

## CRITICAL RAW MATERIALS AS A PART OF SUSTAINABLE DEVELOPMENT

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### **Abstract**

*The presented article deals with the issue of critical raw materials in the European Union with an emphasis on sustainable development and also barite, as an only one critical raw material mined in Slovakia. The article points out in detail the deposits of individual critical raw materials within the European Union. They clearly profile the European area's dependence on imports of critical raw materials in accordance with the Communication from the Commission to the Council, the European Economic and Social Committee and the Committee of the Regions on the European Union's list of critical raw materials. Based on a defined Herfindahl-Hirschman index, which is clearly methodologically described, the article also points to the exploitation of critical raw materials in the European Union, what is in consideration of sustainable development crucial because some inventions are fundamentally dependent on them, as is their production on world markets. This article deals with critical raw materials in the EU, because it is in this area that we would like to experience the 4th industrial revolution, which is characterized by "new products" with a short life cycle, products with the least possible impact on the environment, i.e. innovations that are often impossible without important raw materials. Is it at all possible to talk about sustainable development with such raw material sources in European Union?*

**Keywords:** *critical raw materials, sustainable development, circular economy, barite, European Union*

### **1. Introduction**

Sustainability became very famous topic recently, also in the conjunction with mining (Njuaem, Ogundare, 2021). Due to globalization and the changing in mining industry, which is characterized by aggressive competition and rapidly changing machine-technological development, the development of the market environment is changing and depending on global or local demand for the exploited raw materials (Kusurgasheva et al., 2017). Mining companies therefore focus on the exploitation of raw

materials with a higher rate of profitability, which also includes critical raw materials, which are an integral part of sustainable development (Mancini et al., 2019). Based on valid information on market demand for the exploitation of critical raw materials, mining companies can build and maintain their market share and become sufficiently competitive in the local or supra-regional mining market with the help of theoretical analyzes within their business plans (Rybár et al., 2000).

In order to the above facts, it should be noted that the critical raw materials could be considered as those mineral resources, which means a high economic importance for the functioning of the economy, with the risk of interruption of their supply (EC, 2014). These are also key elements of the 4 Industrial Revolution that the EU places particular emphasis on, because the realization of a climate-neutral digital economy and a "stronger Europe" depending on available, affordable and responsibly sourced raw materials, especially critical ones (Bobba et al., 2020). Their extraction can also cause negative environmental impacts, which makes it clear that their critical economic importance also determines environmental policy (Khouri et al., 2018), what is key according the definition and functioning of the sustainable development, where arise an interconnection because the economy depends on society and the environment while human existence and society are dependent on, and within the environment (Giddings, 2002).

During the years, a draft methodology for determining the "criticality level" of minerals was developed (Dewulf, 2016) and three types of risks have been identified:

- Import risk - if raw materials are imported from a politically unstable region or from a country where a market economy is not functioning.
- Production risk - within the EU, with potential problems such as ground access.
- Environmental risk - based on indicators such as air or soil pollution, where the impact of the use of raw materials is measured from an environmental point of view (EC, 2017).

The result of the summarization of three types of indicators is risk determination, while the key factor is mainly whether the raw material can be easily replaced. The fact that the criticality of raw materials and sustainable development are closely related is also evidenced by the main historical milestones:

- May 2009: Industry ministers supported draft strategy and called for EU "diplomatic" approach to minerals, and ask Commission to propose list of critical raw materials (further only CRM), as a reaction to defining a strategic goal within the Lisbon strategy to become "capable of sustainable economic growth with more and better jobs and greater social cohesion, and respect for the environment".
- June 2009: EU and USA in cooperation sued China against World Trade Organization over restrictions on industrial mineral exports.
- November 2009: an EU expert group started preparing a list of potentially critical minerals (KOM, 2008), while raw materials are essential for the sustainable functioning of modern societies.
- 17 June 2010: The Commission presented the final report on critical minerals called 'Critical raw materials for the EU' where was also suggested that the list of critical raw materials should be updated every three years. Accordingly, in its Communication 'Tackling the challenges in commodity markets and on raw materials', the Commission committed to undertake a regular update of the list at least every three years (COM, 2020).
- 12th-13th July 2010: At the initiative of the Belgian Presidency, environment ministers discussed about the sustainable raw material management.

- 26 January 2011: The Commission presented one of the flagship initiatives of the Europe 2020 strategy for resource efficiency in Europe. At the same year the Commission adopted a plan for minerals markets.
- 22 April 2011: deadline for participation in the Commission's consultation on the preparation of a roadmap for resource efficiency in Europe.
- June 2011: Commission adopted plan for a resource-efficient Europe to strenght synergies between existing policies and the transition to a resource-efficient economy (Gislev, Grohol, 2018).
- 2015: the European Commission adopted its first circular economy action plan as a new support tool for sustainability. At the same time the 2030 Agenda for Sustainable Development with its 17 SDGs was adopted at the UN Sustainable Development Summit in New York in September 2015 (Hák et al., 2016).
- 2019: The EU Green Deal Communication was adopted, to recognize access to resources as a strategic security question to fulfil its ambition towards 2050 climate neutrality and increasing our climate ambition for 2030 (EC, 2020).

## 2. Critical Raw Materials in the area of European Union

The methodology of CRMs identification for the EU is based on the updated methodology developed by the European Commission, in cooperation with the Ad hoc Working Group on Defining Critical Raw Materials. Based on the methodology used in the previous assessments carried out in 2011 and 2014 DG GROW commissioned the DG Joint Research Centre in 2015 to undertake a study on improving the assessment methodology used to define critical raw materials for the EU. This study resulted in a refined methodology for assessing the criticality of raw materials, which is applied in the present assessment. The revised EC methodology introduced methodological improvements while keeping maximum possible comparability of the results with the previous assessments. The two main high-level components of criticality are retained. First is Economic Importance calculated based on the importance of a given material in the EU end-use applications and performance of its substitutes in these applications. Second is Supply Risk calculated based on factors that measure the risk of a disruption in supply of a given material (e.g. supply mix and import reliance, governance performance measured by the World Governance Indicators, trade restrictions and agreements etc.) (Blengini et al., 2017). The list of critical raw materials has changed over time due to evaluation criteria (Table 1).

In the beginning from 2008-2011, when only the initial testing phase of the list was taking, 14 CRMs were identified. Subsequently, in 2014, 6 new CRMs were added, the number of them increased to 20. During the review in 2017, the list was adjusted to a total of 26 CMRs, while 9 new raw materials were added, but 3 were dropped from the list. This also indicates that the evaluation criteria are gradually changing and improving, with the list being reviewed every 3 years, as it was declared by the Commission in 2010 ([rmis.jrc.ec.europa.eu](http://rmis.jrc.ec.europa.eu)). During the last review in 2020, the list was adjusted to a total of 30 CMRs, while only helium dropped out of the list (EC, 2020).

Also in Slovakia, several larger or smaller deposits occurrence of CRMs were identified. However, most of them are not currently mined. In 2014, when magnesite was still on the CRM list, we were literally one of the most famous with deposits in Jelšava. Another raw material in our territory is anti-mony, which is used mainly in the military industry. But as the military industry declined in the 1990s and these plants were largely closed, so it did not needed. Deposits in Dúbrava or Pezinok have closed. Slovakia also has deposits of cobalt and graphite, but the only currently mined critical raw material is barite in Spišská Nová Ves (Šoltés et al., 2020).

Table 1. Overview of CRMs in relation to individual years of their assessment

Critical Raw Materials during the years 2011 – 2020			
CRM in 2011 (Total 14CRMs)		Antimony	Antimony
		Beryllium	Beryllium
		Cobalt	Borates
		Fluorspar	Chromium
		Gallium	Cobalt
		Germanium	Cooking coal
		Graphite	Fluorspar
		Indium	Gallium
		Magnesium	Germanium
		Niobium	Graphite (natural)
		Platinum group metals	Indium
		Rare earths	Magnesium
		Tantalum	Magnesite
		Tungsten	Nickel
CRM in 2014 + 6 news (Total 20CRMs)	Dropped out of the list: Niobium, Tantalum		Platinum group metals
			Phosphate rock
			Heavy rare earth elements
			Light rare earth elements
			Silicon metal
			Tungsten
			Barite
			Bismuth
			Hafnium
			Helium
CRM in 2017 + 9 news (Total 27 CRMs)	Dropped out of the list: Nickel, Magnesite, Chromium		Phosphorus
			Natural Rubber
			Niobium
			Scandium
			Tantalum
			Vanadium
			Bauxite
			Lithium
			Titanium
			Strontium
CRM in 2020 + 4 news (Total 30 CRMs)	Dropped out of the list: Helium		

Source: own processing based on EC, 2020

## 2.1. General characteristics of barite in the European Union

Barite ( $\text{BaSO}_4$ ) is a white to off-white mineral with an approximate weight of  $4.3 - 4.7 \text{ t.m}^{-3}$ , it often contains impurities Sr and Ca, rarely Pb and Ra. Different coloring of barite indicates contamination by Fe oxides, clay or organic impurities. The use of barite is conditioned by its high specific gravity, chemical inertness, high whiteness and ability to absorb X-rays. The crucial component of barite is barium (Ba), which binds to feldspar and mica of acidic and alkaline effluents. Barium-containing minerals are relatively few and rare (witherite, baritecelestine, sanborite). In hydrothermal veins, barite often occurs in association with polymetallic metal minerals (Pb, Zn, Cu sulfides), pyrite and fluorite.

Barite is mainly used for heavy draining in oil and gas wells (2/3 of world production), for the production of glazes, enamels, paints, plastics and is part of poisons on rodents and insects (www.crmalliance.eu). Barite is also used in glassmaking, pyrotechnics (manufacture of signal rockets, detonators) and construction (part of protective coatings and plasters against X-rays and radioactive radiation). Based on the available geological data, we found out that 6 deposits in the territory of the Slovak Republic with total reserves of 12 562kt as of 2015 are registered, while the given deposits are located in the districts of Spišská Nová Ves, Revúca and Gelnica (Šoltés et al., 2020).

The exploitation of barite in Slovak Republic showed a fluctuating development trend, with the highest mining in 2007 and the lowest in 2011. The barite deposit in Rudňany was one of the most important exploited barite deposits in the Slovak Republic where intensively mined until 1993. At present, there is only limited mining of residual barite reserves, which is carried out by SABAR, p. r. in Spišská Nová Ves (Števko et al., 2019). We have exported it from Slovakia mainly to Czech Republic, Poland and Bulgaria (Šoltés et al., 2020). Barite is also mined in Bulgaria, Germany, Great Britain and Italy (Table 2) (Reichl et al., 2008-2018).

**Table 2.** An overview of the extraction of individual CRMs within the EU

CRM t/year	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
<b>Austria</b>											
Graphite	250	750	420	925	219	200	150	150	150	150	150
Tungsten	1122	887	977	861	706	850	819	861	954	975	936
<b>Belgium</b>											
Indium						30	25	20	20	20	20
<b>Bulgaria</b>											
Barite					0	1000	20000	60000	50000	64000	70000
Fluorspar					69700	82500	130800	131900	4400	0	0
<b>Croatia</b>											
	None CRM										
<b>Cyprus</b>											
	None CRM										
<b>Denmark</b>											
	None CRM										
<b>Czech</b>											
	None CRM										
<b>Estonia</b>											
	None CRM										
<b>Finland</b>											
Cobalt	100	27	140	140	1381	2061	2104	2119	2260	2300	1377
Germanium			12	12	16	17	17	13	0	0	0
Phosphates	280800	237000	294200	313100	308900	315800	340640	344360	338230	352300	356070
<b>France</b>											
Indium						33	43	41	0	30	43
<b>Germany</b>											
Indium						10	10	10	10	10	0
Gallium						38	16	11	4	0	0
Barite	78941	45606	55887	55342	52030	45446	87575	68297	49373	34177	39218
Fluorspar	48519	49962	59086	65619	54202	48744	58100	57741	52552	45375	49197
Graphite					109	269	517	398	502	422	222
<b>Greece</b>											
	None CRM										
<b>Hungary</b>											
Gallium	5	3	4	5	4	2	2	0	0	0	0
<b>Ireland</b>											
	None CRM										
<b>Italy</b>											
Indium						5	5	5	5	5	5
Barite	3500	3500	3500	3500	3500	0	0	0	0	-	-
<b>Lithuania</b>											
	None CRM										
<b>Malta</b>											
	None CRM										
<b>Netherlands</b>											
	None CRM										
<b>Norway</b>											
Graphite	4100	4562	6000	7789	6992	6207	8308	9185	9600	9600	10000

Poland	None CRM										
<b>Portugal</b>											
Tungsten	983	823	799	819	763	692	671	474	549	669	716
<b>Romania</b>											
Graphite	0	24352	6633	7000	7000	0	0	0	0	-	-
<b>Slovakia</b>											
Barite	20000	30000	22000	15700	21000	21000	20900	20000	23000	15700	11100
<b>Slovenia</b>											
None CRM											
<b>Spain</b>											
Tungsten	154	225	240	337	393	487	822	835	699	564	730
Fluorspar	148763	122408	123562	109284	101000	96810	120582	130647	130131	125870	110000
<b>Sweden</b>											
Graphite							0	295	0	0	-
<b>Great Britain</b>											
Tungsten							0	155	732	1086	890
Barite	43000	36000	34099	31000	30000	30000	44000	50000	56000	56000	55000
Fluorspar	36801	18536	26420	0	0	16000	25000	17000	12000	12000	11000

Source: own processing based on World Mining Data (overview was not prepared based on the List of CRMs 2020)

### 3. Materials and Methods

Available data from the World Mining Data database were used to evaluate the current situation with critical raw materials mined in the EU area. It is a database that has been processing data on 63 Minerals under review since 2013. The raw materials included in this reports are arranged in five groups – iron and ferro-alloy metals, non-ferrous metals, precious metals, industrial minerals, mineral fuels. What is very interesting as well as critical from the view of European Union about the raw materials are facts which can be seen from the database, that more than 50 % of world production is only from 3 countries if we are taking into account 50 Minerals from database. Situation is more critical if we are looking for 29 Minerals when more than 75 % of world production is from 3 countries, because within 28 Minerals is leading producer China. Database World Mining Data also evaluate 36 Minerals from the view of high concentration in the market (HHI), as well as it also focuses its interest on year-to-year development of CRMs (Reichl et al., 2008-2018).

For closer interpretation of CMRs and their development at market was used the Herfindahl-Hirschman Index (HHI), which was also processed on the basis of World Mining Database. It is a commonly accepted and used measure of market concentration. The HHI shows the concentration on the market taking into account the number of enterprises in the market with a particular CRM as well as their market share. The HHI could be between 1 and 10.000. The value of this index is calculated as the sum of the squares of the market shares of all the analyzed enterprises. HHI is calculated based on formula, where  $n$  is a number of enterprises a  $r_i$  is a market share of the  $i$ -th enterprise. HHI index is calculated from formula:

$$HHI = \sum_{i=1}^n (ir)^2 \quad (1)$$

For example when 1 enterprise with 100 % share on the market, HHI index can be calculated as:  $HHI = 100^2 = 10.000$ . When there are on market 5 enterprises each with 20 % share on the market, HHI index is calculated as  $HHI = 20^2 + 20^2 + 20^2 + 20^2 + 20^2 = 2.000$ .

HHI:	< 1.000	low market concentration
HHI:	1.000...2.000	moderate market concentration (in USA is limit value 1800)
HHI:	2.000...10.000	high market concentration

The HHI takes into account the relative size and distribution of the enterprises in a market and approaches zero when a market consists of a large number of firms of relatively equal size. The HHI increases both as the number of enterprises in the market decreases and as the disparity in size between those enterprises increases (Brezina et al., 2009). Within our analyses were monitored the concentration of producer countries which is calculated by the HHI similarly to the enterprises index.

#### 4. Results and Discussion

If we are looking on the development of the Herfindahl-Hirschman index (HHI index) of concentration of producer countries within analyzed CRMs mined in EU area, we see that in the analyzed years 2011 to 2018, in most cases there was a significant decline in competition in the world markets (Figure 1 and Table 3). It can be said that the concentration has increased over the years. This is also evidenced by the development of the HHI index, which rose from 4128 to 7985 within Germanium. In 2016, the HHI index reached its maximum value of 8163 and in recent years has remained at approximately the same level. In the last analyzed year, the HHI index reached 7985, which suggests that the concentration of producer countries with Germanium can be considered as a high market concentration what is not positive factor in relation to sustainable development of EU.

An interesting course of the HHI index shows a more closely examined barite where it is possible to state also a high market concentration within the analyzed years. However, if we are talking about the development of the HHI index within barite, we can observe a slight year-on-year decrease of concentration of producer countries, as evidenced by the value of the HHI index, which fluctuated between 2688 at that time and fell to 1832, indicating increasing competition with a given critical raw material. At the end of the observed period in 2018, it is already possible to speak about the moderate market concentration. The following table (Table 4) confirms the observed facts, which shows the concentration of analyzed CRMs within individual countries, especially outside the EU, and the EU's strong dependence on imports of these strategic raw materials.

*Table 3. Overview of the HHI index of individual CRMs extracted within the EU*

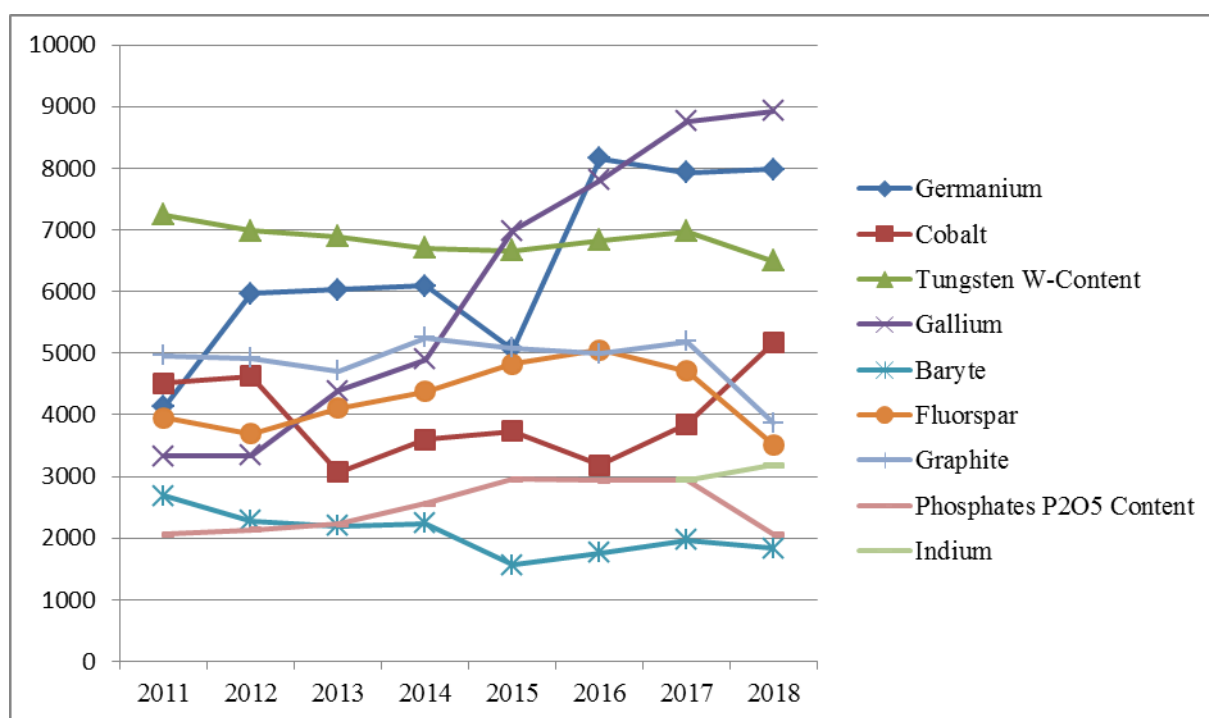
CRM of EU	Concentration of the Market (HHI index)							
	2011	2012	2013	2014	2015	2016	2017	2018
<b>Germanium</b>	4128	5966	6026	6090	5069	8163	7928	7985
<b>Cobalt</b>	4515	4632	3067	3599	3732	3184	3845	5169
<b>Tungsten W-content</b>	7244	6986	6889	6709	6661	6828	6971	6494
<b>Gallium</b>	3326	3339	4386	4901	6985	7811	8764	8925
<b>Barite</b>	<b>2688</b>	<b>2279</b>	<b>2193</b>	<b>2244</b>	<b>1559</b>	<b>1762</b>	<b>1973</b>	<b>1832</b>
<b>Fluorspar</b>	3950	3691	4110	4383	4821	5054	4706	3515
<b>Graphite</b>	4964	4924	4710	5256	5082	4990	5187	3868
<b>Phosphates</b>	2065	2137	2232	2562	2956	2932	2941	2063
<b>Indium</b>							2941	3182

Source: own processing based on World Mining Data

In this case, however, there is concentration of producer countries with germanium based on HHI high, what brings decline competition what means occurrence of analyzed critical raw materials only

in a very small number of countries. Given that these are extremely important raw materials, this may mean dictating prices from the producer country and creating instability in the CRMS market. If we talk specifically about Germanium, it is a strategic CRM, especially as additional material consumption for photovoltaics in renewables, digital technologies, as well as for in unmanned vehicles (drones). Almost all production of Germanium is concentrated in China.

The markets with other CRMs also show a very similar increase in the degree of concentration, and thus a decrease in the level of competition, which is confirmed by the growing value of the HHI index in the period 2011 to 2018. Based on the Herfindahl-Hirschman index, these markets in the analyzed years can be considered as a high market concentration. If we monitor the development of the HHI index within phosphates, we can observe a substantially stable development of concentration of producer countries, as evidenced by the value of the HHI index, which fluctuated between 2063 and 2956 in that period, reaching its minimum at the end of the period.



**Figure 1.** Year-on-year development of the HHI index on world CRM markets.

Source: own processing based on World Mining Data

An overview of the development and extraction of individual CRMs in individual countries around the world is also interesting (Table 4). If we are talking about Germanium, for example, in the years 2011-2015, 16.25 % of this raw material was mined in Finland. In the following years, however, mining is not mentioned further at all. Other changes also took place in cobalt mining, where Russia achieved world leadership, significantly ahead of China year-on-year. In terms of Tungsten mining, Vietnam has overtaken Canada, and the UK reporting mining only since 2015. In Gallium mining, Russia has overtaken Kazakhstan, while the share within the EU has fallen sharply, with countries such as Hungary fallen out. Baryte disappeared from the statistics completely year-on-year in countries



such as Germany and Italy. In Graphite mining, the first ranks were occupied by Mozambique, which overtook India in mining. Indium has completely dropped out of Germany in recent years. Even in this assessment, the criticality is growing and EU countries are gradually losing their share of mining, making them increasingly dependent on the rest of the world.

**Table 4.** Overview of other important variables of individual CRMs extracted within the EU

CRM of EU	Production t/year	Share of 3 world Producers (%)	The 3 biggest Producer countries	Share of EU	Countries of EU (not only partners)	Degree of dependence on imports	Substitutability indices SIEI/SR	End-of-life recycling rate
<b>Germanium</b>	101	97,03	China, Russia, USA	0,99 %	Ukraine	64 %	1,0 / 1,0	2 %
<b>Cobalt</b>	156.483	78,38	Congo D.R., Russia, Canada	0,88 %	Finland	32 %	1,0 / 1,0	0 %
<b>Tungsten W-content</b>	81386	88,97	China, Russia, Vietnam	2,87 %	UK, Spain, Portugal	44 %	0,94 / 0,97	42 %
<b>Gallium</b>	323	98,15	China, Russia, Ukraine	1,86 %	Ukraine	34 %	0,95 / 0,96	0 %
<b>Barite</b>	<b>9207032</b>	<b>64,08</b>	<b>China, India, Morocco</b>	<b>1,48 %</b>	<b>SR, Bulgaria, UK</b>	<b>80 %</b>	<b>0,93 / 0,94</b>	<b>1 %</b>
<b>Fluorspar</b>	6 857 413	87,71	China, Mexico, Mongolia	2,48 %	Spain, Germany, UK	70 %	0,98 / 0,97	1 %
<b>Graphite</b>	1047048	79,35	China, Mozambique, Brazil	2,42 %	Ukraine, Norway, Germany, Austria	99 %	0,95 / 0,97	3 %
<b>Phosphates</b>	72 111 340	65,32	China, USA, Morocco	0,49 %	Finland	88 %	1,0 / 1,0	17 %
<b>Indium</b>	835	83,83	China, South Korea, Japan	8,15 %	France, Belgium, Italy	0 %	0,94 / 0,97	0 %

Source: own processing based on World Mining Data

## 5. Summary

Due to the rising standard of living of the population and the development of the market, increasing demand for tangible goods, the mining industry is increasingly focused on the exploitation of such minerals, which ultimately participate and are irreplaceable in the technological production of final goods. For this reason, specific minerals in the process of mining becoming irreplaceable within the

market to the extent criticality. Critical raw materials have been defined among the exploited raw materials due to high market demand and at the same time their small supply. Deposits of clearly specified critical raw materials are found only in certain territorial areas of global trade and are therefore economically important for the competitiveness of certain countries. In order to this issue, the mining industry has started to deal with deposits of critical raw materials, which are not yet exploited and create usable potential for future market demand.

As can be seen, raw materials are an indispensable condition and component for achieving sustainable development and achieving the 17 goals of sustainable development, as its main priorities include areas such as prosperous economies, regional and global stability, fair and resilient societies and others. This is also evidenced by all historical milestones and steps towards raw materials that go hand in hand with sustainable development and efficient as well as prudent use of resources. This is evidenced in particular by the current extremely “in” trend and the new economic instrument in the EU - Circular economy, which is a support tool for achieving selected goals of sustainable development - Agenda 2030.

At the same time, the creation of many Alliances, we will mention only a few - the European Alliance for Minerals (ERMA), EIT Raw Materials: the EU's knowledge-based raw materials innovation community, or the Action Plan on Critical Raw Materials, which seek to reduce EU countries' dependence on raw material imports. As can be seen from the analysis, it is a paradox how the EU wants to move forward in the context of sustainable development and on the other side is essentially dependent on imports of raw materials necessary to achieve technological progress and maintain competitiveness in the world.

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