Revista Minelor – Mining Revue
ISSN-L 1220-2053 / ISSN 2247-8590
vol. 30, selected papers from the 11th edition of
UNIVERSITARIA SIMPRO / 2024, pp. 32-50

COPPER MINING'S GREEN REVOLUTION – SUSTAINABLE TECHNIQUES AND TECHNOLOGIES SHAPING THE FUTURE

Rodica (STEPANEK) CUJBA[1], Maria LAZĂR[2]*

[1]University of Petrosani, Petroșani, Romania, rodica-1998@mail.ru
[2] University of Petrosani, Petroșani, Romania, marialazar@upet.ro

DOI: 10.2478/minrv-2024-0038

Abstract: *This paper traces the evolving landscape of copper mining, delving into the industry's shift towards sustainable practices and technologies. In this context, a critical case study is presented, with an emphasis on the mining of copper ore from Roșia Poieni. This case study analyzes the application of sustainable techniques in mining operations, assessing their effectiveness, feasibility and potential challenges. It is also evaluated the implementation of renewable energy sources, waste recycling initiatives and the adoption of clean technologies within the operations of the Roșia Poieni quarry. In addition, the study investigates the socio-economic ramifications of these sustainability efforts on the local community surrounding the mine. The research begins with an overview of traditional extraction methods and highlights the importance of adopting green alternatives. Examining sustainable technologies in copper mining and processing, the paper explores the integrate ion of renewable energy, waste recycling and clean technologies to reduce emissions. The social impact of these sustainable practices is explored, including the benefits to local communities and increased workplace safety. Despite the challenges faced, the industry holds economic opportunities in adopting sustainable techniques. The paper concludes with a comprehensive overview of the industry's outlook, highlighting the importance of balancing technological advances with environmental responsibility in shaping the future of copper mining.*
Keywords: *Copper, mining, sustainability, green technology, impact*

1. Introduction

Copper, a vital component in various industries, has long been extracted through traditional mining methods, often at the expense of environmental degradation. However, a paradigm shift is underway in the copper mining industry, with an increasing focus on sustainable techniques and technologies. This change responds to environmental issues and supports the worldwide movement for responsible resource management. This document explores the evolution of copper mining practices, emphasizing the integration of sustainable technologies shaping the industry's future. From innovative extraction methods to digitalization and community involvement, each section delves into the multifaceted aspects driving the green revolution in copper mining. This exploration aims to shed light on the promising advancements, challenges, and opportunities in adopting environmentally conscious practices, ultimately contributing to a more sustainable and responsible copper mining landscape.

2. Global copper mining

Sustainability emphasizes the manner of using natural resources in a way that fulfills present request without compromising the ability of future generations to meet their own requirements. Sustainable development, which emphasizes striking a balance between social equity, environmental protection, and economic growth, is closely linked to this idea. Sustainable exploitation includes managing resources so that they remain available and productive over time, ensuring that ecosystems are conserved and human well-being both now and in the future.

[*] Corresponding author: Cujba (Stepanek) Rodica, PhD stud.eng., University of Petrosani, Petrosani, Romania (University of Petrosani, University Street no. 20, rodica-1998@mail.ru)

Sustainable mining point out practices and strategies designed for minimizing the negative environmental, social and economic impacts associated with mining activities, also contributing to increasing the positive impact. This involves responsible mining methods that ensure the conservation of natural resources, the protection of ecosystems and well-being for local communities.

Sustainable mining practices include:

- Implementation of techniques that reduce pollution, protect water resources, prevent soil degradation, and promote biodiversity conservation. This includes proper management of waste and tailings to avoid contamination of the environment.
- Communication with local people to understand and address their preoccupations, contributing to local economic development. This also involves promoting safe working conditions and providing training and education opportunities for workers.
- Ensuring that mining activities contribute positively to the economy by generating revenue, creating jobs, and supporting local businesses. This includes transparent and equitable distribution of profits and taxes generated from mining operations.
- Reference to national and international laws and standards, implementing robust corporate social responsibility programs, and integrating environmental, social, and governance (ESG) principles into business practices. This helps in gaining trust from stakeholders and mitigating risks associated with mining operations.

Utilizing advanced technologies and innovative solutions to improve operational efficiency, reduce environmental footprint, and enhance worker safety. This includes exploring renewable energy options and adopting circular economy principles to maximize resource utilization [1].

Sustainable mining requires collaboration among mining companies, governments, communities, and other stakeholders to establish and enforce regulations, share best practices, and invest in sustainable technologies and initiatives. By embracing sustainable exploitation, the mining industry can assist in achieving of the Sustainable Development Goals (SDGs), especially that have to do with fair labor, economic expansion, decreasing inequality, and responsible production and consumption.

According to the United States Geological Survey (USGS), global copper reserves were estimated at 1 billion tons in 2023. Nations possessing substantial reserves of copper include Chile (190 million tons), Australia (100 million tons), Peru (120 million tons), Russia (80 million tons), Mexico (53 million tons), and the United States (50 million tons), among others. In terms of production, global copper output from ore in 2023 was 22 million tons. The leading copper-producing countries were Chile (5 million tons), Peru (2.6 million tons), China (1.7 million tons), and the United States (1.1 million tons).

According to a World Bureau of Metal Statistics (WBMS) report, there will be a 65,800-ton supply deficit in 2023 as a result of the world's refined copper production being 27.6261 million tons and consumption being 27.6919 million tons.

As stated by to the International Copper Study Group (ICSG), the global refined copper market experienced a supply shortage of 87,000 tons in 2023, down from a deficit of 434,000 tons in 2022.

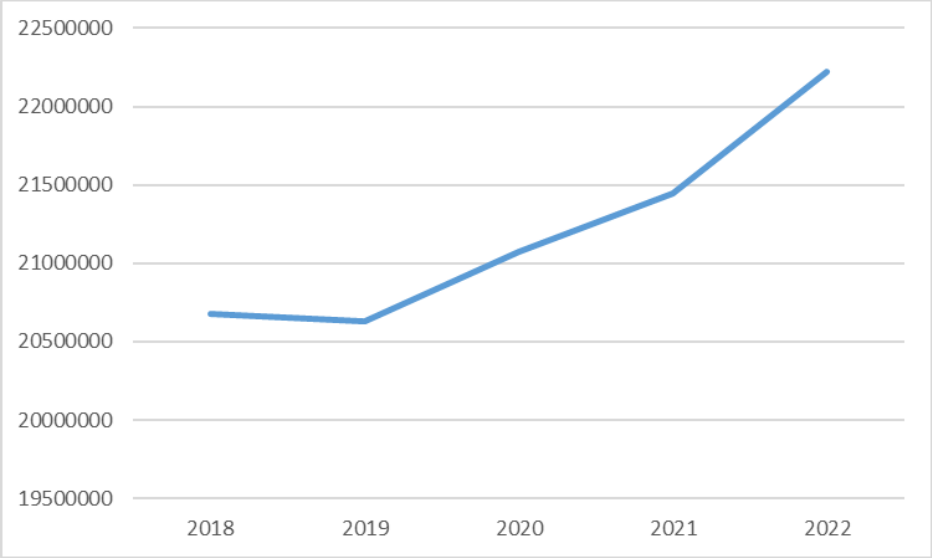

Fig. 1. Evolution of world production of copper (metric tons) [2]

According to figure 1, the world production of copper experienced a minor decline initially but then stabilized and subsequently increased significantly from 2020 to 2022. This reflects a growing demand and possibly increased capacity and efficiency in copper production processes globally. The substantial rise in recent years highlights copper's critical role in various industries, especially those related to technological and green energy advancements.

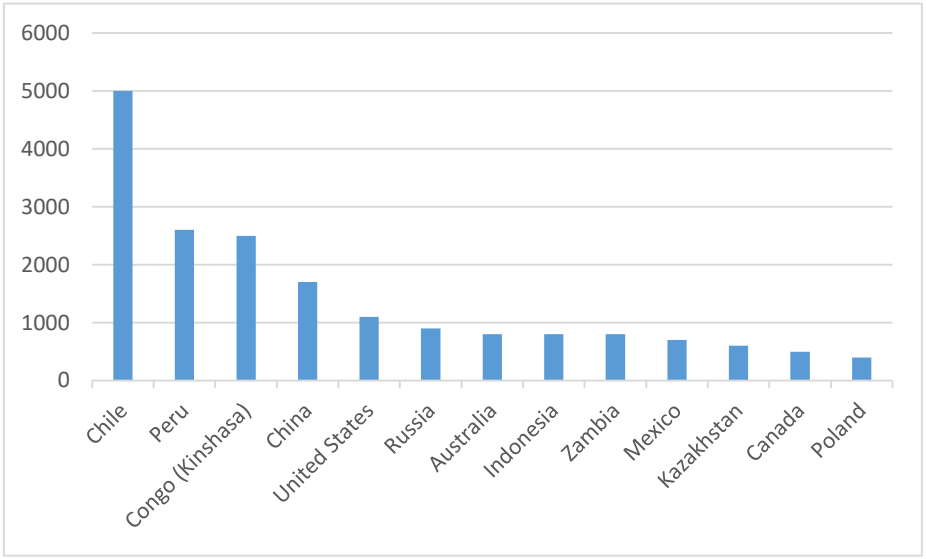

Fig. 2. Copper production by country (thousand metric tons) (2023) [3]

According to the graph above (Figure 2), we can see that, Chile is the leading copper producer in 2023, with production significantly higher than any other country. Peru and Congo (Kinshasa) also have substantial copper production, while other countries like the United States, China, and Russia have relatively lower but notable production levels. The chart shows a steep drop in production figures from the top producer to the lowest among these countries.

Further on a comprehensive overview of sustainable exploitation, consumption and responsible production politics for five top copper – producing countries in 2023 is presented.

2.1 Copper production in Chile

The Chilean Copper Commission reports that in 2023, the country's output of copper fell by 0.5% to 5.33 million tons, the lowest since 2008. The decline in production was ascribed to difficult mining conditions, reduced ore grades, scarcity of water, and setbacks in significant investment projects (Figure 3).

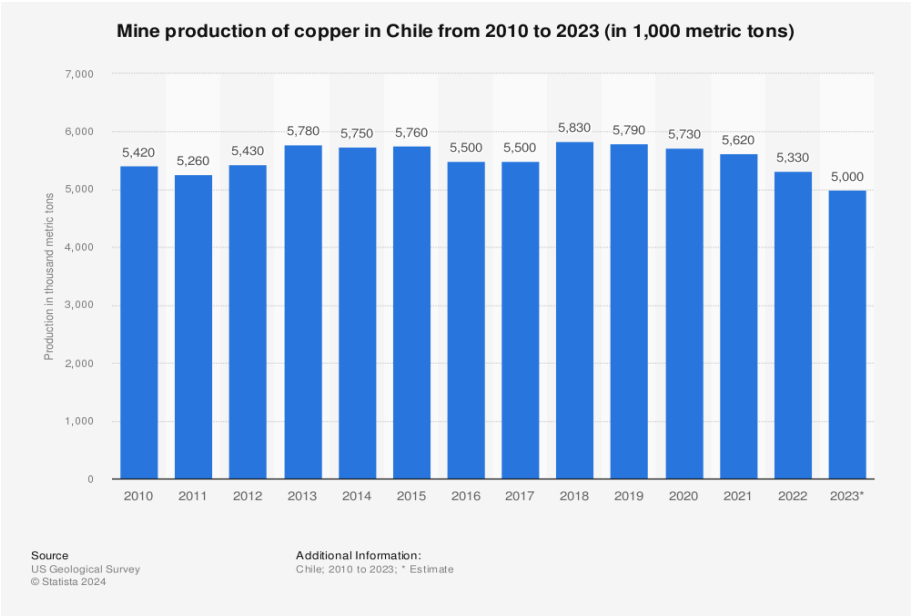

Fig. 3. Mine production of copper in Chile from 2010 to 2023 [4]

The mining industry in Chile deal with several significant challenges, one major issue is atmospheric pollution from smelting processes, leading to substantial investments in emission control technologies to reduce pollutants like sulfur dioxide and arsenic, another critical challenge is the impact on land use, where mining operations cause landscape modifications, erosion, and soil pollution, adversely affecting human health and biodiversity [5].

In 2023, Chile, being the world's top copper producer and a significant player in lithium production, has been focusing on sustainable exploitation, consumption, and responsible production of these minerals. The country's mining sector contributes significantly to its economy, accounting for 13.6% of its GDP in 2022 and 58% of total exports. The sector faces challenges such as investment uncertainties due to potential changes in the mining code through a new constitution and environmental concerns related to water usage and carbon footprint.

To address sustainability, the Chilean mining sector is investing in new technologies and practices aimed at reducing environmental impact and improving efficiency. These investments include:

- Renewable energy - by 2023, an estimated 63% of electricity used in mining operations is projected to come from clean energy sources, significantly reducing the sector's carbon footprint.
- Water management - the mining sector uses less than 4% of the total water consumed in Chile, with approximately three-quarters of the water used being recirculated. This practice minimizes the strain on water resources, especially in arid regions where mining operations are prevalent.
- Automation and remote operations - mining companies are adopting advanced technologies to enhance operational efficiency and safety, thereby reducing the environmental impact and improving working conditions.

Despite these efforts, the sector faces regulatory uncertainties, particularly concerning the management of lithium concessions following the announcement of plans to nationalize the lithium industry. This has left key questions unanswered regarding the future regulatory framework for lithium extraction.

Moreover, the Chilean government introduced a tax reform bill in July 2022, increasing mining royalties. This move aims to ensure that the economic benefits derived from mining activities are shared more equitably with the Chilean society, contributing to sustainable development [6].

In summary, Chile's approach to sustainable exploitation, consumption, and responsible production of copper and lithium in 2023 involves a combination of technological innovation, regulatory adjustments, and environmental stewardship. These efforts are designed to mitigate the environmental impact of mining, ensure the long-term viability of the sector, and align with the country's broader sustainability goals.

2.2 Copper production in Democratic Republic of Congo

According to a report from the Central Bank of the Democratic Republic of the Congo, the country produced 2.84 million tons of copper in 2023, more than Peru's 2.76 million tons, making it the second-largest producer of copper in the world. In terms of copper exports, Congo still lags behind Peru.

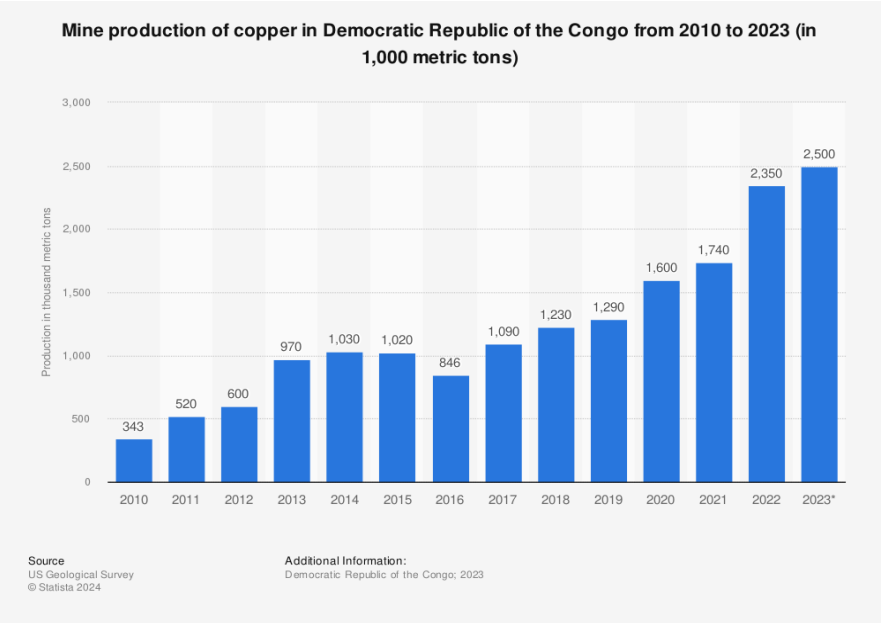

Fig. 4. Mine production of copper in Democratic Republic of the Congo [7]

The Democratic Republic of the Congo has produced (Figure 4) 1.62 million tons more copper in 2023 than it did in 2018 - a notable increase over the previous five years.

The Republic of Congo faced significant challenges in achieving sustainable exploitation, consumption, and responsible production of copper. The industrial mining of copper, particularly for rechargeable batteries, has led to severe human rights abuses, including forced evictions, sexual assault, arson, and beatings. Communities have been displaced from their homes and farmlands to accommodate the expansion of mining operations by multinational corporations.

The growing global demand for clean energy technologies has increased the need for copper and cobalt, essential components of lithium-ion batteries used in electric vehicles and mobile phones. This demand has exacerbated the situation, leading to more forced evictions and threats against local populations. There have been repeated breaches of legal safeguards and international human rights standards, with a lack of accountability and access to justice for those affected [8].

Efforts to promote transparency in the mining sector and create alternative sources of employment have been supported by organizations like the BMZ, aiming to harness the country's natural resources for sustainable development. However, the implementation of these measures has been slow, and much work remains to be done to ensure that mining activities contribute positively to the country's economic and social development [9].

The Extractive Industries Transparency Initiative (EITI) has been implemented in the DRC since 2007 to manage revenues from the extractive sector better and ensure they benefit the citizens. Despite these efforts, the country continues to face challenges related to corruption, mineral smuggling, and the impact of mining on the environment and local communities [10].

Responsible business conduct (RBC) is encouraged in the DRC through initiatives like the Global Compact Network DRC, which promotes sustainable and socially responsible policies among businesses. However, the legal framework to protect consumer rights and prevent adverse business impacts is lacking. Reports of child labor in artisanal mines have led to international pressure for reforms, with some progress made in eliminating the worst forms of child labor.

Environmental implications of copper mining in the DRC are significant, with negative impacts on biodiversity, air quality, and contributions to global warming. The extraction process involves deforestation and road construction, leading to habitat loss and increased greenhouse gas emissions [11].

Addressing these challenges requires a comprehensive approach that includes enforcing stricter regulations, promoting transparency, ensuring responsible business practices, and investing in sustainable development initiatives. It is crucial to balance the economic benefits of mining with the protection of human rights, the environment, and the well-being of local communities.

2.3 Copper production in Peru

According to the Ministry of Mines and Energy in Peru, the country's copper production increased by 13% year over year to a record high of 2.76 million tons in 2023 (Figure 2) from 2.44 million tons in 2022 (Figure 5). Due to sales from previous year's inventory, 2.95 million tons of copper were exported in 2023 - more than the yearly production.

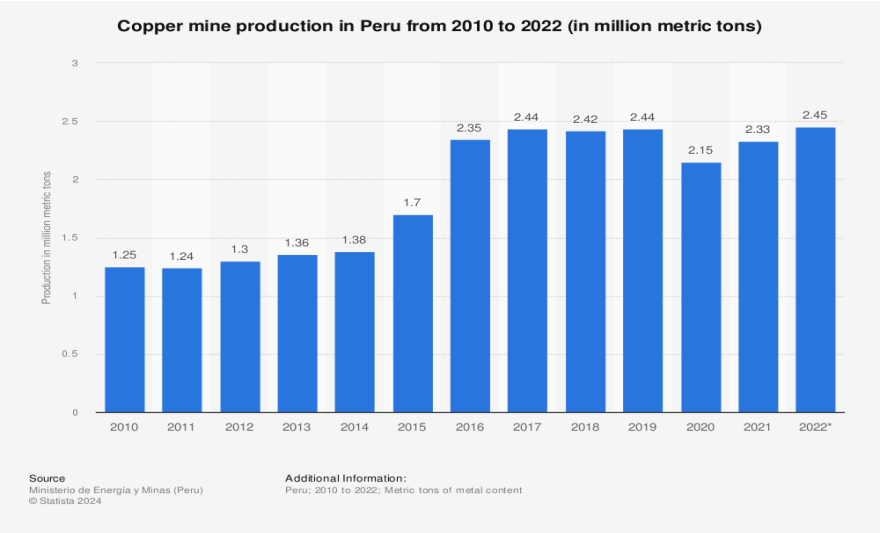

Fig. 5. Copper mine production in Peru [12]

The primary factors behind the increase in Peru's copper production include the full resumption of operations at the Las Bambas copper mine and the increased output from the Anglo American Group's Quellaveco copper mine in the Moquegua region. Quellaveco alone accounts for 11.6% of Peru's copper production, making it the world's fourth-largest copper mine.

Peru's copper production faced both opportunities and challenges in terms of sustainable exploitation, consumption, and responsible production. The country approved the expansion of the Cerro Verde mine, a significant copper producer, indicating a commitment to increasing copper output. This expansion, along with developments in other projects such as Cotabambas, Conga, Galeno, La Granja, and Michiquillay, aims to boost Peru's copper production to compete with Chile's levels.

However, Peru's copper industry is grappling with several structural issues, including declining ore grades, water scarcity, inadequate infrastructure, environmental disputes, and conflicts with local communities. These factors lead to operational disruptions and hinder production growth. The industry's future depends on addressing these challenges through improved mining policies, community engagement, and environmental stewardship [13].

Global copper production in 2023 saw an increase, with Peru playing a key role alongside Chile and the Democratic Republic of the Congo (DRC). Despite facing operational challenges, Peru's contribution to the global copper supply was significant, supported by projects like Quellaveco, Las Bambas, Toquepala, and Antapaccay [14].

2.4 Copper production in China

SMM data indicates that China's output of copper concentrate in metal content was 1.83 million tons in 2023, marking a decrease of 6.6% from 1.96 million tons in 2022 (Figure 6). Many factors contribute to this decline in output: lower copper grades, decreased production, aging domestic copper mines, and environmental regulations forcing the closure of many small private copper mines. More specifically, output reductions of about 50,000 to 60,000 tons were achieved at Western Mining, where the reduction was 13,000 tons, and at China Gold's Jiama Copper Gold Polymetallic Mine, they exceeded 40,000 tons.

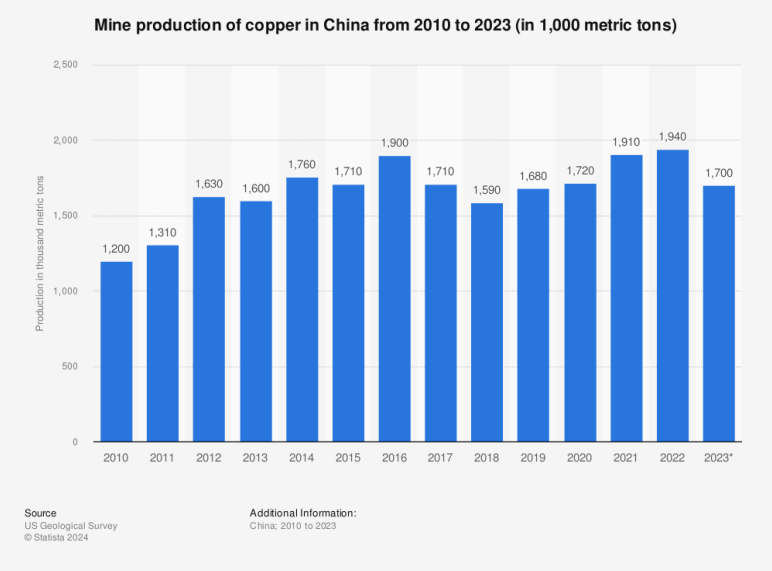

Fig. 6. Mine production of copper in China [15]

China's approach to sustainable exploitation, consumption, and responsible production of copper is influenced by several key factors, including domestic demand, global supply dynamics, and environmental considerations. As the world's largest consumer of copper, China's policies and actions significantly impact the global copper market.

The recovery of China's property market is a critical driver of copper demand. The Chinese government's comprehensive rescue package for the property sector, announced in November 2022, is expected to lead to a robust rebound in building and construction, which accounts for about 30% of total copper end-use in China.

China's push towards clean energy and the electrification of transportation also drives copper demand. Copper is a core material for renewable power grids and electric vehicle (EV) infrastructure, positioning it as a strategic resource in China's transition to a greener economy.

While China is a significant copper producer, it relies heavily on imports due to its vast consumption. Supply disruptions in key producing regions like Chile and Peru, due to factors such as road blockades and tax disputes, raise concerns about potential copper shortfalls. These disruptions can affect global copper prices and availability.

Low copper inventories in major exchanges, including the London Metal Exchange (LME) and the Commodity Exchange Inc. (COMEX), coupled with rising demand, suggest a tightening market. However, inventories in the Shanghai Futures Exchange (SHFE) grew following the Lunar New Year, indicating a seasonal adjustment rather than a fundamental shift in supply-demand dynamics [16].

The environmental impact of copper mining and processing is a concern globally, including in China. Sustainable practices, such as reducing water usage and minimizing waste, are increasingly important. However, detailed policies or initiatives specifically targeting the sustainability of copper production within China in 2023 are not explicitly mentioned in the provided sources.

Regulatory landscape influences the sustainability and responsibility of copper production and consumption. While the sources do not detail specific regulatory changes in 2023, the overall trend suggests a focus on stabilizing the property market and supporting clean energy transitions, which indirectly influence copper demand and production practices.

In conclusion, China's approach to copper in 2023 is shaped by its role as the leading consumer, with policies aimed at stimulating demand through the recovery of the property market and clean energy initiatives. Global supply risks and environmental considerations play a crucial role in shaping the sustainability and responsibility of copper production and consumption practices.

2.5 Copper production in U.S.A

According to data from the US Geological Survey (USGS), copper output from mines in the United States in 2023 totaled approximately 1.1 million tons. This marked a decrease (Figure 7) of 130,000 tons compared to 2022. The largest reductions came from the three largest projects in the US: Morenci, Bingham Canyon, and Safford. Specifically, Morenci saw a decrease of 38,000 tons, Bingham Canyon decreased by 28,000 tons, and Safford decreased by 18,000 tons, resulting in a combined reduction of 84,000 tons from these three projects alone.

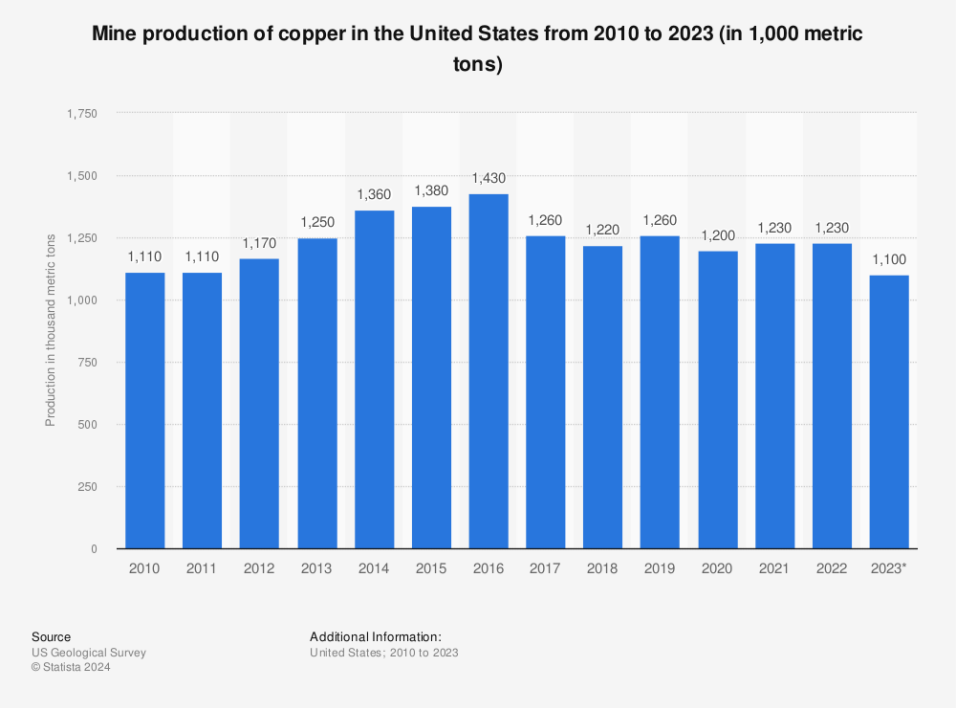

Fig. 7. Mine production of copper in the U.S. [17]

The United States continued to emphasize sustainable exploitation, consumption, and responsible production in its copper mining sector. The country's copper production, primarily concentrated in the western states like Arizona, Nevada, New Mexico, and Utah, faced challenges due to declining ore grades, regulatory hurdles, and environmental considerations. Despite these challenges, the U.S. mining industry has been actively pursuing strategies to enhance sustainability and efficiency.

Key strategies and developments in the U.S. copper mining sector in 2023 include:

Adoption of responsible mining guidance - U.S. copper miners have increasingly adopted guidelines for responsible mining to achieve sustainability goals. The International Copper Association (ICA) created the Copper Mark in 2019, an assurance system for responsible copper production. Over 25% of globally mined copper is now produced by Copper Mark-assured sites, indicating a commitment to environmental, social, and governance (ESG) standards.

Investment in digitalization and technology - in order to decrease their environmental impact and increase operational efficiency, miners are investing in digitalization and new technologies. This includes automation, remote operations, and data analytics to optimize mining processes and resource management [18].

Focus on recycling and low-carbon products - with the growing demand for sustainable copper, companies are investing in recycling facilities and developing low-carbon copper products, approximately 32% of copper used annually comes from recycling, and efforts are underway to increase the recovery rate from electronic scrap and other complex applications.

Community engagement and environmental considerations - projects like the Resolution Copper project, a joint venture between Rio Tinto and BHP, have faced opposition from Native American groups and delays due to environmental and social impact assessments. Engaging with local communities and incorporating their feedback into project planning has become crucial for gaining approval and ensuring the sustainability of mining operations [19].

Regulatory challenges and policy adjustments - the U.S. mining sector navigates a complex regulatory landscape, with ongoing discussions around mining policies, environmental protections, and community relations. Companies are striving to maintain their sustainability profiles while adapting to changing regulatory environments.

In summary, the U.S. copper mining industry in 2023 focused on enhancing sustainability through responsible mining practices, technological innovations, recycling initiatives, and community engagement. These efforts aim to ensure that copper production supports the country's clean energy transition while minimizing environmental impact and promoting social responsibility.

3. Conventional techniques in copper mining

Conventional methods of copper ore involve a series of physical, chemical, and electrochemical processes, with the conversion of copper ores depending on the ore source, local environmental regulations, and other factors. Here are the key traditional methods (Figure 8):

1. Mineral Processing

The first step in mineral processing for copper involves liberating the copper minerals and eliminating waste materials like silica, pyrite, alumina, and limestone. Using this method, valuable nonferrous minerals and copper minerals are concentrated to create a product that contains 20–30% copper. To guarantee that the copper minerals are separated from the waste materials, called gangue, the ore is crushed several times and finely ground after being received from the mine.

For oxide ores, crushing and grinding should only be done to the degree necessary to expose the mineral surfaces to the leaching agent. On the other hand, selective flotation, which calls for the ideal level of liberation, typically comes after the crushing and grinding stage for sulfide ores. During the flotation process, air bubbles are created by mechanically and pneumatically stirring the finely ground ore, water, and special reagents. These bubbles attract the copper minerals, carrying them to the surface where they are collected as froth, leaving the gangue minerals behind. This froth is then dewatered and filtered to produce a filter cake that is sent to a copper smelter [20].

Oxide ores are generally processed using hydrometallurgy, which involves heap leaching, solvent extraction, and electrowinning. Sulfide ores, on the other hand, are processed using pyrometallurgy, which includes froth flotation, thickening, smelting, and electrolysis. Froth flotation is a key process in separating copper minerals from gangue by adding chemicals that make the copper particles hydrophobic, allowing them to attach to air bubbles and be skimmed off for further processing [21].

2. Smelting or Leaching

The second step eliminates a significant amount of impurity elements, especially sulfur and iron in the case of sulfide ores. Procedures like smelting or leaching can be used to accomplish this. Comminution is the process of crushing the rock to create small particles in order to treat sulfide ores, such as chalcopyrite. The gangue is then extracted from these particles by froth flotation [22].

3. Refining

The final step entails refining to get rid of any remaining impurity elements and create a 99.99 % pure copper product. Usually, electrolysis is used to accomplish this, depositing copper ions as copper on the cathode. Traditionally, lead-based alloys were used as the anodes for this process, however, more recent techniques employ titanium or stainless steel.

4. Electrolysis

Electrolysis is a crucial step in the refining process, where copper ions are deposited as copper on the cathode. The anodes for this process were traditionally lead-based alloys, but newer methods use titanium or stainless steel. The cathode is either a strip of very pure copper which the new copper plates on to, or stainless steel which it has to be removed from later [23].

5. Solvent Extraction (SX) and Electrowinning (EW)

In order to obtain impure solutions of copper sulfate from oxidized ores, which are composed of silicates, carbonates, and sulfates, the crushed ore is leached with sulfuric acid. The SX/EW process involves using solvent extraction (SX) to concentrate these solutions and traditional electrowinning (EW) to remove the copper content [24].

The extraction methods are always being improved and developed to extract copper as efficiently as possible from a wide range of ores that come from sources all over the world.

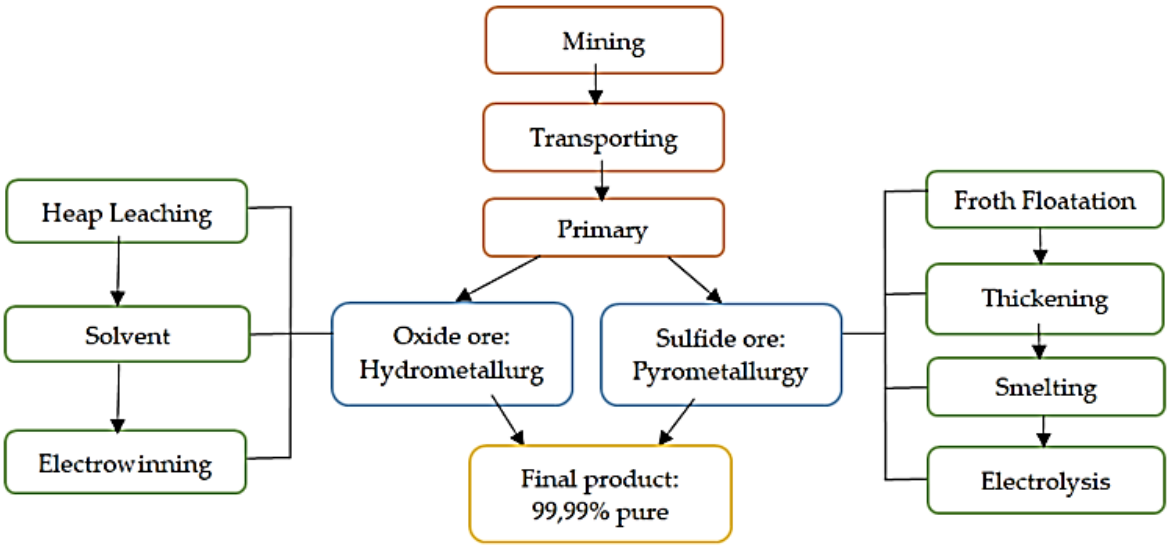

Fig. 8. Copper ore (Oxide ore and Sulfide ore) processes

The environmental impact of conventional techniques of extraction for copper ore is significant and multifaceted, affecting both the immediate surroundings of mining operations and broader environmental and social impacts. Here are the key environmental impacts:

Water pollution

Traditional copper mining methods, especially open-pit mining, can lead to severe water pollution. Heavy metals, chemicals, and other pollutants can contaminate nearby water sources as a result of mining operations. This pollution can affect the quality of drinking water and aquatic ecosystems, posing risks to both human health and biodiversity.

Air quality

The dust and emissions from mining activities can significantly degrade air quality in the surrounding areas. Heavy machinery and the use of chemicals for leaching minerals contribute to air pollution, which can have negative effects on respiratory health and the overall quality of life for local communities.

Soil contamination

Mining activities can lead to soil contamination, affecting agricultural lands and ecosystems. The use of chemicals for leaching minerals can leave behind residues that can contaminate soil, posing risks to agricultural productivity and the health of local flora and fauna.

Land use and landscape alteration

Open-pit mining, in particular, can cause significant alterations to the landscape, including the creation of large holes in the ground and the displacement of local wildlife. These changes can have long-term impacts on local ecosystems and biodiversity [25].

Energy consumption

The energy-intensive nature of traditional copper mining processes, including milling and smelting, contributes to high greenhouse gas emissions. This energy consumption is a major factor in the environmental impact of copper production, contributing to climate change and air pollution [26].

Waste management

Traditional mining operations often generate large volumes of waste, including tailings (residual waste from the leaching process), which can be harmful to the environment if not properly managed. The disposal of these wastes can lead to soil and water contamination, further exacerbating the environmental impact. [27]

Impact on indigenous cultural sites

Mining activities can also pose risks to Indigenous cultural sites, including archaeological sites and sacred lands, which can be irreversibly damaged or destroyed by mining operations.

These environmental impacts highlight the need for sustainable mining practices and technologies that minimize the environmental footprint of copper ore extraction.

4. Case study – Rosia Poieni

Rosia Poieni is situated in the Apuseni Mountains, a mountain range that is part of the larger Carpathian Mountain system in western Romania. The Roşia Poieni mining objective (Figure 9) covers an area of 50 km^2 and is situated on the territory of Lupşa commune, Alba County, in the area Poieni, Vîrsii, Curmătura peaks and the southern slope of the Valley Aries, and from a geographical point of view it falls within the unit structural Metaliferi Mountains. The region is characterized by its rugged terrain and rich mineral resources.

Mining in the Apuseni Mountains dates back to ancient times, with evidence of Roman activity in the area. Rosia Poieni has been a focal point for mining operations for several decades, particularly since the mid-20th century, when industrial-scale mining began.

The open-pit mining operation began in 1978 in the Abrud - Mușca - Bucium area, with copper production commencing in 1983. Feasibility studies identified the Roşia Poieni deposit as the largest disseminated copper and gold deposit in Romania and the second largest in Europe, containing 65% of Romania's copper reserves. The mining area spans 21.9 km² and is situated within the territories of Lupșa, Bucium, Bistra, and Roşia Montană communes, in the northeastern Metaliferi Mountains. The region features rugged terrain with deep valleys and elevated platforms, shaped by volcanic activity. There are multiple sloughy areas, negative forms, and dislevelments on the valley slopes, on platforms as well as in valley terraces or meadows. The area surrounding the deposit is primarily covered by clays and Senonian marls, which have poor consistency. The high relief energy, especially between elevations of 900 m and 400 m, also contributes to the frequent erosion of the land [28].

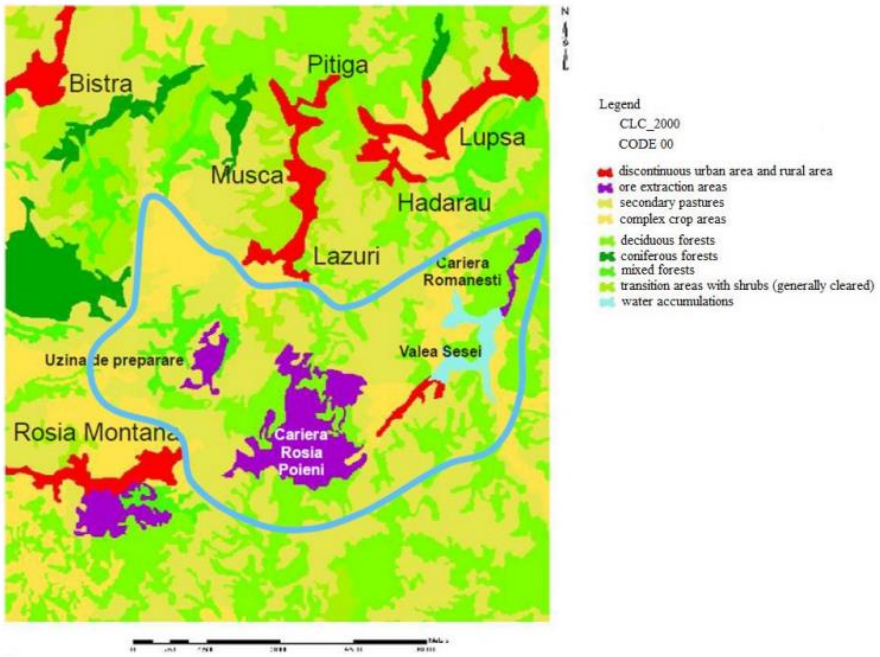

Fig. 9. The perimeter of Roşia Poieni mining project (blue line) [29]

4.1 Current state of Rosia Poieni copper mine

The current state of the Roșia Poieni Copper Mine (Figure 10), is characterized by its significant environmental and social impacts, as well as its economic contributions to the country.

With estimated reserves of 1.5 billion tonnes of ore grading 0.36% copper, Roșia Poieni represents the largest copper reserve in Romania and the second largest in Europe. Miocene eruptive sub-volcanoes (fundoaia andesites or micro-diorite) enclose it.

Fig. 10. Rosia Poieni copper mine [30]

The Fundoaia body measures 660 m (2,170 ft)÷740 m (2,430 ft)/820 m (2,690 ft)÷956 m (3,136 ft). Its shape is that of a vertical column rising to a height of 1,180 m (3,870 ft) (+1,030 m (3,380 ft) → −150 m (−490 ft). The eruptive body interacts with sedimentary Cretaceous rocks and andesite necks (Poieni, Curmătura, Melciu, Piatra Tichileu, and Jgheabului Hills) via tectonic breccia. The porphyry copper deposit is primarily composed of tiny veinlets, nests, and disseminations (0.02·- 3 cm) of magnetite, chalcopyrite, and pyrite; gold is also present in the chalcopyrite and pyrite; and secondary minerals, which are developed in microdioritic rocks, include bornite, covellite, chalcocite, sphalerite, galena, molybdenite, germanite, malachite, and azurite [29].

The mine has been a source of environmental concern, particularly due to its waste management practices. Since its opening in the 1980s, the operator has dumped mining waste into surrounding valleys, leading to the creation of a vast settling basin in the Șesii valley. This basin has expanded significantly, covering more than 130 hectares and receiving over 130 million tonnes of tailings, with 14,000 tonnes arriving daily. The tailings contain various metals, including copper, iron, zinc, lead, and arsenic, posing a risk to the environment and local communities.

The discharge of acidic sludge into watercourses has led to a phenomenon known as "acid mine drainage," which has significantly increased the acidity of the water. This has raised concerns about the impact on local ecosystems and the quality of water sources.

The mining activities have had a profound impact on local communities. The construction of a settling pond near the village of Curmătură led to the eviction of more than 300 families from their homes. Additionally, the expansion of the Geamăna settling basin has erased the village of Geamăna, highlighting the displacement and relocation challenges faced by local communities [30].

Despite the environmental and social challenges, the Roșia Poieni Copper Mine remains a significant economic asset for Romania. It produces around 11,000 tonnes of copper annually, representing 65% of the total copper reserves in the country. The mine is owned by CupruMin, a state-owned company, and its operations contribute to the national economy.

The mine employs approximately 550 people, with daily mining activities involving the extraction of 14,000 tonnes of rock. The ore is processed into a powder containing 20% copper, which is then exported, primarily to China, where it is transformed into copper metal.

4.2 Methods of copper ore exploitation at Rosia Poieni

The Rosia Poieni Copper Mine, located in the Apuseni Mountains of Romania, employs several methods for the exploitation of copper ore.

The mine utilizes open-pit mining, a method that involves extracting copper ore from the earth's surface. This technique is characterized by the removal of a large volume of earth and rock to access the ore beneath. The open-pit method is particularly effective for deposits of copper ore that are found in large, shallow layers.

Once the ore is extracted, it is sent to the ore processing plant. Here, the ore is crushed and chemically

treated, specifically using the flotation method. This process involves the use of chemicals to separate the copper ore from the waste rock. The ore is then concentrated into a powder containing 20% copper. This concentrated ore is the product that is exported, primarily to China, where it is transformed into copper metal.

A significant portion of the mining activities involves the management of waste rock. Half of the mined rock is sent to the ore processing plant, while the other half is dumped into a waste rock pile on the edge of the pit. This waste rock pile is a notable environmental concern, as the mining waste has been dumped into surrounding valleys, leading to the creation of a vast settling basin in the Șesii valley. This basin has expanded significantly, covering more than 130 hectares and receiving over 130 million tonnes of tailings, with 14,000 tonnes arriving daily. The tailings contain various metals, including copper, iron, zinc, lead, and arsenic, posing a risk to the environment and local communities.

The mining operations at Rosia Poieni have raised significant environmental and social concerns. The dumping of mining waste into the surrounding valleys has led to the creation of a vast settling basin, which has expanded significantly over the years. This basin has become a significant environmental concern, as the acidic sludge contains various metals that pose a risk to the environment and local communities. Additionally, the mining activities have led to the displacement of local communities, with over 300 families being forced from their houses in order to make room for the first settling pond close to Curmătură village.

The main exploitation activities at Rosia Poieni are [31] (Figure 11):

- Extracting the mining mass through drilling, blasting, loading, and transportation in a open – pit mine;
- Store the quarry waste in the tailing dumps at Geamăna, Cuibaru and Obârșia Muntari;
- The traditional methods of processing copper ore, which include crushing, grinding, flotation, and filtration to produce copper concentrate;
- Thickening, gravitational transport and sterile hydromass storage in Valea Şesei and Valea Ştefancei tailings ponds;
- Tailings ponds, where flotation tailings from the preparation plant are stored, and tailings dumps, where the quarry sterile obtained from the extraction activity of mining mass are stored, are the tailings dumps for which the environmental balance sheet assessment is made.

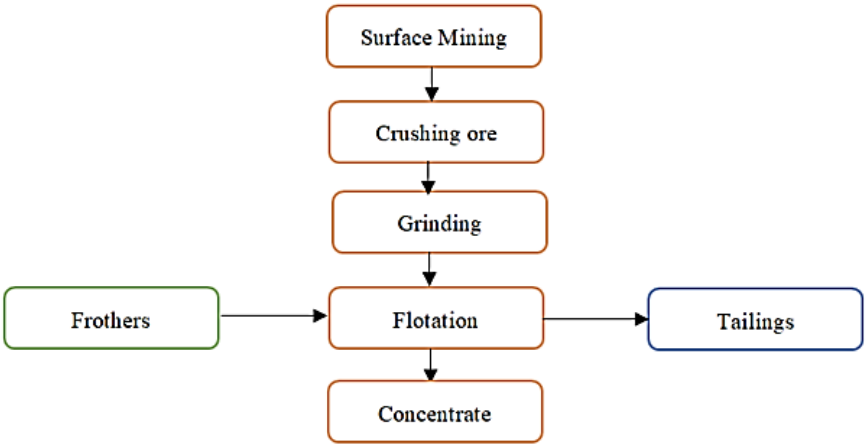

Fig. 11. Methods of copper ore exploitation at Rosia Poieni

The extraction of the mining mass in the Roşia Poieni Quarry is carried out:

- in steps with a height of 15 m.
- no. of steps: 24
- steps width: 12 m
- final height at the hearth of the quarry: 760 mdM, current height of the hearth of the quarry 850 m
- pit depth: 360 m
- drilling methods are applied

The mining mass extracted from the quarry is loaded (Figure 12) with electric excavators type EKG 4.6 m^3, 5 m^3 and 8 m^3 Caterpillar front loaders with a bucket of 12.5 m^3, in 55 and 110 t type DAC and 91 t type KOMAKTSU and Caterpillar, which are directed as follows:

- tailings (overburden) at Cuibarului and Geamăna dumps;

• the ore is transported to the gyratory crusher KKD 1500/180, and after crushing the crushed ore is transported to the preparation plant;

The leg with a relay of conveyor belts with Lt = 2440 m and width l = 1.4 m [32].

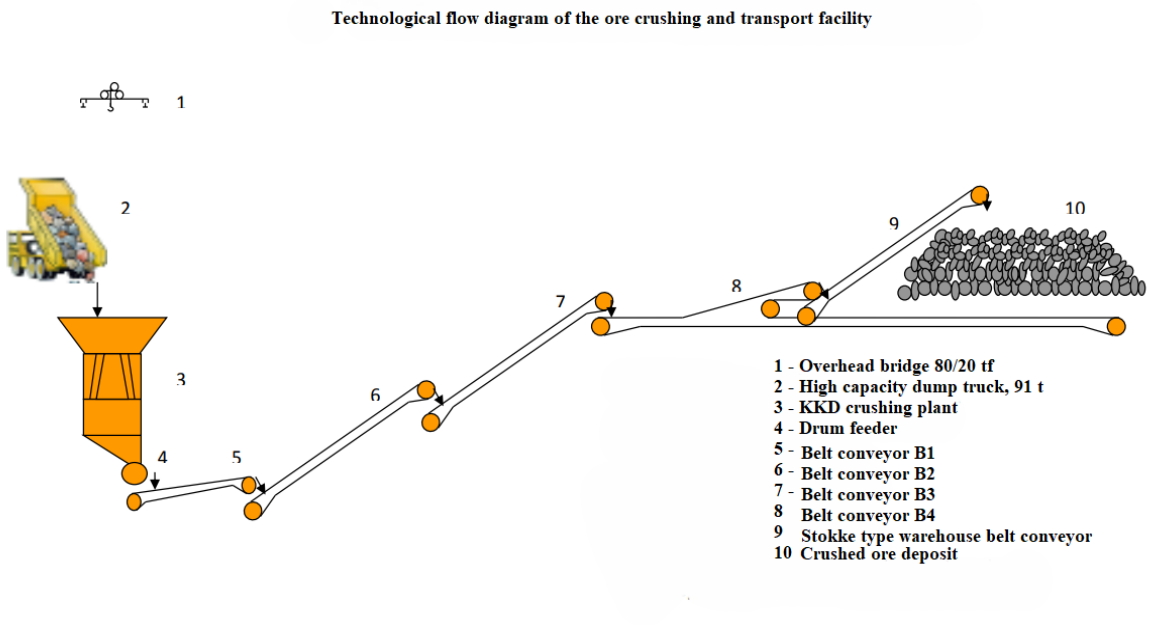

Fig. 12. Technological flow diagram of the ore crushing and transport facility [32]

Preparation plant Dealul Piciorului

There are 2 grinding-flotation lines in operation at the preparation plant, each line having an annual processing capacity of approx. 2,000,000 t/year.

The main technological phases of the current preparation process are (Figure 13):

- crushing of ore extracted from the quarry from size 0 - 1,200 mm, to 0 - 300 mm in the rotary crusher type KKD - 1500/180;
- transport of the crushed ore to the storage of the preparation plant is done with a bus lane relay with a total length of 2,440 mm provided at the end of unloading with a "Stoker" type unloading installation;
- wet grinding of the ore in two stages and its classification in batteries of hydrocyclones;
- selective flotation of copper ore in two modernized preparation lines equipped with 17 m^3 flotation cells, followed by two re-flotations of the primary concentrate. The first two refloats are done in pneumo-mechanical cells of 5.7 m^3 and the third re-flotation can be done in pneumo-mechanical cells of 2.8 m^3 (if this is the case with regard to the quality of the obtained copper concentrate, respectively its content between 18 ÷ 20 % Cu). The dosed flotation reagents are: lime, collecting reagents, foaming reagents.
- thickening of the concentrate in mechanical thickeners with peripheral actuation by Φ 25 m up to densities of 1900 ÷ 2,300 g/l;
- drying of the thickened concentrate is done by filtering with a filter press type PF-25 A1H60 (LAROX) with a filtration surface of 25.2 m^2;
- the storage of the filtered concentrate is done on an open platform, in view shipping to beneficiaries;
- the tailings thickening is carried out in thickeners with a diameter of Φ 80 m at dilution of 2.25:1 liquid/solid with water recirculation in the technological flow of the preparation plant;
- the hydraulic gravity transport of the thickened tailings through steel pipes of and PEHD, with total length L= 7.66 km at the Valea Şesei settling pond;
- decanting and storing tailings in the Valea Şesei settling pond or in case of damage in the settling pond Valea Ştefancei 2 [33].

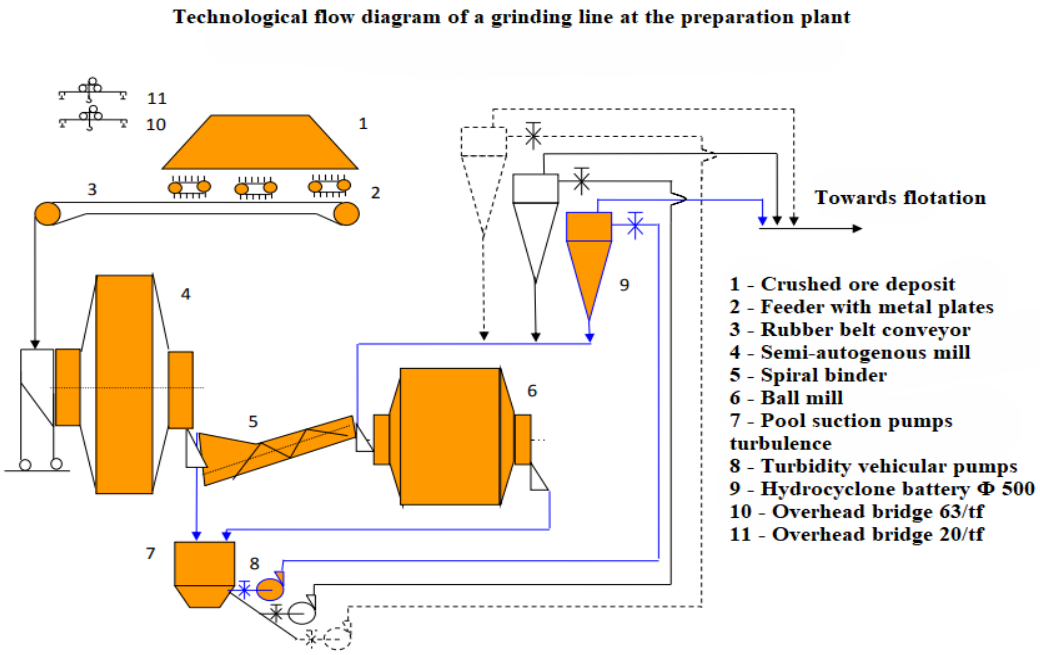

Fig. 13. Tehnological flow diagram of a grinding line at the preparation plant [33]

In summary, the Rosia Poieni Copper Mine employs open-pit mining and ore processing methods to extract and concentrate copper ore. However, the mining activities have raised significant environmental and social concerns, particularly related to waste management and the displacement of local communities.

4.3 The impact on the environment generated by the Rosia Poieni mining operatios

The exploitation of Rosia Poieni, Europe's second-largest copper mine, has significant environmental impacts due to its mining practices and waste management. Here are the key environmental concerns [34]:

- Water contamination

Mining activities at Rosia Poieni have led to severe contamination of both surface and underground water sources. The acidification and movement of metals, including copper, iron, zinc, lead, and arsenic, have negatively affected the water quality across the region. This contamination affects the Arieş river basin, impacting not just the immediate area but also areas as far as 80 km downstream.

- Soil and air pollution

Tailings and waste rock are produced in huge quantities during the mining process, which are often dumped in nearby valleys. This practice leads to soil contamination and can contribute to air pollution through dust emissions. The continuous dumping of tailings into settling basins like the one near Geamăna village has resulted in the expansion of these basins, covering extensive land areas and posing risks to the surrounding ecosystem.

- Habitat destruction

The creation of settling ponds and natural ecosystems are being destroyed and local communities are being uprooted as a result of the growth of mining operations. For instance, more than 300 families were evicted to build a settling pond near Curmătură village, and the village of Geamăna has been partially submerged (Figure 14) by the expanding settling basin.

- Biodiversity loss

The pollution and habitat destruction resulting from mining activities have led to a loss of biodiversity. Incidents such as the death of thousands of fish in the Arieş river due to negligence in activating control devices highlight the direct impact on aquatic life. The overall degradation of the environment threatens the survival of various species in the region.

- Legal and regulatory issues

Despite the environmental damage, there has been limited action against the mining company, Cupru Min. Fines imposed by local authorities have been minimal compared to the extent of the damage, indicating a lack of effective enforcement of environmental regulations. Additionally, the European Court of Justice condemned Romania in 2016 for breaching its obligations under EU directives on waste management from extractive industries, underscoring the broader regulatory challenges [35].

Fig. 14. Geamăna village in 1970, before flooding and in present [36]

In summary, the exploitation of Rosia Poieni has led to widespread environmental degradation, affecting water resources, soil quality, air quality, and biodiversity. The ongoing issues highlight the need for stricter environmental regulations and enforcement to mitigate the adverse effects of mining activities.

4.4 Recommendations for implementing policies, techniques and sustainable technologies in the Rosia Poieni mining exploitation

To enhance environmental sustainability and operational efficiency at the Rosia Poieni Mining Exploitation, consider implementing the following policies, techniques, and sustainable technologies:

Policies:

- Environmental impact assessment (EIA) - mandate comprehensive EIA's before initiating new mining activities to assess potential environmental impacts and develop mitigation strategies.
- Adopt sustainable land management practices - implement practices that balance environmental protection, economic viability, and social equity. This includes managing land use changes, minimizing ecosystem disturbances, and ensuring water quality management.
- Waste management - implement strict waste management protocols to minimize pollution and promote recycling of mining waste where possible [37].
- Secure financial guarantees for environmental liabilities - ensure that mining companies establish and maintain adequate financial guarantees for environmental liabilities, including waste management and site rehabilitation. This helps mitigate the financial risks associated with environmental damage and ensures funds are available for remediation efforts [38].
- Community engagement - establish regular dialogue with local communities to address concerns and ensure transparency in operations.
- Enhance environmental and social governance - Urge mining firms to implement ethical and environmentally friendly procedures that support sustainable growth. This involves creating and sharing value across economic, environmental, and social dimensions, and considering environmental and social practices as part of the company's competitive advantage.

Techniques:

- Precision mining - utilize advanced drilling and blasting techniques that reduce overburden removal and increase ore extraction efficiency.
- Water management - develop sophisticated water management systems to recycle water within the mining process, reducing freshwater consumption and minimizing wastewater discharge.
- Revegetation and land rehabilitation - after mining activities cease, prioritize the rehabilitation of mined areas through revegetation using native plant species to restore ecological balance.

Sustainable Technologies:

- Renewable energy integration Examine ways to power mining operations with renewable energy sources, like wind turbines or solar panels, to lessen dependency on fossil fuels.
- Electric vehicles - transition to electric vehicles and machinery within the mine site to lower carbon emissions and improve air quality.
- Smart monitoring systems - deploy IoT-based monitoring systems to track environmental parameters like air quality, soil health, and water levels in real-time, enabling proactive management and intervention [39].
- I-Rox technology, developed by I-Pulse Inc. and I-ROX SAS, utilizes pulsed-power technology to deliver short, high-intensity bursts of energy that can efficiently shatter rocks and mineral ores. This method targets the tensile weaknesses in rocks, offering a potentially revolutionary approach to mining processes, especially in the areas of crushing and grinding ores, which are traditionally the most energy- and capital-intensive aspects of mining [40].

It is mentioned that Ivanhoe Mines and I-ROX are working together to investigate the possible integration of I-Pulse technology throughout Ivanhoe's operations. The goal of this partnership is to change the way that mining affects the economy and environment by utilizing the mining and processing experience of Ivanhoe Mines, as well as the pulsed-power technology and knowledge of I-Pulse and I-ROX.

Traditional mining processes, particularly comminution (crushing and grinding), are highly energy-intensive, accounting for approximately 4% of global electrical energy consumption. I-Rox technology aims to significantly reduce this power usage through the application of pulsed-power technology, which uses short, high-intensity bursts of energy to fracture rocks [41].

The reduction in energy consumption directly translates to a decrease in carbon emissions, aligning with the mining industry's goals of moving towards carbon neutrality. I-Rox aims to cut the carbon footprint of mines worldwide by as much as 80% [42].

By adopting these measures, Rosia Poieni Mining Exploitation can significantly reduce its environmental footprint, enhance operational efficiency, and contribute positively to the local community and ecosystem.

5. Conclusions

In conclusion, the implementation of sustainable techniques and technologies at Rosia Poieni Mining Exploitation is both feasible and essential for mitigating environmental damage, enhancing community engagement, and guaranteeing the mining industry's long-term sustainability. By adopting strategies such as comprehensive rehabilitation and restoration, effective water and waste management, energy efficiency improvements, community engagement, and rigorous monitoring and compliance, Rosia Poieni can transition towards a model of sustainable mining.

These approaches not only address immediate environmental concerns but also contribute to the broader goals of environmental sustainability and innovation in the rehabilitation of abandoned mining sites. The successful application of these methods requires collaboration between the mining company, local communities, and regulatory bodies to ensure that all stakeholders benefit from the adoption of sustainable practices.

Moreover, the integration of innovative technologies and practices can lead to significant improvements in operational efficiency, reduced environmental impact, and enhanced social responsibility. This aligns with global trends towards sustainable development in the mining sector, emphasizing the importance of balancing economic growth with environmental stewardship and social equity.

By integrating these sustainable practices, Rosia Poieni Mining Exploitation can mitigate its environmental footprint, enhance community relations, and ensure the longevity of its operations through responsible resource management.

Therefore, the potential for implementing sustainable techniques and technologies at Rosia Poieni is substantial, offering a pathway towards responsible mining that benefits both the environment and the community.

References

[1] **Malan, S.,** 2021
How to advance sustainable mining, Earth Negotiation Bulletin, International Institute for Sustainable Development (IISD). Available online: https://www.iisd.org/system/files/2021-10/still-one-earth-sustainable-mining.pdf (Accessed on 14 March 2024)

[2] **Reichl, C., Schatz, M.,** 2022
World Mining Data 2022, Minerals Production, Vol. 37, Vienna.

[3] **Venditti, B., Parker, S.,** 2024
Visualizing Copper Production by Country in 2023. Available online: https://www.visualcapitalist.com/visualizing-copper-production-by-country-in-2023/ (Accessed 14 March 2024)

[4] **Jaganmohan, M.,** 2024
Chile: copper mine production 2010 – 2023. Available online: https://www.statista.com/statistics/254845/copper-production-of-chile/ (Accessed on 16 March 2024)

[5] **Ghorbani, Y., & Kuan, S. H.,** 2016
A review of sustainable development in the Chilean mining sector: past, present and future, International Journal of Mining, Reclamation and Environment, 31 (2), pp. 137–165.

[6] *******, 2023
Mining, Chile - Country commercial guide. Available online: https://www.trade.gov/country-commercial-guides/chile-mining (Accessed on 16 March 2024)

[7] **Jaganmohan, M.,** 2024
Copper mine production in DR Congo 2010 – 2023. Available online: https://www.statista.com/statistics/1276790/copper-production-in-democratic-republic-of-the-congo/ (Accessed on 16 March 2024)

[8] *******, 2023
Democratic Republic of the Congo: Industrial mining of cobalt and copper for rechargeable batteries is leading to grievous human rights abuses, Amnesty International, Press release from 12 September 2023. Available online: https://www.amnesty.org/en/latest/news/2023/09/drc-cobalt-and-copper-mining-for-batteries-leading-to-human-rights-abuses/ (Accessed on 24 March 2024)

[9] *****,** 2023
Democratic Republic or the Congo, BMZ. Available online: https://www.bmz.de/en/countries/democratic-republic-of-the-congo (Accessed on 03 April 2024)

[10] **U.S. Department of State**, 2023
Report: 2023 Investment Climate Statements: Democratic Republic of the Congo. Available online: https://www.state.gov/reports/2023-investment-climate-statements/democratic-republic-of-the-congo/ (Accessed on 09 April 2024)

[11] *******, 2021
Wilson Centre, Press release from 1 September 2021. Available online: https://www.wilsoncenter.org/blog-post/drc-mining-industry-child-labor-and-formalization-small-scale-mining (Accessed on 14 April 2024)

[12] **Jaganmohan, M.,** 2024
Copper mine production in Peru 2010 – 2023. Available online: https://www.statista.com/statistics/789003/copper-production-peru/ eru: copper production 2023 | Statista

[13] **Barnes, J., Mpangala, L.,** 2024
Peru greenlights Cerro Verde expansion, Project blue, Press release from 11 June 2024. Available online: https://projectblue.com/blue/news-analysis/909/peru-greenlights-cerro-verde-expansion (Accessed on 15 June 2024)

[14] *******, 2023
Global copper supply in 2023 will be supported by increased output from the DRC, Peru, and Chile, Mining technology, Press release from 17 November 2023. Available online: https://www.mining-technology.com/analyst-comment/global-copper-supply-2023/ (Accessed on 15 June 2024)

[15] **Textor, C.,** 2024
China's copper mine production 2010 – 2023. Available online: https://www.statista.com/statistics/254847/copper-production-of-chile/ (Accessed on 15 June 2024**)**

[16] **Reddy, R.,** 2024
Copper Update: China's Demand and Renewed Supply Risks to Be Supportive of a Market Rebound, Globalx, Press release from 12 April 2024. Available online: https://www.globalxetfs.com/copper-update-chinas-demand-and-renewed-supply-risks-to-be-supportive-of-a-market-rebound/ (Accessed on 28 May 2024)

[17] **Jaganmohan, M.,** 2024
Copper mine production in the U.S. 2010 – 2023. Available online: https://www.statista.com/statistics/254849/copper-production-of-the-us/(Accessed on 28 May 2024)

[18] **Butler, R.,** 2024
How copper miners can remain competitive amid transition towards the greener economy, EY, Press release from 07 March 2024. Available online: https://www.ey.com/en_us/insights/mining-metals/sustainable-and-efficient-operations-for-copper-miners (Accessed on 30 May 2024)

[19] *****,** 2024
Western USA Copper Production and Development, Global business reports, Press release from 05 April 2024. Available online: https://www.gbreports.com/article/western-usa-mining-copper-production-and-development

[20] **Butts, A., Taylor, J. C., and Schlechten, A. W.,** 2023
Copper processing, Encyclopedia Britannica. Available online: https://www.britannica.com/technology/copper-processing Ores (Accessed on 02 June 2024)

[21] **Stanley, J., Wilkinson, S.T., Moreno Ramírez, D., Maier R.M., & Chief, K.,** 2015
Tribal Mining Educational Modules: Copper Mining and Processing. Available online: https://www.superfund.arizona.edu/resources/learning-modules-english/copper-mining-and processing (Accessed on 3 June 2024)

[22] *****,** 2024
Copper extraction, Wikipedia. Available online: https://en.wikipedia.org/wiki/Copper_extraction (Accessed on 4 June 2024)

[23] **Clark, J.,**
The extraction of copper, Supplemental Modules and Websites (Inorganic Chemistry). Available online: https://batch.libretexts.org/print/url=https://chem.libretexts.org/Bookshelves/Inorganic_Chemistry/Supplemental_Modules_and_Websites_(Inorganic_Chemistry)/Descriptive_Chemistry/Elements_Organized_by_Block/3_d-Block_Elements/1b_Properties_of_Transition_Metals/Metallurgy/The_Extraction_of_Copper.pdf (Accessed on 7 June 2024)

[24] **Calcutt, V.,** 2001
Introduction to copper: Mining and extraction. Available online: https://www.copper.org/publications/newsletters/innovations/2001/08/intro_mae.html

[25] *******, 2021
How the rise of copper reveals clean energy's dark side, The guardian, Press release from 09 November 2021. Available online: https://www.theguardian.com/us-news/2021/nov/09/copper-mining-reveals-clean-energy-dark-side (Accessed on 15 June 2024)

[26] *****,** 2021
Copper production and environmental impact, Greenspec. Available online: https://www.greenspec.co.uk/building-design/copper-production-environmental-impact/ (Accessed on 16 June 2024)

[27] ***, 2024
Rosia Poieni copper mine, Wikipedia. Available online: https://en.wikipedia.org/wiki/Ro%C8%99ia_Poieni_copper_mine (Accessed on 17 June 2024)

[28] ***, 2018
The dark side of Rosia Poieni, Europe's second largest copper mine, Mining SEE, Press release from 18 February 2018. Available online: https://www.miningsee.eu/dark-side-rosia-poieni-europes-second-largest-copper-mine/ (Accessed 19 June 2024)

[29] **Toderas, M.,** 2021
Mining risks at exploitation in Roșia Poieni open pit mine, Romania, Revista Minelor – Mining Revue, 27 (1), pp. 1-11.

[30] **Toderas, M., Filatiev, M.,** 2021
Slopes stability analysis from Rosia Poieni open pit mine, Romania, MATEC Web of Conferences. 342 no. 02005.

[31] **Toderaș M.,** 2022
Determination of Mining Risks at Exploitation in Rosia Poieni Open Pit Mine, Romania. Techniques and Innovation in Engineering Research, Vol. 3, pp. 66–87.

[32] *****,** 2018
Carier, CupruMin. Available online: ttps://cuprumin.ro/wp-content/uploads/2018/05/CARIERA-cu-desene.pdf. (Accessed on 25 June 2024)

[33] *****,** 2018
Uzina, CupruMin. Available online: https://cuprumin.ro/wp-content/uploads/2018/05/UZINA-cu-desene.pdf (Accessed on 25 June 2024)

[34] **Lazăr, M, Faur, F.**, 2013
Identification and assessment of the risk and impact generated by Roşia Poieni quarry and Dealul Piciorului processing plant, Annals of the University of Petroşani, Mining Engineering, 14, pp. 129–143. https://www.upet.ro/annals/mining/pdf/Annals%20of%20UPET%20-%20Mining%20Engineering%20Vol%2014-2013%20(XLI).pdf

[35] *****,** 2016
The dark side of Rosia Poieni, Europe's second largest copper mine, SystExt. Available online: https://www.systext.org/node/697#:~:text=With%20no%20regard%20for%20the,zinc%2C%20lead%20and%20even%20arsenic (Accessed on 20 June 2024)

[36] **Chapple, A.,** 2017
This Church Spire Is All That Remains Of A Village, Soon It Will Be Buried Completely, Photography. Available online: https://www.boredpanda.com/geamana-village-sinking-industrial-waste-romania-amos-chapple/?utm_source=share&utm_medium=top&utm_campaign=user (Accessed on 20 June 2024)

[37] *****,** 2024
Sustainable Mining Practices: 5 Strategies to Consider, Veriforce. Available online: https://veriforce.com/blog/sustainable-mining-practices-5-strategies-to-consider (Accessed on 26 June 2024)

[38] **Popović, V., Miljković, J.Z., Subić, J., Andrei, J.V., Nedelcu, A., Nicolăescu, E**., 2015
Sustainable Land Management in Mining Areas in Serbia and Romania, Sustainability, 7, 11857-11877

[39] **Smith D., Wentwort, J.,** 2022
Mining and sustainability of metals, Parliamentary Office of Science and Technology (POST). Available online: hhttps://researchbriefings.files.parliament.uk/documents/POST-PB-0045/POST-PB-0045.pdf (Accessed on 27 June 2024)

[40] *******, 2024
New Copper Technologies, Goehring & Rozencwajg Associates, Press release from 05 March 2024. Available online: https://blog.gorozen.com/blog/new-copper-technologies#:~:text=Friedland%20has%20also%20advanced%20a,The%20implications%20could%20be%20transformative (Accessed on 02 July 2024)

[41] *****,** 2023
Ivanhoe Mines, I-PULSE. Available online: https://www.ivanhoemines.com/wp-content/uploads/2023/07/20230615_ipulse_hpx_loan_conversion_vf2.pdf (Accessed on 02 July 2024)

[42] *******, 2024
I-ROX Breakthrough in Mineral extraction, Ipulse. Available online:https://www.ipulse-group.com/our-businesses/i-rox/ (Accessed on 01 July 2024)