible means maximizing resource productivity. We examined this indicator, and Figure 6 clearly shows that the resource productivity in the EU is on the rise, which proves that countries are aware of the importance of the efficient use of inputs. However, after detailed scrutiny, we found out that the level of resource productivity differs between the individual countries; still, the unified trend of increasing this indicator is a positive sign (see Figure 7).

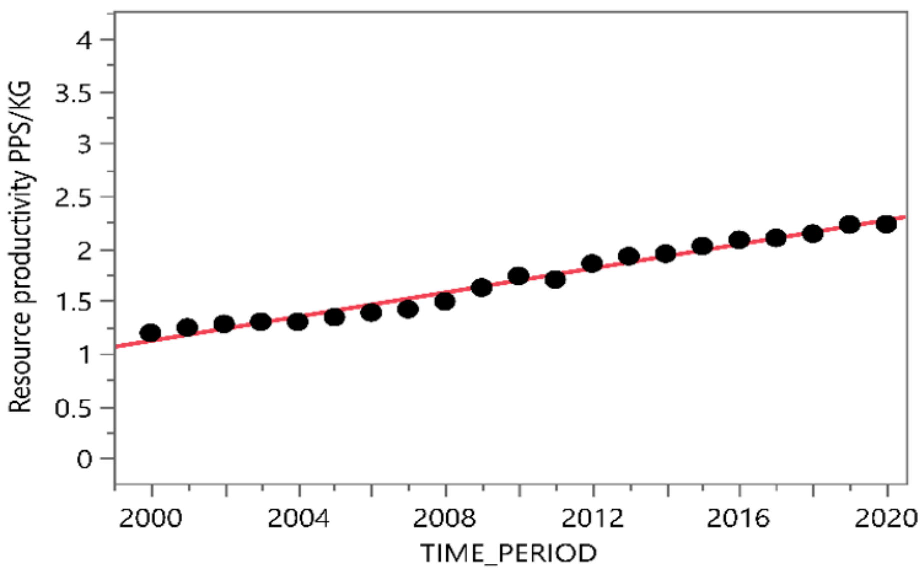

Figure 6. Resource productivity for the EU 28 in summary.

The circular material use rate must be observed from the perspective of the challenge in the circular economy, which recycles, reduces the consumption of materials, and increases resource productivity. The results are illustrated in Figure 8.

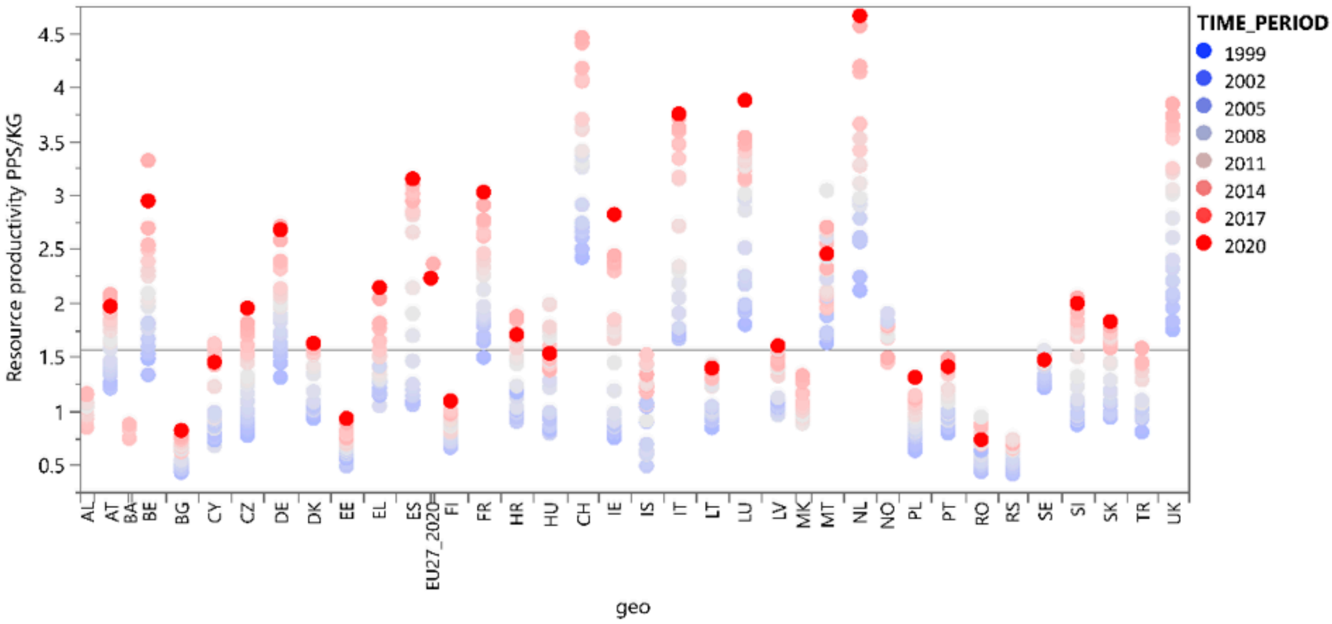

Figure 7. Resource productivity comparison of countries in the years 1999–2020.

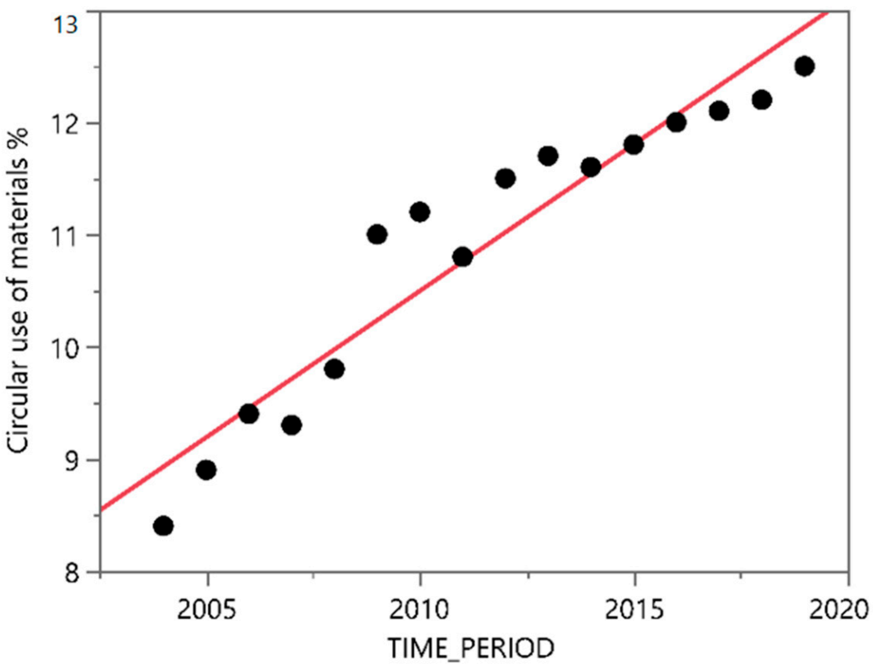

Figure 8. Material circulation rate in the EU, 2003–2020.

Fortunately, just as in the case of resource productivity, member states are enhancing their circular use of materials, thus contributing to the efficient use of raw materials. The circular material use rate in the EU has a rising trend, which is clearly shown in Figure 9.

This section may be divided into subheadings. It should provide a concise and precise description of the experimental results, their interpretation, and the experimental conclusions that can be drawn.

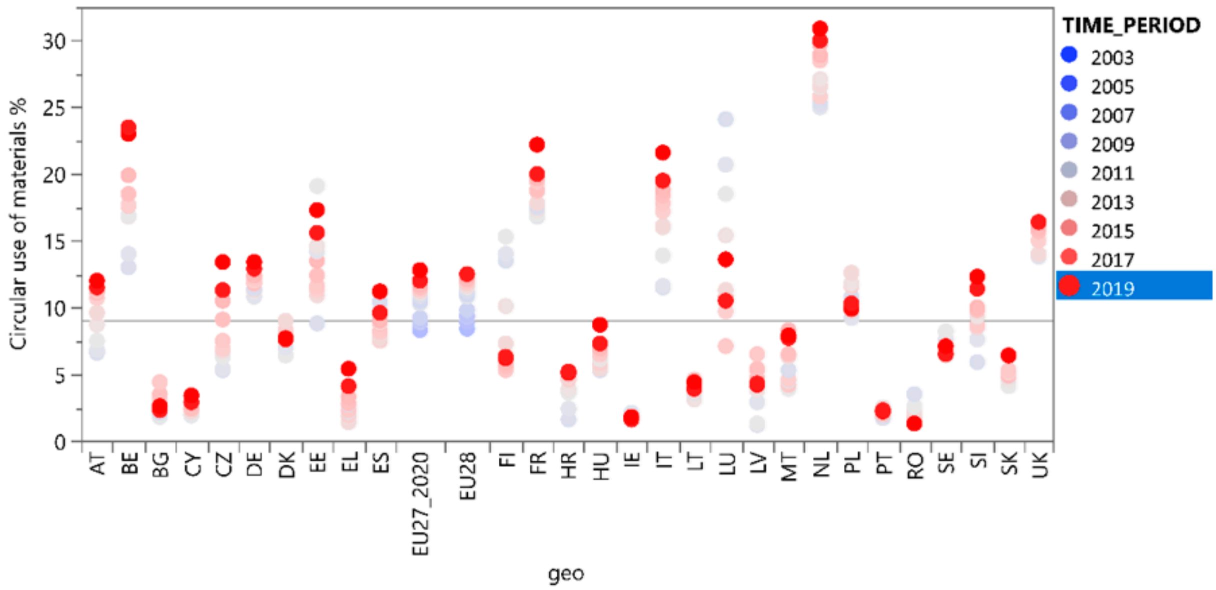

Figure 9. Material circulation rate comparison of countries, 2003–2019.

5. Discussion

The article assesses the consumerist model of behavior in EU member states based on various indicators in terms of the consumption of mineral raw materials and the utilization rate of materials. By using selected indicators, we studied the behavior and consumption of critical raw materials, but an issue that is still to be dealt with is the increasing consumption of mineral raw materials. The assessment of critical raw materials is even more difficult due to several variables that countries using CRMs cannot substantially influence, such as the price, which depends on the political–economic negotiations and development. Furthermore, the direction that the world is heading towards fails to solve problems stemming from the use of CRMs.

This includes extraction in third countries, which cannot be secured socially, economically, or ecologically. The transportation of materials through enormous distances places a burden on our planet and the unbearable use of mineral raw materials to their complete exhaustion poses a questions of how to move on in terms of energy, policies, and economy, where we stand now, how to transition from fossil fuels to new energy sources, and what new technologies we should use. The issue of fossil fuels moved to new mineral raw materials, including CRMs, which utilize new technologies, but the problem of excessive consumption and the lack of solutions to socio-economic problems associated with extraction and use of mineral raw materials remains unsolved.

Based on the above-mentioned circumstances, we examined indicators which are directly and indirectly associated with economic factors. Both metallic and non-metallic materials have an increasing trend of consumption over time. The reason is the growth of all EU economies and the continuous rise in the consumption of materials.

Net additions to stock are an indicator of the physical growth of an economy. Materials used for building structures, modern infrastructure, and durable goods (cars, industrial machinery, household appliances, portable devices) are added to the materials stocks of the economy every year.

This variable indirectly indicates the rise in raw material consumption. The analysis shows that the highest additions to stock are in Sweden and Finland, with Iceland having a decreasing trend in the additions to stock. Changes in the domestic consumption of different countries are never the same. Some countries decrease their consumption (Iceland, Denmark, Greece, etc.), while other countries (Romania, Lithuania, Estonia, and others) keep increasing their consumption.

The efficient use of critical raw materials may possibly be achieved in the future by decreasing consumption and using raw material sources to their maximum potential. Fortunately, the resource utilization rate indicator marks an increasing trend. This means that countries are aware of the importance of implementing a circular economy in businesses, towns, and regions. The results are supported by the analysis of our indicators: the rate of material circulation and resource productivity.

6. Conclusions

The European Union is a major player in the fight against global climate change and together, we are trying to secure a strong economic growth along with decreasing the number of emissions, with the biggest burden being the extraction of coal and its use as a source of energy.

The European Commission has temporarily included natural gas and nuclear energy among clean energy sources, which not all EU member states agree with. The individual EU member states will decide on their own what resources they will use. The common objective of all EU member states is to reduce carbon emissions and secure the transition to climate neutrality by 2050. Decisions adopted by the member states must be in line with this common objective. Renewable sources of energy lead to lower energy prices and lower reliance on energy supplies. To reduce the reliance of the EU on natural gas from Russia, the transition to renewable energy sources must accelerate. All of this is the primary common objective of the EU. The EU is committed to achieving carbon neutrality by 2050, which is why it is making an effort to scale down the use of fossil fuels and close coal mines. This has a considerable impact on people's lives as well as the local economy. The EU has undertaken objectives to help mitigate the impact of the economic transformation of mining regions. In 2018, the EC launched an initiative for sustainable funding. By doing so, it reacted to the goals of the European Green Deal, which is supposed to ensure Europe becomes the first climate-neutral continent in the world by 2050. It proposed a plan on how to shift the financial sector on the path toward carbon neutrality, and, in 2021, it presented the Strategy of Financing the Transition to a Sustainable Economy [31].

In March 2020, the European Commission proposed to the European Parliament "A New Industrial Strategy for Europe", with the aim to reinforce the open strategic autonomy of Europe by warning that the transition of the European industry toward climate neutrality could replace the current reliance on fossil fuels with reliance on raw materials. The communication states that the open strategic autonomy in the EU in these sectors will need to be anchored in diversified and undistorted access to global commodity markets, but at the same time, that in order to minimize external reliance and environmental pressures, it is necessary to solve the fundamental problem of the rapidly increasing demand for global resources by reducing and reusing materials prior to their recycling [32].

This is why we believe it is necessary to observe the behavior of countries and react not only by providing a sufficient amount of raw materials but also by reducing the material consumption of EU countries. It is crucial to make an effort to maximize the use of materials and to apply innovations which will support this process.

Another way to reduce the reliance on critical raw materials is to substitute them with non-critical raw materials of similar performance. Innovations in the field of resources, sustainable design, and the development of alternative technologies using different raw materials may also help reduce the risk of endangering supply.

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