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DEVELOPMENT OF AUTOMOTIVE INDUSTRY TRENDS AND DEMAND FOR CRITICAL RAW MATERIALS WORLDWIDE

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Abstract. Innovative technological solutions appear in the economy as a response to expected social, economic, technological and environmental changes. Modern ideas can become a driving force for new investments and the spread of innovative ideas. One of the greatest challenges of modern times is environmental protection, which drives change and development in many sectors of the economy. The response to environmental protection by reducing exhaust fumes is the development of electric car production. With the growing demand for electric vehicles, the demand for key critical minerals has increased dramatically. However, their production is associated with an adverse impact on the environment. Furthermore, the production of critical minerals is limited to a few countries, with China being the leader. The article examines the problems of sustainable development, considering the often contradictory effects of environmental protection activities. It also addresses the issue of the stability of supply chains of critical minerals necessary for the implementation of modern technological solutions.

Keywords: critical minerals; environmental protection; electric cars

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1. Introduction

The world economy is driven by the need for innovative products that meet current quality and environmental requirements. Focusing on industrial trends, one can see their dominant role in the automotive industry and the production of various everyday appliances. In particular, the development of automobiles is one of the fastest-growing areas of the economy, drawing innovations from technological advances. A comparison of cars from 30 years ago to those in use today clearly shows that the progress in this field is enormous. Several main directions of automotive development can be distinguished. These are electromobility, autonomous vehicles, automatic transmission, equipment individualization, and car operation intuitiveness. The demand for new solutions requires significant economic outlays and achievements in electronics and computer engineering. Research is launched in connection with implementing new ideas in line with current trends, and numerous institutions and industrial plants are involved, where staff of people, professionals, scientists and engineers are employed, thanks to which new and increasingly innovative cars are created.

The environmental aspect of new automotive production significantly impacts emerging technical solutions. It should be noted that all automotive solutions always require different types of metals and other materials, fuel

and electronic instrumentation (Schmid, 2020)—various energy sources power vehicles. The materials, components and instrumentation used by the automotive industry require the extraction of certain minerals, their metallurgical processing and the development of industrial production. These activities are closely related to environmental protection and the pursuit of a circular economy.

Internal combustion engines, for example, have undergone a spectacular transformation over the past few years, with the primary goal of protecting the environment (Bielaszyc et al., 2013; Razek et al. 2023). Engines have been equipped with exhaust gas filtration systems. There are four fractions of particulate matter in diesel engine exhaust: (1) soot, (2) SOF (soluble organic fractions; heavy hydrocarbons), (3) sulfur compounds, and (4) ash. Diesel engine exhaust particulate emissions depend on a number of parameters, including engine type, engine operating conditions, and fuel and lubricating oil composition. Studies have shown that particulate formation occurs when exhaust gases are cooled and diluted in the atmosphere (Bielaszyc et al., 2013; 2003). The exhaust of vehicles equipped with a particulate filter in emission tests achieved particle counts below the standard of European Euro 5/Euro 6 regulations for passenger cars and light commercial vehicles (Filippo & Maricq, 2008). The example of neutralizing the harmfulness of exhaust gases is a spectacular success of innovative technological solutions forced by European directives on ecology. In this case, ecological trends, the original source of which was not related to automobiles, have tremendously impacted the development of modern automotive technologies.

Electric car production has developed due to strong pressure to protect the environment (Szumska & Jurecki, 2023). Today, it is already a strongly developed industry with a significant share in the economy of many countries. Automotive industry sources materials and components from various fields of the economy. It is the driving force behind such productions as sheet metal, engines, car components such as seats, windshields, catalytic converters, filters, batteries and many others. It engages the surface engineering industry through body painting and protective coating of drivetrain components and exhaust components.

The growth of the automotive industry is due to the increasing demand for passenger, transportation, military and other vehicles. The global proliferation of vehicles for both business and personal use has created one of the dominant industries in the economy and a source of powerful income for automakers. The introduction of environmental standards has forced the automobile industry to continually progress and develop more environmentally friendly vehicles such as electric cars.

Automobile transportation is mainly responsible for the production of nitrogen oxides, carbon dioxide (exhaust emissions), and particulate matter (non-exhaust emissions) (Wojtal, 2018; Su, 2022). Vehicles are not the main cause of environmental pollution but remain a significant part of it and a source of many pollutants (nitrogen and carbon oxides) and noise. It is expected that reducing the number of vehicles on the streets and introducing electric vehicles will translate into better air purification.

Further research into improving vehicles, particularly in terms of meeting environmental requirements, constantly continues. However, the carbon footprint of vehicle production and use is never zero. The manufacture of components and the materials from which they are produced runs on energy sources that often come from non-renewable sources. According to the World Health Organization, the energy sector accounts for about 60% of global greenhouse gas emissions. The biggest "polluters" are the U.S. and China, which emitted more than 250 gigatons of CO₂ from 1970 to 2021 (Paddison & Choi, 2024). Russia is third on the list and responsible for about 100 gigatons of CO₂ emissions. Of the remaining countries, Japan, for example, emitted more than 50 gigatons of carbon dioxide into the atmosphere.

China has the largest CO₂ emissions in the world and the second largest population. For a fair comparison of emissions, one would have to analyze emissions in terms of CO₂ per capita. The automotive industry is an essential branch of the EU economy. The automotive industry (directly and indirectly) employs 12.7 million Europeans, accounting for 6.6% of all jobs in the EU. 11.5% of manufacturing jobs in the EU - about 3.5 million - are in the automotive sector. The automotive industry generates a trade surplus of 76.3 billion euros for the European Union. Turnover generated by the automotive industry accounts for more than 8% of the EU's GDP.

The demand for metals in the automotive industry has a very strong impact on the world economy. In particular, the transition to electric cars has dramatically increased the demand for some metals, which have been designated as critical. This group includes rare earth metals (RRE).

2. Literature review

Gases such as carbon dioxide, carbon monoxide, sulfur dioxide, nitrogen oxides, hydrocarbons and particulate matter (CO₂, SO₂, NO_x, CO, HC, PM) suspended in the air cause an increase in the earth's temperature, which manifests itself in global warming (Razek et al., 2023). Emissions of these pollutants are largely related to the use of internal combustion vehicles. One way to improve the environment is to introduce green fuels. Studies have shown that the use of biofuel made from waste cooking oil reduces vehicle emissions (Ibeto & Ugwu, 2019). A paper (Pilusa et al., 2012) presents the purification of the exhaust gas of cars with a Diesel engine through the use of a South African patented filter (Whale filter is a South African patented secondary diesel filter designed by Mr. Hennie Joubert. This diesel filter design is currently filed under patent number 2005/08375).

In 2019, Europe's average new passenger vehicle produced 122 grams of carbon dioxide per kilometre of mileage (Peyravi et al., 2022). The 2020/21 CO₂ target for the passenger car fleet in the European Union was 96 grams per kilometre (Statista Research Department). It should be noted that electric car registrations in the EU have grown rapidly since 2020, accounting for about 11% of newly registered passenger vehicles, which promotes the realization of environmental protection and the reduction of harmful emissions.

In the past few years, many materials have been developed that reduce the overall weight of cars, improve their performance, and increase driving safety while reducing the emission of polluting gases (Asghar et al., 2025). Studies on these cars have shown that reducing the weight of a car by 10% can save up to 8% of fuel consumption. One of the key materials for producing lightweight cars is aluminium alloys. In particular, aluminum alloys with Si and Mg admixtures are used. Due to the inclusion of Si and Mg among critical metals, the latest research trend is to reduce or possibly replace these elements in aluminium alloys with other elements. However, even the works initiating this very interesting direction state that due to the unique nature of the influence on properties, there is a small probability of replacing Si and Mg in aluminium alloys with other elements (Asghar et al., 2025).

Aluminum is recognized as the choice material for clean technology, especially in uses involving renewable energy, electrical systems, batteries, resource-efficient packaging, and even energy-efficient buildings—and of course, aluminium alloys for cast automotive parts (Djurdjevic et al., 2023). Changing the alloying additions content in aluminum alloys, including Mg, can their strength properties. The mechanical properties of these alloys can also be further improved by appropriate heat treatment processes (T5, T6 and T7).

The year-on-year increasing production rates of electric vehicles lead to an increasing demand for critical materials (Schmid, 2020; Vidal et al., 2013). Critical raw materials (CRM) are also a potential bottleneck in the transformation process of the automotive industry (Ziemann et al., 2013; Olivetti et al., 2017; Ortego et al., 2018). A smartphone, for instance, contains up to 50 different kinds of metals, such as indium in its touch screen and silicon in the many chips it contains. Permanent magnets made of rare earth elements (REEs – a family of 17 elements with exceptional magnetic properties, composed of scandium, yttrium and the lanthanides) are critical in the health sector for magnetic resonance imaging and in low carbon technologies for generators in wind turbines and motors in electric vehicles (Ragonnaud, 2023).

One of the directions of development of the automotive industry is the modular method of vehicle construction (Pandremenos et al., 2009). Modular design divides the design task into separate production units. This increases the potential for outsourcing significantly, especially in car body design. Separate tasks are also associated with using different materials from different sources. This may involve diversification of supply.

In the pursuit of improved fuel economy, the automotive industry is embracing lighter materials in vehicle manufacturing (Auto House, 2024). High-strength steel, aluminium, and composite materials are used to reduce vehicle weight, improve performance, and reduce environmental impact. According to a report by the American Chemistry Council (ACC), the use of plastics in cars increased by an average of 16% between 2012 and 2017 (Microban, 2024). Using lighter materials such as plastics or aluminum in cars reduces carbon dioxide emissions, energy consumption, and fuel costs.

Aluminium is characterized by a high strength-to-weight ratio, high plasticity, corrosion resistance and complete recyclability. These features make aluminum alloys a priority for their use in car construction (Miller et al., 2000). The global automotive lightweight material market size is expected to reach USD 112.50 billion by 2030, registering a CAGR of 3.2% from 2023 to 2030 (Research and Markets, 2024). A rise in demand for weight reduction in passenger cars and commercial vehicles to support fuel efficiency is expected to increase the demand for lightweight materials over the forecast period.

Aluminum is a standard component in batteries used in electric cars, but it's also a supply crunch point. Demand is shifting from traditional aluminium castings to extrusions, high-quality castings, and even foil sheets, which are the easiest to recycle. New forms require aluminium with fewer impurities, which impacts scrap costs and can require higher additions of primary aluminium to alloys (Pope, 2024). There are significant obstacles to the development of reprocessing of bauxite residue, also known as red mud and other mining waste. The reasons are likely low-profit margins, long payback periods, high planning risks, and high sensitivity to operational excellence. This affects investment, which means that the mineral recovery market is not supported to the extent that it would be expected. Research conducted by S&P Global Mobility in 2023 showed interest in refining waste for mineral recovery, but there was difficulty in finding enough investors.

Advanced High Strength Steels (AHSS) are among the metals used in vehicles due to their high energy absorption potential, reduced vehicle weight resulting from the use of thinner high-strength steel sheets, and increased passenger safety due to improved crashworthiness (Kuziak et al., 2008; Perka et al., 2022; Hu & Feng, 2021; Kučera, 2023). The global automotive advanced high-strength steel market size was estimated at USD 16.95 billion in 2023 and is projected to grow at a CAGR of 6.4% from 2024 to 2030 (Market Analysis Report, 2024). Rising demand for lightweight vehicles is increasing the need for advanced high-strength steels (AHSS) in the automotive industry, driving market growth. The latest grades of AHSS have the potential to significantly reduce vehicle weight by 35.0-40.0% compared to that of traditional steel.

An analysis of the passenger car market indicates the increasing adoption of electric cars, driven by the realization of environmental trends (Figure 1) (Global EV Outlook, 2024).

New technologies related to the development of electromobility have caused strong demand for rare earth metals and critical metals (Habib et al., 2020; Haq et al., 2022; Richert et al., 2023; Tvaronavičienė, 2024). Metals such as steel, aluminium, critical metals, and rare earth metals are mostly extracted and processed in selected countries that supply the automotive industry. China is the leader in rare earth metal production (Hynek, 2023; Wendling, 2024).

The largest producer of electric cars is China, which experienced the dire effects of smog in Beijing, among other things, due to the accumulation of internal combustion engine exhaust from 2002-2003 and beyond (Józwiak, 2015). Since 2006, China has emitted more CO₂ than any other country in the world. In addition to coal-fired power plants and industrial plants, automobile exhaust, which accounts for about 50% of all pollution, was and still is a very troublesome source of contamination in Chinese cities (China - a general introduction..., 2020). A similar situation to Beijing has also been reported in Shanghai, Wuhan, the Pearl River Delta, and other major cities in China (Report, 2021). The response to catastrophic pollution has been to reduce the use of internal combustion vehicles and introduce electric vehicles. In 2023, China had more than 20 million plug-in electric cars, and by the end of June 2024, there were 440 million vehicles in China, including 345 million passenger cars, of which 24.72 million were electric and hybrid vehicles (18.134 million EVs, fully electric cars), accounting for 7.2% of all vehicles. A total of 31.4 million vehicles were sold in 2024 in the world's

biggest market by sales, up 4.5% compared from a year earlier, the China Association of Automobile Manufacturers reported (Swift, 2025). Experiencing the effects of air pollution has made policymakers and the Chinese people aware of the need to change their approach to transportation, heat sources, industrial emissions and other causes of environmental disaster. It is difficult to predict whether China's air pollution prevention measures will bear fruit and over what period of time a significant improvement in the situation can be expected. In 2015, China announced a policy to "combat smog" and joined the Paris Agreement (Przychodniak, 2018).

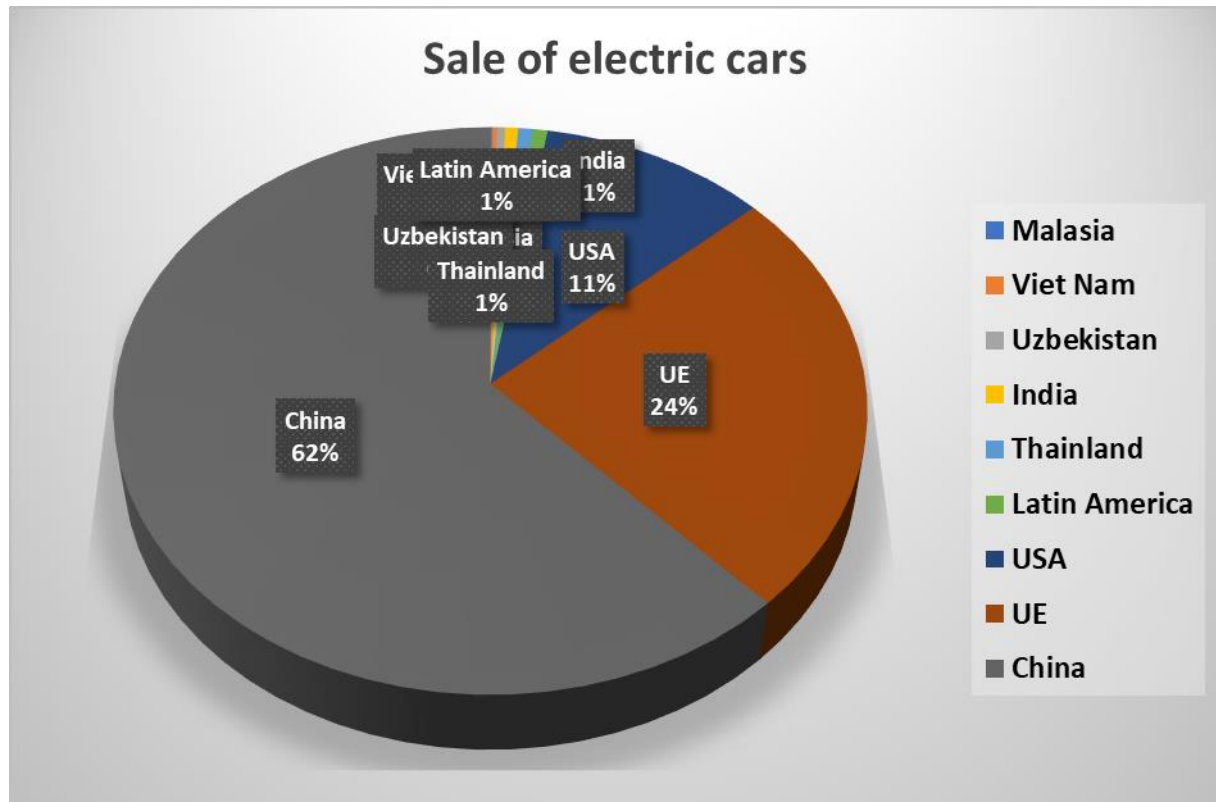


Figure 1. Percentage of electric car sales by countries (Global EV Outlook, 2024)

Electric passenger car sales are predicted to reach 45% of global passenger car sales by 2030 (Rovito, 2024). This will be the result of environmental trends and the growing awareness of environmental protection among car users and the introduction of zero-emission car regulations. Battery efficiency and EV charging infrastructure continue to improve, which will encourage drivers to use electric vehicles. There has been continued progress in battery design, as well as a decline in battery prices. Battery manufacturers CATL and BYD believe that the price of these batteries could drop by as much as 50% by the end of 2024. This could make EVs competitive with ICE vehicles. The range of EVs is increasing, and manufacturers Chevrolet, Hyundai, Jaguar, Kia, Nissan, Tesla and others are offering affordable EVs. The latest trends in automotive materials also include the use of plant-based leather, recycled steel, wood and antibacterial materials, which will reduce the need for potentially polluting cleaning agents (Rovito, 2024).

The growth in electric car production is and will continue to be associated with increasing demand for key metals used in their production, such as high-strength steels, aluminum and critical metals, including rare earth minerals. Decarbonization strategies require renewable energy generation and encourage the use of electric vehicles and low-voltage manufacturing of appliances, which can reduce energy consumption. Adopting these strategies worldwide can help achieve a low-carbon planet (Gbadeyan et al., 2024).

The aim of the study is to analyze the international market and potential sources of key materials for the automotive industry.

The research was conducted using an objective combination of primary and secondary information, including available data from key industry participants reported publicly. A market outlook and analysis of possible sources of key materials for the automotive industry are provided.

The article contains 8 chapters that present data on raw materials and analyze their prospective sourcing in the European Union (EU). The first chapter is “Introduction” introducing the issue at hand. The second chapter is “Literature review”. Next, third section is “Methodology” The fourth chapter is titled “Steel in road transport” and illustrates the sourcing of steel for the automotive industry. The fifth chapter is titled “Aluminum in road transport” and illustrates the sources of aluminum production. The next, sixth chapter is: “Critical minerals” discussing the production of critical minerals, in which rare earth metals play a large role. The seventh chapter is “Discussion,” which presents a discussion and analysis of the data presented. The eighth chapter, “Conclusions,” summarizes the results into several main conclusions relevant to the issues discussed.

3. Methodology

The article is a review article. It includes an overview of the available knowledge and trends in the use of metal materials in the automotive industry. In particular, it refers to the use of metals in electric cars. The conducted research consisted of using data obtained from a systematic literature review. It was a review based on which existing research and review papers related to the automotive industry and the use of metal materials in this industry were developed and analyzed.

The data collection method included collecting information from existing literature, including research articles, industry reports, market data, standards and publications from academic societies and journals related to materials science, automotive engineering and manufacturing, as well as automotive market development forecasts and management. The sources used are listed in the Literature section.

In the article, qualitative and descriptive data analysis methods were used to develop and summarize the results. The authors conducted systematic bibliographic research.

They reviewed, analyzed and systematized information obtained from various sources. Based on the conducted, comprehensive review of current trends, development prospects and research information, they presented their own opinion on future opportunities and limitations of obtaining metals for car production, in the context of sustainable development of the automotive industry.

The research scope is limited to the key metals currently used in automotive construction - steel, aluminum and critical metals, with a special focus on rare earth metals. The review focuses on the sourcing, applications, constraints and supply chain risks of these materials.

4. Steel in road transport

One of the key factors affecting fuel consumption and thus the amount of harmful exhaust gases produced is the weight of the car. The choice of materials for the construction of cars and its components therefore has a very strong impact on the ecology of vehicle use.

The basic material for car bodies is steel. The European steel industry is a world leader in innovation and environmental protection. It achieves a turnover of 130 billion euros and directly employs some 300,000 highly skilled workers in the EU (Statista Research Department, 2024). The steel industry in Europe is concentrated in more than 500 steel production facilities, in 22 EU member states.

Iron ore is mined in about 50 countries ma the world. Most iron ore come from Brazil, Australia, China, India, the US and Russia. Australia and Brazil account for about one-third of global iron exports (González and Kamiński, 2011). The steel industry accounts for 7 - 9% of global CO₂ emissions, so this issue is currently receiving a lot of attention (Basson, 2024).

The largest steel producers in 2023 and previous years were China, followed by India, Japan, the US, South Korea and Germany. China's dominance of steel production has persisted for a long time (Figure 2). Referring to China's population, it seems natural that steel production is highest in China, as it is simultaneously associated with high demand for steel products. An example is the demand for cars counted in millions.

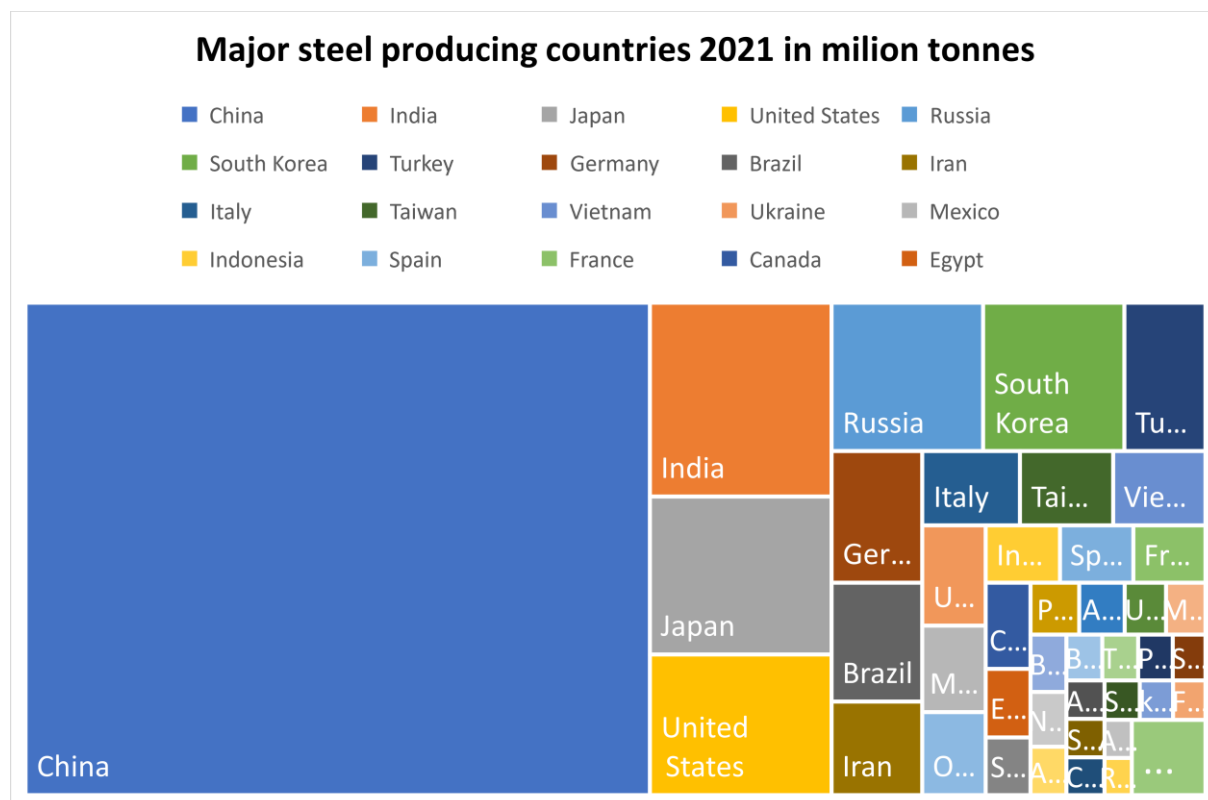


Figure 2. Major steel producers (Basson, 2021)

In 2022, 97.65% of the metallurgy's raw materials were processed into steel products or by-products. According to the Worldsteel Association steel production has been stable since 2020 (The European Steel Association, 2022). Globally, 219 kg of steel was used in new products per person in 2023. Top steel-producing companies in 2023 are: China Baowu Group (China), ArcelorMittal (India), Ansteel Group (China), Nippon Steel Corporation (China), HBIS Group (China), Shagang Group (China), POSCO Holdings (South Korea), Jianlong Group (China), Tata Steel Group (India), Delong Steel (China). As can be seen from the data presented, the vast majority of steel is produced in industrial plants in China and India, where environmental concerns are not a priority. China is currently the world's largest producer of steel and also its largest consumer. However, buyers are increasingly asking about environmental indicators and want to buy so-called green steel.

The concentration of heavy metallurgical industry in countries with low concern for environmental protection is characteristic. Europe, through the introduction of strict environmental directives, is influencing the development of the industry, including energy-intensive metallurgical plants processing primary iron ore. Through restrictive environmental regulations, the EU has opened the way for competition, not only in the steel industry.

There are 9 iron ore-producing member states in the EU, including Sweden, Norway, Austria, Slovakia and Germany. However, Sweden and Norway are the only countries where economically significant amounts of iron

ore are mined. Sweden is the largest iron ore producer in the EU and the 11th largest in the world. The rest of the producers import the raw material. Russia is a large supplier of iron ore to the EU. Supplies are used by Germany, Finland, Slovakia, France and the UK, among others, and in smaller quantities by Serbia, Austria and the Czech Republic.

About 75% of steel is still produced mainly in coal blast furnaces, which emit large amounts of carbon dioxide into the atmosphere. Huge amounts of energy are also needed to heat the furnaces to temperatures well above 1,000°C, which is required by iron ore metallurgy technology (iron has a melting point of 1,650°C). According to the International Energy Agency (IEA), emissions associated with steel production must be reduced by about 50% by 2050, and should continue to decline thereafter to meet global climate targets. Some of the world's largest manufacturers plan to reduce their carbon footprint by increasing the use of electric furnaces. However, a report by the NGO Global Energy Monitor shows that the transition from traditional blast furnaces to electric arc furnaces is very slow and well behind targets for decarbonizing steel technology.

Calculations show that a capital expenditure (CAPEX) of 2 to 3 trillion euros will be required to build the capacity necessary to bring EU “green steel” production to the forefront (Stamm & Naujok, 2023). Despite the enormity of this investment, the changes will only involve converting capacity in the iron and steel sector, not building the necessary sources of green energy to power production. The shift toward green energy will require another trillion euros.

On the one hand, a total product carbon footprint (PCF), which includes emissions across 3 supply chains (according to EU company reporting regulations), is considered a leading KPI for assessing “how green” a steel product can be. This KPI must be determined through a thorough cradle-to-gate life cycle analysis (LCA) according to globally accepted standards (e.g., ISO 14067), and then verified by a third party.

In order to multidimensionally assess the “environmental performance” of a steel product, many other ESG criteria must be taken into account, such as social justice, human rights, lack of child labor, other environmental detriments such as water consumption, land use and circular economy.

H2 Green Steel and Fortum companies have signed a framework agreement for the supply of emission-free electricity for H2 Green Steel's operations in northern Sweden (Fortum will use green energy with Swedish H2 steel, 2023). Initially, the annual volume of green steel produced at H2 Green Steel's Boden plant will be 2.5 million tons. In the second phase, the company will increase production to about 5 million tons.

For comparison, global steel production in 2023 was 1,885 million tons, and China's steel production in 2023 was 1,018 million tons (World Steel in Figures, 2023). This means that despite H2 Green Steel's laudable goals, the share of green steel in global steel production is negligible.

So far, one of the more successful ventures has been steel recycling, which has even reached an impressive 90 percent in many parts of the world. However, the amount of scrap steel currently available is only enough to meet a quarter of the world's demand (Anderson, 2024). Increasing pressure to advance the sustainability trend will encourage a shift to more sustainable steel production, particularly using renewable minerals. However, it is difficult to assess how quickly the changes, which require significant financial resources, will take place.

The market size of iron and steel is estimated to be USD 1,599.4 trillion in 2022 and is projected to reach 1,928.6 trillion by 2027 at GAR of 3.8% (Iron and Steel Market, 2024). The largest growth in steel demand is projected in construction, transportation and heavy industry. The greatest growth and development in this industry will be in China and Asian countries, regions with low environmental awareness (Table 1, Figure 3).

Table 1. Crude steel production by process, 2021 (Basson 2021)

	million tons
New Zealand	0.6
Australia	5.8
Africa	20.4
Middle East	45.8
Central + South America	46.3
rest UE	52.3
Russia + Ukraine	105.4
USMCA	117.2
European Union (27)	152.6
Asia	1403.4
Above countries in total	1949.8

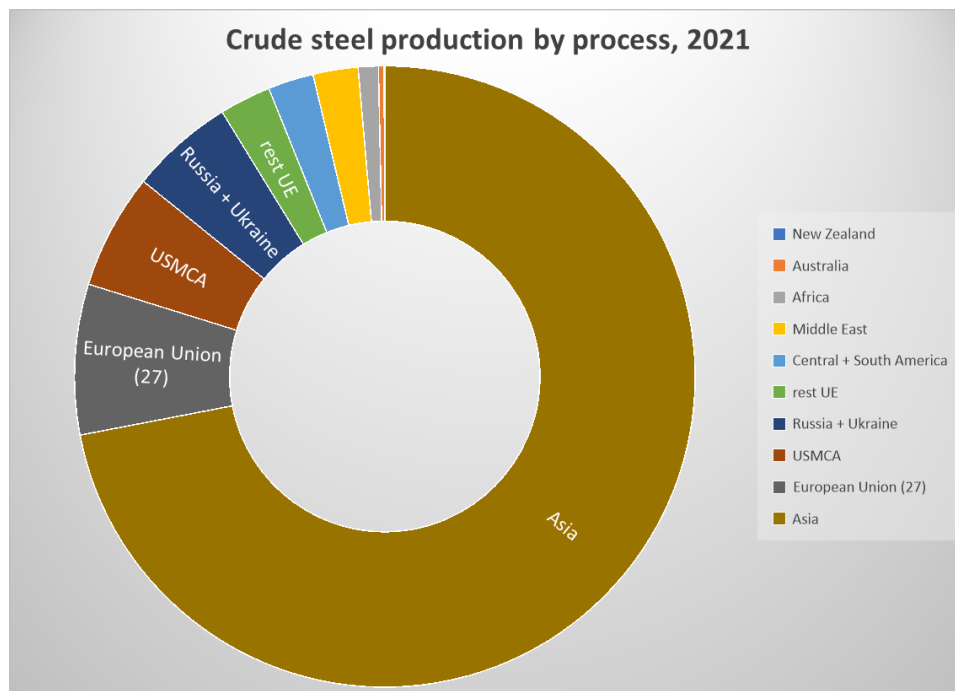


Figure 3. Crude steel production by process in 2021 by countries (Basson 2021)

5. Aluminium in road transport

At present over 130 kgs of aluminum goes into the average European car, and this is rising steadily (UK Aluminum Industry, 2024). The transportation sector across the world is estimated to use 26.7 million tons of aluminum in 2022. The passenger car segment is the major end user sector among other transportation sectors with an estimated consumption of more than 16.5 million tons of aluminum in 2022. Many structural and functional automotive components which were previously made of steel are now being fabricated using aluminum. In the EU, aluminum use in transportation is projected to increase from 0.6 million tons to 1.6 million tons between 2022 and 2027 (Future of Aluminum in Transportation Sector, 2024). The global automotive aluminum market size was valued at USD 73.21 billion in 2021 and is predicted to reach at USD 156.53 billion by 2030, increasing at a CAGR of 8.81% from 2022 to 2030. The production of greenhouse gases associated with aluminum recycling is many times lower than obtaining the metal from bauxite. Recycling aluminum is about 60 to 95% cheaper. On top of that, aluminum does not lose its properties during recycling and we can recycle it indefinitely.

The most common use of aluminum is in cans and food packaging. Aluminum material is also used in the automotive and aerospace markets to produce a variety of parts.

Recycling aluminum (Kuchariková et al. 2016) and steel (WorldSteel Associaton, 2022) saves resources and uses less energy than producing these metals from raw materials. Aluminum can be recycled many times without losing its quality. The European aluminum market was estimated to be worth USD 54.59 billion in 2023. It is expected to reach USD 74.75 billion by 2030, with a compound annual growth rate (CAGR) of 3.9% between 2024 and 2030. According to the International Aluminum Institute (IAI), Europe has the highest recycling efficiency rate (RER) in the world, recovering 81% of available aluminum scrap by December 2020 (International Aluminum Institute, ²⁰²⁴). The report by Triton Market Research predicts that the European aluminum market will advance with a CAGR of 4.92% in the forecast years from 2023 to 2030 (Europe Aluminum Market 2023-2030). However, China is the largest producer of recycled aluminum (Figure 4). The recycling rate remains stable at a high level (Dai et al, 2019). The target is 100 percent by 2030. In terms of aluminum recycling rate, the leading countries are: Austria (59%), Wales (59%) and Taiwan (53%) (Statista, Recycled aluminum production worldwide in 2021, by main territory, 2024). The larger exporters of aluminium waste and scraps were countries such as: USA, Gernmay, Canada (Figure 5).

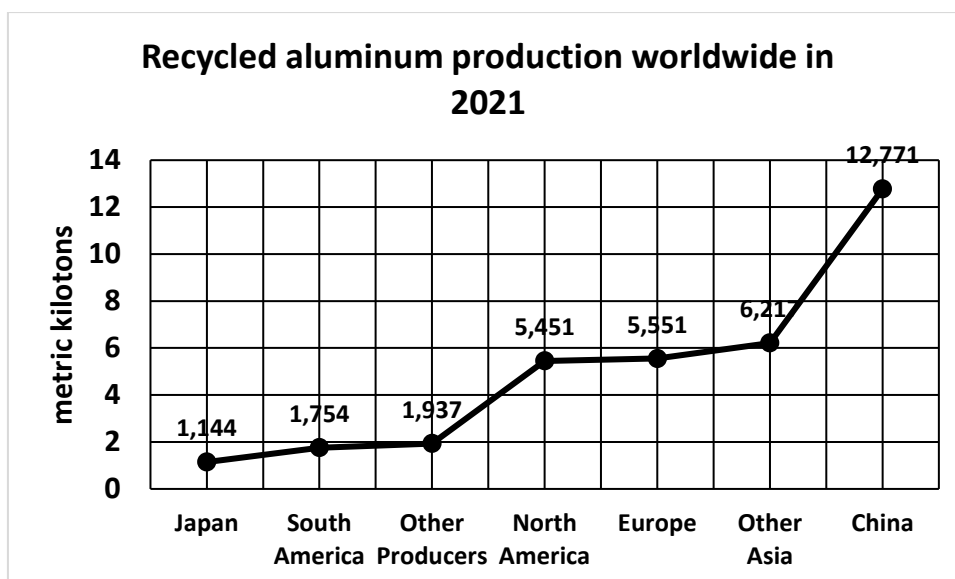


Figure 4. The largest exporters of aluminum waste in 2023 (Top Exporters of Aluminium Waste and Scrap in 2023).

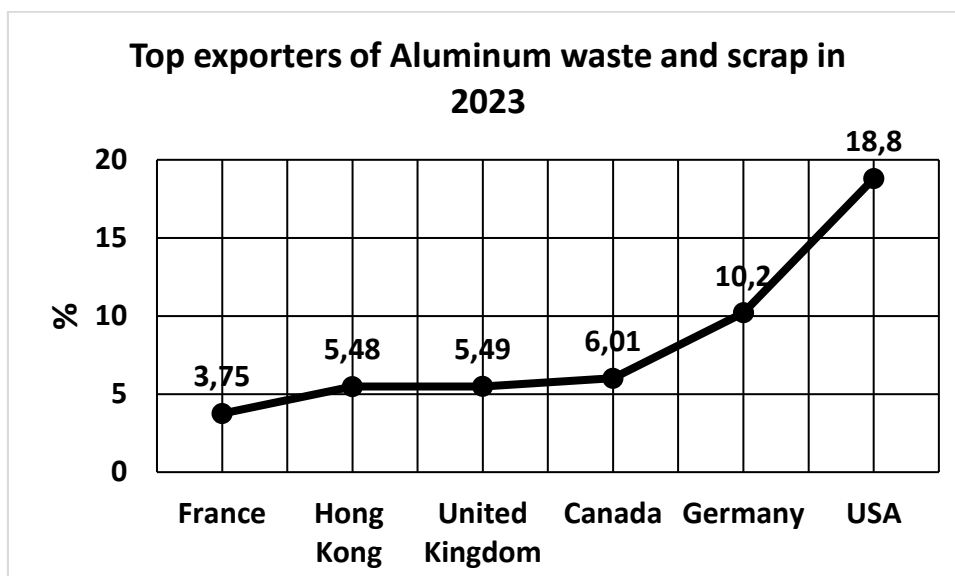


Figure 5. Top Exporters of Aluminium Waste and Scrap in 2023 (Business Research, Aluminum Recycling Market Report Overview, 2024)

In 2023, global imports of “aluminum waste and scrap” exceeded USD 19.8 billion. The largest importers of aluminum waste and scrap in 2023 (Trend Economy, Aluminium waste and scrap | Imports and Exports | 2023) were India - 18.2%, and other countries in the global import of aluminum scrap are: (USD 3.62 billion), China - 17.3% (USD 3.44 billion), Germany - 8.62% (USD 1.71 billion), the US - 5.97% (USD 1.18 billion), Italy - 5.344% (USD 1.06 billion) (Figure 6). China imports aluminum scrap from countries such as Japan, Malaysia, Thailand, the UK and the US. India, on the other hand, imports aluminum scrap from Saudi Arabia and the US.

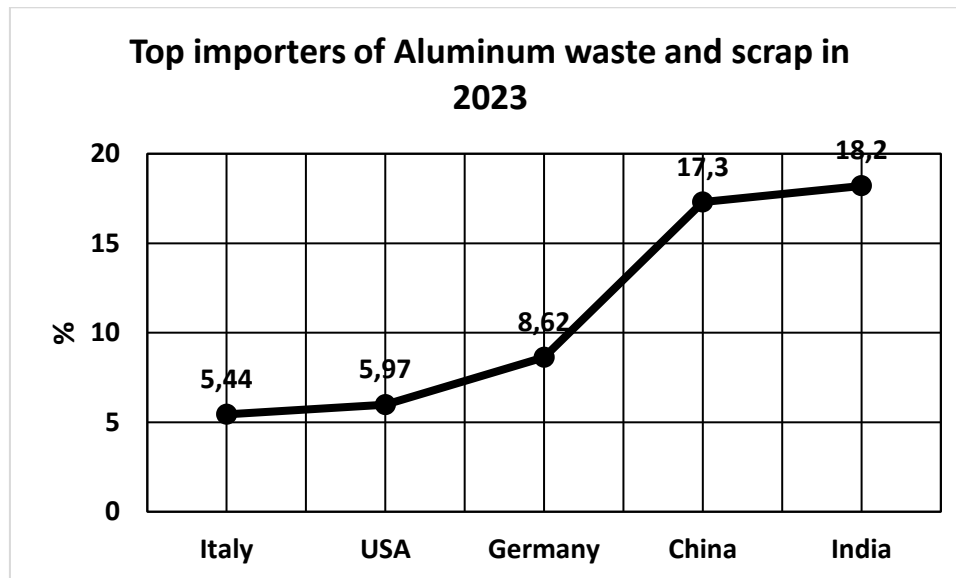


Figure 6. Top importers of aluminum waste and scrap (Trend Economy, Aluminium waste and scrap | Imports and Exports | 2023).

Europe accounts for more than 15% of global aluminum consumption, and the main market for aluminum in Europe is Germany, home to the world’s largest automakers. Germany accounts for 25% of Europe’s total aluminum consumption, hence the growth of the global aluminum industry is heavily dependent on this market. The German automotive industry has great potential for growth as it exports cars around the world, satisfying the growing consumption of motor vehicles.

German aluminum producers and processors produce about 560,000 tons of aluminum. This includes about 260,000 tons of primary aluminum and 300,000 tons of recycled aluminum.

Since 2002 the EU has continuously been a net exporter of aluminum scrap year-on-year. On the other hand, the EU’s high level of scrap exports threatens the development of the recycling industry and the closed-loop economy in Europe. More than 80% of scrap produced in the EU goes to Asia, with 37% going to China and 28% to India.

The global aluminum recycling market size was valued at USD 100165.8 million in 2023 and will reach USD 136566.08 million in 2032, with a CAGR of 5.3% during 2023-2032 (Business Research, Aluminium Recycling Market Size, Share, Growth, And Industry Analysis, 2025). The global aluminum recycling market size was USD 107.09 billion in 2023 and is projected to grow from USD 112.03 billion in 2024 to USD 160.83 billion by 2032, exhibiting a CAGR of 4.62% during the forecast period. Asia-Pacific holds leading position in aluminum recycling market share in 2023 (Business Research, Aluminium Recycling Market Report Overview, 2025).

The most common form of transportation worldwide is by car. However, because the automobile industry is more concerned with improving CO₂ emissions, fuel efficiency, and design, aluminum is playing a bigger role in modern cars. The expansion of automotive production and the greater usage of aluminum in contemporary vehicles are the primary drivers of this development. The usage of aluminum helps lower the weight of vehicles

by one kilogram overall. The primary factor anticipated to drive the market expansion is the increased usage of aluminum in the automotive industry and the rise in the use of aluminum recycling procedures.

According to Cognitive Market Research, the global aluminum scrap recycling market size will be USD 5814.2 million in 2024. It will expand at a compound annual growth rate (CAGR) of 8.80% from 2024 to 2031 (Cognitive Market Research, 2025). America held the major market share with more than 40% of the global revenue with a market size of USD 2325.68 million in 2024, which will grow at a compound annual growth rate (CAGR) of 7.0% from 2024 to 2031.

- Europe accounted for a market share of over 30% of the global revenue with a market size of USD 1744.26 million.
- Asia Pacific held a market share of around 23% of the global revenue with a market size of USD 1337.27 million in 2024 and will grow at a compound annual growth rate (CAGR) of 10.8% from 2024 to 2031.
- Latin America had a market share of more than 5% of the global revenue with a market size of USD 290.71 million in 2024 and will grow at a compound annual growth rate (CAGR) of 8.2% from 2024 to 2031.
- Middle East and Africa had a market share of around 2% of the global revenue and was estimated at a market size of USD 116.28 million in 2024 and will grow at a compound annual growth rate (CAGR) of 8.5% from 2024 to 2031.
- The diesel generator category is the fastest-growing segment of the aluminum scrap recycling industry

6. Critical Minerals

Critical minerals and their extraction are closely linked to the development of the environmental megatrend, which is forcing new transportation solutions such as electric cars and the development of green energy to power industries that produce materials and components for the transportation industry.

Critical minerals are essential for the development of the modern electric car industry, as well as renewable energy generation. The extraction of critical minerals and their subsequent processing is mostly carried out in non-European countries with little emphasis on environmental protection. These are raw materials that are of great importance in the economy but have a high risk of bottlenecks in supply chains, with the possibility of breaking them (European Commission, 2020; Leon and Daphne, 2023).

Despite the risks, economic analysis of the market indicates a relatively stable development of macroeconomic exchange and distribution of critical minerals. Demand for these raw materials is growing year after year. Demand for critical minerals experienced strong growth in 2023, with lithium demand rising by 30%, while demand for nickel, cobalt, graphite and rare earth elements all saw increases ranging from 8% to 15% (IEA Global Critical Minerals Outlook, 2024).

For the six key energy transition minerals - copper, lithium, nickel, cobalt, graphite and rare earth elements in some cases a significant increase in demand is forecast (Figure 7). The global increase in demand for rare earth elements is shown in Figure 8 (Watari et al., 2020).

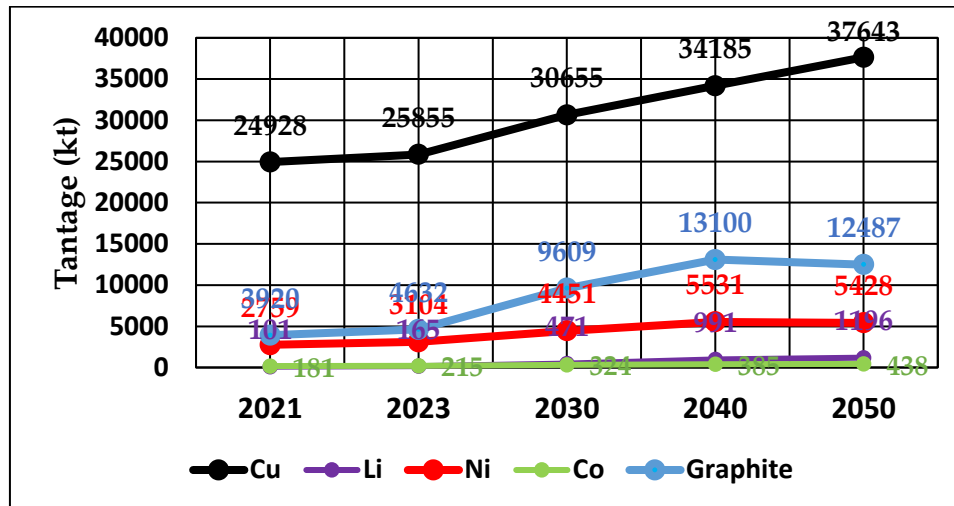


Figure 7. Projected growth in demand for Cu, Li, Ni, Co and graphite until 2050 (IEA Global Critical Minerals Outlook, 2024)

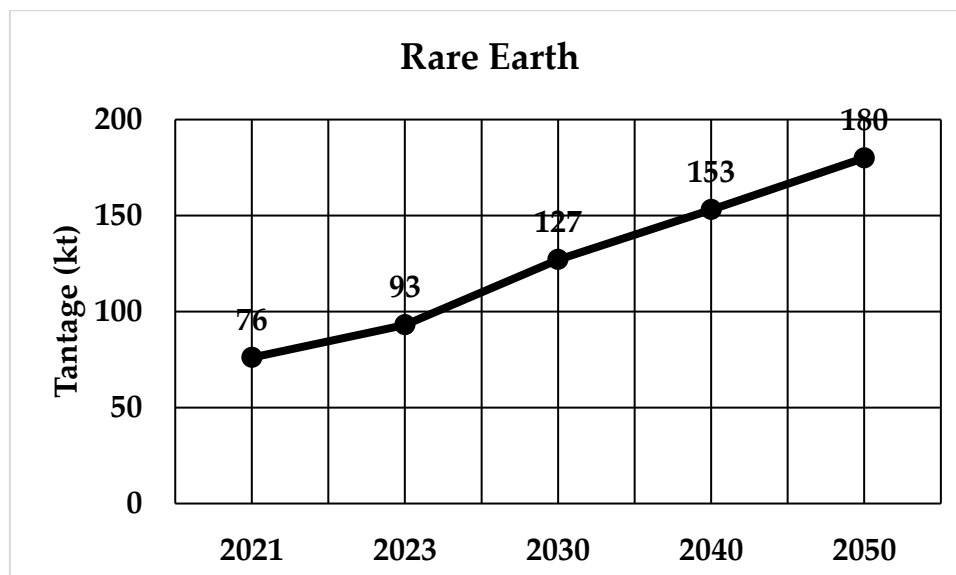


Figure 8. Projected global growth in demand for rare metals (IEA Global Critical Minerals Outlook, 2024)

Table 2 shows 10 critical minerals and their use in energy and transportation technologies (Firestone and Garofalo, 2022; Namibia Critical Metals INC 2017; Müller et al. 2025). Modern transportation and energy technologies cannot be developed without these minerals. Therefore, these are the minerals that have caught the attention of industry, science and economic managers alike.

Table 2. Use of critical metals (Firestone and Garofalo, 2022)

Vanadium	redox flow batteries
Cobalt	EV batteries and wind technology
Indium	solar technology
Chromium	wind technology
Titanium	EVs and batteries
Graphite	Evs and batteries
Tungsten	rocket engines and microwaves
Antimony	flame retardants, as alloys for car batteries and bullets
Rhenium	turbine blades in fighter jet engines and electrical components
Dysprosium	permanent magnets, data-storage devices, nuclear reactors as a cermet

In addition to the critical minerals listed in Table 4, U.S. and EU government studies list about 50 minerals that they consider critical. Some of these are shown in Table 5. Critical raw materials are called commodities of

great economic importance whose supply shows a high risk of disruption due to concentration of sources and lack of good, affordable substitutes (Eurostat, 2024).

The following critical minerals can be mentioned (US Department of Energy, 2023). The Secretary of the Interior, acting through the director of the U.S. Geological Survey, published in 2022 final list of critical minerals that includes the following 50 minerals: aluminum, antimony, arsenic, barite, beryllium, bismuth, cerium, cesium, chromium, cobalt, dysprosium, erbium, europium, fluorspar, gadolinium, gallium, germanium, graphite, hafnium, holmium, indium, iridium, lanthanum, lithium, lutetium, magnesium, manganese, neodymium, nickel, niobium, palladium, platinum, praseodymium, rhodium, rubidium, ruthenium, samarium, scandium, tantalum, tellurium, terbium, thulium, tin, titanium, tungsten, vanadium, ytterbium, yttrium, zinc, and zirconium.

This list is based on the latest U.S. Department of Energy (DOE) critical materials assessment entitled DOE Critical Materials Assessment 2023.

The final list of critical materials for 2023 includes all materials that have been assessed as “critical” or “near-critical” in the short to medium term - with the exception of uranium (EU <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52011DC00250>).

Article 7002(a) of the 2020 Energy Law limits the list of critical materials to “any mineral, element, substance or material that is not fuel.” In the usual understanding of fuel, uranium used in commercial nuclear reactors is a fuel material. Since the DOE’s 2023 critical materials assessment only covers the use of uranium as a fuel, the DOE did not identify uranium as a critical material in the final 2023 critical materials list.

The EU relies on the supply of critical minerals because it has no sources of these minerals of its own. Table 3 shows the countries where critical minerals are sourced and the countries from which the EU imports them. China’s dominance in both sourcing and importing these minerals to the EU is evident. China is an economic powerhouse and a leading country in the production of materials necessary for the development of the transportation and energy industries. The stability of this country determines the stability of the supply of critical raw materials.

Table 3. Critical minerals, production, imports into the EU (Eurostat, 2024)

Mineral	Main producers	EU imports
Antimony	China (78%), Vietnam (11%), Russia (4%), Tajikistan (4%)	China, Tajikistan, Vietnam, South Korea, Türkiye, and Thailand
Beryllium	United States (60%), China (23%), Kazakhstan, Brazil, Mozambique, Canada, Namibia, Portugal, and Zimbabwe, Uganda, Rwanda, Madagascar	Kazakhstan, United States, China
Cobalt	China (70%), Democratic Republic of Congo, Indonesia, Russia, Madagascar, Philippines, Cuba, New Caledonia, Papua New Guinea, Turkey	Democratic Republic of Congo (DRC) and Zambia, China, Australia, Russia and Canada
Fluorspar	Mexico, Mongolia, South Africa, Vietnam	China, Mexico, Pakistan, South Africa, Morocco, Turkey, Mongolia, Thailand, United States
Gallium	China (98%), Japan, Republic of Korea, Russia,	China, Japan, United States, United Kingdom, Switzerland, Canada, Korea Rep., Singapore
Germanium	China (60%), Canada (25%), United States, Russia, Finland	China
Graphite	China (77%), Madagascar, Mozambique, Brazil, South Korea, Russia, India, North Korea, Norway, Tanzania,	China, Tanzania, and Mozambique

Indium	China (40%), South Korea (31%), Canada (9%) and Japan (9%)	United Kingdom (13% of EU sourcing), United States (5% of EU sourcing) and China (4% of EU sourcing)
Magnesium	China (85%), Russia, United States, Israel, Australia, Turkey, Brazil, Austria, Spain, Kazakhstan	China (97%), Israel
Niobium	Brazil (60-70%), Canada, Congo, Russia	Brazil (84%), Canada, Korea
Platinum group metals	South Africa, Russia, Zimbabwe, Canada, United States, China	South Africa (71%)
Rare earths	China (69%), United States (12%), Myanmar (11%), Australia (5%), Thailand, India, Russia, Madagascar, Vietnam, Brazil	China (40%), Malaysia (31%), United States
Tantalum	Democratic Republic of Congo (45%), Rwanda (17%), Brazil (16%), Nigeria (11%), China	Democratic Republic of Congo (36%), Rwanda (30%), Ethiopia (6%), Nigeria (5%)
Tungsten	China (83%), Vietnam, Russia, North Korea, Bolivia, Spain, Rwanda, Austria, Australia, Portugal	United States (29%), China (28%), United Kingdom (10%), Switzerland, Turkey, India, Canada, Kazakhstan, Japan, Thailand
Dysprosium		

The EU produces only 1% of all battery raw materials. The global mine production of antimony was estimated at 83.000 metric tons (Anderson, 2019) China is the largest producer of antimony. In addition to China, smaller quantities are produced in several other countries (Figure 9).

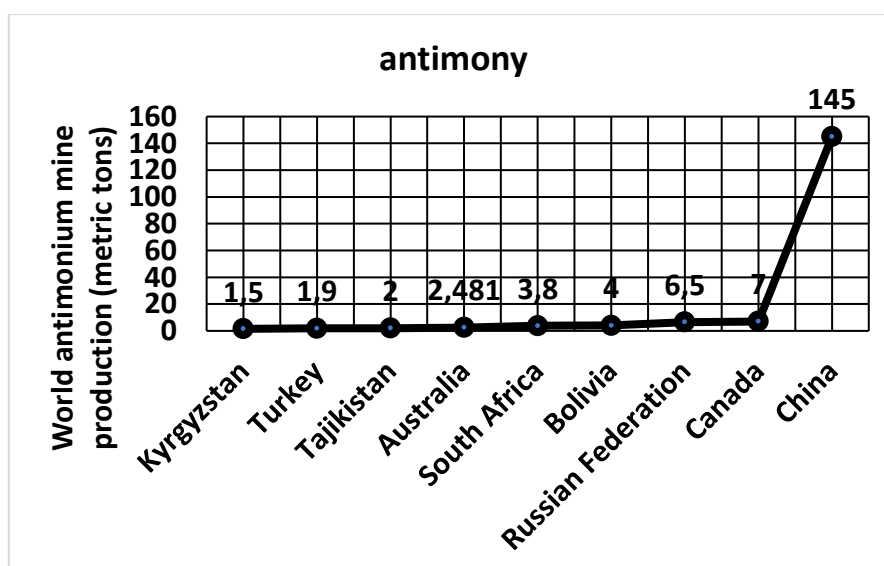


Figure 9. World mine production of antimony by country (metric tons) (United States Geological Survey (USGS) Minerals Resources Program, Antimony Production by Country)

The United States is the world's largest beryllium mine producer by far, with production amounting to an estimated 190 metric tons in 2023 (Figure 10) (Kramer, 1999; Top beryllium producing countries; Beryllium unwrought powders, 2024; Jaganmohan, 2024). The automotive industry utilizes beryllium as a connector material for high – temperature and battery application (Beryllium Market Growth Drivers & Opportunities, 2023) . China was distantly the second-biggest producer in the world, with an output of 74 metric tons. Beryllium-bearing pegmatite districts occur in Brazil, Canada, China, Mozambique, Namibia, Portugal, and Zimbabwe.

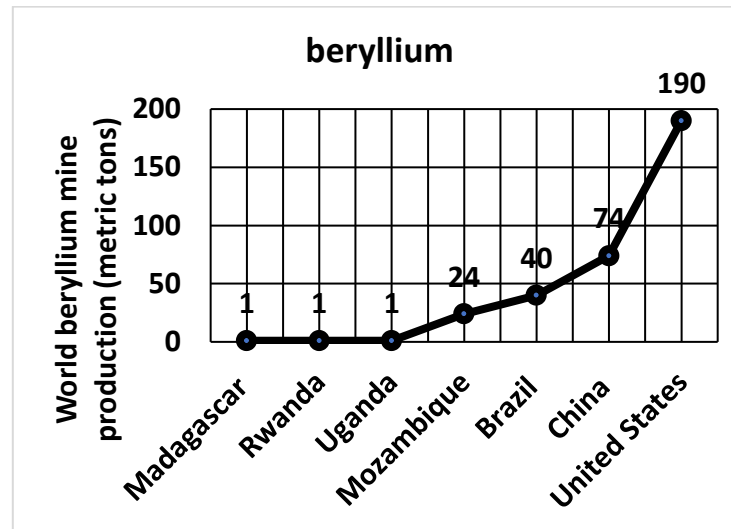


Figure 10. World mine production of beryllium by country (metric tons) (Kramer, 1999; Top beryllium countries)

The 54% of global cobalt mine production comes from the Democratic Republic of Congo, followed by China (8%), Canada (6%), New Caledonia (5%) and Australia (4%) (Figure 11). Refined cobalt comes from China (46%), Finland (13%), Canada and Belgium (6% each) (European Commission, Critical materials for strategic technologies and sectors in the EU - a foresight study, 2020)

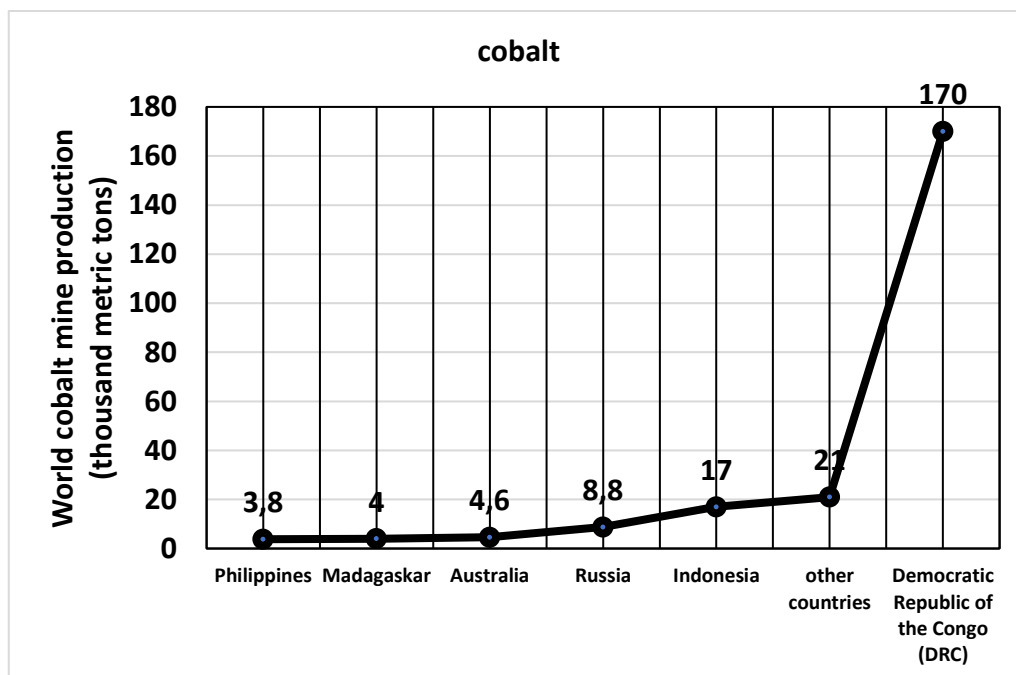


Figure 11. World mine production of cobalt by country (thousand metric tons) (European Commission, Critical materials for strategic technologies and sectors in the EU - a foresight study, 2020)

China is the world's largest mine producer of fluor spar, with an estimated output amounting to 5.7 million metric tons in 2023 (Figure 12) (Statista, Global fluor spar production by country, 2023; Londono, 2024; Iha, 2023). World production of fluor spar was estimated to have increased by 6% in 2023, primarily from increased production in Mongolia. Mines in Canada, Germany, Italy, Spain, and the United States, some of which had been idle for decades, were preparing to restart operations. Synthetic fluor spar may be produced from neutralization of waste in the enrichment of uranium, petroleum alkylation, and stainless-steel pickling; however, undesirable impurities constrain use. Primary aluminum producers recycle HF and fluorides from smelting operations. Fluor spar demand from the lithium ion battery sector is expected to exceed 1.6 million tons

by 2030, representing a significant portion of the overall market, according to Benchmark's Fluorspar Market Outlook.

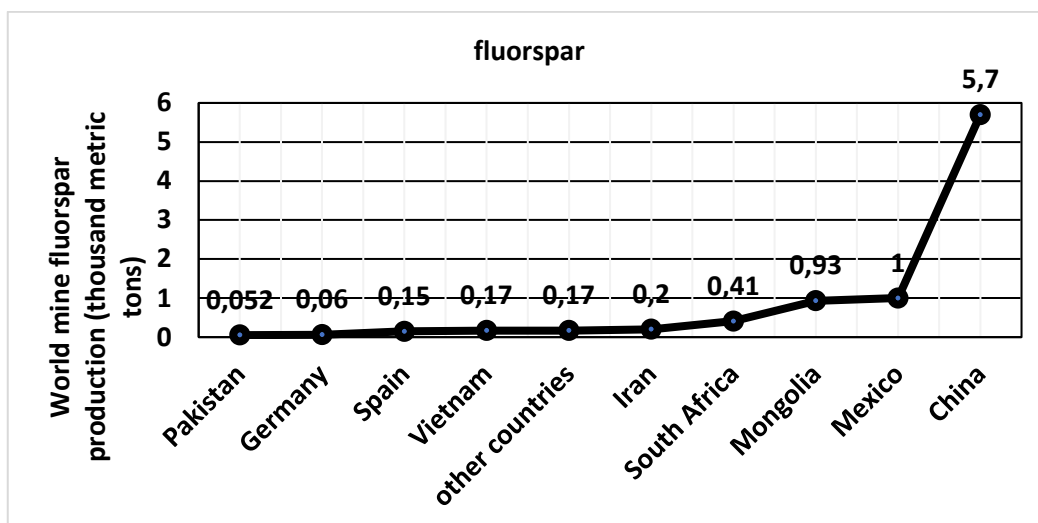


Figure 12. World mine production of fluorspar by country (metric tons) (Statista, Global fluorspar production by country, 2024)

In 2022, China was the largest primary producer of gallium in the world, with production having amounted to 600 metric tons (Figure 13) (Jaskula, 2024). Russia was the second-largest primary producer of gallium that year with a distant five metric tons. Current world production of gallium is about 200 mt per year, with the main producing nations being China, Germany, Kazakhstan and Ukraine. Gallium is found in trace amounts in zinc ores and in bauxite, and gallium metal is produced when processing bauxite to make aluminum. Around 80% is produced in China, according to the CRMA. Gallium is used to make gallium arsenide for use in electronics. Gallium is found in trace amounts in zinc ores and in bauxite, and gallium metal is produced when processing bauxite to make aluminum. Gallium occurs in very small concentrations in ores of other metals. Most gallium is produced as a byproduct of processing bauxite, and the remainder is produced from zinc-processing residues. The average gallium content of bauxite is 50 parts per million. Some domestic zinc ores contain up to 50 parts per million gallium and could be a significant resource, although no gallium is currently recovered from domestic ores. Gallium contained in world resources of bauxite is estimated to exceed 1 million tons, and a considerable quantity could be contained in world zinc resources. However, less than 10% of the gallium in bauxite and zinc resources is potentially recoverable. According to the CRMA, around 80% is produced in China. Gallium is used to make gallium arsenide for use in electronics.

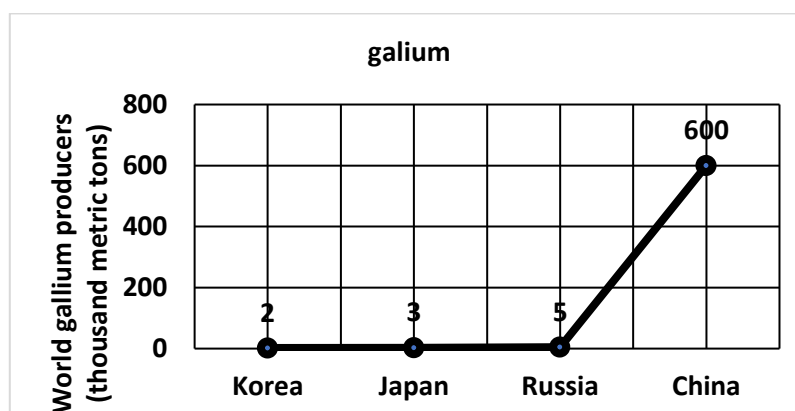


Figure 13. World production of gallium by country (metric tons) (Jaskula, 2024)

Global germanium refinery production and recycling data were limited, and available estimates were difficult to verify (Nagrle, 2025; Germanium Market Size, 2024). China continued to be the leading global producer and exporter of germanium in 2023. Exports of germanium metal (China's export codes 8112.92.10 and

8112.99.10) for the year through September increased by 34% to 34,600 kilograms compared with those in the same period in 2022. These exports were mostly sent to Russia (21%), Germany (19%), Hong Kong (18%), the United States (17%), Belgium (9%), and Japan (8%). Major germanium producers in China included Yunnan Chihong Germanium and Zinc Co. Ltd. and Yunnan Lincang Xinyuan Germanium Industry Co. Ltd (U.S. Geological Survey, Mineral Commodity Summaries, Germanium, 2024).

China was the world's largest graphite producer in 2024, producing 1.27 million metric tons of the metal (Leading graphite producing countries worldwide in 2024, Graphite Mining Market Analysis by Reserves, 2024) (Figure 14), 50 percent higher than the amount it produced in 2021. Graphite is an essential component for lithium-ion batteries and other energy storage solutions. Future demand for graphite is projected to be high as interest in battery-storage technology rises.

In 2023, the world's total production of natural graphite amounted to an estimated 1.6 million metric tons. China accounted for the highest Graphite reserves, followed by Brazil and Mozambique. Global natural graphite production is expected to grow by 4.3% to 1,677.4 thousand tons (kt) in 2024, backed by an anticipated growth in supply from Madagascar, Tanzania, Mozambique and Canada. China, Madagascar, Mozambique, Brazil and Canada are the world's top five producers of natural graphite, accounting for 94.0% or 1,512.0kt of the global total in 2023 (Global Graphite Mining Industry Report 2024-2030). Looking further ahead, global natural graphite production is expected to grow steadily through to 2030 with a compound annual growth rate (CAGR) of 10.2% to reach 3,007.9 kt. Growth will be primarily supported by output from Tanzania, Mozambique and Canada.

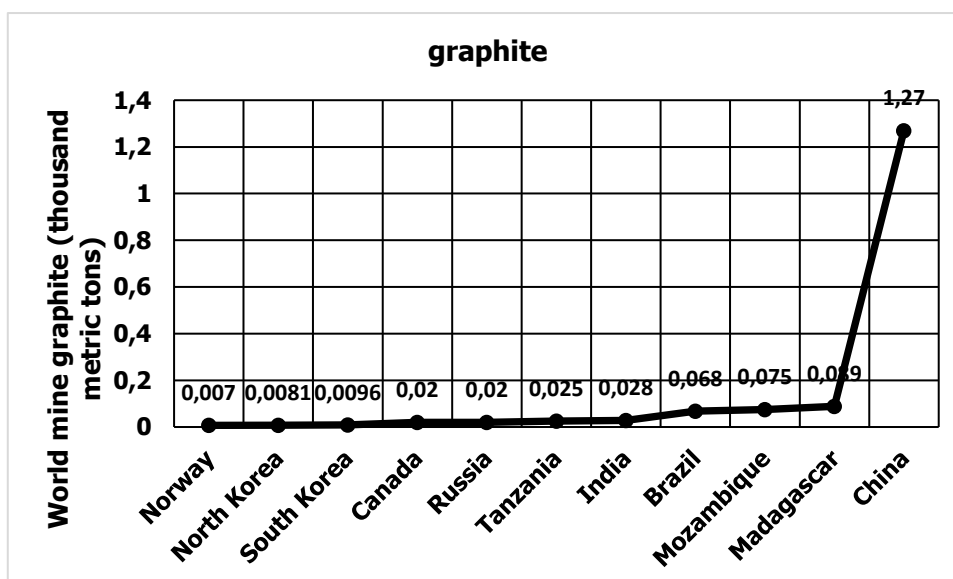


Figure 14. World production of graphite by country (metric tons), (Leading graphite producing countries worldwide in 2024)

The vast majority (~90%) of indium is obtained as a by-product of zinc mining (Global Indium Market, 2023; Indium Market Size, 2025; Pangarkar, 2024). The main producers of indium are China (40%), Korea (31%), Canada (9%) and Japan (9%) (Figure 15). There is no indium production in the United States. Indium is relatively rare, with its content in the Earth's crust estimated at about 0.1 parts per million. In contrast, it is commonly found in zinc ores and is mainly produced from residues generated during the processing of zinc ores.

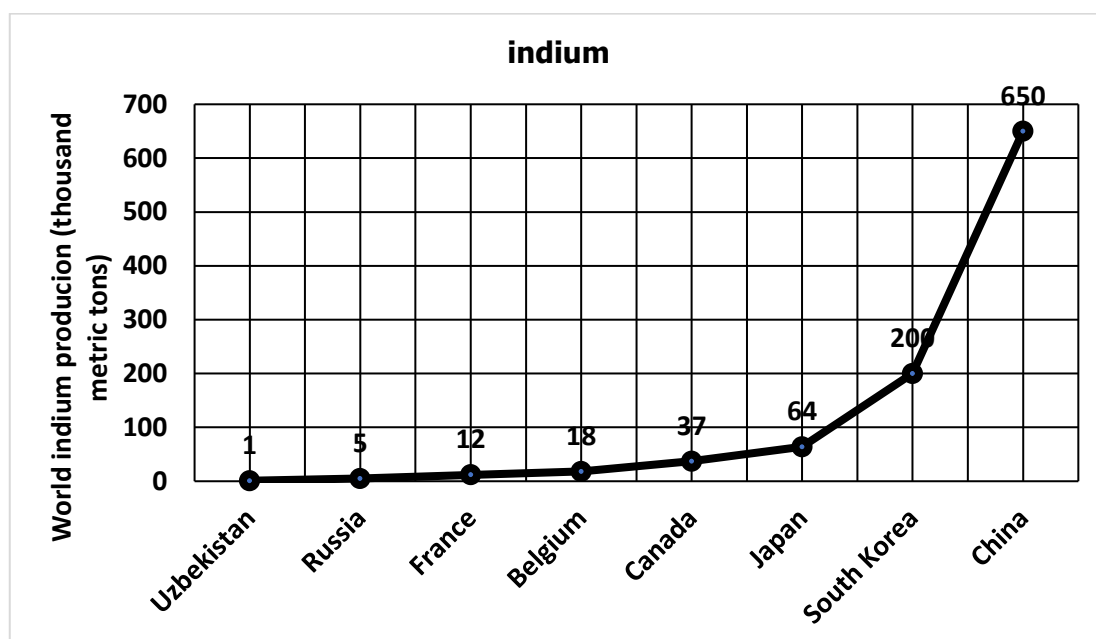


Figure 15. World production of indium by country (metric tons) (Leading countries based on production of indium worldwide in 2023)

China accounts for 85% of Mg production (Figure 16). Almost 95% of all magnesium imported into the EU is from China. Magnesium finds its main application in the automotive industry (Kulkarni, 2024; Magnesium Metal Market, 2024; Magnesium Market Size, 2024; Magnesium Market Analysis APAC, 2024).

The dominant production method is electrolysis. Global magnesium production has grown at a rapid pace (5% to 7.5% per year on average), driven by the continued growth of magnesium production in China (Metal Magnesium Market Size & Share Analysis - Growth Trends & Forecasts, 2024), where magnesium is produced by a thermal reduction process “the so-called Pidgeon process.”

Magnesium demand and supply are expected to grow in the long term. Battery production could be one of the important drivers of demand (European Commission, 2020; Metal Magnesium Market Size & Share Analysis - Growth Trends & Forecasts, 2024). Given the wide availability of magnesium resources (e.g., dolomite and magnesite resources in the EU), raw material availability is unlikely to be a limiting factor for future supply growth (Magnesium Market Annual Review, 2024). However, magnesium production has been pushed out of the EU. The last of the older smelters in Europe closed in 2001, as European-based smelters were unable to compete with low-cost Chinese production.

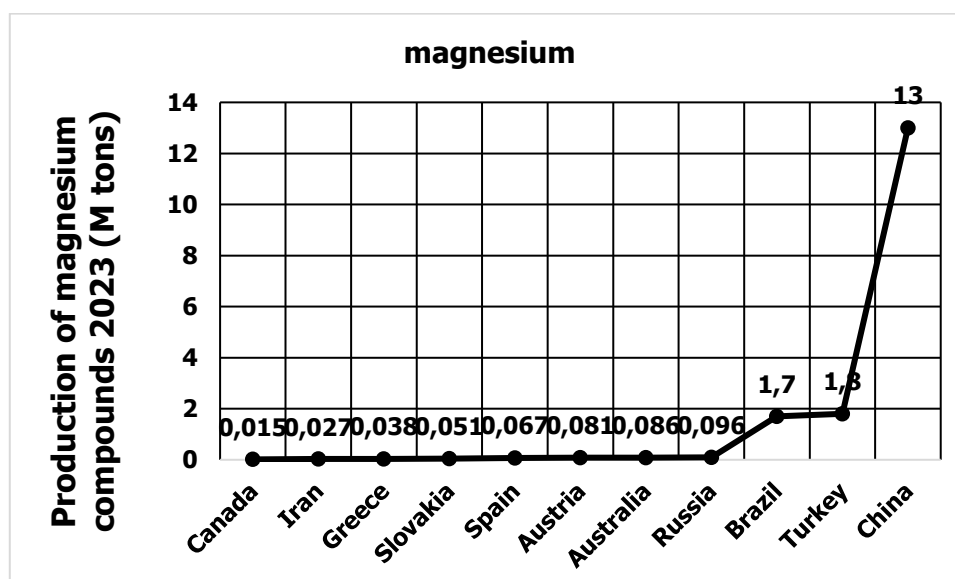


Figure 16. Magnesium production (tons) (Magnesium Production by Country, 2025)

Brazil is the leading producer of niobium and ferroniobium an alloy of 60-70% niobium with iron (Figure 17) (Niobium Market Size & Share Analysis, 2024; Jha, 2024; Gałaś et al., 2024; Mine production of niobium worldwide in 2023 by country). Niobium is used mostly in alloys, the largest part in special steels such as that used in gas pipelines. The Niobium Market size is estimated at 106.85 kilotons in 2024, and is expected to reach 171.49 kilotons by 2029, growing at a CAGR of 9.92% during the forecast period 2024-2029 (Niobium Market Size & Share Analysis - Growth Trends & Forecasts (2025 - 2030)).

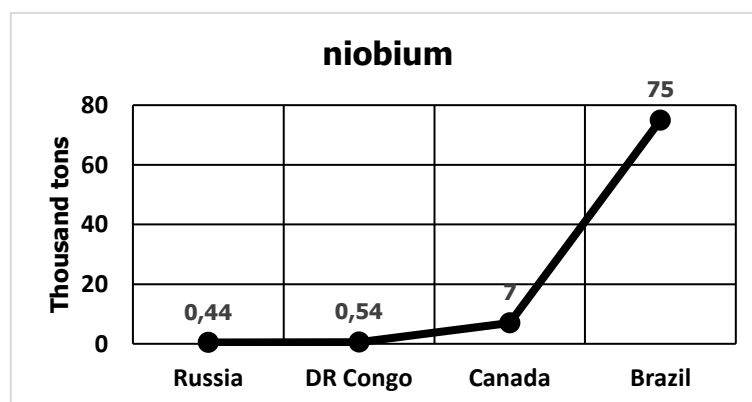


Figure 17. Mine production of niobium worldwide in 2023 by country, (Niobium Market Size & Share Analysis - Growth Trends & Forecasts (2025 - 2030))

South Africa is by far the largest producer of platinum in the world, with production amounting to an estimated 120 metric tons in 2023 (Figure 18) (Raymond, 2024; CME Group, 2025; Ligid, 2024; Platinum Market by Form). Russia came in a distant second place, having produced some 23 metric tons that same year. Platinum is used in vehicle catalytic converters, often in conjunction with palladium and, at times, rhodium. Within a catalytic converter, platinum expedites chemical reactions without undergoing consumption itself. As exhaust gases from an engine pass through the catalytic converter, platinum enables a series of chemical transformations. These reactions minimize harmful pollutants such as nitrogen oxides (NO_x), carbon monoxide (CO), and unburned hydrocarbons, transforming them into less detrimental substances, namely nitrogen (N_2), carbon dioxide (CO_2), and water vapor (H_2O). Given its pivotal function in the automotive industry, approximately 61% of platinum group metals (PGMs) are allocated for use in this sector.

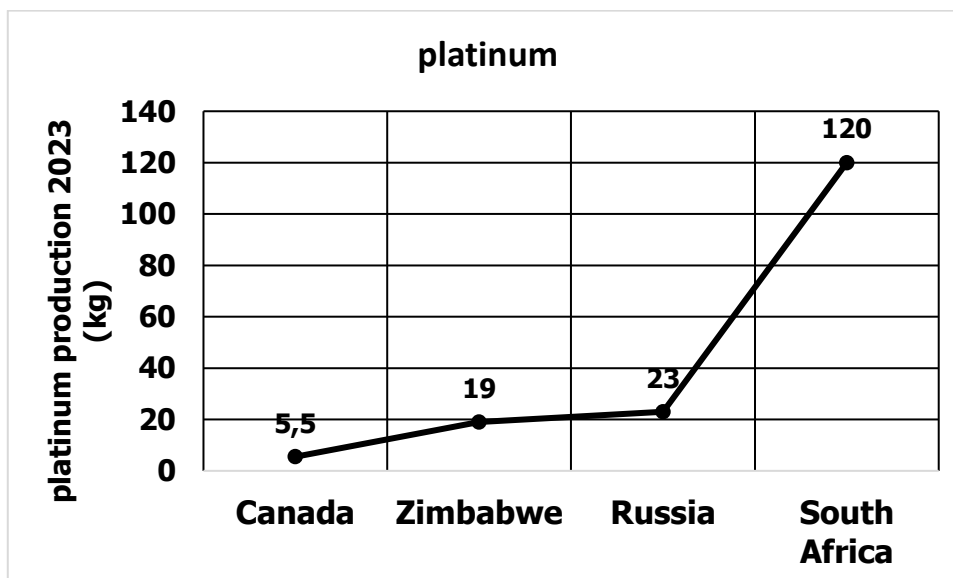


Figure 18. Platinum producer top countries (Platinum Production by Country, 2025)

Tantalum producers are shown in Figure 19 (Tantalum, 2024). Tantalum is the rarest stable element in our entire solar system, with just one atom of tantalum for every 181 billion atoms of other elements (Tantalum Market, 2024; World-Tantalum-Market Analysis, 2020). That makes tantalum far less abundant than gold, or any of the traditional precious metals.

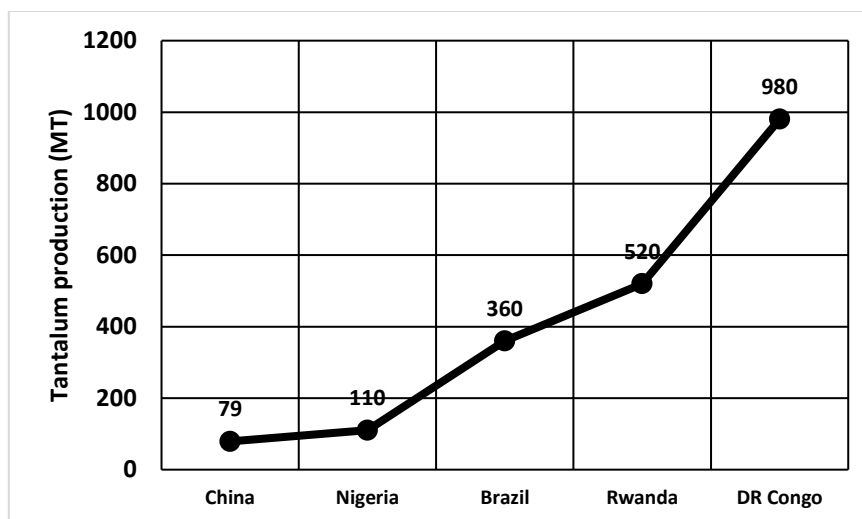


Figure 19. Main producers of tantalum by country (Tantalum, 2024)

Tungsten is found in ores such as scheelite and wolframite. These ores are found around the world but the country that accounts for the most tungsten concentrate production is China, supplying about 83% of the tungsten concentrate produced globally (Figure 20) (Pistilli, 2025; Tungsten Market, 2025). Australia's Tungsten resources are the 2nd largest in the world, accounting for 12% of world economic demonstrated resources, but Australia's current production levels are negligible (Resources, About Tungsten, 2018). Tungsten is nearly as hard as diamond, has the highest tensile strength of all metals, has high electrical conductivity and is thermally and chemically stable. For this reason, tungsten alloys and some tungsten compounds cannot be substituted in its various applications. It is a critical component of engine valves, ballpoint pen tips, tungsten filaments in light bulbs, turbine blades, LCD panels, TV tubes, laser printers, window heating wires, car horns, electrical switch gear, airplane flaps, and is even used in golf clubs. It is also used in the vibrating mechanism of mobile phones, used in the manufacture of specific steels for jet engines, medical and dental equipment and high-temperature resistant alloys. It is a high-tech metal essential for all developed economies.

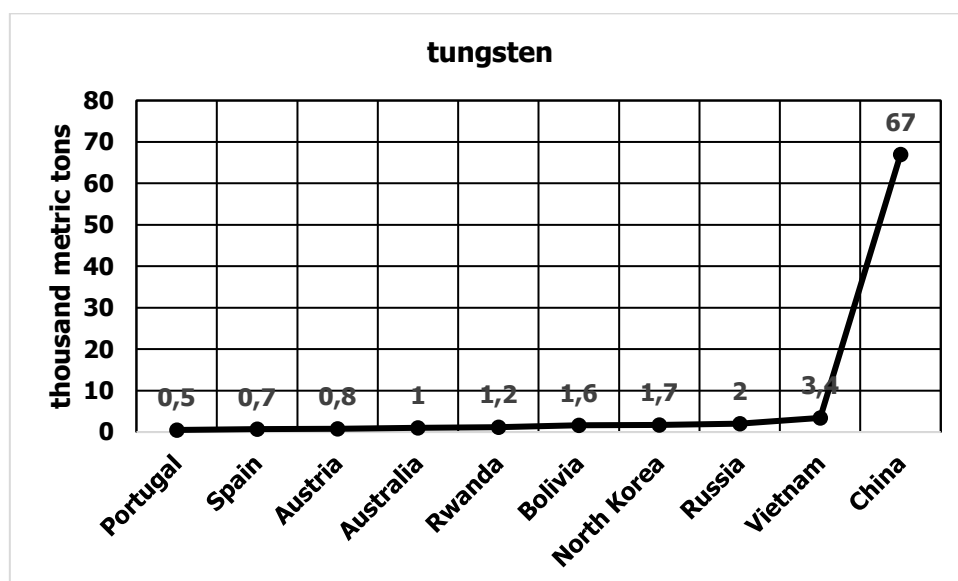


Figure 20. Tungsten main producers, (Pistilli, 2025)

Global dysprosium production was 708 tons in 2022. Of this, 1.13 tons were consumed in the EU. A total of 38,580 metric tons (t) of Dy had entered to the global mining phase, of which Mainland China contributed 87% (Eheliyagoda et al., 2023). Mainland China was the dominant trade partner and accumulatively exported 2,674 t of Dy primary products, 6,354 t of Dy intermediate products, and 3,897 t of Dy final products to the international market between 1988 and 2021. The global dysprosium compounds market was valued at USD 9.63 million in 2023 and is projected to reach USD 13.42 million by 2030, exhibiting a Compound Annual Growth Rate (CAGR) of 4.8% during the forecast period (2024-2030) (Dysprosium Compounds Market 2024-2030).

Dysprosium is used in alloys for neodymium-based magnets. This is because it resists demagnetization at high temperatures. This property is important for magnets used in motors or generators. These magnets are used in wind turbines and electric vehicles, so the demand for dysprosium is high. Dysprosium iodide is used in halide discharge lamps. The salt enables the lamps to emit a very intense white light. Dysprosium oxynitride (a composite material of ceramic and metal ceramics) is used in the control rods of nuclear reactors. It easily absorbs neutrons and does not swell or shrink after being bombarded with neutrons for a long time.

Furthermore, new trends such as electric mobility, clean energy, energy efficiency, and automation are projected to increase the usage of dysprosium, propelling the worldwide dysprosium market growth. Alternatively, different technical advances in dysprosium manufacturing are expected to provide profitable prospects for the development of the dysprosium market in the future years.

The major use of dysprosium is as an alloying addition to $\text{Nd}_2\text{Fe}_{14}\text{B}$ (Yan et al., 2010) permanent magnet materials (in which some of the neodymium is substituted with dysprosium) to increase both the Curie point and especially the coercivity and, therefore, improve the high-temperature performance of the alloy. The metal is also a component of magnetostrictive Terfenol D ($\text{Tb}_{0.3}\text{Dy}_{0.7}\text{Fe}_2$) (Mech & Kaleta, 2017). Dysprosium is used in control rods for nuclear reactors because of its relatively high neutron absorption cross-section. Its compounds have been used for making laser materials and phosphor activators, and in metal halide lamps.

China is the largest country producing rare earth elements, but it is not the only producer (Figure 21) (Pistilli, 2024). As at 2023, China produced more than two-thirds of the total global rare earth mine production. At a distant second place was the United States, accounting for a 12.29 percent share of the global rare earths production that year. The global rare earth elements market size was USD 3.39 billion in 2023 and is projected to grow from USD 3.74 billion in 2024 to USD 8.14 billion by 2032, exhibiting a CAGR of 10.2% during the

forecast period (2024-2032). Asia Pacific dominated the rare earth elements market with a market share of 86.14% in 2023. As much as 98% of the rare-earth elements imported by the EU come from China. Extraction is also highly concentrated in other categories of raw materials: the EU imports 99% of the borate it consumes from Turkish mines, 71% of the platinum it consumes from South Africa, and 85% of the niobium it consumes from Brazil.

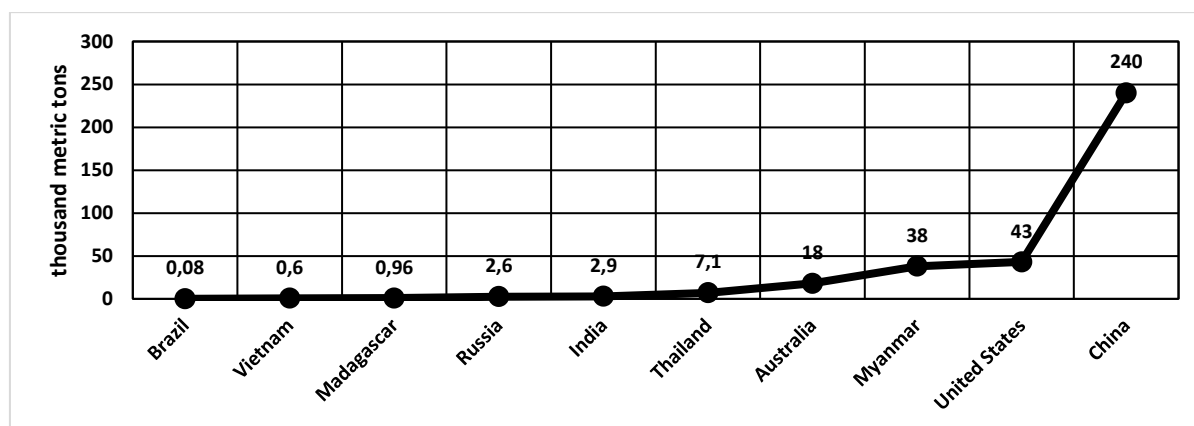


Figure 21. Main producers of rare earths metals (Pistilli, 2024).

Discussion

The market for metals used in the automotive industry is concentrated in several countries around the world. China is the largest producer of steel, aluminum and rare earth metals (Figures 2, 4 and 8) (Bela, 2025; Armstrong, 2023; Andrews-Speed and Hove, 2023; Pistilli, 2024).

In terms of area, China is the third country in the world (9.6 million km²) (Figure 22). In terms of population, the order of countries is as follows: India, China, EU, US, Indonesia, Pakistan, Nigeria, Brazil, Bangladesh, Russia. Economically, China ranks second after the United States of America.

Rare earth metals are a family of 17 metals that includes two scandiums (scandium and yttrium) and all lanthanides (lanthanum, cerium, praseodymium, neodymium, promethium, samarium, europium, gadolinium, terbium, dysprosium, holmium, erbium, thulium, ytterbium and lutetium). They co-occur in minerals and have similar chemical properties. They are obtained from bathnaesite (China and the US) and monazite (India and, to a lesser extent, Brazil, Malaysia, Vietnam and Australia), as well as loparite (Russia). They are not as rare as their name would suggest (they account for a seventh of all elements found in nature). The problem is that the deposits rarely occur in high concentrations. Moreover, the process of extracting them and converting them into usable materials is costly and harmful to the environment. This is because the waste generates radioactive water, toxic fluoride and acids (Śleszyńska, 2023).

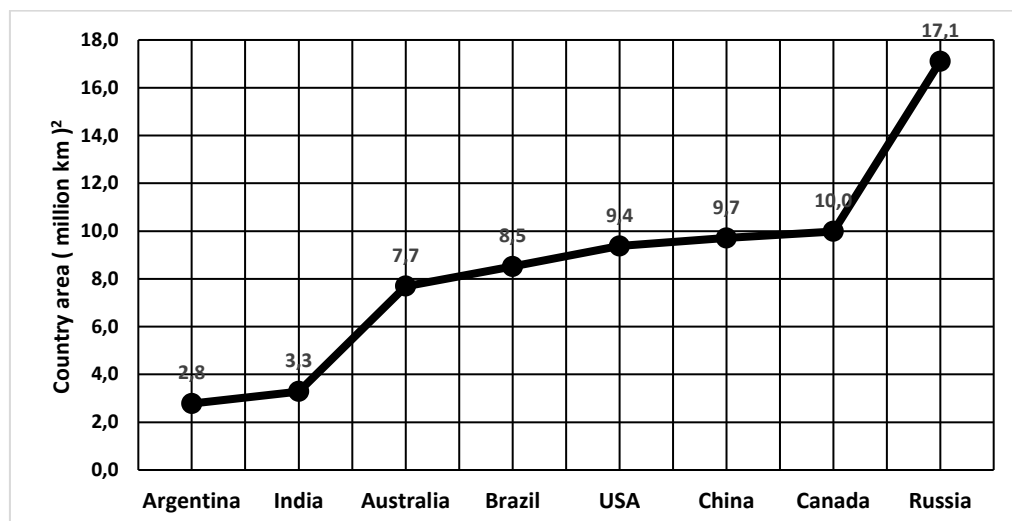


Figure 22. The largest countries in the world in terms of area (Statista, The 30 largest countries in the world by total area)

The concentration of production of critical metals in a few countries around the world leaves economically important raw materials at risk of supply disruption or even interruption. There is also a global dependence on suppliers. The current state of the economy and management of raw materials is due to the search for the cheapest possible materials. The result of this approach is the production of materials sought by the automotive industry mainly in China, which has cheap labor and is not overly burdened by strict environmental directives.

Rare earth metals are also used, among other things, to make lasers, battery electrodes, magnets, magnetic resonance contrast agents, catalysts, precision weapons, satellite technology, and are also used in unmanned vehicles and advanced communications systems (Cieřlik, 2022). China has already mastered almost all of the world's supply of rare earth elements and accounted for 92 percent of global production in 2012. This is due to its huge investment in the industry, low production costs and low environmental standards. In 2010 -2014, China, as a result of the incident with Japan, reduced the supply of these metals which caused a strong increase in prices. This critical incident prompted the search for alternative suppliers. One of them could be Australia, which considered the mining and production of rare earths as a strategic activity. The U.S., too, has changed its approach to sourcing critical materials and has begun to invest in the mining and processing of rare earth metals on its territory. The production of these metals is very much related to the growing demand of the automotive industry focused on the production of electric vehicles. It is predicted that the growth of the automotive industry is likely to result in a several-fold increase in demand for rare earth metals (Figure 8).

Rare earth elements are mined by open-pit mining. This process not only consumes huge amounts of energy, but can also cause environmental problems, such as water pollution and radioactive waste generation, as well as ecosystem disruption (León & Daphne 2023). This is why the US, Australia and other countries did not develop exploration for deposits of these metals until their supply chains collapsed.

Rare earth metals are crucial to economic development. Without them, technological progress would not be possible. Their potential scarcity significantly limits any economy's ability to grow its GDP.

The vast majority of resources of these key raw materials for the world's development are found in China. In addition to China, the largest resources of these elements are found in the US, Australia, India and Russia. There are no sources of these raw materials in the EU. Possible potential sources of rare earth elements in the EU are mainly secondary raw materials, e.g. apatite phosphogypsum, waste electrical and electronic equipment. Due to demand and the need for rare earths in key industries, the search for sources of these raw materials is also underway in the EU.

Vanadium deposits have been discovered in Norway (cire.pl, 2025). In addition, it has been found that 70-80 billion tons of phosphorite ore exist in the studied region. These would be the world's largest phosphorite

reserves, ahead of Morocco (about 50 billion tons) and China (about 3 billion tons). In Norway's Telemark region, 8.78 million tons of rare earth metals have been discovered (Kowal 2024), including neodymium, as well as praseodymium oxide (cire.pl, 2025).

Nickel and cobalt are found in Poland. The use of minerals such as cobalt and nickel, among others, necessary for the production of electric vehicles and energy storage will increase more than 50 times by 2050 (TVN24 Biznes, 2024). Poland can also potentially obtain critical raw materials from waste, e.g. apatite phosphogypsum, waste electrical and electronic equipment. Fly ash from coal combustion also appears to be a prospective secondary source of rare earth elements (Jarosinski, 2016).

In 2008 the European Commission proposed the implementation of the so-called European Raw Materials Initiative, on the premise that "access to and extraction of minerals is essential for the well-being of the EU economy" (Salamon, 2023). In turn, in 2011 the European Commission (EC) identified rare earth elements on the EU's List of Basic Raw Materials and announced its readiness to cooperate with any country that contributes to their mining. In 2013 the European Innovation Partnership Minerals announced a Strategic Plan for their extraction.

Demand for rare earth metals is expected to increase sevenfold by 2040, and for lithium by up to 42 times (Wesołowska, 2023). Currently, the European Union's demand for these metals is met by China, which is the source of as much as 98 percent of the rare earth metals imported by the European Union. The EU is making efforts to ensure a stable and secure supply of key rare earth elements (Secure European Critical Rare Earth Elements, 2022).

Critical raw materials are a loosely defined broader group of chemical elements that includes all rare earth elements. They are raw materials that are critical to industrial and economic development and without which no major large-scale technological achievement in the 21st century will be possible.

Mining and refining rare earth ores present considerable technological challenges and are often harmful to the environment. Ores that contain metals must first be finely crushed. This requires the use of large quantities of toxic chemicals. The process generates hundreds of thousands of liters of toxic wastewater per day, which contains radioactive thorium and uranium, among other things. This is compounded by greenhouse gas emissions and progressive pollution of air, soil, water, leading to environmental destruction. The production translates into health effects for mining workers and a higher incidence of serious diseases among the local population. In addition, intensive exploitation of rare earth ores leads to gradual depletion of deposits. This in turn makes their extraction require more and more energy and chemicals.

The Middle Kingdom has an extensive program of investment in rare earths projects around the world, including in Australia, Canada and Tanzania. Currently, the key region in the world for rare earth elements and the acquisition of what are termed critical raw materials in general is Africa. The interests of not only China but also the United States intersect in Africa.

Africa is home to about 30% of the world's deposits of critical minerals, as well as larger quantities of other minerals (Dadura & Piłkuła, 2024). The Democratic Republic of Congo alone has as much as 70 percent of the world's cobalt deposits. Nearby Gabon has the second-largest manganese deposits in the world and is now the third-largest producer. Countries in need of these precious minerals are struggling with diminishing or no resources on their territory, as is the EU. At the same time, countries whose territories contain deposits of valuable raw materials are so underdeveloped that they are unable to either extract them effectively, let alone use them. In addition, the situation is aggravated by the weakness of the political systems of these countries, which are either shaky democracies or dictatorships. China in 2022 alone imported rare earth minerals from Africa with an average value of about USD 10 billion. African countries see China as a desirable partner for mining operations not only because of the huge sums the Middle Kingdom is willing to invest on their soil. Chinese investments usually do not come with any restrictions or requirements regarding human rights or sustainable development, which often accompanies cooperation with Western countries. That's why today the

extraction of critical minerals in Africa is dominated by Chinese mining companies. China is by far the dominant player in the African mining sector. It has invested more than USD 25 billion in its global Belt and Road Initiative since 2020 alone.

Rare earth metals are mostly sourced outside the European Union, which means that the European community will never be able to achieve self-sufficiency in this area. The only solution to avoid the risk of supply collapse is to diversify the sources of supply of critical raw materials. For the time being, the European Union depends almost exclusively on China for some key raw materials.

Critical raw materials are linked to virtually all industries and at all stages of the supply chain in the EU economy. These include the rapidly growing technologies from the defense and space sectors, which, given the strategic threat to Europe from Russia, gives the issue great importance.

EU arrangements stipulate that at least 10% of the EU's annual consumption of critical raw materials is to come from extraction in the EU; at least 40% of the EU's annual consumption is to come from processing in the EU; at least 25% of the EU's annual consumption is to come from internal recycling; and no more than 65% of the EU's annual consumption of each strategic raw material at the relevant processing stage is to come from a single third country (Ministry of Climate and Environment PL 2024).

The opacity and unpredictability of the rare earths market is compounded by the fact that their largest producer is one country, the People's Republic of China, which dominates the market and can dictate to the entire world the terms of their purchase (Wiejaczka & Wilczyński, 2021).

The intensification of the green deal in the EU, the lack of sources of critical raw materials and the low recovery from recycled materials result in dependence on external supplies.

The environmental trends prevalent in the EU are a significant barrier to manufacturing activity, a source of increased production costs and reduced product competitiveness. The EU tries to prevent the competitiveness of cheaper products by imposing tariffs, which in turn causes political friction between countries and economic retaliation.

Thus, it can be concluded that the policies of countries significantly affect their economies. Despite the apparent independence of the market, it is strongly controlled by political ideologies, ecological approaches to the economy and the resulting regulations.

In light of the facts presented, the assumptions of the introduction of a green deal in the EU, manifested in trends in the automotive industry, and especially the huge time pressure for their introduction, will not be conducive to the development of the economy. The production of electric cars, which requires the use of critical metals, includes non-organically sourced components and raw materials, hence, in principle, does not meet the environmental criterion (The World Bank, 2022). Production itself is expensive and not everyone can afford these cars. The question arises as to whether the mode of economy chosen by the EU is correct. The ecological trends currently prevailing in the EU impose many restrictions on the conduct of technological processes that, on the one hand, benefit the environment and protect against pollution (Zgnilicki, 2025). On the other hand, they reduce competitiveness due to higher production costs. It is necessary to balance leading to sustainable development that ensures the most favorable production conditions while protecting the environment. It is difficult to assess to what extent environmental trends should influence automotive development and whether the chosen direction of electromobility will actually lead to meeting the requirements of green production. It seems that multidirectional measures involving innovative cleaning of exhaust gas from combustion cars, production of electric and hydrogen-powered cars should proceed in parallel. None of the solutions exhausts the assumptions of green transportation, but neither do any of the solutions have zero environmental impact in terms of the entire manufacturing and product life cycle, including recycling and waste disposal.

The conducted research on the subject literature and data obtained from studies of the most important institutions analyzing the world economy lead to the conclusion that the source of basic raw materials decisive for technological progress are several countries, with China occupying the decisive position as the producer of the most important critical minerals. The practical value that arises from this proposal is the awareness of the need to make significant changes leading to greater EU independence from supplies of critical minerals. It is clear that the current distribution of mineral sources is not possible to change quickly. This is particularly true for the European Union, which is fully dependent on supplies from other continents. This is associated with supply risks and the prospect of economic dependence. Building supply diversification, and even more so independence in obtaining critical metals, in conditions of Chinese hegemony, is practically impossible. The EU does not have a developed flexible strategy for supply and sources of the necessary minerals. The technological policy to date has caused delays in the search for critical mineral deposits in the EU. China not only processes domestic minerals but also raw materials from other countries, which is why it is a monopolist, e.g. in lithium production. Investments in the processing industry in the EU are hampered by EU environmental protection directives. This policy does not allow for the creation of competition with foreign production and independence from supplies, and is also associated with high risk. Greater openness to the possibilities of processing minerals obtained from countries outside the EU, intensive search for deposits, which is already beginning to be observed, is the expected direction of development of the EU. It is certain that in order to meet the current economic challenges, a flexible and open approach to multidirectional solutions based on various technological possibilities that shorten supply chains to the maximum is necessary.

Conclusions

The influence of the environmental megatrend extends throughout the global economy, affecting the production of consumer goods in different countries of the world to varying degrees. In this context, focusing on the automotive industry, there are some specific factors affecting its development.

1. Environmental megatrends in the automotive industry have spearheaded the development of electric car production, which involves the need for critical raw materials, which the EU does not have deposits of and must import.
2. Automobile production in the EU depends on the supply of critical raw materials from China and other countries, sourced and produced in violation of environmental and ecological standards.
3. Growing awareness of the need to protect the planet is influencing the search for green industrial solutions, but progress has been slow and requires huge investments.
4. The simultaneous production of electric vehicles and technically innovative conventional vehicles is potentially the most favorable prospect for individual mobility

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