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The Supply Chain of the Mining Industry: The Case of Copper Mining

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Abstract:

Purpose: *The aim of this article is to identify processes and recognise determinants in the copper mining industry supply chain creation and activity taking into account the influence of COVID-19 pandemic.*
Design/Approach: *The research was conducted using qualitative methods. As part of the research procedure, process analysis was carried out using the method of mapping processes in the mining industry supply chain (on the example of copper mining). To analyse and evaluate the examined processes were presented in the form of graphical maps developed using the ADONIS software. A case study was used to show the specificity of the studies case (copper mining supply chain) and accompanying phenomena.*
Findings: *The results of the study indicate that the coordination and integration of logistics processes has a significant impact on the mining supply chain. It is necessary to point out that the mining processes are separate from production processes. The individual tier of copper mining supply chain has their specific determinants that can be identified in the following groups: natural and geological, political, economic, legislative, social, environmental, and technological. The COVID-19 pandemic increased the intensity of the search for new technologies, human security, remote communication processes and process tracking tools; it also increased the need for cooperation and searching for cooperative solutions regarding sustainable development and the circular economy.*
Practical Implications: *The results can be used to improve the operation of the supply chain. The conducted analyses have significant practical implications for the design of efficiency, security, and resilience of supply chains.*
Originality/Value: *The comprehensive analysis of the supply chain creates opportunities for comprehensive improvement of both the entire system and its individual components.*

Keywords: *Mining supply chain, mining industry, process management.*
JEL classification: *O33, L7, Q01, Q56.*
Paper Type: *Case Study.*

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1. Introduction

The industrial development resulting from the level of industrialisation of the country depends on access to natural resources, especially fossil resources - the subject of interest of the mining industry. Mining produces three types of mineral commodities—metals, industrial minerals, and fuels—that all countries find essential for maintaining and improving their standards of living (NAP, 2002).

Mining is defined as the process of extracting raw materials from the Earth’s crust and involves a full life cycle from exploration through production to closure with provisions for potential post mining land use. This means engagement of various stakeholders representing many sectors of the economy and the institutions that support the sphere of research and development. The development of new technologies benefits every major component of the mineral industries: exploration, mining (physical extraction of the material from the Earth), processing, associated health and safety issues, and environmental issues (NAP, 2002). In this context, the functioning of the mining industry is exposed to the impact of several macro-environmental factors, such as globalisation processes and related technological, social, economic, political, legal and environmental changes. One of the key challenges is sustainable development and concepts which, by definition, direct businesses towards the needs of environmental protection. The peculiarities of the national policy in the field of mining industry and the readiness of the companies’ management act as critical determinants to the investment attractiveness and sustainable development of the industry (Sikhimbayev *et al.*, 2019).

Taking this into account and due to changes in the world economy the concept of the circular economy deserves special attention. The circular economy is an alternative economic model that is a challenge for traditional linear industrial economy, which is “based on a linear process, optimised towards high throughput and low production costs relying on the abundant availability of raw materials at relatively low cost” (Taranic *et al.*, 2016). The circular economy is an economic model that is based on a radical, comprehensive, strategic change in the functioning of socio-economic systems, including processes related to: re-use, repair, renovation, and recycling (closure, slowdown of resource loops, narrowing of resource flows) and oriented towards ensuring sustainable development, maximising the functioning of the ecosystem and human well-being, creating environmental, social, and economic benefits (Dymyt, 2019).

The main circular economy processes include: 1) use fewer primary resources: recycling, efficient use of resources and utilisation of renewable energy sources, 2) maintain the highest value of materials and products: remanufacturing, refurbishment and re-use of products and components, product life extension and 3) change utilisation patterns: product as service, sharing models and shift in consumption patterns (Rizos *et al.*, 2017). Ellen MacArthur Foundation indicates four essential building blocks of the circular economy, such as circular design to facilitate product reuse, recycling and cascading, new innovative business models that either replace existing ones or seize new opportunities, reverse cycles (cascades and the final return of materials to the soil or back into the industrial production system), enablers and favourable system conditions focused on collaboration, rethinking incentives, providing a suitable set of international environmental rules, leading by example and driving up scale fast and access to financing (EMF, 2018).

However, apart from long-term challenges, the mining industry is affected by current phenomena that are sudden and unexpected. Such phenomena undoubtedly include the coronavirus pandemic, which, since the end of 2019, has been generating disruptions in global and local flows of goods and services. According to the Organization for Economic Cooperation and Development, the coronavirus pandemic represents the largest public health crisis that has led to a severe economic crisis, with production halt in the affected countries, consumption and confidence collapsing, and stock markets reacting negatively to increased uncertainty (OECD, 2020).

It is recognised that the collapse of supply chains and circular flows will have a cascading effect, which results from the high degree of interconnection and specialisation of production activities (Brodeur *et al.*, 2020). The changes and disruptions in supply chains caused by the spread of the coronavirus have radically increased the volatility of supply and demand (Araz *et al.*, 2020). The disruptions caused by the coronavirus pandemic are visible in both the demand and supply spheres of the economy. On the demand side, there is a noticeable reduction in expenditure and consumption, while on the supply side; the crisis refers to a decline in labour supply and the use of production capacity, disruptions in the supply chain leading to shortages of parts and intermediate goods (OECD, 2020).

In the face of several long-term and short-term challenges, it is justified to consider the conditions for the efficient and stable operation of supply chains in the mining industry. The main goal of the article is to identify processes and identify the conditions in the creation and operation of the copper industry supply chain, considering the impact of the COVID-19 pandemic.

2. Literature Review – Supply Chain

The supply chain is broadly defined as "any combination of processes, functions, activities, relationships and pathways along which products, services, information and financial transactions move in and between enterprises" (Gattorna, 2006) or "a connected set of resources and processes that starts with the raw materials sourcing and expands through the delivery of finished goods to the end consumer" (Bridgefield Group, 2006). By emphasising the institutional nature of the supply chain, it is considered to be "a network of connected and independent organisations mutually and cooperatively working together to control, manage and improve the flow of materials and information from suppliers to end users" (Christopher, 2005). Mentzer *et al.* (2001) defines a supply chain as "a set of three or more entities (organisations or individuals) directly involved in the upstream and downstream flows of products, services, finances, and/or information from a source to a customer". According to Chopra and Meindl (2007) "a supply chain consists of all parties involved, directly or indirectly, in fulfilling a customer request. Within each organisation, such as a manufacturer, the supply chain includes all functions involved in receiving and filling a customer request. These functions include, but are not limited to, new product development, marketing, operations, distribution, finance, and customer service".

The multiplicity of entities involved, and the complexity of their relationships is one of the key challenges for the effective functioning of supply chains. Therefore, it is emphasised that relations, connections, partnership, coordination, and integration are the essence of supply chain management. Christopher (2011) indicates that the supply chain management is "the management of upstream and downstream relationships with suppliers and customers in order to deliver superior customer value at less cost to the supply chain as a whole". Effective supply chain relationship management is one of the key indicators of companies' operational excellence as it integrates suppliers and customers to improve their responsiveness and flexibility (Uddin, 2016). According van der Vorst (2004) supply chain management involves the integrated planning, coordination and control of all business processes and activities in the supply chain to deliver the highest value for the consumer at lower cost for the entire supply chain, while meeting the requirements of other stakeholders in the supply chain.

However, controlling business processes in supply chains becomes particularly difficult in the event of unpredictable, rapid changes caused by the coronavirus pandemic. Dysfunctions occurring in individual cells caused disruptions in the functioning of entire supply chains, both on a global and local level. In the supply chain, defined from a flow and process perspective, as a series of nodes (representing transformation processes) connected to arcs (representing flows of information, products and/or service offerings), it is possible to identify disruptions caused by changes in quantity, lead time, quality, and technology (Vakharia and Yenipazarli, 2009).

In this context, greater emphasis should be placed on the concept of resilience, agility, and adaptability of the supply chain functioning. Generally, resilience is defined as "the capacity of a system to recover from disturbance and maintain its structure function and controls with the human element of socioecological systems able to proactively avoid or benefit from such disturbances" (Higgins *et al.*, 2010). Supply chain resilience means the ability to:

(1) "reduce the probabilities of a disruption, to reduce the consequences of those disruptions once they occur, and to reduce the time to recover normal performance" (Zobel and Cook, 2008);
(2) "proactively plan and design the Supply Chain network for anticipating unexpected disruptive (negative) events, respond adaptively to disruptions while maintaining control over structure and function and transcending to a post-event robust state of operations, if possible, more favourable than the one prior to the event, thus gaining competitive advantage" (Ponis and Koronis, 2012).

The main capabilities that make the supply chain resilient relate to four main issues such as: flexibility (supplier; product; process; transportation), collaboration (information sharing; joined decision making; working together); structure of chain (physical; information) and agility (visibility; velocity) (Goncalves and Chicareli, 2014). According to Christopher (2000), agility means overall business ability that includes organisational structures, information systems, logistics processes and a mind-set, and the key feature of an agile organisation is flexibility. The main goals of an agile supply chain are to react quickly to short-term changes in demand (or supply) and to deal smoothly with external disturbances (Lee, 2004).

Traditionally understood extractive industry is the opposite of the concept of agile management. However, the changes that have occurred in the world economy in recent years have also forced the search for new solutions increasing reactivity in the mining industry. The organisation of industry that prevails in the mining sector often follows the form of hierarchical value chains that may hinder or foster to the creation of new suppliers in the sector (Molina *et al.*, 2016). Hierarchy governance tends to prevail in mining value chains, with very large and strong (often multinational) lead firms operating in several countries, bearing the high costs of long and risky explorations and developing a network of reliable "first-tier" suppliers that provide essential intermediate inputs and services in several mines across the globe. The mining value chain - which includes everything from extracting raw material to delivering products to customers—is the backbone of the industry (Görner *et al.*, 2020) and provides the basis for the design of supply chains.

The current level of innovation and strategic partnerships within the mining technology space demonstrates the agility of businesses and bodes well for the future of the industry (Handra *et al.*, 2011). Metals companies seek to add mining assets and assure the delivery of raw materials (Kudelko, 2012). The transition from the concept of integration to the concept of supply chains was of particular importance in creating agile and flexible solutions.

In the context of the supply chain analysis, it is important to point out that the mining processes are separate from production processes. The individual links of the mining supply chain have their specific determinants that can be identified in the following groups: natural (natural and geological), political, economic, legislative, social, and technological.

One of the main global trends in the development of the mining company management system is the priority of sustainable development, i.e., the functioning of the company should cause the minimum harm to the environment and provide social guarantees for the company's personnel and, at best, for both the region and country (Asr *et al.*, 2019).

3. Research Approach

3.1 Methodology

The starting point for the conducted research was the assumption that the growing importance of copper for the modern economy. Observations of changes in the mining industry allowed for the conclusion that also in the copper mining industry the creation of supply chains as an alternative to vertical integration is becoming more and more important. To identify the determinants of the copper supply chain, it was necessary to properly identify and visualise the course of the supply chain processes. In the context of pandemic changes in the world, changes have also occurred in the copper supply chain that should be identified to be able to effectively manage.

The article is conceptual and research. Authors attempt to answer the following questions:

(1) what is the essence of the copper mining supply chain, what is its specificity,
(2) what processes are carried out in the copper mining supply chain, what factors determine these processes,
(3) how the pandemic COVID-19 affects the functioning of the copper mining supply chain and its entities.

The aim of this article is to identify processes and recognise determinants in the copper mining industry supply chain creation and activity also considering the influence of COVID-19 pandemic**.** The research process included the following stages:

(1) description of the nature and character of the mining supply chain,
(2) identification of logistics processes implemented as part of the mining supply chain in the copper mining, process modelling and analysis of their course and conditions,
(3) formulation of conclusions and recommendations regarding of the analysed processes in the pandemic COVID-19 time to ensure its effectiveness in the conditions of a changing environment.

The article focuses on the analysis of the copper mining supply chain, to identify needs and determinants related to the exploration, mining, and processing of copper in the conditions of a changing environment. To achieve the adopted objectives, the following research methods were used: literature research (review and in-depth analysis of scientific literature), document analysis (review and analysis of documents, reports), participant observation and case study (the copper mining supply chain).

3.2 Case Study

Copper has been known for thousands of years. The metal was used in the sixth and fifth centuries BC in the basin of the Euphrates and the Tigris (Brymora, 2016). Copper is one of the three most useful metals in the world, after iron and aluminium. Pure native copper is rarely found in nature and accounts for about 1% of all its compounds. Typically, copper is obtained from ore minerals, over 160 of which have been found in nature. The main copper minerals are chalcocite, bornite, chalcopyrite, digenite, covelline, cuprite, malachite, djurleite, aniline and ideate. Copper deposits are closely related to the occurrence of silver deposits (PGIN-RI, 2020a). Bornite is also one of the most important silver carriers (about 15% Ag). In 2015, the mined copper ore in Poland (31.6 million tonnes) produced: 1,200 tonnes of metallic silver, 431 kg of gold, 29,000 tonnes of lead, 3,000 tonnes of nickel sulphate, 87 tonnes of selenium and 137 kg of Pt-Pd concentrate (PGIN-RI, 2020a).

It is difficult to imagine the modern world without copper. Among the main properties of copper are good electrical conductivity, good thermal conductivity, corrosion resistance, easy alloying, antimicrobial, easy to bond, ductility, strength, non-magnetic, attractive, fully process able, catalytic (Copper Alliance, 2020). Due to its properties, it is used in construction (pipelines, lighting, air conditioners, roofs), in the electric and energy sector (wind farms, transformers and electric generators), in telecommunications (cables, computer connectors), in the automotive industry (cars and trucks, trains, planes), in coinage. Due to its durability and unique colour, copper is also used in the production of jewellery and in interior design. Its bactericidal properties make it more and more often used in the production of door handles, kitchen worktops and tables. Copper is an important raw material in high-tech products. In a future driven by more stringent environmental constraints and economic growth, the increasing copper content of all decarbonisation innovations, particularly in the transport and power sectors, could, due to copper resource availability, be a hindrance to the diffusion of these technologies (Bonnet *et al.*, 2019). Therefore, it is important to develop copper secondary production based on the recycling of copper-containing products.

In the area of primary copper production, it can be distinguished processing of solvent extraction and electro winning and also processing of froth flotation, thickening, smelting and electrolytic refining. The second one is the most popular form of copper manufacturing now. As far as the total refined copper production is consist of primary refined copper production (over 80% world wild production) and secondary copper production (recycling of copper scrap through smelting and refining). Considering the requirements of sustainable development, the volume of copper secondary production should constantly increase.

Copper is primarily mined through open-pit or underground mining techniques. Open-pit mining, which accounts for approximately 90% of copper production, extracts ores near the earth's surface. When ore is too deep to mine via open-pit operations, underground mining may be utilised, which involves digging shafts into the earth's surface (Jacobs, 2018). Ores located close to the surface can be mined after the overburden is removed. The ore is treated with dilute sulfuric acid. It flows slowly through the ore dissolving the copper and forming copper sulphate. The copper is recovered in the electrolytic refining process. There are two primary types of copper deposits: porphyry and sediment hosted. Porphyry copper deposits form from hydrothermal fluids coming from magma chambers below the copper deposit. These are currently the largest source of copper in the world. Sediment-hosted copper deposits occur in sedimentary rocks that are bound by layers. They are formed by the cooling of copper-bearing hydrothermal fluids.

Currently, copper mines are built where the copper content is higher than 5 kg per ton of rock (0.5% by weight). Copper mining companies are extremely specific entities, with very strong culture and hierarchy and also environmental relations (Table 1).

Table 1. *Characteristics of copper mining companies*

Feature	Characteristic
Location	Place and spatial extent depend on geological conditions – the copper ore deposits
Critical resource	The minimum content of copper (Cu) in the ore deposit sample – 0,5%, minimum deposit capacity (Cu) 35 kg/m²
Human resources	The big numbers of staff consisting of high-qualified employees that have belong for years to a professional group with specific traditions and values. Physical strength and technical competence are important
Operations	Limited due to the high number of geological and mining and environmental laws and strong safety and security regulations influence on restrictions of freedom of choice of working methods and tools.
Technique	Requires a specific technology, adapted to the conditions of access to the deposit
Structure	Complex but repetitive organisational structures - vertical functional structures and strong hierarchy.
Obligatory relations	Strong relations between mining industry and R&D sector, especially in the field of control and expertise - to make sure that existing working system ensures an appropriate level of security and new solutions don't create risks. The increasing difficulty of excavation conditions require highly advanced technologies and equipment without which it would be impossible to ensure a suitable level of efficiency.

Mining culture	Loyalty, respect for natural forces, authority and leadership of experienced workers, team working, difficulty in making changes, the primacy of security. Acknowledgment of common values which establishes a certain harmony and social order among the members of the organisation. In a mining company, the presence of work value relates to the quality of its performance.
Capital	Significant capital employment, from the very beginning of the operation.
The amount of excavable mineral	It determines in some manner undertaken actions of planning and exploitation due to the willingness to achieve a maximum economic effect during long-term operation of a given Company.
Local relation	Strong link with the region and considerable impact on the development of its social capital, standard of living and prosperity of its residents - the regions where mines are located are one of the richest. Frequent high corporate social responsibility, reflected by involvement in the development of sports facilities and schools, activity of foundations, environmental protection, public health protection, development of culture and science in the region, etc.
Environment	It has a strong and unfavourable impact on the natural environment, requires advanced technology of neutralizing the impact and constant monitoring

Source: *Own elaboration based on: Kudełko, J., Juzyk, A., Zaremba, L., 2014. Conditions of Management by Values in Mining Companies, Revista Minelor- Mining Revue no 3, pp. 23-30 and Zieliński, K., Speczik, S., Małecka, K., 2014. The strategy, instruments and results of deep copper and silver deposit exploration in the Fore-Sudetic Monocline,* Scientific Papers, *No. 100, Institute of Mineral and Energy Economy of the Polish Academy of Sciences, pp. 313-328.*

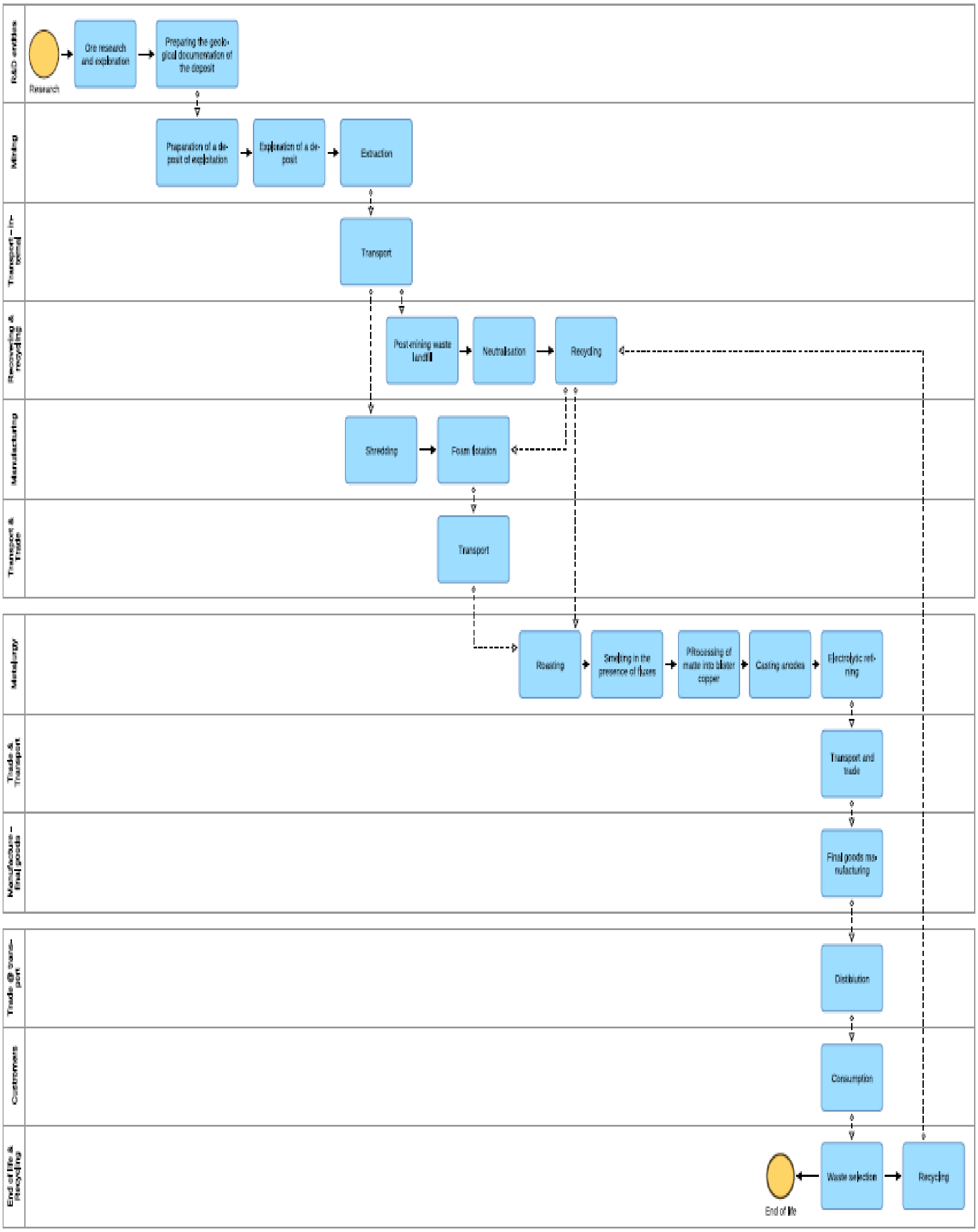
The largest source of raw material is copper mines. More than 21 million tons of copper are obtained each year. About 65% of documented copper resources are in just five countries: Chile, Australia, Peru, Mexico and the United States. Mining.com and Mining Intelligence have compiled a list of mining projects aimed at mining the top 10 currently known but unexploited copper ore deposits and ranked them according to proven and probable reserves. They are: 1) Udokan in Russia, 2) Kamoa-Kakula in the Democratic Republic of Congo (DRC), 3) El Arco in Mexico, 4) Nueva Union in Chile, 5) Quellaveco in Peru, 6) Frieda River in Papua New Guinea (PNG), 7) Aqua Rica in Argentina, 8) Wafi Golpu in PNG, 9) Namosi in Fiji, and 10) Galeno in Peru (Cuprum, 2019).

4. Results and Discussion

4.1 Copper Mining Supply Chain - Process Mapping and Analysis

To analyse and evaluate the processes carried out in the copper mining, the supply chain was presented in a graphic form (a process map) developed in ADONIS (Figure 1).

Figure 1. *Copper mining supply chain*



Source: *Own study.*

The first step in creating a copper supply chain is to start an exploration program. This stage is carried out by specialised research and development entities. At this stage, it is necessary to obtain reconnaissance and exploration licenses. The search for archival boreholes (results and samples of rock material) and field research are carried out. The conducted geological research is accompanied by research in the field of organic chemistry and geophysics, which allows estimating the size of resources (deposits). Based on the conducted research, a model of the spread of mineralization is created and the so-called sweet spots for further drilling exploration. The drilling program is then defined for the most promising concession areas. Because of the drilling program being carried out, the location and value of the deposit are determined as well as its initial documentation. This is the basis for deciding to start the creation of a mining plant - mine - on a selected license area, and above all, to apply for a license to mine - exploit a deposit. The field is also explored while mining operations to be able to define the directions of its development. When preparing the geological documentation of the deposit, the parameters defining the mineral deposit and its boundaries, specified in the relevant national regulations, should be followed (Speczik *et al.,* 2020).

After confirming the profitability of mining activities, creating a feasibility studies and obtaining appropriate legal acts allowing for the organisation and conduct of mining activities, it is possible to start the process of preparing the deposit for exploitation. Preparation of a deposit for exploitation should consider geological and technical conditions, which differ, inter alia, depending on the type of mine – open-pit, deep (underground), borehole. The process is implemented by mining entities with competences and technical capabilities related to the construction and expansion of mines.

The exploitation of a deposit requires not only formal components, but also specific resources, including machinery and equipment related to mining technology, infrastructure and equipment for vertical and horizontal transport, specialised human resources and systems of safety, control, and rescue. Natural conditions are also important for the functioning of the mines. They influence both the characteristics of the deposit and the safety conditions (underground shocks and rock masses, gas, water, temperature, lack of oxygen).

It should be noted that the mining process is not the same as the production process. Extraction is a variable element. It is carried out in various places (progressive work front) with the use of variable techniques of charm acquisition (manual, mechanical, and explosive), which affects the variable length and shape of transport routes and transport techniques. Due to the risks, it is often necessary to change the site of excavation operation.

Transport processes are an important element of the ore extraction process. Depending on the type of deposit, the technique of its exploitation and the specificity of the mining plant, horizontal and vertical transport are used to a different extent. This transport is used both in the transport of people, spoil, as well as machinery, equipment, and materials for construction, as well as securing workings and transport roads. It also plays a special role in security systems.

Mineral processing (following the ore is extracted) encompasses unit processes for sizing, separating, and processing minerals, including comminution, sizing, separation, dewatering, and hydrometallurgical or chemical processing. The entities carrying out their activity in the mining area also include entities implementing shredding and foam flotation processes (Table 2).

Table 2. *Copper ore processing steps - electrolytic refining*

Shredding	Crushing and grinding in cylindrical ball mills
Foam flotation	Powdered ore is mixed with special paraffin oil, which causes the copper mineral particles to become water-repellent. The ore is then fed into a water bath containing a foaming agent that produces foam. The air jets introduced into the bath cause the hydrophobic copper mineral particles to be collected by the air bubbles. They float to the surface, creating foam. The undesirable waste rock sinks to the bottom and is removed. The foam is scraped off the surface and the enriched ore (mainly the copper mineral) is sent to roasting. The mixture of water, foaming agent and paraffin is recycled. At this stage, the enriched ore already contains about 25% copper by weight. This is called copper concentrate that can be shipped to other plants or countries for processing.
Roasting	This is where the chemical reactions begin. They convert copper minerals into metallic copper. This process involves the roasting of the ore concentrate from foam flotation. The concentrate is heated in air to a temperature between 500ºC and 700ºC. The product obtained from the roasting furnace is roasted ore. It is a solid mixture of oxides, sulphides and sulphates. One solution is to convert sulphur dioxide to sulfuric acid, which is either sold for industrial use or is used to extract oxide ores by leaching.
Smelting in the presence of fluxes	The roasting is heated to above 1200ºC with fluxes such as silica and limestone the roasting melts and reacts with the fluxes. Some contaminants form a slag (e.g., FeO.SiO2) that floats (like oil on the surface of water) and can be easily removed. A shaft furnace for smelting copper from sulphide ores also produces sulphur dioxide gas. It is captured from the off gas in a scrubber. Flue gas desulphurization also protects the environment. This is a process like removing contaminants in a shaft furnace. The remaining fluid material is a mixture of copper sulphides and iron sulphides. This is called copper stone.
Processing of matte into blister copper	Liquid matte is oxidized with air in the converter; the product obtained is converter copper. Anodes are made of blister copper obtained in a shaft furnace. They are cast in foundry melds. The anodes are copper plates, approximately 1 square meter in area, with lifting and hanging lugs at the top corners.
Casting anodes	The blister copper produced in this process is 99% pure copper. The copper name "blister" comes from the sulphur dioxide blisters that are formed in this process on the copper surface. Blister copper is used to cast

	anodes ready for electrolytic refining. This huge carousel is used for casting anodes. Molten copper is poured into the meld, the rotating carousel moves to the next meld. Meanwhile, the molten copper cools and solidifies into anodes more than a meter high. The cast anode has short lifting and hanging arms.
Electrolytic refining	The blister copper is practically pure (it contains over 99% copper). The copper is thus further purified by electrolysis. This process is known as electrolytic refining. Large plates are cast from blister copper, which serve as anodes in the electrolyser. The electrorefining process produces high-quality copper of high purity required by the industry. Even with the best chemical methods, it is not possible to remove all impurities from copper, but electro-refining produces 99.99% pure copper. Copper cathodes are suspended between the anodes. The process of their purification follows. Purification occurs because other metals present in the anode (impurities) do not pass into the electrolyte solution. They fall to the bottom of the tank. The cathodes contain copper with a purity of 99.99%. Blister copper anodes are immersed in an electrolyte containing copper sulphate and sulfuric acid. Pure copper cathodes are placed between the blister copper anodes and a current of more than 200 A is passed through the solution. Gold, silver, platinum, and tin do not dissolve in this electrolyte and therefore do not deposit on the cathode. They form a valuable "sludge" that collects under the anodes.

Source: *Own elaboration based on Copper Alliance, https://copperalliance.pl.*

The entities associated with the recovery and recycling processes are also of great importance for the functioning of the mining area of the supply chain. Mining waste is of particular concern here. In the mining process, besides the semiliquid mixture, mud, slurry, and rocks, there are large volumes of water to remove in order to keep production moving (Qazizada *et al.*, 2018). The basic waste is waste rock, formed mainly in the current mining operation, most often deposited in mining dumps/ heaps (neutralization facilities) and waste from the copper ore enrichment process (flotation) deposited in sedimentation tanks (post-flotation waste tanks). The basic methods of mining waste management include reclamation and depositing in underground mining excavations, storage in waste treatment facilities, the so-called landscape structures, depositing in post-mining waste landfills, neutralization, and transfer for further use.

The final quality of copper is determined by a properly conducted metallurgical process, including roasting, smelting in the presence of fluxes, processing of matte into blister copper, casting anodes, electrolytic refining (Table 2). As a result of the works of the smelter, a copper cathode is obtained with the content of 99.99% pure copper. Copper cathodes may then be shipped as melting stock to mills or foundries, where they are cast into wire rod, billets, cakes, or ingots used to manufacture products (International Council on Mining and Metals, 2010).

Copper transport and trade is global. Most often in international trade, copper as a raw material - the subject of the transaction - takes the form of refined copper (a highly processed product) or concentrates and copper ores (Table 3). While copper is a global business, there are clear leaders in the production and refinement of copper based on geology and demand. In a list of the 20 biggest copper mines, 11 reside in Chile and Peru accounting for 40% of mined copper. Meanwhile, China is a leading importer and exporter of refined copper, and its home to 9 of the 20 biggest copper smelters in the world (Visual Capitalist, 2020).

Table 3. *Copper trade flows 2019*

Transaction types	Countries
Major exporters of refined copper	Chile, Russia, Congo, Japan, Australian, Kazakhstan, China, Poland, South Korea, Peru
Major importers of refined copper	China, United States, Germany, Italy, Taiwan, UAE, Thailand, Turkey, Malaysia, Vietnam
Major exporters of copper ores and concentrates	Chile, Peru, Australia, Canada, United States, Brazil, Mexico, Mongolia, Spain, Indonesia
Major importers of copper ores and concentrates	China, Japan, South Korea, Spain, Germany, Bulgaria, India, Taiwan, Brazil, Finland

Source: *Own elaboration based on: https://www.visualcapitalist.com/coppers-supply-chain/*

Copper goes to the production process and then it is distributed in the global economy. Due to its attributes, copper is an indispensable raw material in modern industry, as evidenced by the catalogue of selected applications of copper and copper alloys (Table 4).

Table 4. *Attributes and Applications of Copper and Copper Alloys*

Property	Industry/Type of Application
Aesthetics	Architecture, sculpture, jewellery, clocks, cutlery.
Bactericide	Door hardware, marine internal combustion engines, and crop treatments.
Biofouling resistance	General, hydraulic, and marine engineering, metalworking, aerospace, power generation, shipbuilding, offshore oil and gas platforms.
Corrosion resistance	Plumbing tubes and fittings, roofing, general and marine engineering, shipbuilding; chemical engineering, industrial processes including pickling, etching, and distilling; domestic plumbing, architecture, desalination, textiles, papermaking.
Ease of fabrication	All the above plus printing.
Electrical conductivity	Electrical power generation, transmission and distribution, communications, resistance welding, electronics.
Environmental friendliness	Essential for health of humans, animals, and crops
Fungicide	Agriculture, preservation of food and wood.
Low temperature properties	Cryogenics, liquid gas handling, superconductors.
Mechanical	General engineering, marine engineering, defence, aerospace.

strength/ ductility	
Non-magnetic	Instrumentation, geological survey equipment, minesweepers, offshore drilling.
Non-sparking	Mining and other safety tools, oxygen distribution.
Elasticity	Electrical springs and contacts, safety pins, instrument bellows, electronic packaging.
Thermal conductivity	Heat exchangers and air-conditioning/refrigeration equipment, automotive radiators, internal combustion engines, mining.

Source: *Calcutt V. 2001, Introduction to Copper: Applications. Copper Applications in Metallurgy of Copper & Copper Alloys retrieved from: https://www.copper.org/publications/newsletters/innovations/2001/08/intro_to_copper.htm*.

Changes in consumer awareness and the development of the circular economy concept change the approach to the copper supply chain. Already at the stage of designing the use of products from the mining sector of the supply chain, we start thinking about their possibility of re-use as part of the recirculation process - secondary production. Today, used products containing copper are of interest to the selection system, which is part of the recycling infrastructure. The aim is to ensure that as much of the secondary raw material as possible goes to the "recovering & recycling" cell, where it is processed using modern technologies. This allows the raw material to be reused and reintroduced into metallurgical processes in the supply chain - refined copper production using recycled scrap feed. Currently, it is only the beginning of the development of this type of technology, but efforts are being made in this industry to increase the use of secondary raw materials as much as possible. Along with the development of copper secrecy production processes, it is also necessary to adjust the manufacturing processes of finished products. They should meet customer requirements both technically and economically, but also in terms of increasing consumer awareness of the reuse of raw materials.

4.2 Copper Mining Supply Chain Determinants

According to the analysis of the European Innovation Partnership on Raw Materials copper supply chain determinants should by recognised in the groups of 5^{th} thematic clusters: raw materials in the global context, competitiveness and innovation, framework conditions for mining, circular economy and recycling, environmental and social sustainability (European Commission, 2018). An extremely important dimension of copper supply chain is the location of the deposits and local technical, economic, social, and demographic infrastructure, as well as the availability of production factors (Kudełko *et al.*, 2015).

The extraction of copper ore depends on the geological location of the ore sources, although in recent years European mines have lost much of importance in favour of locations in South America. In the sphere of copper production, the importance of Asian producers increased significantly. Nonetheless, the EU is still the word leading exporter of mining equipment, accounting for almost a quarter of world's total exports. Many countries see development opportunities thanks to the exploitation of natural resources, which contributes to the global expansion of large mining companies. At the same time, it should be remembered that the conditions of functioning in individual countries differ, especially in legal and economic, social and political terms. A stable and efficient minerals policy framework remains crucial in encouraging and reinforcing sustainable mining developments. It can either impede or expedite the development of mining operations.

The supply of primary copper is determined ultimately by mine output and smelter and refining capacity, while the supply of secondary refined copper is determined by the supply of high-grade scrap and secondary refining capacity and to some extent by smelting capacity for low-grade scrap (Mikesell, 2011).

In the field of international trade, copper is an important subject of global trade and its volume increases with ever new areas of application. In the global context in order to reduce risks, an important element is the creation of an appropriate diversification of supply sources and the appropriate design of flows throughout the chain, taking into account natural, technical, legislative and social constraints.

In contrast to aluminium or steel, where you have a liquid metal melt as the final product of refining which can be cast into billets and cakes directly, copper cathodes can be transported and traded and must be melted for further processing (Langner, 2015). This is a reason why the value chain of cooper is strongly fragmented. So, the copper companies have specialised on mining, smelting, and refining, or producing semis. Large mining concerns made attempts to integrate vertically. However, due to their international reach, it turned out to be ineffective and especially inflexible. Therefore, creating supply chains seems to be a more forward-looking form of action.

The copper supply chain is an important source of jobs - both directly around copper production and products made of it, and also in the network of entities providing services and producing for it. The recycling area is also an increasingly important workplace. Therefore, the location of supply chain actors (entities) is an important factor in regional economic and social development. In recent years, there has been a significant increase in R&D investments, which influences the creation of solutions meeting not only the needs of customers and consumers, but also the functioning of individual entities in the supply chain and the whole supply chain- especially in the field of security.

Public acceptance is another factor that greatly affects copper mining companies' operations. On the one hand, aspects related to innovation and green technologies are gaining in importance. On the other hand, the impact on health is an extremely important factor. On the health front, miners have long been aware of the hazards posed by the gases, dusts, chemicals, and noise encountered in the work environment and in working under conditions of extreme temperatures (hot or cold) and high altitudes. And, the environmental impact of enterprises related to the copper supply chain (Table 5).

Table 5. *Impact on the environment of copper mining supply chain*

Chain link	Environmental impact factors
Search and recognition	Land take, drillings carried out
Ore mining	Energy consumption, water consumption, impact on biodiversity, dust, mining damage, shocks, micro-shocks, water discharges, mining waste landfills, post-mining waste landfills
Ore enrichment	Energy consumption, water consumption, noise, flotation waste, water discharges, post-flotation waste tanks
Metallurgy	Energy consumption, air emissions, water consumption, waste, dust, soil acidity/alkalinity
Refining and processing and manufacturing	Energy consumption, air emissions, water consumption, consumption of raw materials and materials, waste, dust
Sales and trade	Fuel consumption, air emissions, post-consumer waste
Reclamation	Land reclamation and preservation of biodiversity, revitalisation

Source: *Own elaboration*

Mining operations (including ore processing and related activities) are complex and high-risk. In part, this is due to the physical and technical environment (Lööw and Nygren, 2019). Uncertainty about rock stability and gas and water conditions that will be encountered during underground mining impedes rapid advances and creates health and safety hazards. Because of the security important is an environmental monitoring system and its main function is to collect environmental parameters, like CO and methane gas, temperature and humidity, status of ventilation fans and dam levels, and many more operational parameters which are essential to the safe and effective operation of a mine. Mines and open pits are obvious places where explosions can occur. But they could also happen where the flammable vapours, gases or combustible dusts are likely to occur the quantities of sufficient to cause a fire or explosion (Stochitoiu and Utu, 2019).

The implementation rate of the circular economy concept is relatively low and should be improved by increasing the re-use and recycling rates of materials. Moving from the traditional, linear ‘make, use, dispose’ economy to the circular economy requires increased reuse, remanufacturing, recycling as well as increased material efficiency (European Commission, 2018).

Countries such as Japan and China have made particularly good progress in creating circular copper supply chain. As for the EU, differences in waste management in the Member States indicate the potential to increase the recovery of valuable raw materials. A considerable amount of secondary copper raw materials leaves Europe and does not contribute directly to the circularity of the European economy.

5. Conclusion

The crisis caused by the COVID-19 pandemic has demonstrated the need to increase the resilience of the entire copper supply chain. Despite the high level of technologization (technology saturation), the dependence on the form (condition) of the human factor is high. Starting from the processes of copper ore extraction through transport and processing processes, it becomes necessary to increase the share of high technologies minimising human participation (automation, robotisation - currently it is expensive and difficult due to the variability of the tasks performed) and transferring as many activities as possible to cloud-based systems network. As part of the existing relationships, it has become necessary to establish closer links with suppliers of equipment and services (support repairs, expert opinions, technical condition assessments, transport services), and where possible, switching to 3D printing as a short-term replacement of supplies (where possible).

There is a move away from the one supplier system in favour of two/three entities. The pandemic situation also forced cooperation with competitors (coopetition). There has been an increase in demand for new technologies in the entire copper supply chain. This applies to production (technological) innovations as well as solutions in the field of tracking the workforce and the work of machines or remote work systems. An important aspect has become the implementation and development of health control technology (measuring temperature, pressure, and alcohol level or drug tests) and disinfecting people, things, and rooms. Improving hygiene solutions and hygiene control has also become an important subject of interest not only for company management boards, but also among employees themselves. Laundry and disinfection services at mines and processing plants or metallurgical companies are an important element of the organisation and ongoing operation. The current conditions have forced greater control of working conditions - especially in mines and in metallurgical and manufacturing companies. All this contributed to an increase in investment in higher level of transparency of the supply chain. Technologies related to process tracking have gained particular importance.

Due to the current conditions, it became necessary to improve the quality of communication processes - to search for new, common solutions. This applies to systems that enable communication between mines and other units, especially in emergency situations. It has become commonplace to continuously monitor safety and process flow for all participants in the supply chain. Solutions to increase visibility and performance have become indispensable across supply chain.

An important issue now is to increase the flexibility of planning the staffing of shifts (shift workers) in mines and cooperating entities. The suddenness of the disease, its unpredictable course and duration, quarantine, and isolation procedures, resulted in the need to create ad hoc solutions, which at the same time affect the safety and stability of work in the longer term.

Disruptions in economies, which occurred because of the coronavirus pandemic on the demand side and the supply side led to the need to pay more attention to the social and environmental aspects. Building resilient supply chains, in the long term, requires considering the challenges resulting from the pursuit of sustainable development, care for the ecosystem and human well-being. According to the idea of the circular economy, all participants, and stakeholders in the supply chain, from the mining industry to the final consumer, are responsible for creating environmental, social, and economic benefits.

An extremely difficult challenge is to condition the functioning of the entire system on political decisions - the epidemic situation resulted in a short time horizon and variability of government decisions and increased the autonomy of decisions on the scale of individual countries, which increases the need to diversify solutions throughout the supply chain. Hence emerges a need to analyse the implemented processes to achieve their transparency and be able to increase the reactivity of the system to sudden changes.

In conclusion, it should be emphasised that at the current stage of research it is not possible to identify all disruptions in the supply chains caused by the pandemic and their consequences. The considerations undertaken in the article made it possible to answer the formulated research questions and achieve research goals. Nevertheless, the presented conclusions and proposed recommendations may be helpful in a practical and scientific dimension and constitute a starting point for broader, in-depth research.

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