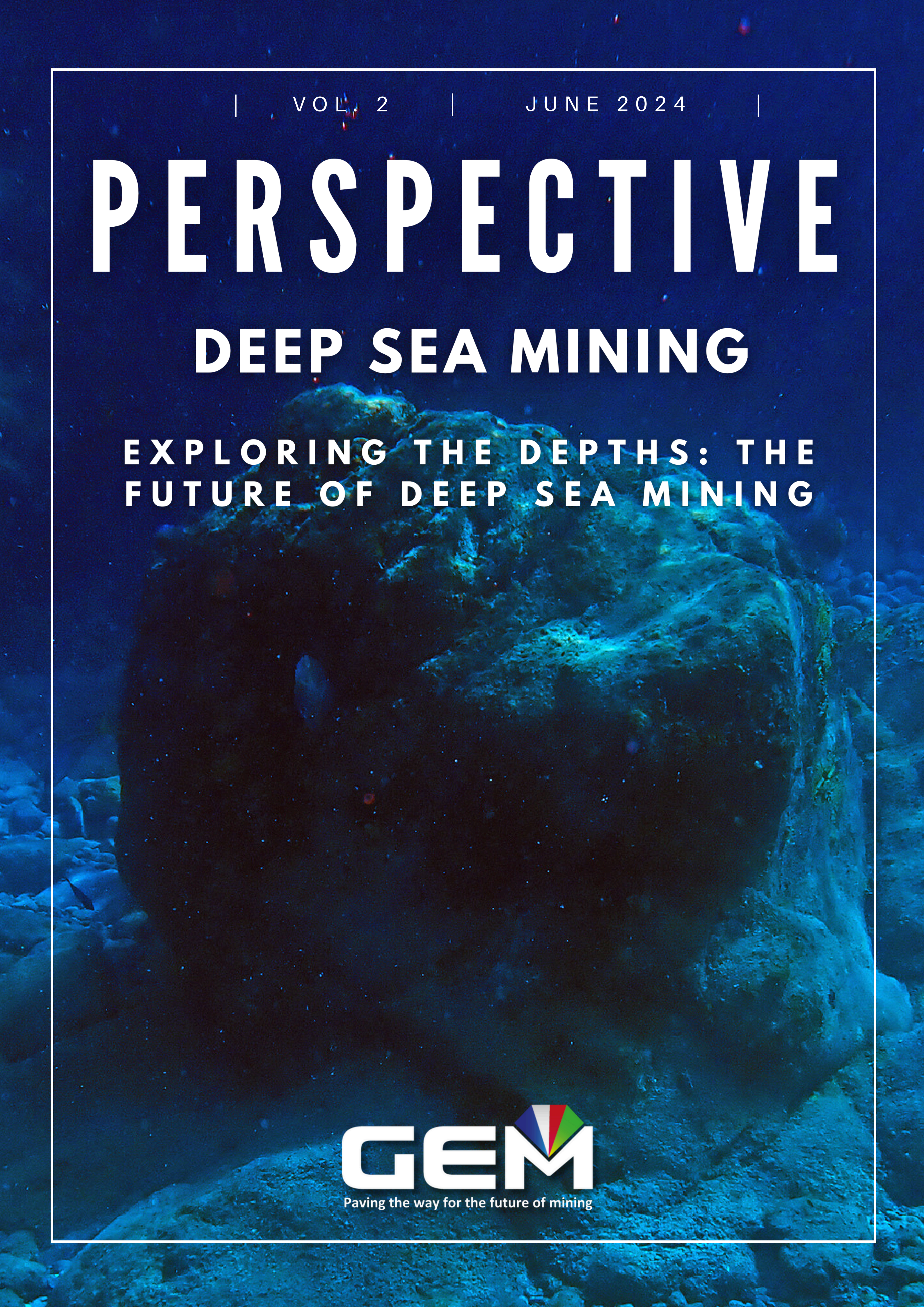

| VOL. 2 | JUNE 2024 |

PERSPECTIVE

DEEP SEA MINING

EXPLORING THE DEPTHS: THE FUTURE OF DEEP SEA MINING

GEM

Paving the way for the future of mining

INDEX

ABOUT GEM

We are a specialized Industrial Engineering company that provides support to the mining industry in matters related to management and economics. Our expertise covers various fields as we develop the most advanced tools applied in the mining sector. With over 14 years of experience and the successful implementation of more than 400 projects worldwide, we stand out for our solid track record and commitment to excellence in the sector.

MISSION

We are a company providing products and services in industrial engineering that enable the path for the future of mining while maximizing the business value for our clients.

At GEM, we are committed to becoming a beacon for the global mining industry.

Our core highlights the main service areas of GEM, which include:

Analytic: Use of advanced analytical tools such as machine learning and statistical analysis.
Training: Provision of training on complex topics tailored to specific mining cases.
Economics: Generation of mineral economics studies, market analysis, and econometric analysis.
Evaluation: Identification and quantification of risks with Monte Carlo simulations to evaluate their impact.
Strategy: Support in strategic decision-making to maximize business value.
Optimization: Utilization of tools and programming languages to find optimal solutions.

Additionally, the central image shows GEM's commitment to the future of mining, addressing areas such as climate change, collaboration, social impact assessment, nature, underwater mining, and in-situ leaching.

EDITORIAL

Humanity today faces the challenge of addressing climate change. For this, we need metals whose abundance on Earth is becoming increasingly critical: copper, nickel, manganese, cobalt, among others. The quality of the mineral resources we need for the coming decades on Earth is decreasing exponentially, making their costs increasingly higher. On the other hand, social and environmental awareness regarding the environmental implications of continental mining is making it increasingly difficult to develop the projects humanity requires. Hence the need to start exploring what we might call "exoterrestrial mining," such as underwater mining and space mining (extraterrestrial mining refers exclusively to mining conducted outside of Earth). Both offer opportunities for humanity, not only to reduce the need for continental mining, where people and most of the planet's biota live, but also because it will eventually allow us to advance towards technologies that are expected to even improve current mining technologies and reduce environmental impact.

In this Perspective, we present a summary of the results of a study we developed at GEM with the aim of gaining a deeper understanding of the potential of underwater mining. This study, in which we reviewed the technical, economic, and environmental components, leads us to conclude that underwater mining of Polymetallic Nodules is not only economically viable for minerals such as nickel, cobalt, and manganese, but also that its environmental footprint in the depths of the sea is relatively controlled and is definitely smaller than the footprint of continental mining.

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JUAN IGNACIO GUZMÁN
CHIEF EXECUTIVE OFFICER GEM

In this way, although scientific and environmental impact studies still need to be advanced to obtain social license, underwater mining will most likely be part of the sources of minerals for the coming decades.

At GEM, we are committed to paving the way towards the mining of the future. We believe that underwater and space mining will be key to solving humanity's challenges, including our long-term survival as a species. Hence, we are developing the capabilities that will allow us to support the industry in sustainably achieving this challenge - economically, environmentally, and socially.

INTRODUCTION

In the coming decades, a sustained increase in the demand for critical metals and a deficit in production at the global level are projected. This scenario occurs alongside the global drive towards decarbonization, promoting electromobility and technologies that reduce carbon emissions. In Figure 1, which presents several possible scenarios, it is visualized that the demand for minerals essential for renewable energies could increase significantly. It is estimated that by the year 2030, the demand could double compare to that of the year 2022, and could triple by the year 2050 (IEA, 2023).

The first scenario, 'Stated Policies' (STEPS), considers a trajectory based on the current policies of the world. Then, the 'Announced Pledges' (APS) scenario assumes that energy and carbon neutrality goals are achieved, regardless of whether the policies for this are currently in place. Finally, the third scenario, 'Net Zero Emissions by 2050' (NZE), considers the pathway for the energy sector to achieve carbon neutrality by the year 2050 (IEA, 2023).

In the face of concerns about the scarcity of critical minerals on land, deep-sea mining emerges as a potential alternative, thanks to the abundance of discovered seabed deposits in explorations and technological advances that have enabled the development of efficient extraction methods. There are three types of seabed deposits: Polymetallic Nodules (PN), Cobalt-Rich Crusts (CRC), and Seafloor Massive Sulfides (SMS) (See Figure 2). PNs are found on abyssal plains, which are flat and extensive areas in deep waters

Between 13,123 and 19,685 feet below sea level. PNs are potato-shaped with a diameter between approximately 1.6 and 3.9 inches, and their formation process is estimated to take millions of years. They consist mainly of manganese (28%), nickel (1.3%), copper (1.1%), cobalt (0.2%), molybdenum (0.059%), and rare earth metals (0.081%). On the other hand, CRCs form on the slopes and summits of underwater mountains and contain manganese, iron, and a wide variety of trace metals. Mining CRCs is more technologically challenging than mining PNs because the crusts are attached to rocky substrates.

Finally, SMS deposits are found between approximately 3,280 and 13,123 feet deep in active and inactive hydrothermal vents of up to 752°F, which are cracks on the ocean floor from which hot mineral-laden fluids emerge, and they result from volcanic and geothermal activity. These have a high content of sulfide, copper, gold, zinc, lead, barium, and silver. However, their mining presents significant complications, as around 85% of the species inhabiting hydrothermal vents are considered endemic,

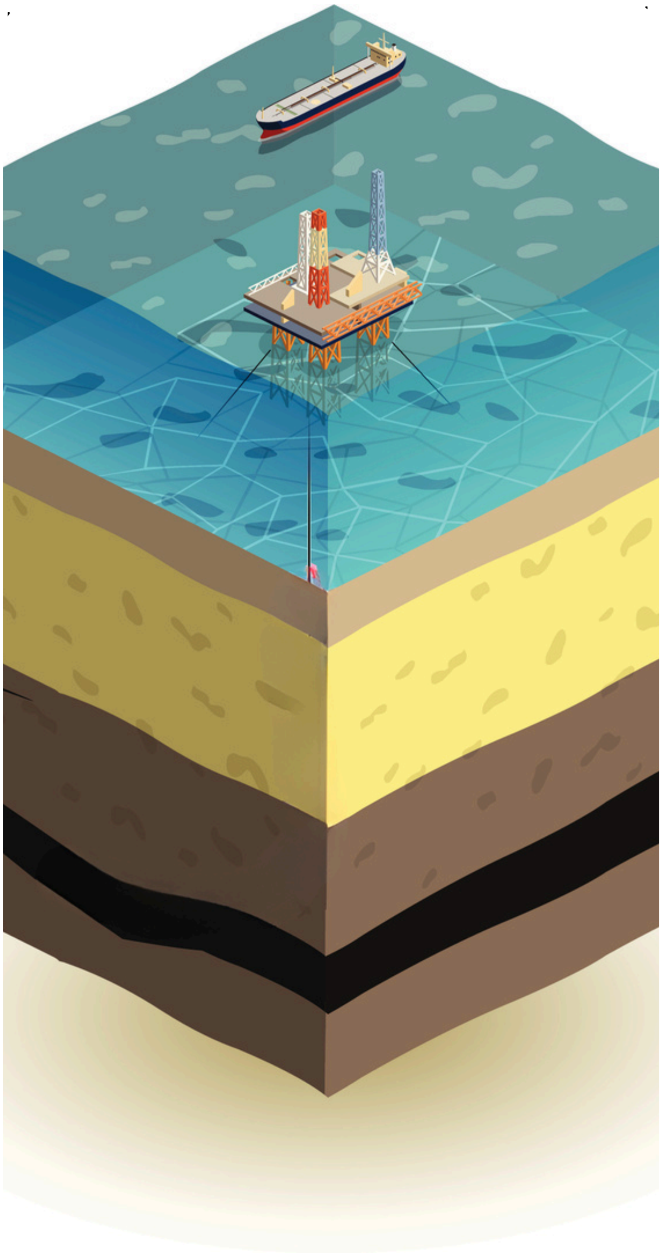
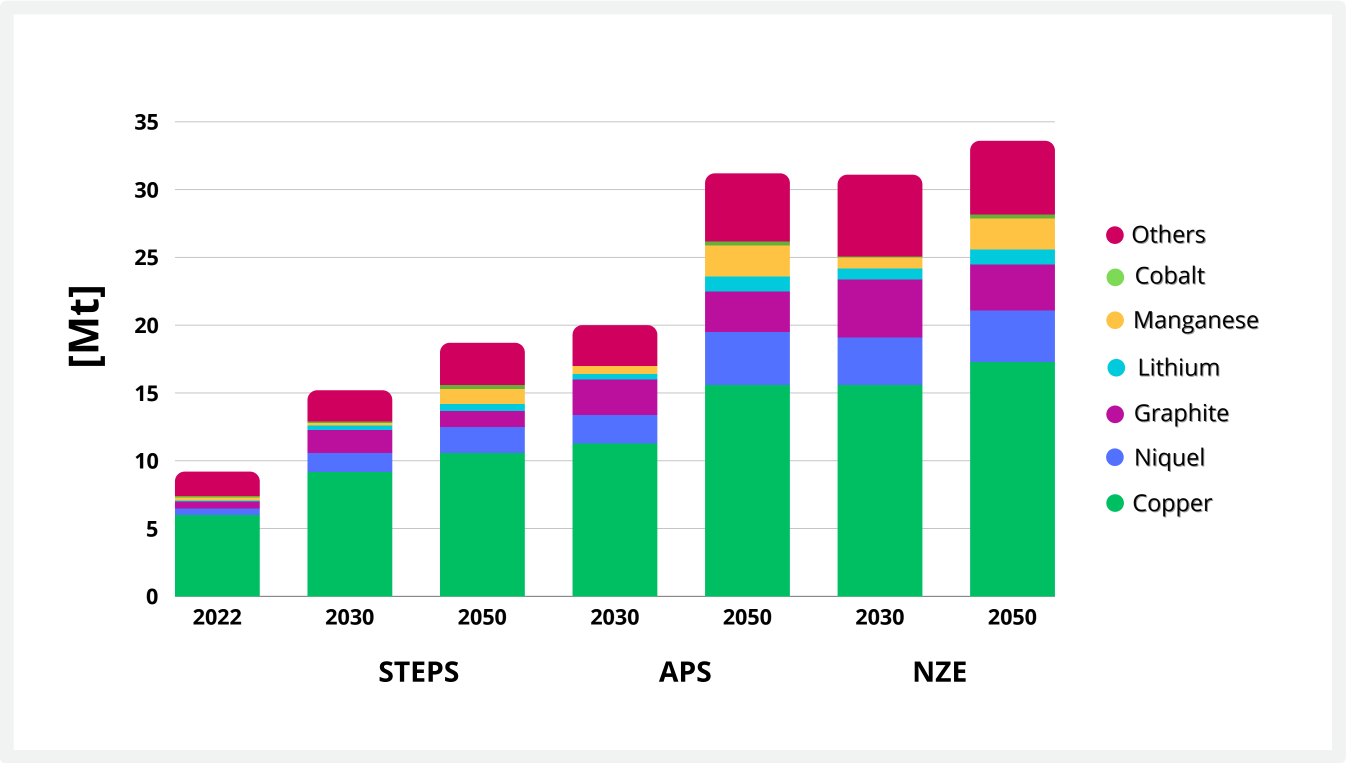
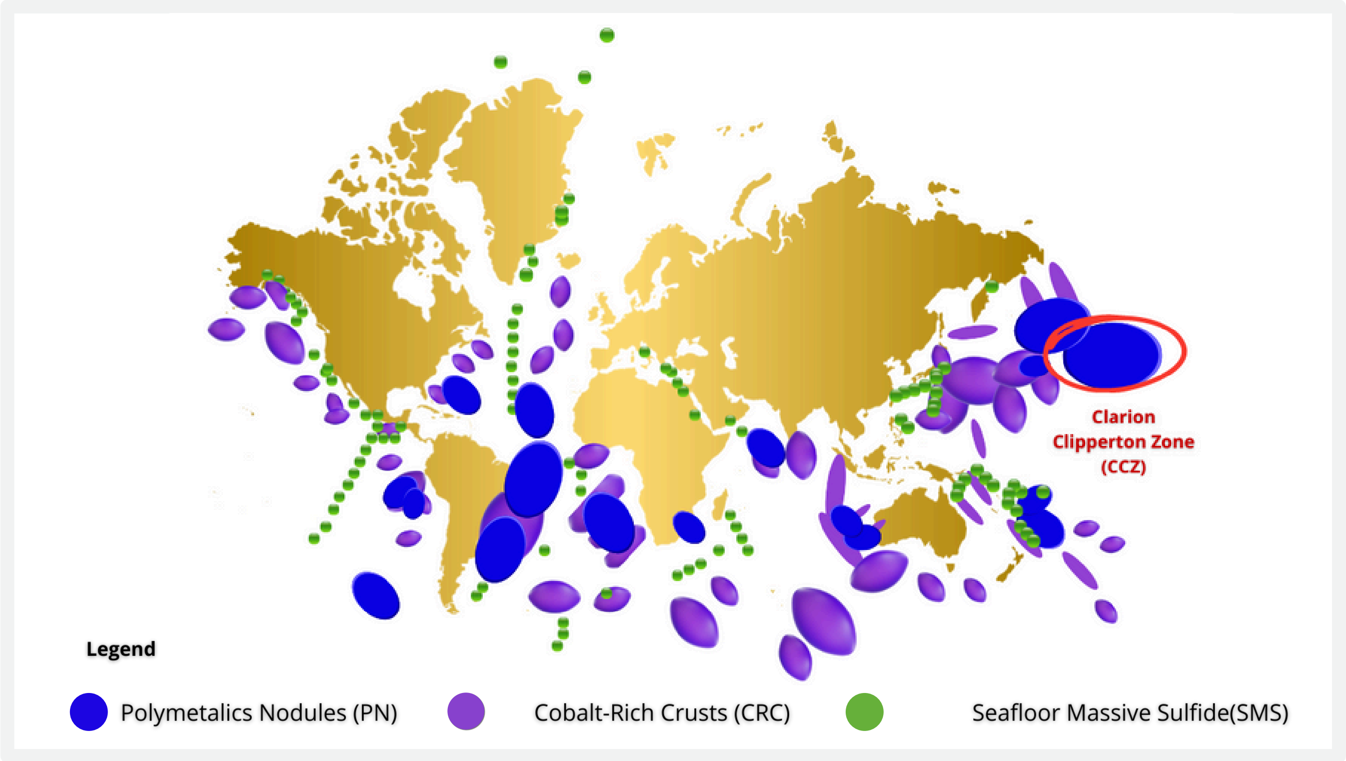


FIGURE 1. DEMAND FOR CRITICAL MINERALS FOR RENEWABLE ENERGIES



Source: GEM based on international Energy Agency (2023)

FIGURE 2. MAJOR SUBMARINE MINERAL DEPOSITS



Source: GEM based on international Energy Agency (2023)

The present study focuses on the mining of Polymetallic Nodules, due to their greater technical and economic viability, the characteristics of their deposits, and the development of extraction technologies.

The Vertical Transportation System (VTS) is the expected method to use for nodules extraction, and it has been used both conceptually and in pilot tests conducted around the world. This method involves lifting minerals from a mining vehicle located on the seabed to a ship on the sea surface. For the lifting, a hydraulic system is generally used, which consists of a rigid pipe and a pump, a damping station, and a hose (See **Figure 3**).

The rigid pipe connects the ship with the damper and has a pump that provides energy to the lifting process. The damper acts as a temporary storage space when the mining vehicle collects nodules at a faster rate than the pump can support to transport them to the surface through the rigid pipe. Below the damper, a hose is connected, which is attached to the mining vehicle moving along the seabed (Wu et al., 2020).

FIGURE 3. SCHEMATIC OF THE VERTICAL TRANSPORT SYSTEM (VTS) IN DEEP SEA MINING

Source: GEM based on Wu et al. (2020)

CONTEXT

2. Context/Background

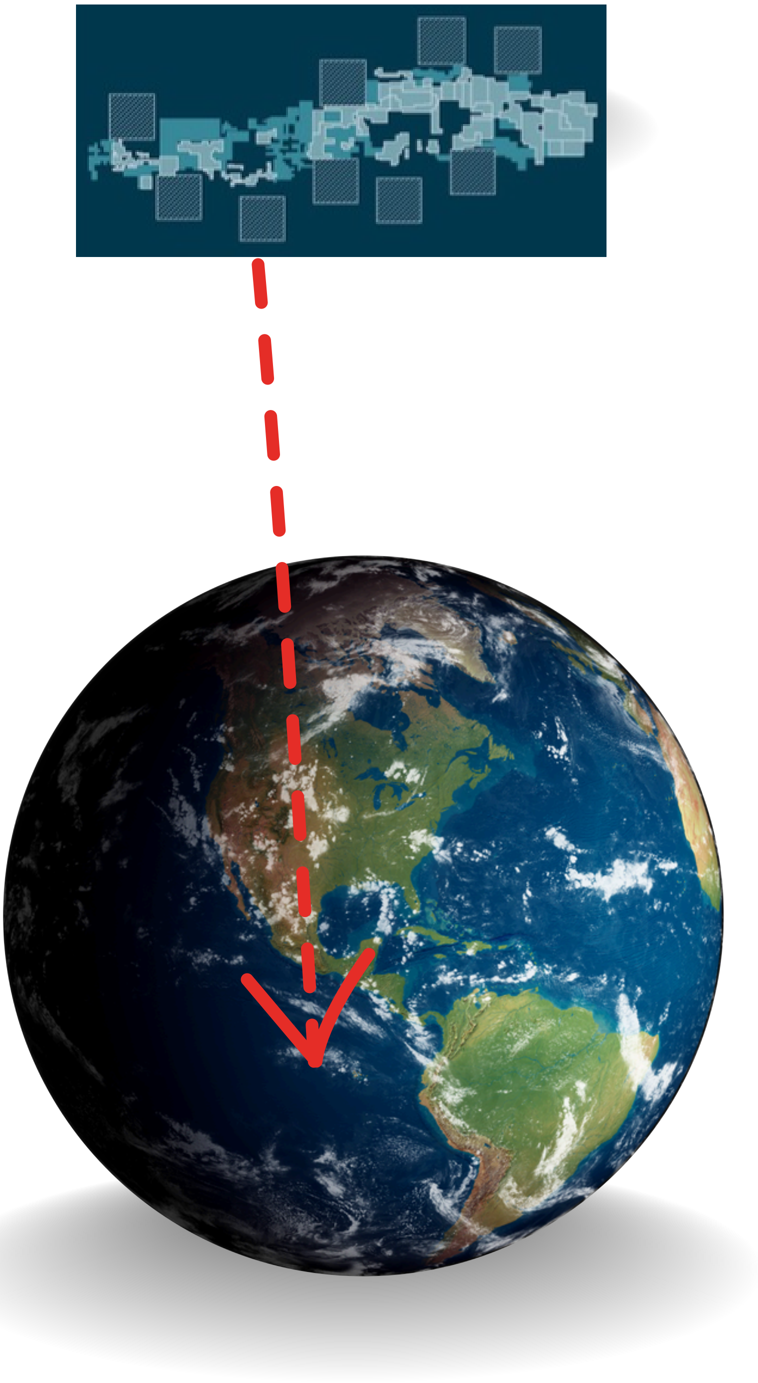
Currently, the most studied area containing **Polymetallic Nodules is the so-called Clarion-Clipperton Zone (CCZ), located in the Pacific Ocean**, With a total area of approximately 3,475,920 square miles and a mining interest area of approximately 1,726,160 square miles. It is estimated to have an average nodule abundance of 13 to 15, equivalent to approximately 6.06 to 6.61 billion short tons (Abramowski et al., 2021).

It is worth noting that previous operations of deep-sea mining have been carried out, such as diamond extraction in Namibia since 2002, at approximately 393.7 feet below sea level, Through a vessel with a capacity of 12,000 metric tons in a permitted total area of approximately 2,317 square miles (Scott, 2018). Additionally, in 2017, the state-owned mining company Japan Oil, Gas and Metals National Corporation (JOGMEC) extracted zinc at approximately 5,249 feet below sea level, off the coast of Okinawa (Carver et al., 2020).

Regarding these underwater operations, different stances have been taken around the world (see Figure 4), and countries like France have declared themselves against this activity, despite having sponsored exploration at great depths (McVeigh & Michael, 2023). On the other hand, approximately 21 countries have adopted a precautionary pause (Chile, Brazil, Spain, Portugal, among others) or moratorium stance (Canada, Mexico, New Zealand, among others). A precautionary pause in deep-sea mining would entail stopping for a period until ensuring that it does not cause significant or irreversible damage to the marine environment.

On the other hand, a moratorium goes further and considers potential environmental, social, and economic harms before making decisions about deep-sea mining, temporarily halting mining activity to better assess its impacts before proceeding (Watson Farley & Williams, 2023).

CLARION CLIPPERTONE ZONE



However, countries like Russia, India, South Korea, and China have supported its development and have sponsored or conducted underwater exploration (Alberts, 2023). Regarding their Exclusive Economic Zones (EEZ), Japan, the United Kingdom, and Norway have a higher mapped percentage, with 97.7%, 90.6%, and 81.9%, respectively (Muñoz, 2021). It is worth noting that in 2024, Norway became the first country to support and accelerate deep-sea mining, opening up the opportunity for mining exploration along its coasts (Frost, 2024).

On the other hand, in the United States, a bill titled "The Responsible Use of Seafloor Resources Act of 2024" was introduced to Congress, highlighting the opportunity to access minerals without relying on China and calling for the necessary scientific and technological research to analyze the benefits of deep-sea mining of Polymetallic Nodules (Khan, 2024).

FIGURE 4. COUNTRIES STANCE ON THE DEVELOPMENT OF SUBMARINE MINING

Source: Own elaboración based on a Deep Sea Conservation Coalition (2024), Symons (2023), Seas at Risk (2023) y Reuters (2023)

MAIN CHALLENGES OF DEEP-SEA MINING

Deep-sea mining faces a series of challenges arising from various causes. Firstly, it faces the inherent operational complexity of exploration and extraction in the deepest zones of the oceans, **where marine deposits of interest, such as Polymetallic Nodules, are located**. These are usually found at depths close to approximately 13,123 feet below sea level, which implies the development of specialized equipment capable of withstanding the pressures present at such depths.

Secondly, we must consider the significant degree of uncertainty that the scientific community has regarding the marine species inhabiting these areas. This lack of understanding includes both the variety of marine life and the roles they play in marine ecosystems. Additionally, many species remain unidentified, and those that have been identified are just beginning to be studied. The above allows to demonstrate that there is a lack of understanding about the potential ecological impacts derived from the alteration of the seabed, and that if underwater mining is carried out, it could have environmental repercussions.

Thirdly, it is important to consider that underwater mining could trigger sedimentation phenomena and the deposition of solid particles on the seabed, altering the way sediments move on the seafloor and the distribution of nutrients. This could modify habitats of marine species reliant on these nutrients for survival, potentially having adverse effects on water quality and the health of surrounding ecosystems, thereby threatening biodiversity and the ecosystem services they provide.

Therefore, it is crucial that deep-sea mining continues to be researched with the aim of fully understanding its potential environmental consequences, in order to then develop effective strategies for mitigating and managing environmental impacts.

BENEFITS AND RISKS OF DEEP-SEA MINING

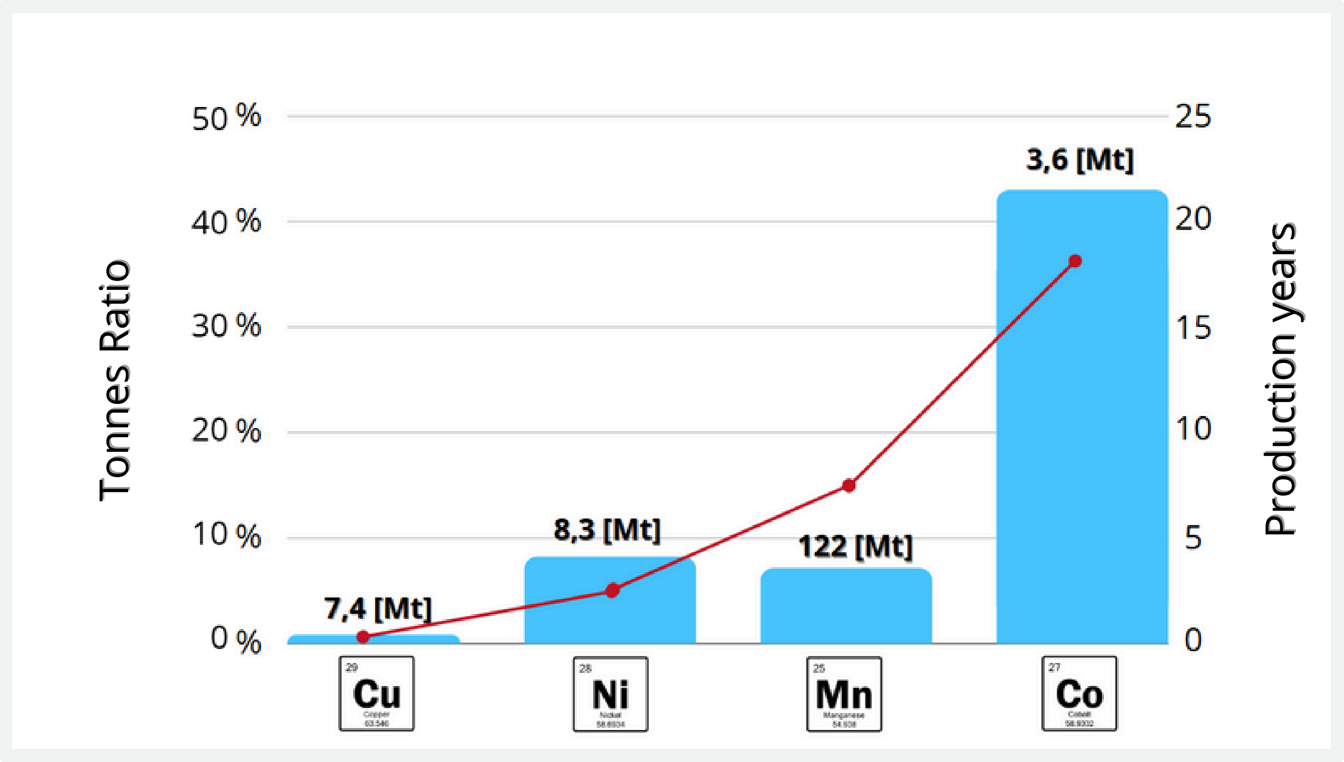
1) Benefits of deep-sea mining

Deep-sea mining of Polymetallic Nodules holds great appeal when comparing the potential of marine resources to current terrestrial reserves. Specifically, commodities with the highest resource abundance would be cobalt, manganese, and nickel, while copper would exhibit lower abundance as a byproduct of extracting the other minerals.

Global reserves on the seabed for each of these elements would be 3.6, 122, 8.3, and 7.4 [Mt], respectively (Glasby, 2000; Ministry of Earth Science, 2017; Lipton et al., 2018; Volkmann et al., 2019; Ellefmo et al., 2019; García et al., 2020; Toro et al., 2020; Abramowski et al., 2021; Muñoz, 2021; Kuhn & Rühlemann, 2021; JOGMEC, 2023).

In turn, these figures would represent a tonnage ratio of 43.0%, 7.2%, 8.3%, and 0.8% compared to the current terrestrial reserves of each of the mentioned commodities. Considering production rates, this would ensure a global production of at least 18.8 years for cobalt, 6.1 years for manganese, 2.5 years for nickel, and 0.3 years for copper, taking into account the mapped reserves in the depths of the seabed, as shown in **Figure 5**.

FIGURE 5. RATIO OF TONNES PRESENT ON THE SEAFLOOR TO TERRESTRIAL RESERVES AND GUARANTEED PRODUCTION YEARS BASED ON TONNAGE



Source: Own elaboration

In the **Figure 5**, The bars represent the percentage of each commodity's quantity available in the sea compared to what is currently recognized as resources on land. The red line represents the guaranteed production years when exploiting those quantities.

It is worth noting that the mineral grades of interest in CCZ submarine deposits tend to be higher compared to those of terrestrial deposits, meaning that the mineral concentration is greater. The average grades on the seabed are 0.16% for cobalt, 29% for manganese, 1.3% for nickel, and 1% for copper (Hein, 2016).

GEM conducted an energy study[1] to estimate long-term prices and incentive prices for minerals that would enhance the development of deep-sea mining (see **Table 1**). It can be observed that there is a significant discrepancy between long-term prices and the incentive prices required for the exploitation of reserves to be attractive under current market conditions. Furthermore, it is evident how long-term prices would exceed incentive prices, providing further reason to understand why deep-sea mining is economically viable when operating in areas over 13,123 feet deep.

TABLE 1. ESTIMATION BASES FOR INCENTIVE PRICES REGARDING THE EXPLOITATION OF COMMODITIES ON THE SEABED

	UNIT	CCZIOM CO	CCZIOM NI	CCZIOM MN
INCENTIVE PRICE	[US$/t]	16.800	15.900	460
PRICE IN THE LONG TERM	[US$/t]	35.000	25.000	2.750

Source: Own elaboration based on Abramowski et al. (2021).

From **Table 1**, it can be inferred that there will be market entry at considerably lower prices than those forecasted in the absence of deep-sea mining. Particularly for cobalt, this would be mainly due to the high tonnage in seabed deposits, generally in cobalt-rich crusts, as well as their relatively high content in Polymetallic Nodules. For manganese, the tonnage of submarine resources represents around 7% of current global production. This, combined with the incentive price, suggests significantly lower values compared to commercial ones that would exist without deep-sea mining.

Finally, for nickel, in the long term, its contribution to current production would be an extra 8% to global supply and could potentially lead to a drop in the price of the mineral from $25,000 [US$/t] to about $15,900 [US$/t], making it one of the most promising commodities under the scenario of deep-sea mining.

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1 For further information, please refer to the presentation "Incentive Prices for Deep-Sea Mining" prepared by GEM.

(2) Direct risks of deep-sea mining

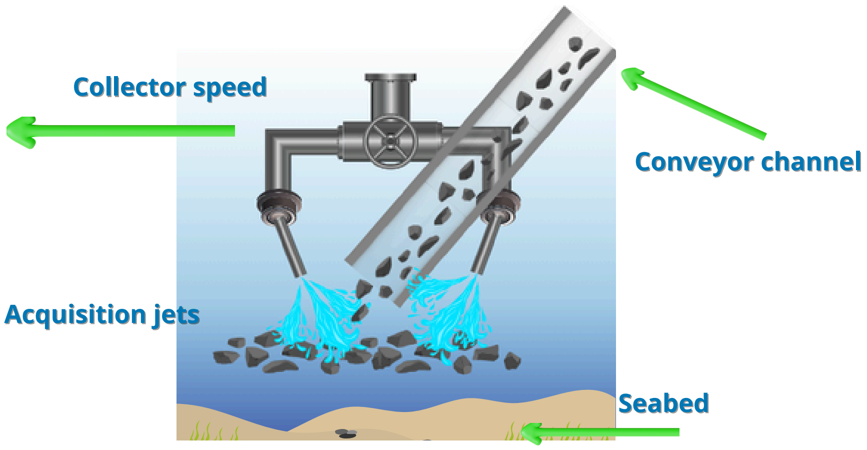
Scientific advancements in deep-sea mining agree that the most appropriate mechanism for collecting Polymetallic Nodules is the hydraulic collector (see Figure 6), due to its higher efficiency and lower interaction with the seabed compared to mechanical collectors (Wang et al., 2023). The passage of this collector through the seabed generates a sediment plume that expands behind it (see **Figure 6**). However, this plume could alter the environment of benthic[2] organisms, increase the concentration of suspended solids, and change the chemical properties of the water (Zhang et al., 2024). In order to study the dimensions that the plume could have, GEM constructed a model[3] that allows predicting its height (H) and maximum extension (L). Using characteristic parameters of the CCZ, the results suggest that the maximum height of the plume could be between 6.56 and 36.09 feet, while its horizontal extension could vary between 426.51 feet and 52,493.44 feet.

FIGURE 6. HYDRAULIC COLLECTOR AND SEDIMENT PLUME BOOM

COLLECTOR MECHANISM

This device extracts polymetallic nodules by expelling jets towards the seabed through two parallel rows of nozzles called acquisition jets. The inclined and opposing arrangement of the nozzles in both rows is designed to converge on the seabed, thereby facilitating the lifting of the nodules towards the vehicle's transport channel.

Hydraulic collector (side view)



Source: GEM based on Wang et al. (2023) and Zhang et al. (2024)

2, Living organisms that inhabit the ocean floor.

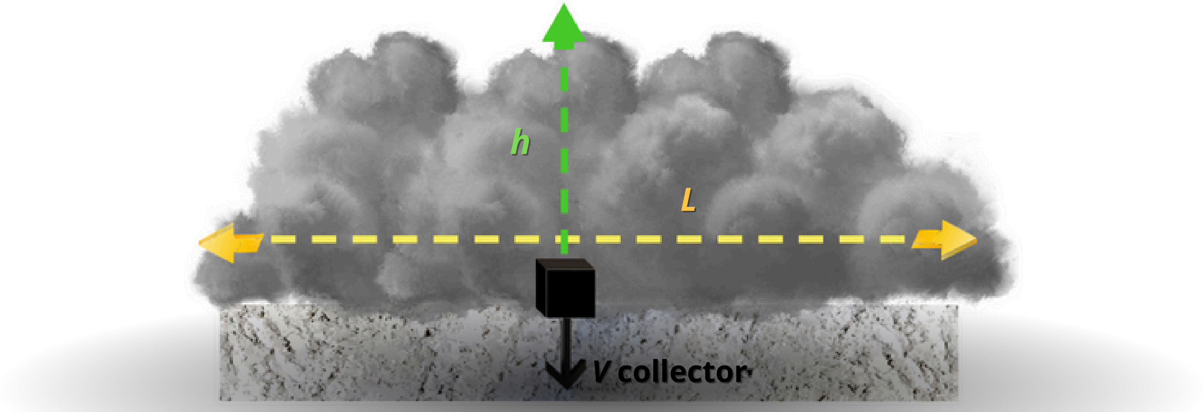
3, This model allows for the calculation of the maximum height of a particle based on the principle of energy conservation, and its horizontal displacement through Stokes Law and the velocity of the ocean current.

FIGURE 6. HYDRAULIC COLLECTOR AND SEDIMENT PLUME BOOM (CONT.)

SEDIMENT PLUME

The lifting and displacement of sediments resulting from the impact of the acquisition jets against the seabed lead to the formation of a plume that expands behind the collector, as a consequence of particle dispersion in the sea. This plume has a maximum height h and a maximum horizontal extension L.

Sediment plume (cross-sectional view)



Source: GEM based on Wang et al. (2023) y Zhang et al. (2024)

According to the results of the model, combined with the review of bibliographic background, it can be concluded that the height of the plume would not generate a relevant direct impact on the photic zone, given that the plume would be confined to the seabed. However, the risk could lie in the horizontal extension of the plume due to its larger dimension resulting from currents and negative effects it could generate on the environment and marine bottom fauna.

To compare the impact generated by the contamination of this plume with that of a land mining equipment, the GEM model was used to calculate the amount of contaminants produced by a terrestrial mining truck. This is because it has been shown that extraction trucks generate between 78% and 97% of all dust emissions at surface mining sites (Cole & Zapert, 1995).

The results reveal that the plume generated by land mining is approximately 500 times larger in its vertical dimension and 2,000 times larger in its horizontal dimension compared to what would be produced by subsea mining.

Particles in suspension could travel up to 9,100 kilometers in the atmosphere; in other words, dust generated by the Chuquicamata mine in Calama could reach New York, USA.

The continuous suspension of particles, specifically PM10, led to the declaration of Calama city in Chile as a saturated zone in 2009.

Consequently, in 2021, an Environmental Decontamination Plan (PDA) was approved, which establishes goals for reducing PM10 emissions in mining operations (BCN, 2022). Finally, in 2023, a bill was drafted proposing that mining activities have a minimum distance of 10 kilometers from human settlements (Cám. Dip., 2023). Therefore, reducing the dust cloud generated by trucks is of vital importance as it directly affects people's health and quality of life.

To compare the plume from subsea mining with other industrial activities in the sea, the pollution plumes from underwater outfalls and desalination plants were studied. These plumes carry wastewater and brine into the sea, affecting water quality and the marine ecosystem.

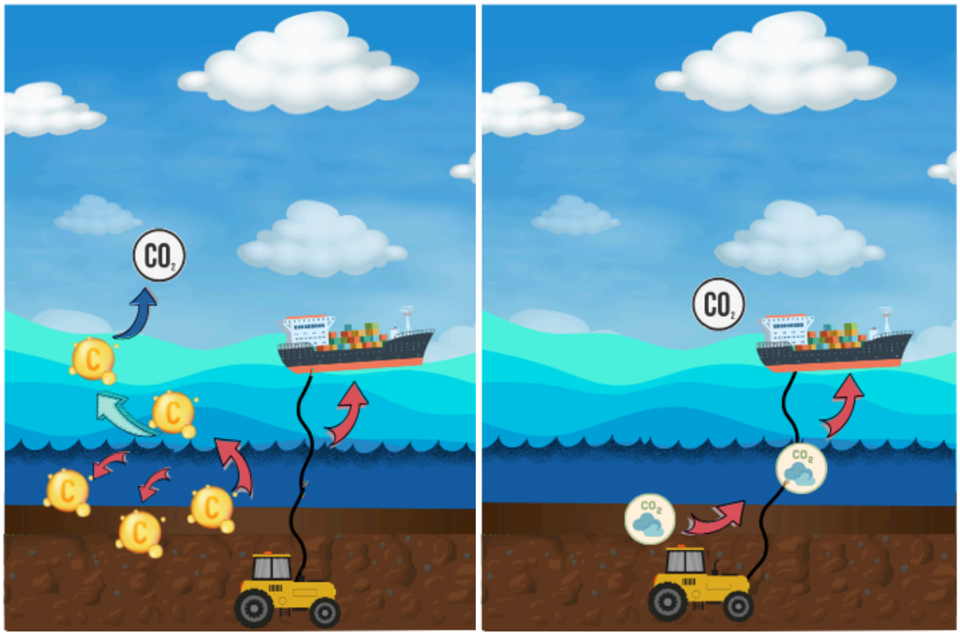
While the plumes from these industries may be smaller than those generated in subsea mining, their impact is notable as they are released at depths shallower than 70 meters and within 4 kilometers of the coast (Megías, 2021), posing threats to human health and marine life (see **Figure 7**). It is important to note that these studies are based on measuring the plume until it reaches a level considered acceptable for pollutant concentration. Therefore, it's possible that the actual size of these plumes is underestimated when comparing them to the method used by GEM for land and subsea mining, where the maximum distance reached at the particle level is observed.

FIGURE 7. COMPARISON OF PLUMES BY INDUSTRY

INDUSTRY	DEEP SEA MINING	LAND MINING	SUBMARINE OUTFALLS	DESALINATION PLANTS
HORIZONTAL SPAN RANGE (L)	130 [m] - 16 [km]	60 [km] - 9.100 [km]	90 [km] - 5 [km]	100 [km] - 4 [km]
ENVIRONMENTAL IMPACT	Increase in suspended solids concentration, alteration of water chemical properties, and benthic organism habitat disruption	Increase in particulate matter and impact on air quality, potential respiratory problems, cardiovascular issues, and irritation	Increase in fecal coliform concentration and decrease in water quality, posing risks to marine life and activities near the coast (fishing and swimming)	Increase in water salinity and contamination due to chemical usage, affecting the life and coastal ecosystems that require specific conditions

Source: GEM based on Arregui (2012), Macías (2020), Montojo (2016), Muchiut (2016), Roberts et al. (2010) y Zhang et al. (2024)

FIGURE 8. RISK OF CARBON RESERVES RELEASE



Release of carbon reserves

Potential emission of 2.95 [Mt CO2] into the atmosphere, considering the extraction for the production of one million electric vehicle (EV) batteries

Source: GEM based a Paulikas et al. (2020) y Amadi & Mosnier (2023)

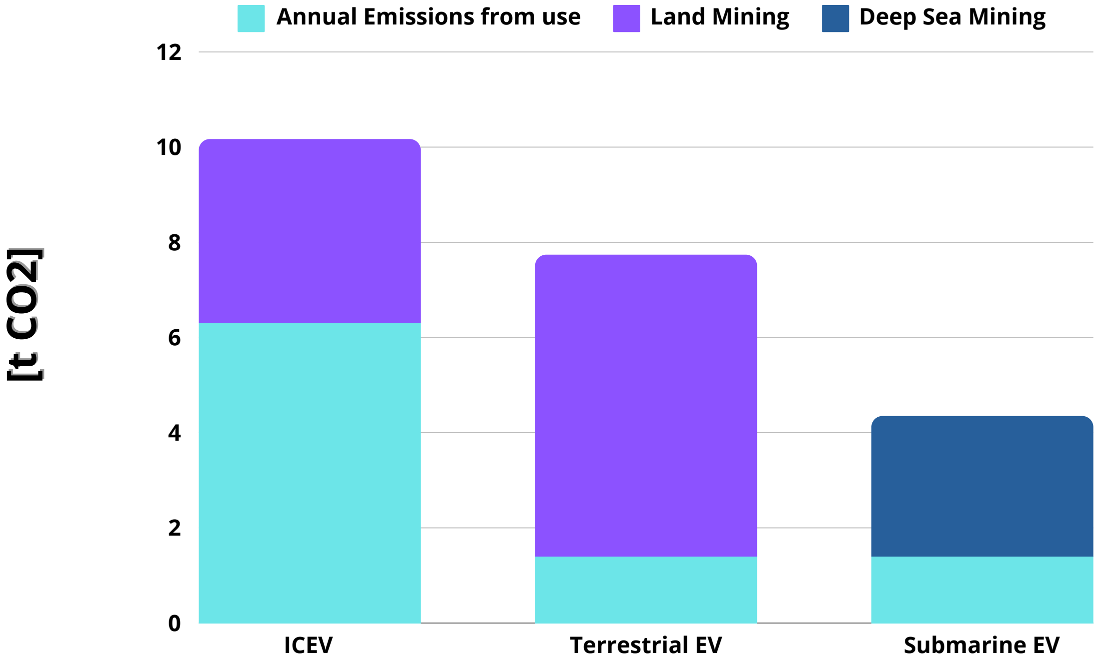
INDIRECT RISKS OF UNDERWATER MINING

GEM has identified five potential indirect risks related to deep-sea mining and the environment.
The release of carbon reserves (see **Figure 8**), reduction of microbial activity (see **Figure 10**), diffusion of trace metals (see **Figure 11**), alteration in the nitrogen cycle (see **Figure 12**), and loss of biodiversity.

Regarding the risk of carbon reserve release, the annual carbon dioxide emissions to the atmosphere of a conventional internal combustion engine vehicle (ICEV)—considering its production through terrestrial mining and annual use were compared with those of an electric vehicle (EV) manufactured through terrestrial mining and underwater mining (considering the release of carbon reserves from the ocean floor).

In **Figure 9**, it can be observed that the production of **an average electric vehicle through underwater mining could reduce emissions by 59% compared to an average conventional vehicle** and by 44% compared to an average electric vehicle produced through terrestrial mining (EPA, 2019; Davis & Boundy, 2021; U.S. Department of Energy, 2024b).

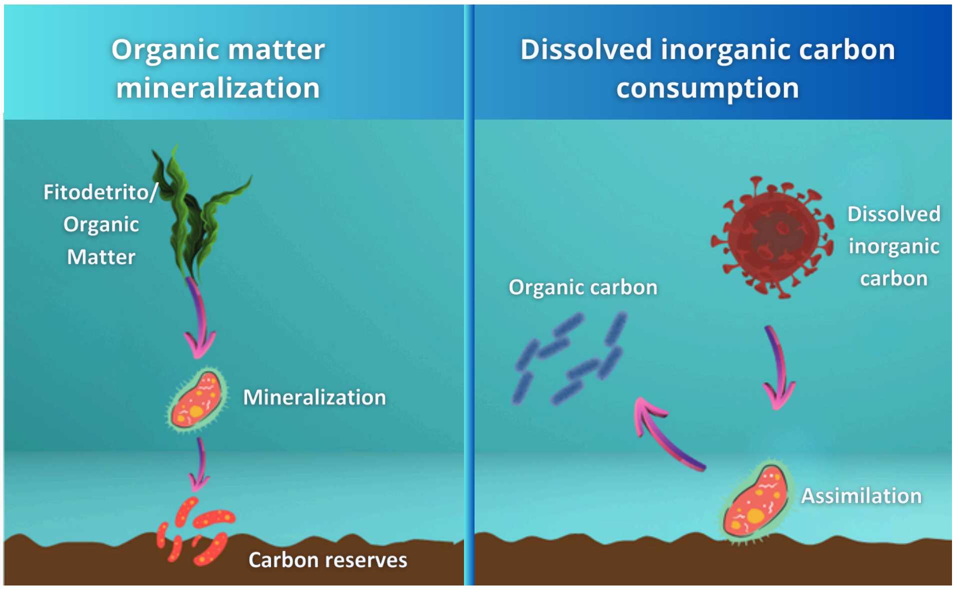
FIGURE 9. COMPARISON OF CARBON EMISSIONS BY SOURCE AND TECHNOLOGY



Source: Own elaboration based on Paulikas et al. (2020), Guzmán et al. (2022) and U.S. Department of Energy (2024)

FIGURE 10. RISK OF MICROBIAL ACTIVITY REDUCTION

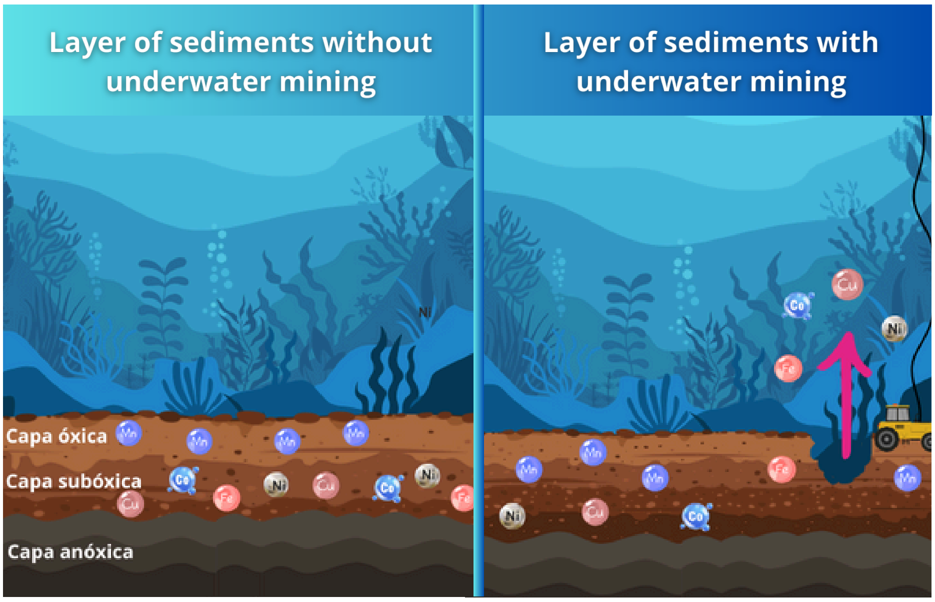
Reduction of microbial activity



Potential damage to abyssobenthic bacteria, causing organic matter to remain in the crust for hundreds of millions of years and inorganic carbon in the water column

Source: Own elaboration based Paulikas et al. (2020), Guzmán et al. (2022) and U.S. Department of Energy (2024)

FIGURE 11. RISK OF TRACE METAL DIFFUSION FROM SUBOXIC LAYER

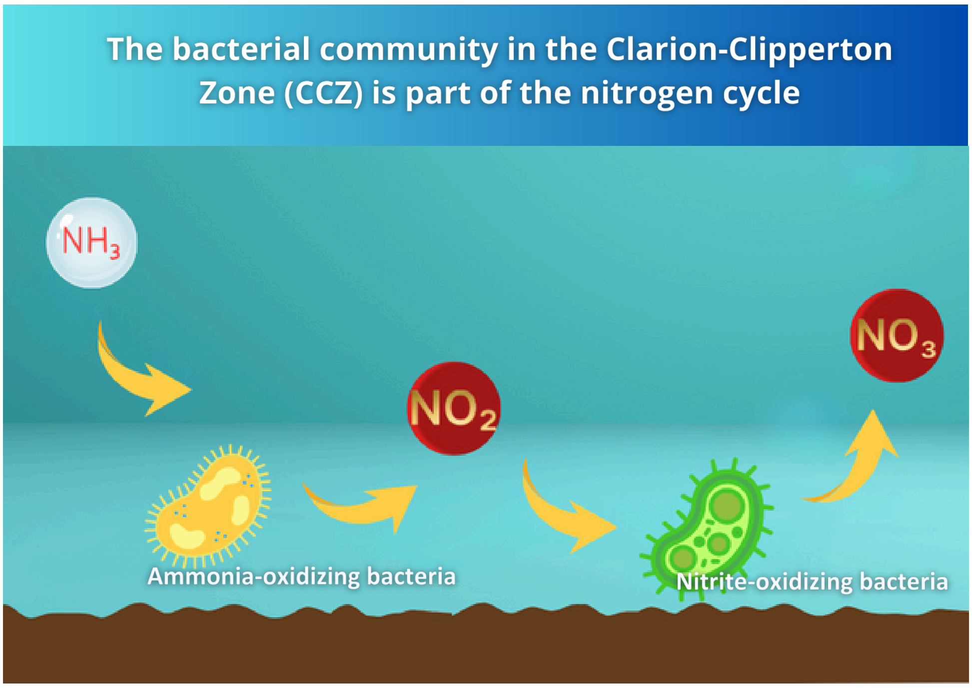


Diffusion of trace metals from the suboxic layer

The ascent of trace metals could generate reactions that alter the bioavailability of metals already present in the seabed, along with their speciation to levels toxic to the ecosystem

Source: Own elaboration based a Thiel &Tiefsee-Umweltschutz (2001), Paul et al. (2018), Braeckman et al. (2013), Jorgensen & Katsen (2006), Koschinsky et al. (2003) and Luise (2018)

FIGURE 12. RISK OF DISRUPTION IN THE NITROGEN CYCLE



Disruption in the nitrogen cycle

The disturbance of the microbial community could lead to an accumulation of nitrogen and eutrophication in the ocean, increasing the concentration of ammonia which could be toxic to the marine environment

Source: Own elaboration based on Molari et al. (2020), Hollingsworth et al. (2021) and Franklin & Edward (2018)

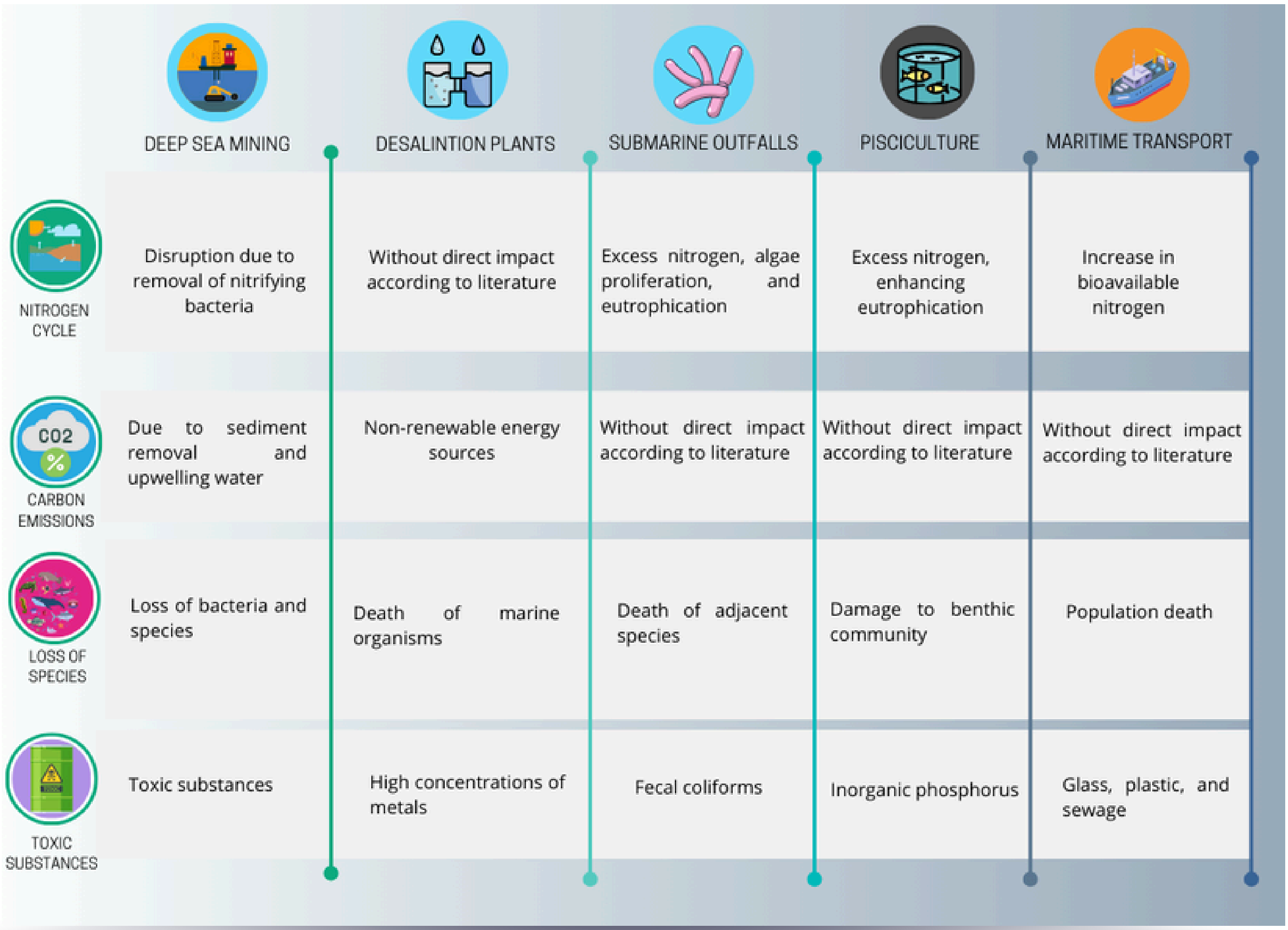
Regarding biodiversity loss, species at potential risk have been identified, such as Xenophyophorea (single-celled organisms), Holothiruidea (sea cucumbers), Hydrozoa (jellyfish), Ophiuroidea (brittle stars), Polychaeta and Nematoda (worms), Porifera and Anthozoa (anemones and sponges), and Echinoidea (sea urchins) (Vanreusel et al., 2016; Thiel & Deep-Sea Environmental Protection, 2001; Stratmann, 2023; Ebbe et al., 2010).

These species are part of food webs, provide habitats for other organisms, reduce organic load, and enhance the activity and recovery of coral reefs (Hammond, 2024; Simoes et al., 2019; Hang et al., 2020; Morris & Fautin, 2024; Gornik et al., 2021; Koporc, 2015; Bionity, 2024; Hay, 2024; Myers, 2024). Furthermore, bacteria have been identified, such as Alphaproteobacterias, Gammaproteobacterias, Thaumarcheotas and Alteromonadales, which are part of the ammonia oxidation, manganese cycle, and other metal cycles. (Molari et al., 2020; Lindh et al., 2017; Hollingsworth et al., 2021; Wear et al., 2021).

EIt is important to note that the potential effects of deep-sea mining have been reported in terms of their impacts on the surface, comparing them with other ongoing industrial activities. These reports and comparisons are summarized in **Table 2**, of which the most relevant ones are biodiversity loss and alteration in the nitrogen cycle, causing eutrophication.

Eutrophication occurs when excess nutrients, such as nitrogen and phosphorus, cause aquatic plants to grow faster than usual, thus contaminating and damaging aquatic life. Specifically, activities such as desalination plants (McCaig, A., et al., 1999; Commoy et al., 2005; Naylor, 2005; Holmer, 2010; Zhou, J., Chang, V.W.-C., & Fane, A.G. (2013); Missimer, T., & Maliva, R. (2018); (Jagerbrand et al., 2019;); Cornejo et al., 2014), (Goldburg & ; Kucuksezgin et al., 2021). Emisarios submarinos (Tuholské, C., et al., 2021; Filippos et al., 2023). are considered contributors to this phenomenon.

TABLE 2. COMPARISON OF IMPACTS OF DEEP-SEA MINING WITH OTHER CURRENT INDUSTRIAL ACTIVITIES

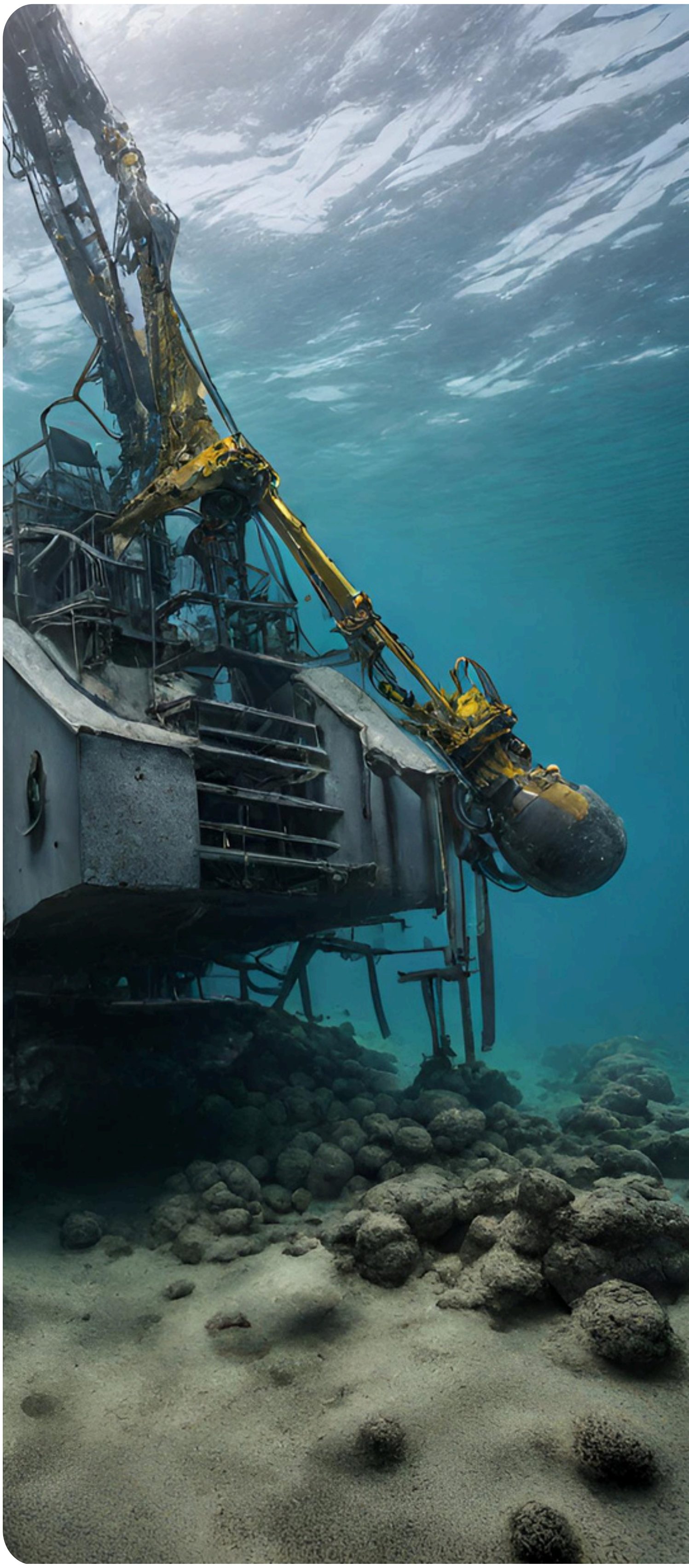


	DEEP SEA MINING	DESALINTION PLANTS	SUBMARINE OUTFALLS	PISCICULTURE	MARITIME TRANSPORT
NITROGEN CYCLE	Disruption due to removal of nitrifying bacteria	Without direct impact according to literature	Excess nitrogen, algae proliferation, and eutrophication	Excess nitrogen, enhancing eutrophication	Increase in bioavailable nitrogen
CARBON EMISSIONS	Due to sediment removal and upwelling water	Non-renewable energy sources	Without direct impact according to literature	Without direct impact according to literature	Without direct impact according to literature
LOSS OF SPECIES	Loss of bacteria and species	Death of marine organisms	Death of adjacent species	Damage to benthic community	Population death
TOXIC SUBSTANCES	Toxic substances	High concentrations of metals	Fecal coliforms	Inorganic phosphorus	Glass, plastic, and sewage

Source: Own elaboration

CONCLUSION

This study concludes that deep-sea mining is economically viable for some commodities.
However, it is important to consider the potential environmental risks associated with deep-sea mining.
Due to the difference between incentive prices and long-term prices of resources found in **Polymetallic Nodules** on the ocean floor. It is important to highlight that deep-sea mining is not something new, as it has been previously developed in different parts of the world, such as in diamond extraction in Namibia and zinc extraction in Japan. However, potential risks associated with deep-sea mining must be taken into account. Although the direct impact may not be significant, there is a possibility of substantial indirect impact on the marine ecosystem.



This could manifest through the release of carbon stocks, reduction of microbial activity, dispersion of trace metals, alteration of the nitrogen cycle, and loss of biodiversity.

It is essential to conduct thorough and ongoing research on these risks to properly quantify them and implement effective management and impact mitigation measures. Despite the lack of knowledge and the potential risks identified, some estimates of the environmental impact that deep-sea mining could cause have been made, such as CO2 emissions and the dimensions of the sediment plume generated by these operations. When comparing these findings with land mining, the possibility of a decrease of up to 59% in emissions and a reduction of the dust cloud by 2,000 times is evident. It is important to note that this cloud would be in deep-sea abysses, several kilometers below sea level, which would help mitigate problems caused by particulate matter in the atmosphere and directly affect human quality of life.

It can be emphasized that there are considerable benefits to deep-sea mining, **as it would provide critical minerals for the energy transition and its direct impacts could be less than those of land mining. However, indirect environmental impacts must continue to be studied**, both in terms of their magnitude and their mitigation, and foundations must be established for the development of deep-sea mining geared towards the mining of the future. This is with the intention of developing more sustainable and responsible practices that minimize environmental and social impacts, while maximizing efficiency and profitability.

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