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Case Report

Selected Metal Materials in Automotive Electrical Engineering—A Brief Overview of the State of the Art

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Abstract The work presents selected material issues related to the development of modern motorization. The advantages and threats of obtaining key materials for the automotive industry were analyzed. Aspiration to radically reduce CO_2 emissions sets the main trend in the automotive industry focused on the production of electric cars. The production of electric cars is closely related to the development of innovative battery production technologies using such critical elements as lithium, magnesium, nickel, cobalt, and graphite. Their acquisition and production of components is concentrated in several countries around the world, including China, which is their main supplier. The lack of diversification of supplies and the huge expected increase in demand for these materials, resulting from the exponential growth in the production of electric cars, pose threats to supply chains. One of the solutions is the development of effective technologies for battery recycling. There is a risk of losing many jobs as a result of changes in the automotive market and the withdrawal of classic cars from production. Taking into account the scope, pace, and changes resulting from changes in the automotive industry, in particular in the field of materials, one should expect their global impact on the economy.

Keywords electric cars; raw materials; aluminum alloys; trends; supply chains

1. Introduction

Modern cars, apart from steel elements, contain mostly aluminum alloys, plastics, and composites. The development of new concepts and designs in the automotive industry is closely related to material advances, such as multifunctional materials [1]. The focus of the automotive industry on new lighter materials entails an increase in production costs, which results in higher prices for cars. New generation cars, such as electric cars, use critical elements such as lithium, cobalt, magnesium, nickel, and graphite, which have been used to build lithium batteries for over 10 years [2,3]. Innovative solutions in the automotive industry are not only new materials and technical solutions, but also digitization and computerization of the cars themselves [4]. There are already many different solutions, including connecting the car to the World Wide Web, providing cars with cameras, displays, digital keys, security systems, and others.

The directions of development of the automotive industry are constantly changing, due to not only innovative material and drive solutions, but also restrictive and government regulations (EU, the European Union). Many studies highlight the risks associated with, among others, the high purchase price of electric and hybrid cars, low maximum range on a full charge, extended charging times, and lack of related infrastructure [5]. Trends of importance to the automotive industry are derived from megatrends that affect all areas of modern social life [6]. Globalization, the fourth industrial revolution, climate change, and the aging of societies are the main sources of the observed key changes [7]. The most important trends that are responsible for the pace and direction of changes in the automotive industry are the growing importance of alternative drives and electromobility, the drive to introduce autonomous (self-driving) vehicles, moving away from owning a car in favor of sharing, designing networked vehicles and frequent updating of the offer of available motor vehicles, adequate to the constantly changing needs of consumers. The prospects for the development of the automotive industry are also related to the elimination of their emissivity and the availability of cars for consumers [8,9]. The development of the infrastructure supporting electric cars is of key importance [10]. Another issue is the smooth supply of materials and components for car construction. The disruption of the supply chains of certain materials, which is currently felt, is a challenge for the global economy and has a significant impact on the

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automotive market [11]. In particular, the sourcing of lithium, nickel, cobalt, magnesium, and graphite is crucial for the construction of batteries used in electric cars [12,13]. Disruptions in the supply chain account for a third of the increase in delivery times in the last six months of 2022 [14]. Also, empirical analysis confirms that supply chain shocks account for about a third of tensions in global manufacturing networks in 2022 [15]. Organizations may have limited access to critical data and production inputs, spare parts, and critical maintenance items for existing equipment, tools, and consumer goods. As a result of these disruptions, the prices and availability of key commodities can fluctuate. Building resilient supply chains to fight future disruptions and adapt quickly to new changes will be key to dealing with such threats [16]. A certain solution to this situation may be the diversification of supply, which, by drawing supplies from various sources, will at least partially overcome supply difficulties [17]. Critical raw materials that are used in the automotive industry have a high risk of supply disruption, which affects and matters for the entire economy of the European Union [18]. An increase in demand for these raw materials is expected in relation to the current supply and difficulties in scaling production. The EU must closely monitor strategic and critical material supply chains with risk management tools to help identify and manage potential disruption risks.

This review paper represents the technological and materials trends in motorization. The rest of the paper is organized as follows. Section 2 presents the benefits of aluminum alloy application in motorization, especially the ability to absorb the kinetic energy of a collision in crash boxes. Section 3 elaborates on concepts of trends and materials used in electrical cars. Section 4 analyzes the possibility of battery recycling sources of obtaining critical elements for electric car batteries and threats in the supply chains of these materials. Section 5 is the discussion of the paper. In Section 6 conclusions are presented.

2. Aluminum Alloys in Cars—Benefits

Aluminum alloys successfully replace steel elements in cars. A lot of such elements are found especially in higher-class cars. For example, in Audi, the space frame of the car consists of extruded, cast, and forged sections made of aluminum alloys, which effectively absorb kinetic energy in the event of a collision [19]. The use of aluminum elements in cars has the advantage of reducing the weight of the car, which translates into lower fuel consumption and lower CO_2 emissions [20]. However, aluminum components are more expensive to produce than steel components [21], which in turn results in a higher price for the car [22–24]. However, when it comes to the cost of steel vs aluminum, steel is usually less expensive. In saying this though, we must distinguish which type of steel we are talking about. Mild steels and carbon steels tend to be less expensive than aluminum, but stainless steel is more expensive than aluminum. New high-strength materials, such as various grades of DP, TRIP, and TWIP steels, are being researched, as well as press hardening steel (PHS) and its use in the production of high-strength car body components [21]. Strength is often one of the first properties considered when selecting a material, especially in high-stress applications. Generally speaking, steel is stronger than aluminum. That said, once the lighter weight of aluminum is factored into the equation, aluminum comes out on top with a superior strength-to-weight ratio.

Identifying which metal has the better strength for your application will depend on your design's flexibility. For example, a larger aluminum part may offer more strength at a lower weight than the steel alternative. The cost of materials is obviously a significant factor that will affect the cost of the project. The price of steel and aluminum varies depending on the market and the specific alloy, so it is difficult to say that one material will be cheaper than the other in any context of application. However, it is widely accepted that carbon steel is generally less expensive per pound than a comparable aluminum alloy.

Reducing the weight of electric cars by replacing steel with aluminum alloys and composites will lead to a reduction in the demand for battery power. This would reduce energy consumption. The perfect element that meets the requirements of reducing the weight of cars is aluminum, and basically its alloys [21]. The use of aluminum for the production of electric cars results from its high resistance to corrosion, good absorption of the kinetic energy of a collision, and above all, lightness [25]. Studies have shown that Aluminum Intensive Construction (AIV) can achieve a 25% reduction in vehicle weight. This results in a 20% reduction in total primary energy consumption over the vehicle's life cycle and a 17% reduction in CO_2 emissions (Figure 1). The vehicle's AIV design showed the best mileage break-even point in terms of both energy consumption and climate protection [26,27].

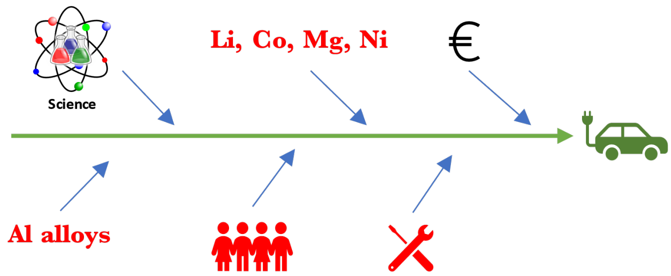

Figure 1. Electric cars value chain.

Aluminum is fully recoverable through recycling [28]. The production of primary aluminum, when all the electrical generation, transmission losses, and transportation fuels have been accounted for, requires ~45 kWh of energy and emits ~12 kg of CO_2 for each kilogram of metal. By contrast, the recycling of aluminum requires only ~2.8 kWh of energy and emits only ~0.6 kg of CO_2 for each kilogram of metal. Thus, ~95% of the energy and ~95% of the environmental emissions are saved when aluminum is recycled [29].

The future perspectives for aluminum application in electric cars result from not being the only way to reduce the weight of cars. A beneficial solution would be to reduce the average size of cars and reduce the consumption of aluminum in order to reduce the weight of the batteries [30]. There are also other lightweight automotive materials such as Advanced High Strength Steel (AHSS), advanced composites, plastics, or multi-material solutions [31]. However, their production requires mastering the technology and is associated with costs, carbon footprint assessment [32], and recycling studies. However, the automotive industry still seems to favor aluminum, at least in the near future [33–36].

Different car brands design and use aluminum to varying degrees in specific body parts. Very often these are elements such as crash boxes [37,38]. The energy absorption of the crash boxes, made of extruded aluminum alloy sections, reduces the risk of a crash and increases safety [39–42]. It is safety in the operation of cars that is one of the priority areas of interest in transport engineering, to which car designers and manufacturers devote a lot of attention. The crashworthiness of the structure was investigated in the work of Asri et al. [43]. The paper of Kamboy et al. [44] focuses on analyzing the potential of aluminum alloy as a candidate material in leaf springs so as to make the suspension system lighter and more reliable. A separate issue related to the use of different materials in cars, as well as different types within a given material, is their safe connection [45]. Testing of welded elements made of EN AW-6082 and EN AW-7075 alloys was the subject of the paper by Wojdat et al. [46]. Aluminum welded joints in transport were also tested in the paper by Szczucka-Lasocka et al. [47].

Thin-walled tubes and sections provide excellent energy absorption during axial loading. This is used in cars as an element that compensates for the kinetic energy of a collision. When thin-walled tubes are axially compressed, they undergo symmetrical or asymmetric deformation, depending on the ratio of their diameter D to wall thickness t (D/t). The deformation is also dependent on the ratio of pipe length L to its diameter D (L/D) [48]. An important issue in the strength of materials, in addition to strength and deformability calculations, is the stability of the system. The equilibrium is stable if any slight deformation of the system causes forces to restore it to its original form. If the compressive force P increases, then at a certain value P_{kr}, the minimum impulse will cause the system not to return to the rectilinear equilibrium state, but to remain in a curvilinear form. The ratio of the pipe wall thickness to its diameter is the dominant factor in the method of crushing the pipe [49]. This factor determines the type of buckling during compression. Asymmetric or diamond buckling is possible. The thinner the walls of the compression section, the more the diamond crushing method is preferred. Symmetrical compression deformation of hollow sections (e.g., pipes) is often referred to as annular mode or concentric mode, while when the crushing is unsymmetrical, it is referred to as diamond mode [50,51].

The diamond mode is characterized by the number of humps that appear on the pipe during compression. For certain values of D/t, the tube may start deforming from the ring mode and then change to the diamond mode, thereby exhibiting a mixed mode. Pipes and sections can also be crushed by Euler mode, for example, warping, which is a catastrophic load that causes the pipe to flex so much that it results in a significant loss of energy absorption capacity [52,53]. Research is being carried out on the stability of deformation and the possibility of increasing the absorption of kinetic energy during the deformation of thin-walled sections under compression. It has been shown that the complete diamond mode is more efficient in terms of energy absorption than the symmetric mode [54]. In the work of Sadighi et al. [55], it has been shown that by the use of the new axially half-corrugated tube, there is much more efficient crushing via a more uniform force-displacement result as well as a considerable improvement in other crashworthiness characteristics. The latest attempts concern the deformation of hybrid aluminum alloy pipes reinforced with carbon fibers [56]. Compression tests of hybrid pipes showed better energy absorption during a car collision than classic pipes. Mondal et al. [57] present an interesting study of crash boxes filled with aluminum foam. It was observed that crash boxes filled with this foam perfectly absorbed impact energy. At the same time, due to the negligible weight, the weight of the vehicle was hardly increased.

3. Electric Cars—Effect of Green Perspective

According to analysts, the increase in popularity and sales of electric cars is a key trend in the automotive industry [58]. This is due to at least two factors: legal regulations established on the international forum and the attitudes of modern consumers, in particular citizens of highly industrialized countries, who are increasingly involved in activities preventing further negative climate change [59]. Government agencies play a significant role in the growing emphasis on sustainable practices [60]. New directives such as the European Green Deal and the Paris Agreement are forcing automotive companies to look for solutions to meet stringent carbon neutrality goals. For example, the European Commission is demanding a reduction of CO_2 emissions from vehicles by 55% by 2030 and 100% by 2035. Compliance with this recommendation makes it practically impossible to sell vehicles powered by fossil fuels in the European Union. The forcing actions of politicians are therefore the main reason for focusing the development of the automotive industry on electric cars. It is controversial to ensure that cars are powered by green energy, which currently in many cases still comes from production based on fossil fuels. In electric cars, critical elements are used, the production of which is not always ecological [61].

Currently, lithium-ion batteries are the dominant type of rechargeable batteries used in electric vehicles (EVs) [62,63]. The most commonly used varieties are lithium cobalt oxide (LCO), lithium manganese oxide (LMO), lithium iron phosphate (LFP), lithium nickel cobalt aluminum oxide (NCA), and lithium-nickel-manganese cobalt oxide (NMC). Graphite is currently widely used as the anode in lithium-ion batteries [64]. These EV battery chemistries depend on five critical minerals whose domestic supply is potentially at risk for disruption: lithium, cobalt, manganese, nickel, and graphite. The US Geological Survey designated these and other minerals as "critical" according to the methodology codified in the Energy Act of 2020. China accounts for over 70% of global electric vehicles' battery cell production capacity.

The growing demand for electric vehicles contributes to a significant increase in the demand for a key component of this type of vehicle—lithium-ion batteries. According to the BNEF forecasts global lithium-ion battery production capacity is projected to increase eightfold by 2027 reaching about nine Gigawatt-hours (GWh) [65]. The largest lithium-ion battery factory in the world is currently operating in Poland, launched by LG Energy Solution in Biskupice Podgórne near Wrocław. Its target output will reach 115 GWh per year.

Lithium production's predicted to triple by 2025, due to a surge in electric vehicle (EV) purchases [62]. The leading producer of lithium from brine is Chile and the leading producer of lithium from pegmatites is Australia. The combination of lithiophilization and inexpensive liquid coating techniques could be suitable for the battery manufacturing industry [66,67].

Cobalt is an element mined in Congo, Finland, Australia, Brazil, and Canada [68]. The Democratic Republic of the Congo (DRC) is by far the largest producer of cobalt, accounting for 62% of global production since 2010 and 70% in 2021 [69]. Global cobalt reserves are currently around 7600 kilotonnes. Similar to production, cobalt resources are concentrated in the DRC, which accounts for around 46% of global reserves. Important cobalt ore deposits are also found in Australia, Cuba, the Philippines, Russia, and Canada. This increase in demand will continue even as scientists around the world, including those from the Faraday Institution, are developing alternative battery chemistries that require less of its use [70].

Manganese, being a Strategic Raw material, used in steelmaking and batteries became critical due to Supply Risk increase at the extraction stage caused by lower domestic supply dropping from 32t to 10t (Bulgaria and Hungary production stopped) increasing import reliance and by more concentrated imports from South Africa 41% (33% in 2020) and Gabon 39% (26% in 2020 [71].

Nickel is one of the most widely used metals on the planet [72,73]. According to the Nickel Institute, the main sources of magnesium extraction are Australia, South Africa, Gabon, China, and Brazil. Russia was the leading producer of nickel in 2011, followed by Indonesia, the Philippines, and Canada [74]. The bulk of the world's known nickel reserves are concentrated in Australia, Brazil, Canada, Cuba, New Caledonia, and Russia.

Today, graphite is used across various industries such as automotive, steel-making, the nuclear industry, powder metallurgy, fuel cells, and flame retardants [75]. This wide use is the result of graphite's many different properties. Graphite is strong yet flexible, a good conductor of electricity and heat, but it is also fire and cold-resistant [76,77]. Graphite is a key mineral for the energy transition, contributing to cleantech solutions. The global demand for graphite could grow by up to 500% by 2050, compared to 2018 levels [78]. Expected sharp increases in demand combined with perceived high supply risks led to the categorization of certain minerals as "critical minerals" (in the US [79] and Australia [80]) or "critical raw materials" (in the EU [81]) [82]. There are two different sources of graphite: natural and synthetic graphite. Although both are called graphite, they are essentially very different commodities with unique properties. Natural graphite occurs in a variety of geological settings around the world. It is classified into three—physically distinct—deposit types: amorphous graphite, vein graphite, and flake graphite. In 2021, China remained the world's largest producer of natural graphite, with a global market share of 79% [68]. Europe only provides about 3% of global natural graphite. Notably, Ukraine is the largest natural graphite producer in Europe, providing approximately half of all European production, followed by Norway with 38%, Turkey with 8%, and Germany and Austria with only approximately 1% each. Other important actors in the global mining of natural graphite are Mozambique, Brazil, Madagascar, India, and Russia [83].

As a result of changes in car drives, the automotive industry is forced to work closely with the oil and gas industry. Oil and gas companies are turning into companies offering electric charging stations for vehicles and other alternative fuels in order to sustain the growing mobility sector based on new car power solutions.

The pressure exerted by government agencies is significantly changing the perception of consumers, employees, and leaders of the automotive industry. First of all, despite various controversies related to the insufficient development of service facilities, the production of electric cars is growing.

As a result, some jobs have become redundant and the traditional production process on the assembly line has become obsolete. It can therefore be concluded that changes in the automotive industry have a significant impact on the global economy by affecting employment and the required qualifications [84]. The production of electric cars is modular. The car is parked in one place, and specialized, highly qualified teams come to the car and carry out the various stages of its construction. This has a positive impact on sustainable means of production as it reduces the amount of workspace and lowers energy and manpower consumption. The industry faces significant challenges related to the development of value chains [85], supply chains [86,87], secure data transfer and data management [88], electrification of industry [89], including vehicles and charging stations [90], battery life cycle management [91] and sustainable business practices [92], which are to lead to a reduction in carbon dioxide emissions and a reduction in production space [93] (Figure 2). Cars, not only electric ones, are changing as a result of the expectations of customers, investors, and even employees. This has a big impact on the industry. Technologically advanced and environmentally conscious consumers are increasingly demanding intuitive information technology and sustainable practices in vehicles [94]. In addition to external pressure from customers and investors, many automotive companies are also experiencing internal pressure from a changing workforce that rejects traditional methods and ways of thinking [95]. A new generation of employees is tech-savvy and environmentally conscious, which is conducive to changes in the automotive industry toward an increase in the production of zero-emission cars [96–99].

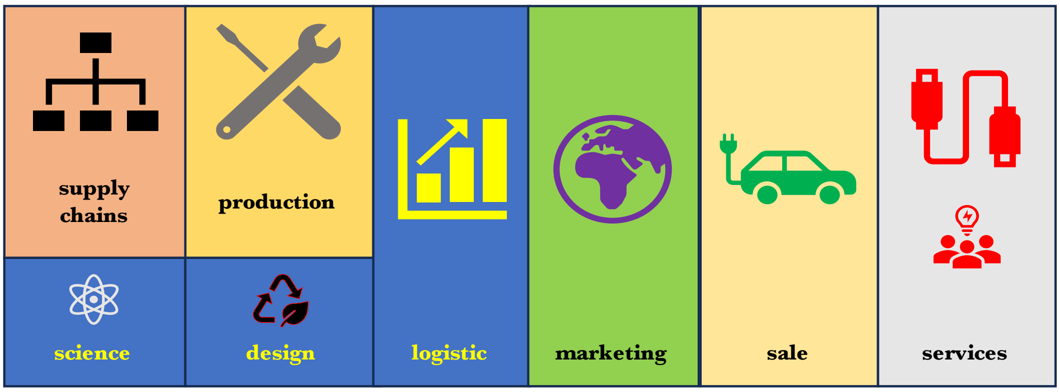

Figure 2. Supply value in electric car production.

The main megatrend in the automotive industry that is driving innovative change is the focus on the production of electric cars. Shifting to electric car production will make some jobs redundant and obsolete the traditional assembly line production process [100]. Sustainable development requires cooperation and joint actions along the entire value chain in the automotive industry [101]. In particular, this concerns closer cross-industry cooperation and the use of advanced technologies to increase the flexibility and resilience of supply chains [102–104]. Supply chain issues focus on secure data transfer and management, access to charging stations, battery lifecycle management, and sustainable business practices that should lead to carbon reductions [105–107].

4. Acquisition and Recycling of Key Materials Used in the Automotive Industry

The type of connection between components and parts directly affects the recyclability of scrapped vehicles and other products. Some materials cannot be recycled individually because they are combined with other materials and cannot be separated or disassembled [108]. Hence initiative to design devices in such a way that they are as accessible as possible for future recycling at the end of their useful life. Such a design is not always possible but highly recommended.

A typical lithium battery used in electric cars, in weight percentage (g material/g battery), comprises about 7% Co, 7% Li (expressed as lithium carbonate equivalent, 1 g of 5.17 g LCE), 4% Ni, 5% Mn, 10% Cu, 15% Al, 16% graphite, and 36% other materials [109]. All the elements listed above belong to the so-called critical elements [110].

On average, an electric car requires six times more critical minerals than a conventional car. The risk of supplies of these materials is high due to disruptions in the supply chains resulting from both the location of the sources of extraction of critical elements and global economic systems.

The largest producers of lithium are: China, Chile, Argentina, Australia, Brazil, Zimbabwe, and Portugal (Figure 3) [111]. The biggest producers of nickel are: Indonesia, the Philipines, Australia, Brazil, New Caledonia, Russia, China, Canada, and the US [112,113] (Figure 4). The biggest producers of cobalt are: Congo (DRC), Russia, Australia, Canada, Philipines, Cuba, PapuaNew Guinea, Madagascar, and China (Figure 5) [114].

China is the largest consumer of lithium because of its booming electronics and electric vehicle industries. Close to two-thirds of the globe's lithium-ion batteries are made in China and it controls most of the world's lithium-processing plants [115]. China is also the biggest consumer of nickel (Figure 6) [116]. On a regional basis, China is the largest and fastest-growing cobalt consumer, sweeping approximately 32% of global consumption in 2020 when the second-ranked Europe seized about 23% and the No. 3 United States 18%. The global cobalt resource reserves are roughly 7.1 million tons, as is revealed by the data from USGS [117].

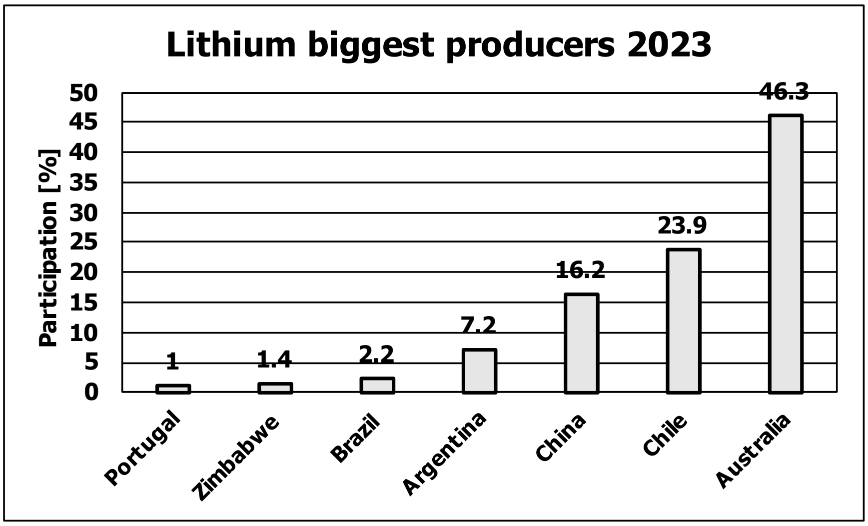

Figure 3. Lithium biggest producers, 2023.

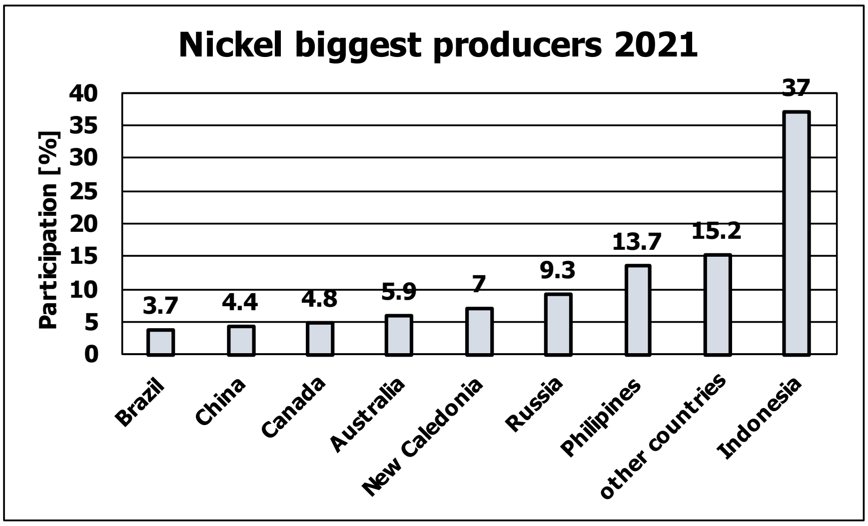

Figure 4. Nickel biggest producers, 2021.

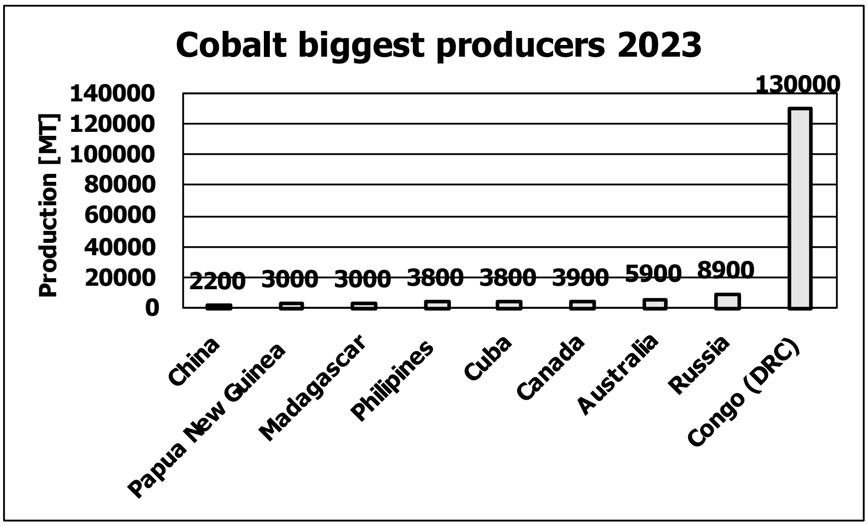

Figure 5. Cobalt biggest producers, 2023.

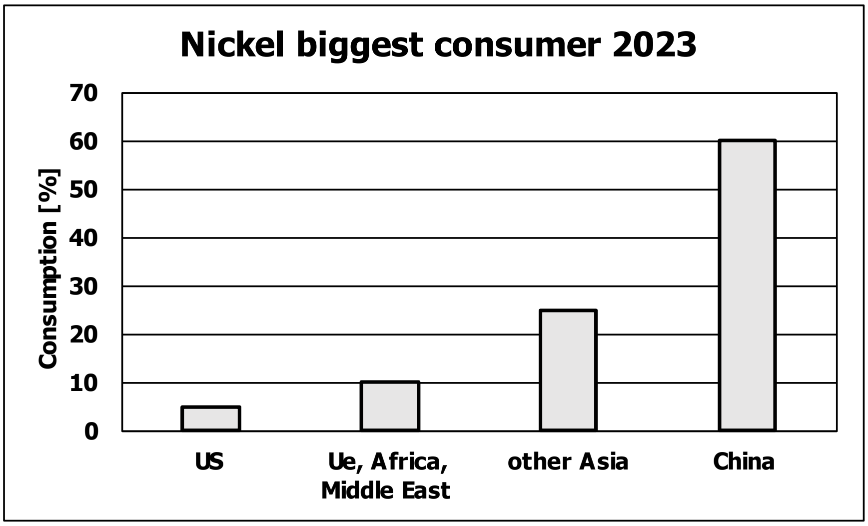

Figure 6. Nickel biggest consumers, 2023.

An important problem is the dependence of deficit elements on supplies from several countries in the world. The risk arises because the diversification of supplies is limited, which, with increasing demand, makes supply chains inflexible. In particular, battery production is dependent on China, which has the largest share of supply chains.

Given the enormous expected growth of the e-mobility sector in the coming decades, compared to its relatively low market share currently, this sector includes the materials with the highest relative increase in demand. This applies primarily to such strategic materials as lithium, graphite, cobalt, nickel, and manganese, the most relevant for batteries [118]. In this regard, there is a heavy dependence on imports from one country, namely China. This dependence, combined with increased demand and global competition to secure access to the same pool of resources, significantly increases the risk of disruptions due to environmental and geopolitical reasons. In many cases, alternatives for diversifying supply from like-minded and reliable countries may not exist. Li-ion batteries (LIBs) are strategically important to the attainment of a more sustainable and decarbonized Europe. The main components of a LIB are the cathode, anode, electrolyte, and separator. Cathodes and anodes are made of different materials that characterize the battery's performance. Forecasts reveal that the Chinese dominance across all segments of the LIB supply chain is expected to continue over 2030 but to a lesser extent, as supply globally will be diversified (e.g., for lithium). Regarding the EU, Australia and Canada are the two countries with the greatest potential to provide additional and low-risk supply to the EU for almost all battery raw materials [119]. In addition, Serbia [120] is a likely source of lithium minerals for conversion to chemicals, and Norway [121] is a reliable source of flake and, potentially in the future, of refined graphite.

The most frequently used LIBs installed in electric vehicles are made from battery cells consisting of nickel manganese cobalt mixed oxide (nickel-manganese-cobalt NMC) [122] as cathode active material and graphite as anode active material [123]. More than half of the cell volume of nearly 200 GWh installed in the first half of 2022 was based on the NMC technology. Consequently, their components lithium-nickel-manganese-cobalt-graphite (natural and artificial) are not only necessary for the functionality of the NMC but also directly linked to the success of electromobility, due to the cost factor [123,124]. Developing the ability to reuse and recycle batteries could significantly reduce costs and reduce dependence on international supply chains [125].

The growing demand for batteries for global light-duty and heavy-duty vehicle electrification is directly linked to increasing demand for battery materials, such as lithium, cobalt, manganese, and nickel. For some of these materials, especially cobalt and lithium, the majority of the current mining capacities, as well as future reserves, are regionally concentrated in only a few countries. To reduce the corresponding dependence on raw material imports, it can be of strategic interest for an economy to utilize the full lifespan of end-of-life vehicle batteries in second-life applications, and to ramp up the recycling infrastructure for efficient recovery of those materials [126–128]. Assuming that only battery technologies currently available on the market will be used in the future, the cumulative demand for battery raw materials from 2020 to 2040, with or without recycling, would be 11 or 12 million tonnes of lithium, 48 or 55 million tonnes nickel, 3–4 million tonnes of cobalt and 5–6 million tonnes of manganese.

In the case of lithium, nickel, and cobalt, this corresponds to about half of the world's economically recoverable reserves from 2022 and about 13–18% of the total estimated resources [126,129]. For this reason, it is necessary to develop battery production technologies that are less dependent on critical minerals, as well as to reduce the demand for new vehicles. In light of these data, the trends in the green automotive development policy probably need to be deeply reconsidered.

5. Discussion

With regard to the classic production of combustion cars, the reduction of emissions results from the use of modern catalytic converters. Catalytic converters eliminate more than 95 percent of harmful emissions from gasoline engine exhaust. BASF's Three Way Conversion Catalyst (TWC) has a patented platinum, palladium, and rhodium design that enables the oxidation of hydrocarbons (HC), carbon monoxide (CO), and nitrogen oxides (NOx) [129]. TWC technology has a lower light-off temperature and minimizes hydrogen sulfide emissions without the use of nickel. The technology of reducing emissions through the use of catalytic converters in classic cars, at the moment, seems unmissable as one of the ways to cleaner air [127]. The answer to the postulate of further reduction of CO_2 emissions and zero emissions in the middle of the 21st century is the introduction of electric cars into production. Their production requires the use of lightweight materials, such as aluminum alloys, to compensate for the heavy weight of the batteries. With regard to battery production, it is necessary to manage the life cycle of batteries and electric vehicles, sourcing and recycling critical raw materials. In many ranges, their development cannot be predicted precisely, and are even highly uncertain in many instances. Helbig et al. [130,131] predict that despite the changes taking place classic core competence of OEMs, vehicle production remains the core business. Manufacturing 4.0 and e-mobility could reduce OEM manufacturing by 24%. The management of such processes is likely to cause considerable controversy on the internal scale of enterprises as well as on the scale of the public debate.

It is likely that reduced demand for workers in the automotive sector due to technological transformation will not be offset by higher demand for labor in other parts of the economy [132]. Such a situation may involve significant adjustment costs, at least in the short or medium term.

A particular challenge of the future automotive industry is to support measures to reduce CO_2 emissions [133]. Therefore, there is a need for batteries with increased energy capacity and fast charging capabilities. Therefore, high-performance battery materials are being developed to help advance the development of electric vehicles and contribute to cleaner air [134].

So far, key materials for the green automotive industry, such as aluminum, lithium, magnesium, cobalt, nickel, and graphite, are sourced in several countries such as Australia, China, Norway, and Argentina. This affects supply chains and can be a source of risk. Recycling of batteries, and not only batteries, is becoming an important long-term requirement of the electrical market due to increasing demand and material shortages, and lack of supply diversification.

Capacities for the recovery and recycling of critical materials are highly desirable due to the projected strong growth in the production of electric cars, and on the other hand, the weakness and threats to the supply chains of these materials [126–128].

There are very intensive efforts to replace combustion cars with electric cars in the European Union. The changes largely result from the EU and government directives [60]. Carrying out such a step change is associated with numerous challenges, including the construction of infrastructure that cannot keep up with the increase in the number of electric cars. Despite limitations in infrastructure and the high prices of electric cars, the number of cars sold is growing [65,135].

The very construction of electric cars requires significant changes, in particular, it concerns the material side based on a significant share of critical elements and the need to use light but expensive materials such as aluminum alloys [21]. Materials used for the production of electric cars are not only expensive, which entails an increase in the price of electric cars, but also difficult to obtain. The supply chains of materials for the construction of electric cars are characterized by significant risk [110] related to the limited number of places of their sourcing (Figures 3–5). One of the solutions is the recycling of materials used in electric motoring, but it does not fully meet the needs. The presented problems of electric motorization do not exhaust all issues related to it. The material side is only part of the problem. The transition to electric car production is also expected to result in major changes in terms of employment and sales. Although people are aware of the need to protect the environment, they are not necessarily convinced of such rapid changes. It seems that facing consumers with only one solution may lead to difficult situations if the price of electric cars remains relatively high and the infrastructure does not keep up with the changes. It is also necessary to look for other solutions for the development of the automotive industry, e.g., hydrogen-powered cars. Less popular solutions, such as car sharing and car rental, may also be future-oriented. This could lead to a reduction in the number of cars and reduce emissions.

The diversification of the directions of development of the automotive industry is just beginning. Some solutions may be alternatives to electromotorization. Research on other solutions is necessary due to the harmonious development and diversification of choices. Developing the most expensive solution is not justified in the long run.

6. Conclusions

1. There is a high risk in the supply chains of critical metals due to the limited number of places to obtain them and limited resources in relation to needs, which can significantly affect the production of electric cars.
2. A limited number of critical metal supply locations, mainly from China, does not ensure safe supplies for the rapidly growing production of electric cars and encourages the search for suppliers from markets related to the European Union, e.g., Norway.
3. The problem of a complete replacement of electricity currently produced from various sources with green energy is not possible to be solved quickly.
4. Acquisition of aluminum for automotive purposes has good prospects due to the possibility of its complete recycling.

Conflicts of Interest

The author has no conflict of interest to declare.

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