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Marine mining and its potential implications for low- and middle-income countries

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Abstract: After 50 years of optimistic predictions that marine mining will soon take off, it still remains to be seen if and when this will happen. In 2018 the total value of all marine mining, including both offshore mining and the so far non-existing deep-seabed mining, was estimated to be around US$35 billion, less than 1 per cent of land-based mining. This paper focuses on the potential economic effects for LICs and MICs of expanding the extraction of marine deposits. The importance for these countries of creating a tailor-made tax regime to capture the optimum benefits from future marine mining is highlighted. Environmental problems are also discussed. The current status of marine mining is outlined and the likelihood of progress in the near- and mid-term future is assessed. It seems likely that offshore mining will be of more immediate interest to LICs and MICs than deep-seabed mining, which is much more challenging. Marine mining is a sub-part of the larger blue economy. The economic, social, and environmental effects of marine mining should always be seen alongside other vital parts of the blue economy, notably fishing and tourism, which generate considerable economic value. The paper outlines the history of deep-seabed mining and its close connections in the 1960s and 1970s with the Cold War and the fight for independence by former colonies. The paper summarizes the long road leading up to the United Nations Convention on the Law of the Sea, a unique international agreement to share the resources of the least exploited part of planet Earth for the benefit of humankind.

Key words: marine mining, UNCLOS, offshore mining, deep-seabed mining, tax regime, low-income countries, middle-income countries

JEL classification: F55, L72, O13, Q32

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1 Introduction

> ‘Behind us are the demonstrations of the mineable deposits, the mining system and the extraction process.’ (Rothstein 1971)
>
> ‘Nodules will be in full scale economic production within the next five to ten years.’ (Mero 1977)
>
> ‘Deep sea mining is no longer a dream.’ (Fellerer 1980).

During the 1970s the potential to harvest mineral riches from the seafloor was for the first time seen as a possibility to secure scarce mineral resources. A wave of research and investment into all kinds of deep-sea ventures swept the world. In the 1980s, however, interest in the deep seas faded away. It was only late into the ‘super cycle’ of high metal prices around 2010 that plans to exploit the seabed surfaced again. Ten years later, most of these plans had been buried—again—as prices fell back. Will the new price momentum of 2020–22 and the projected increase in metal demand from the green transition finally mark the opening of marine—including seabed—mining, or is it all a pipe dream?

This issue has profound consequences for the public revenues and foreign exchange earnings of the developing world, not only because they may derive taxes, royalties, and other revenues from marine mining, but also because their other natural resources—the fisheries and coasts—may be impacted, perhaps negatively, by marine mining. That natural capital is valuable not only in itself as an environmental resource, but also because it underpins millions of livelihoods and is a source of economic growth and public revenue. It is therefore crucial to consider whether marine mining has now become a realistic commercial possibility, not only in terms of revenues and economic growth but also from an environmental perspective. This will help policy-makers to strike the right balance between the use of non-renewable (mineral) resources and renewable resource (fisheries, biodiversity, etc.) and to create an appropriate fiscal framework.

The overarching goal of this study is therefore to discuss the likelihood of a start to the extraction of marine mineral resources and their potential economic implications for low-income countries (LICs) and middle-income countries (MICs).

To create a platform from which to frame the discussion, the study starts with a definition of marine mining and then provides a brief historic background to the economic importance of the seas, focusing on the extraction of minerals and metals from the oceans. The development of the set of international rules governing the seas outside territorial waters, the United Nations Convention on the Law of the Sea (UNCLOS), is also presented and discussed.

In detail, the paper will:

- define the different aspects of marine mining (Section 2);
- summarize the development in broad terms of marine mining, including deep-seabed mining from an economic, technological, environmental, and legal perspective (Section 3);
- evaluate the present status of marine mining to identify which commercial and research projects are running today, how close they are to starting operations, and which countries and companies are involved (Section 4);

- discuss what effects seabed mining could have on existing land-based producers of minerals found on the seabed, and also which countries could benefit from seabed mining, including the mineral processing and refining stages (Section 5.1–5.4).
- discuss what consequences these trends might have for the revenues of LICs and MICs, in the form of taxes and royalties, together with any further benefits and/or problems that exploitation could create (Section 5.5).
- provide a discussion of the future viability of marine mining and, in particular, DSM (Section 6)
- draw conclusions from the arguments presented (Section 7).

2 What is marine mining?

Marine mining refers to the extraction of non-fuel minerals[1] and metals from the sea, whether the mining activity is carried out at the bottom of the sea, from seawater itself, or on beaches between land and sea. Marine mining can therefore be divided into three main branches: offshore mining, deep-seabed mining (DSM), and the extraction of minerals from seawater.

Offshore mining refers to exploitation activity in the shallow seabed on the continental shelf, not deeper than around 500 m, relatively close to land, and thus within national boundaries. Offshore mining is today carried out using existing, proven technologies. Examples are diamond mining in Namibia, iron-bearing beach sands in New Zealand, heavy mineral sands in South Africa and Mozambique, and tin mining in Indonesia, as well as sand and gravel mining in various parts of the world.

DSM refers to mining activities using non-traditional methods specifically developed for great depths (generally more than 1,000 m) that can be within or outside territorial waters. So far, no commercial exploitation using DSM has been undertaken, although trial mining has been carried out, for example off the coast of Okinawa in Japanese territorial waters (Carver et al. 2020; Okamoto et al. 2018). In Papua New Guinea (PNG) territorial waters, a permit has been granted to the Solwara 1 project, but this is not proceeding at present (see Section 3).

In this paper we are primarily concerned with DSM. The mining of deposits found under the seabed using conventional technologies, where an underground drift is drilled from land, is not discussed. Nor are mines located close to the sea that also go below sea level. However, any mines constructed that involve building seawalls to dry out the seabed or creating water pools to dredge are included in our definition.

The extraction of minerals from seawater is discussed in the next sub-section.

The technology required for marine mining is different depending on where the mining takes place: in the deep seabed, offshore in shallow waters, on beaches, or the extraction of minerals from seawater. This will be further discussed below.

[1] We undertook some comparisons between offshore oil and gas production and marine mining of metals and minerals in order to gauge the relative size of the two branches of marine mineral extraction.

2.1 Marine mineral resources

There are a wide variety of marine mineral resources, which can be divided between those that are formed on or near land and those formed in the sea. We focus here on the marine mineral categories that have the greatest resource potential.

Minerals from seawater

Salt has been extracted from seawater since ancient times. Recently, the demand for fresh water obtained through desalination has grown dramatically—a trend supported by the decreased production costs of the available technologies. Examples of new desalination technologies are electrodialysis, membrane distillation, membrane distillation crystallization and absorption/desorption crystallization. The by-product from all these processes is a seawater brine with mineral concentrations roughly twice that of pure seawater. Although a large number of elements such as sodium (Na), calcium (Ca), magnesium (Mg), potassium (K), lithium (Li), strontium (Sr), bromine (Br), boron (B), and uranium (U) can be extracted, there is a serious problem to be solved: how to deal with the brine waste stream.

Proponents of expanded extraction from seawater point to the increasing difficulties facing land-based mining, hoping that these will make extraction from seawater increasingly attractive (Loganathan et al. 2017; Shahmansouri et al. 2015); and the possibility of extracting lithium has received additional attention because of that metal's key role in the transition to a fossil-free energy supply (Creamer Media 2016).

The conclusion from recent studies, however, is that, even if the recovery of usable elements from the brine will improve the economics of desalination of seawater, these effects will only be marginal unless disposal costs can be significantly lowered. There is also still a need to develop the extraction processes to make them more selective.

Offshore mineral resources

Offshore alluvial resources were formed by eroded mountains washed to the sea. Alluvial resources are found close to land—e.g. the diamond resources off the coast of southern Namibia—and thus are under national jurisdiction. Other examples of near-coast mineral resources are aggregates such as sand and gravel; metalliferous sediments, placers, and evaporites, which are predominantly found in continental shelves and hence fall under national jurisdictions; and iron-bearing beach sand found, for example, on the west coast of New Zealand's North Island, where black iron sand, formed 2.5 million years ago from rock deposited on the coast by volcanic activity, has over the centuries been transported by ocean currents along the coast and deposited in shallow waters and on beaches.

Marine phosphorite is formed in regions of oceanic upwelling where large volumes of phosphate-nutrient-rich cold water rise from great depths to the surface. In the warmer surface waters, phosphate precipitates out of solution and then sinks to the seafloor, forming deposits of phosphorite (Wang et al. 2014). These are found primarily along the continental margins and thus are also under national jurisdictions. Such areas include the Namibian coast, the Peru–Chile margin, plateaus such as Chatham Rise off New Zealand, and the Blake Plateau off the south-eastern United States, but they can also form on seamounts where ferro-manganese crusts grow.

Deep-seabed mineral resources

Presently known deep-seabed minerals can be divided into three main categories: polymetallic ferromanganese nodules (PMN), polymetallic sulphides (PMS) or seafloor massive sulphides (SMS), and cobalt-rich ferromanganese crusts (CRC) (Table 1). The metals in focus in recent years are cobalt, copper, manganese, and nickel.

Table 1: Potential mineral resources in the deep seabed

	Geological setting	Major elements
PMN	Located in the soft seabed at ocean depths of 4,000 to 6,000 m in distal parts of the oceans.	Manganese, iron, nickel, copper, cobalt, REE, (lithium)
PMS/SMS	Formed by hydrothermal vents along the central ocean spreading ridges at depths of 700 to 3,500 m.	Copper, zinc, lead, iron, silver, gold
CRC	Found on the surface of base rock on seamounts and other seafloor highs, typically at 800 to 2,400 m depth.	Nickel, manganese, cobalt, platinum, REE

Source: authors' construction based on ISA (2008a, 2008b, c).

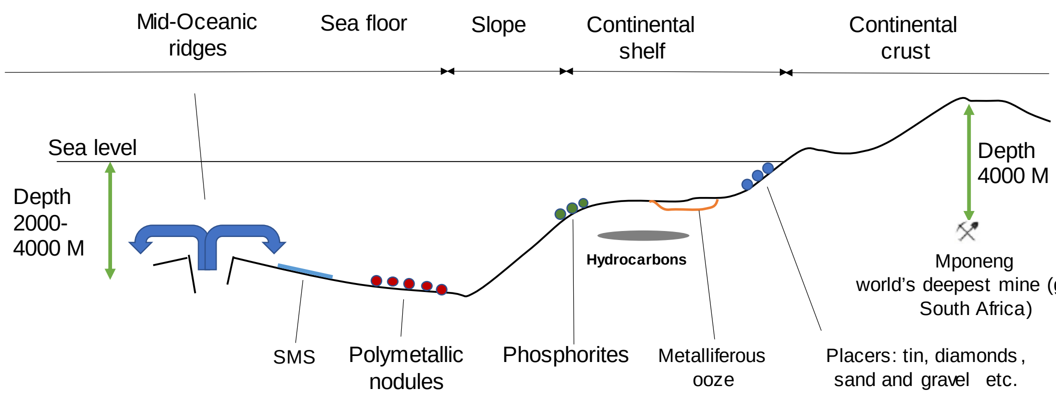
PMN—or polymetallic nodules or manganese nodules—form by the accretion of iron and manganese oxides around a tiny nucleus over millions of years. Nodules are estimated to grow by a centimetre over several million years (ISA c). The nodules vary in size from micro-nodules to about 20 cm, most nodules measuring 5–10 cm in diameter. They are composed mainly of manganese, iron, silicates, and hydroxides, but also contain high levels of nickel, copper, cobalt, rare earth elements (REE), and sometimes also lithium (ISA c). PMN occur in different sedimentary environments, in all oceans, and at all depths—even in lakes. However, areas with deposits of greater economic importance occur at depths of 4,000–5,000 m (ISA b). Nodules cover vast areas of the ocean floor and are most abundant in areas off the west coast of Mexico in the Pacific, known as Clarion-Clipperton Fracture Zone (CCZ); in the Central Indian Ocean Basin (CIOB); and in the Peru basin (ISA c).

PMS/SMS form at hydrothermal vents when hot hydrothermal fluids (350–400 ^{0}C) are discharged from black smokers and precipitate sulphides as they cool upon mixing with seawater (ISA 2008b). A wide variety of minerals form through hydrothermal activity, including metals such as copper, zinc, lead, iron, silver, and gold. The hydrothermal vents forms along mid-ocean ridge spreading centres, extensional systems associated with subduction zones, volcanoes, and intraplate hotspots. They are an outgrowth of the formation of new oceanic crust. Hydrothermal vents are formed as seawater seeping into subterranean chambers of the ocean's crust becomes heated and chemically modified through interaction with crustal rocks and, sometimes, by the input of magmatic fluids brought back into the ocean through black smokers. Hydrothermal vent fields provide the habitat to a host of animal life. Examples are giant tube worms, clam shells, crabs, and micro fauna (ISA b). These animals use chemosynthesis—they do not depend on sunlight, direct or indirect for energy, but derive energy from the bacterial oxidation of chemicals in the vent fluids—for survival (ISA b).

CRC occur at shallower depths, from 400 m to about 4,000 m (ISA 2008a). The crusts grow very slowly, generally by 1–6 mm per million years—one of the slowest natural processes. They grow on hard-rock substrates of volcanic origin by the precipitation of metals dissolved in cold seawater, likely with the aid of bacterial activity (ISA 2008a). CRC grow on seamounts, ridges, and plateaus where prevailing currents prevent the deposition of sediments. Crusts do not form where sediment covers the hard rock. CRC seldom exceed 25 cm in thickness (ISA b). In many cases, the deposits occur within the Exclusive Economic Zone of countries. Similar in general composition to polymetallic nodules, cobalt crusts have a high cobalt percentage (up to 1.7 per cent) and also contain titanium, cerium, zirconium, nickel, platinum, molybdenum, tellurium, copper, and manganese, among other materials (ISA 2008a).

Figure 1 shows the major types of mineral deposits on and under the sea floor. The average depth of the mid-oceanic ridges is 2,500–3,000 m, while nodules on the sea floor are found at depths of around 4,000–6,000 m. The Solwara 1 DSM project in PNG is at around 1,600 m and the proposed projects on the Norwegian part of the Mid-Atlantic Ridge are located at depths between 2,500 and 3,000 m. The deepest mine on land—the Mponeng gold mine in South Africa at around 4,000 m deep—is included as a point of comparison.

Figure 1: Major types of mineral deposits on and under the sea floor



Source: authors' illustration based on Borgese (1985).

It is, however, necessary to mention that reserves, defined as a mineralization that can be exploited economically, do not yet exist in the deep seabed. 'Reserve' is an economic term and is influenced by the price of a mineral/metal and technology, i.e. costs. With increased investments in exploration and new refined production technology, deep-seabed resources will eventually be transposed to reserves. It is not possible to say when this will happen, but the International Seabed Authority (ISA) regime (see below) will make all grades and volumes public. After at least 60 years of deep-seabed exploration and research, a recent study concludes that turning resources into reserves is 'an open-ended, reversible and sometimes incomplete process' (Sparenberg 2019: 842).

There are two essential factors to be considered in any discussion of the viability and impacts of seabed mining: technological and legal.

2.2 Technology

All seabed mineral exploration and exploitation is complicated by the fact that it takes place under water. However, for deposits closer to shore in shallower waters there exist well known technologies for extracting minerals. Sand and gravel, for example, are commonly extracted using trailer suction hopper dredgers (Selby and Ooms 1996).

By contrast, for the deep seabed, as a result of the extreme conditions such as high pressure and the potential for underwater volcanic activity, robust state-of-the-art equipment is required. The type of equipment needed depends on the resources to be explored and exploited. However, a key technology required in both deep-seabed and offshore exploration and exploitation is purpose-built ships. Several ships already undertake exploration of the deep seabed. These ships are often linked to research institutions and geological surveys.

An example of the use of offshore technology is diamond mining off the coast of Namibia (Box 1). Since the early 1960s, the country has developed a unique, world-leading, high-tech offshore diamond industry, operating at depths of more than 500 m. The technology presently used involves both airlift-drilling using drill bits 6.8–7.2 m in diameter working in overlapping circles on the sea floor, and crawler technology using a 280-ton track-mounted crawler dredging on the sea floor. On board the ships, sediment is washed and sifted, and non-diamond-bearing material is passed back to the ocean. Eventually, a diamond concentrate is produced and flown from vessels to shore for further treatment (Schneider 2020).

Box 1: Offshore diamond mining in Namibia

The story of offshore diamond mining in Namibia began in 1910, when the first diamonds were found on the bottom of the harbour in Lüderitz. The country was at the time in German South West Africa. Richer deposits were found onshore, but it was not until 1958 that the first offshore diamonds were found in gravel scooped up from shallow waters and recovered onshore. By the end of 1961, an inventive local entrepreneur, Johann Vivier, had found conclusive evidence of the presence of diamonds on the seabed and became the first to successfully suck diamonds from the seabed at a depth of some 20 m. Samuel Collins, a Texan with experience in oil and gas offshore production in the Mexican and Persian Gulfs, bought Vivier's business and introduced barges with on-board recovery plants. In 1962, 51,000 diamonds of gem quality were recovered. Collins had proven that diamonds on the seafloor could be exploited with profit, but many hurdles remained and, when technical problems arose, Collins ran into financial problems. De Beers swiftly acquired a majority share in the company, the Marine Diamond Corporation, in 1965.

Towards the end of the 1960s, however, many technical problems remained unsolved and diamond prices were low. In 1971, offshore mining was stopped by De Beers, but exploration continued and in 1983 it was clear that there was a world-class deposit of diamonds off the Namibian coast. Technical development continued with bottom crawlers and large rotary drills, along with a new generation of specialized ships, but only major companies could manage the necessary massive investment. Production did not restart until 1990, after almost 20 years of exploration and technical development. In addition to De Beers, Ocean Diamond Mining, Namibian Minerals Corporation, Sakawe Mining Corporation, Diamond Field Resources were all active in periods over the 1990s and into the 2000s. After the global financial crisis in 2008/2009, however, only the company originally started by Sam Collins was left.

After a long and difficult struggle Namibia became an independent state in 1990. The new government negotiated an agreement with De Beers in 1994 and gradually the marine mining operations were transferred to Namibia from South Africa. Finally, in 2011, Debmarine Namibia was set up with equal ownership by the Republic of Namibia and De Beers.

In 2005, the production of marine diamonds equalled land production, having reached 1 million carat (ct) in a single year. During the 2010s, offshore production steadily grew and towards the end of the decade, at 1.2 million ct, accounted for 75 per cent of the total output. Today, Debmarine Namibia is the undisputed global leader in marine mining of diamonds, a highly sophisticated industry.

It has been a long a winding road towards this leadership position. A combination of large, financially strong investors and daring entrepreneurs laid the technical and commercial foundations for success. The fruitful cooperation between the government holding the mineral rights and the companies has also been a necessary condition for positive development. Finally, the process has required more than half a century to create a mature industry with a resource to tap into during many years to come (Schneider 2020).

The Namibian example deserves to be studied and learnt from by other developing countries trying to make use of their marine resources.

Deep-seabed exploration

Exploration and prospecting in the deep seabed is similar in many ways to oceanographic research. Basic methods and backgrounds stem directly from the well-developed disciplines of geological, physical, and biological oceanography, though with a focus on potential exploitation (ISA 2009).

The techniques are therefore more mature than those for exploitation: vessels and tools are available for all stages of exploration.

The exploration of PMN and CRC is easier than that of PMS/SMS. Various techniques and equipment have been developed for the exploration of the deep seabed. Most of these involve remote sensing (ISA a). Remotely operated underwater vehicles (ROUVs or ROVs), often self-propelled while guided by their mother ships above, are generally used. However, technologies are still missing for many activities. For example, no device has yet been developed that can drill some 100 m into hard rock in the deep seabed, something that is needed for geologists to investigate deposits of frozen natural gas in the form of methyl hydrates (ISA a).

Exploration involves finding, retrieving, measuring, and recording samples. The remote sensing used at depth must usually be supplemented by direct study by geologists of samples brought up to the research vessel and often transported ashore for further analysis by laboratories (ISA a).

Deep-seabed mining

A typical proposed DSM system has four main components:

1. an extraction tool;
2. a lifting system;
3. a surface platform;
4. a disposal system.

The above components will differ according to the type of deposit to be exploited (PMN, PMS/SMS, or CRC). Nodules, which are located loosely on the seabed, are excavated through a gathering mechanism. The challenge with nodules is the extreme depths (> 3,000 m). SMS is hard rock and therefore needs force to be extracted. SMS deposits are located in areas with a high degree of topographical variability, which could hinder an ROV, as these are unable to handle steep slopes. It may also be difficult to exclude waste material from extraction. CRC deposits present challenges similar to SMS deposits in that the material is very hard. The challenges are to remove the thin crust while minimizing the waste rock extraction.

The testing of systems for the recovery of PMN at depths of up to 5,000 m, where they can be lifted off the seabed, have indicated that there are theoretically no technical reasons preventing the mining of these or similar deposits (Kang and Liu 2021; Okamoto et al. 2018). However, these conclusions are based on tests of equipment that are yet to be designed for actual commercial mining. Furthermore, most technology for the exploration and exploitation of the seabed has been developed for shallower depths, where current commercial seabed operations exist. The exception is technology for the exploration of PMN, which is in development. In the future, according to ISA, it is likely that new and improved deep-seabed mining technology will develop through advances in conventional systems, many from other industries. ISA specifically mentions new drilling systems, improved transfer of energy to the deep seabed for the mining operations, more processing of the raw materials on the seabed, and differential recovery of selected metals through boreholes by hydrometallurgical processes such as leaching as probably outcomes (ISA a).

Table 2 shows the technological readiness level (TRL) for the different types of DSM.[2] Some of these technologies are used in land-based mining, but the extreme conditions of DSM make their use difficult. The low values of the TRL across many parts of the value chain point to the fact that

[2] TRL is measured on a scale from 1 to 9, where 9 is the highest level of readiness.

more technology improvements will be necessary if DSM is eventually to become a realistic alternative to land-based mining. In comparison, TRL levels for deep-seabed exploration are generally between 8 and 9 (Rademaekers et al. 2015).

Technologies for mine closure and site remediation have not been discussed in the literature to date, and no reclamation requirements have yet been set, either by ISA or by national governments. However, it will be necessary for all parties to plan for mine closure well ahead of any mining commencing. Currently, the impacts are relatively unknown from both an economic and an environmental perspective. Even if the start of DSM is not imminent, there are many aspects that need more research and require attention to a number of questions, such as: what are the long-term ecological effects of mining of the different types of minerals? How can closure be effectively monitored? Who is liable in the event of, for example, contractor bankruptcies after environmental damage has been made in the Area (see Section 2.3).

Table 2: Technological readiness levels for DSM

Ore deposits	Technique	Comments	TRL
Extraction			
PMN	Passive collectors	Advantageous due to its simple design and low operating costs. However, it has become an abandoned method, due to lack of control over the quality and quantity of nodules collected, along with great environmental hazards in the form of large sediment plumes.	5
PMN	Hydraulic collector system	The system applies a type of seawater spray to separate the nodules from the seabed, which results in a limited environmental impact. Hydraulic machines have been tested at shallow depths.	4
PMS/SMS	Conceptual drum cutter (ROV)	Based on methods used for terrestrial coal mining. The vehicle minimizes the production of ultra-fine particles. Experiments have been conducted at depths of 1,600 m, but no material was collected.	3
PMS/SMS	Auxiliary cutter (ROV)	Used to flatten the surface, enabling the drum cutter to excavate resources on the seabed.	2
PMS/SMS	Rotating cutter head (ROV)	Based on deep-sea diamond mining. A rotating cutter head is more flexible than a drum cutter. However, further testing is needed to find out whether it is applicable in a deep-sea environment.	2
PMS/SMS	Clamshell grab (ROV)	Not used for excavation, but rather to remove top layers of SMS deposits. Its applicability for gathering rock is uncertain, along with its economic viability.	2
CRC	-	Due to the difficulties of mining this resource, an economically attractive option has not yet been proven. The basic principles have been observed but the methods have yet to develop.	1
Lifting systems			
Seabed ores	Continuous line bucket system	A series of buckets on a line towed across the seabed. The method was first tested in 1972 but later abandoned due to a lack of control over the system, along with a large environmental impact.	5
Seabed ores	Air-lift system	Involves injecting compressed air into a pipe and pumping the ore up to the surface. It has been tested in very deep waters but is very vulnerable to clogging and requires large amounts of energy.	5
Seabed ores	Hydraulic pump system	A simple and reliable system with high lifting capacity, often applied during drilling for oil and gas. Appears to be a promising concept for DSM but further research is needed.	3
Seabed ores	Batch cable lifting	Similar to what is used in terrestrial mining, this is essentially a hoisting system and therefore much simpler than the hydraulic or air-lift equivalents. The question is mainly whether it will be efficient enough to be commercially viable.	2
Surface platforms			
Seabed ores	Dewatering	One of the simplest techniques to upgrade the value of ore, which is crucial in order to increase the economic viability of DSM. The system is well known and should easily be applicable to vessels or offshore platforms.	7
Disposal			

Tailings	-	Due to the fact that large-scale commercial operations have yet to take place, this is a highly unexplored area. A clear plan for the handling of tailings is needed.	1

Source: authors' construction based on Ecorys (2014) and Rademaekers et al. (2015).

2.3 Legal aspects

Seabed mining may take place in territorial waters or in international waters. Within territorial waters a country's national laws govern mining activity. Within international waters the guiding principle is the United Nations Convention on the Law of the Sea (UNCLOS) through ISA.

It is beyond the scope of this brief paper to go into any detail concerning the laws of individual nations; however, the paper will give an overview of the legal system of DSM within international waters.

UNCLOS and ISA

UNCLOS is an international agreement that defines the boundaries of territorial waters and establishes a comprehensive legal regime for all marine and maritime activities including mineral exploration and exploitation in the 'Area' beyond territorial waters. The 'Area' is defined as the seabed and ocean floor and subsoil thereof, beyond the limits of the Exclusive Economic Zone (EEZ), usually 200 nautical miles from land. It covers over 50 per cent of the total area of all oceans. The Area thus belongs to all countries—coastal states as well as landlocked states—and any state may participate in the exploration or exploitation of the Area.

With the ratification of UNCLOS, ISA was also established. ISA is the autonomous organization through which states organize and control all mineral-resource-related activities in the Area. These activities should benefit humankind as a whole and all benefits, economic and non-economic, should be shared fairly and equitably. All States party to UNCLOS are automatically members of ISA. To date, ISA has 168 members: 167 countries and the European Union. The USA is not a member and among other non-member states are Turkey and some of the Central Asian states of the former Soviet Union, though Russia and China are members.

Over the past decade, ISA has been developing a comprehensive mining code but, as yet, only regulations that govern the exploration phase have been completed. A draft regulation for exploitation was produced in 2019 and is currently undergoing a process of wide stakeholder consultation. ISA is developing a process that is intended to put a legal regime in place before mining starts—a unique process with the participation of all member states of UNCLOS and other stakeholders. This way of handling permission for exploration and mining is in stark contrast with the way national legislations and rules are developed: ex-post and often with limited consultation of stakeholders.

The key questions in the process are what royalties should be levied and how potential future profits should be treated. The UNCLOS framework stipulates that the tax regime for DSM should not favour DSM nor land-based mining but be competition-neutral. For the division of profits after covering the cost of ISA, various models have been developed in order to benefit all developing countries including land-locked ones.

In June 2021, the government of Nauru notified ISA of its intention to submit a plan of work for exploitation in the CCZ in the North Pacific Ocean, by July 2023. This, as stipulated by UNCLOS, requires ISA to provide certainty as to the legal framework by completing the exploitation regulations within two years.

Exploration and, in the future, exploitation activities for mineral resources in the Area are regulated through contracts between ISA and an entity, the Contractor, which could be a state enterprise, or a private or commercial company. Each contractor must have a 'sponsoring state', which should guarantee that the provisions of UNCLOS are followed. This is the process by which it should be guaranteed that the UNCLOS provisions, which are only binding for states, are also followed by the contractors.[3] In applying for a contract, each contractor must also: (i) establish the financial and technical capacity to comply with all rules and regulations; (ii) be sponsored by a state that is party to UNCLOS; and (iii) submit a formal written plan of work, which must be approved by ISA. The plan of work is then converted into a contract, with standard contract terms set out in the regulations of ISA. For the exploitation phase the plan is to set up an entity called 'the Enterprise', which will be the commercial arm of ISA. When initiated, the Enterprise will be able to carry out DSM activities, in parallel to other contractors, on its own, or through joint ventures.

3 History of marine mining

To understand how this regulatory system, and the eventual fiscal framework, has evolved requires an examination of the history of marine mining. Marine mining has evolved as new technologies have arrived, thereby altering the commercial calculus. Governance of the oceans has also changed over time, affecting the property rights upon which regulation is founded, and geopolitics has played an important role as well.

Fishing and trading have historically been the two most important uses of the oceans. While shipping and trading still are (and will remain) of fundamental importance politically, militarily, and economically, fishing has become a minor part of the global economy, although it does still support millions of livelihoods. It is only during the last 70 years that the full economic potential of the oceans has become evident and their mineral riches, especially oil and gas, have been exploited more intensively.

The late development/exploitation of the mineral riches of the seas can be explained by a few main factors, acting together:

- Land-based resources have been sufficient to cover global demand, often with high profits for investors and mining companies.
- Technologies for operating under extreme conditions above and below water (e.g., resisting storms, corrosion in salty waters, and high pressures at depth) were not developed until relatively recently, when the commercial incentives became sufficiently strong. Only when the expected profits outweighed the high risks of investing in complex new technologies did such processes and equipment develop.
- Political control over the oceans was not clearly defined. The 'high seas' were considered to be 'open for all' but in reality, it was the countries with the strongest naval powers that were in control.

But even if large scale exploitation of minerals from the oceans is a relatively recent phenomenon, one mineral has been extracted from the seas for centuries. Salt was produced in this way by the Chinese 4,000 years ago and by the Romans 2,000 years ago. Solar salt is still today a major product of Western Australia, Mexico, China, and Brazil. Magnesium was also once predominantly

[3] There is an important ongoing discussion about which party—the sponsoring state or the contractor—is liable for environmental damage in the Area (Hinrichs Oyarce 2018; Svendsen 2020).

extracted from seawater, although nowadays processes based on hard rock minerals or brines are more common. Oil and gas are by far the most important mineral products obtained from marine underwater resources. Among the non-fuel minerals, sand and gravel dominate. There is also the mining of diamonds and tin, as well as of titanium and iron from beach sands. Intermittently, gold has also been mined from offshore deposits. The most economically important mineral products from the oceans are summarized in Table 3 (in Box 2).

US oil companies were the first to exploit offshore oil and gas resources in the Gulf of Mexico off the Texan coast in the late 1940s. After this modest beginning, the necessary technology was slowly developed, and experience accumulated. In Europe the discovery of the North Sea oil and gas fields in the 1960s marked an explosion of new technology development as well as a regional economic boom. At the same time, the de-colonialization process was running at high speed and corporate control over land-based mineral resources was curtailed by nationalizations in many 'third world' countries. These countries demanded a 'New International Economic Order' of the UN in 1973 and claimed control over their mineral riches. The formation of mineral export organizations followed. The best-known of these was OPEC, but there were also organizations for the copper-exporting countries (CIPEC), those producing bauxite (IBA) and iron ore (APEF), and others. Together, these added to worries about future supplies among industrialized countries and the mining companies. The Club of Rome report was also highly influential in this regard. Published in 1972, it claimed, wrongly, that serious deficits of metals and minerals were likely to develop in the following decades (Meadows et al. 1972). All these developments contributed to the interest in offshore and deep seabed deposits accelerating during the 1970s (Glasby 2002; Råvarugruppen 1980). Great hopes were pinned to seabed minerals[4]—with the benefit of hindsight, over-optimistically so (see Box 2).

Box 2: Historic development of offshore and deep-sea extraction of oil & gas and minerals compared with land-based activities

Optimism about the future of offshore mining knew no limits in the 1970s. It was projected that gold production from the sea floor would be possible. 'Uranium-rich oozes' would be mined from the bottom of the Black Sea and nuclear-powered dredgers would be used to harvest tin from the Laptev Sea. These examples were given in a critical summary written by Elisabeth Mann Borgese, 'The Mines of Neptune' (Borgese 1985). In less critical studies the future of marine mining was even brighter.

Borgese summarizes the situation in 1972 in a table. We have calculated the same figures for 2018. The result is given in Table 3.

Table 3: The economic size of marine extraction, 1972 and 2018

	1972			2018			Tendency
	Volume	Value (US$M)	% of total production of each raw material	Volume	Value (US$M)	% of total production of each raw material	Volume
Oil & gas		10,300	18		600,000	30	Increase, flattening
Sulphur (Frasch)[1]	Na	25	33	Low	Low	30	Decrease
Sand & gravel (Mt)	Na	100	<1	4,500	20,000	10–15	Increase
Tin (kt)	14	53	7	56	1,300	22	Increase
Titanium sands (Mt)	na	76	20	2	1,00	24	Increase
Iron ore (Mt)	3	10	<1	3	200	0.13	Flat
Diamonds (Mct)[2]		0	0	1.2	230	1.6	Increase

[4] There was also early research indicating that to estimate the future impacts of seabed mining is an 'extremely complicated and difficult endeavour' (Tilton 1983).

Salt (Mt)	42	173	29	100	12,000	34	Increase
Magnesium (kt)[3]	143	75	61	Low	Low	0	Decrease
SUM[4]		512			34,730		

Note: 1 sulphur from offshore oil not included; 2 offshore production of diamonds in Namibia temporarily stopped in 1972; 3 almost all magnesium production based on seawater stopped in the 1990s; 4 excluding oil and gas; na = not available

Source: authors' calculations based on Borgese (1985) for 1972 and RMG Consulting (2020) for 2018.

The figures demonstrate that progress in marine mining has at best been mixed—and, of course, how difficult it is to make predictions about the future. Oil and gas production from offshore wells has increased rapidly both in absolute terms and in comparison with onshore production. The technological developments have been tremendous. Drilling for oil and gas at depths of more than 200 m had not been possible before the late 1960s. Today, drilling is undertaken at depths of several thousand metres. The development of fracking technology has, however, meant that large on-land resources can be exploited at low cost, so the steady increase in offshore oil and gas production has been all but halted.

The value of offshore oil and gas production dwarfs the figures for other minerals obtained from the oceans, as is the case for onshore production. The value of offshore oil and gas production is estimated at around US$600 billion, while the total production of all metals and minerals is less than US$50 billion.

Among the raw materials obtained from the sea, sand and gravel are the most important economically. Salt is of the same order of magnitude but its growth potential seems to be smaller. The most advanced technologies for seabed mining are applied to diamonds offshore in Namibia (see Box 1).

In sum, for a number of reasons nothing has come of the great hopes for mining of nodules and crusts at depths of several thousand metres. Most importantly, the technology is even today not fully developed and proven; hence production costs are not competitive with traditional land-based mining.

The freedom of the seas doctrine has governed the use of the riches of the high seas and the right of passage for everyone since the 16th century. Spain and Portugal tried to secure not only the rights to the newly discovered parts of the world but also the right of passage to them. In these efforts they had strong support from the Pope in the form of a bull issued in 1493. But these claims were successfully refuted by Britain and the Netherlands. Their global empires were growing and access to all the oceans was of crucial importance. Later it was generally accepted that coastal states have jurisdiction only over a narrow strip of the sea (3 nautical miles) along the coastline.

This division of the seas continued to be accepted into the 20th century. During the 1920s, however, the League of Nations highlighted some issues which had not been effectively handled under the prevailing regime: issues of maritime safety, conservation of living resources in the seas, and rights to mineral resources. The League of Nation attempted to establish legal rights to the oceans by international negotiation. The Codification Conference held at The Hague in 1930 did not, however, succeed in adopting any international convention. Continued pressure from several organizations and countries, including the International Law Commission and the American Commission to Study the Organization of Peace, similarly came to nothing.

Instead, it was the US, backed by its strong position as one of the victors of the Second World War, that in September 1945 unilaterally issued the so-called Truman Proclamation declaring that it held sovereignty over all resources of the subsoil and seabed of its continental shelf. There was a strong demand for minerals, and the resources of the shelf had by then been recognized.

A chain reaction followed as other nations asserted their exclusive rights to the sea outside their land: in 1945 Mexico and Panama, in 1946 Argentina (all within a 200-mile limit), then Chile and Peru in 1947, and eventually all Latin American countries with a coastline. These claims did not go unopposed and a 'fishing war', mainly between Chile, Peru, and the US, lasted throughout the 1950s and 1960s. Expansions of the jurisdiction of coastal states were also made in Europe by

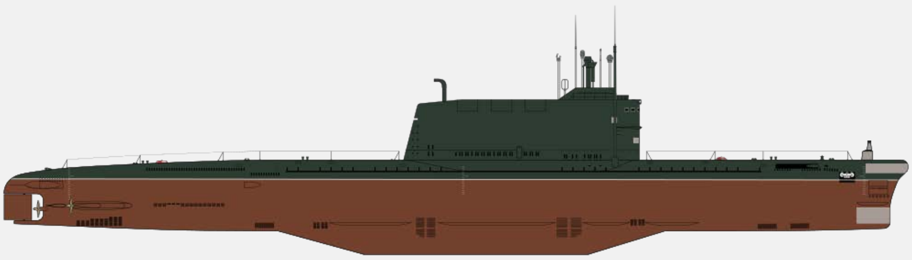
Norway, Iceland, and others. The so-called Cod Wars between Iceland and the UK continued until the 1970s.

The establishment of the United Nations in October 1945 had provided a much-needed forum for continued international discussion of these issues, but it was not until 1958 that the First UN Conference on the Law of the Sea was held in New York. This resulted in conventions on the Territorial Sea and the Contiguous Zone (CTS), the High Seas (CHS), the Continental Shelf (CCS), and Fishing and Conservation of Living Resources of the High Seas (CFCLR).

A second conference was held in Geneva in 1960 without any tangible results. In 1967, amid Cold War fears of the militarization of the oceans (see Box 3), the Maltese ambassador to the UN, Arvid Pardo, made a well-known speech in which he referred to the concept of 'a common heritage of mankind' and proposed 'an effective international regime over the seabed and the ocean-floor beyond a clearly defined national jurisdiction' and the 'creation of a special agency with adequate powers'. The emergence of a large group of developing countries in the UN, the 'Group of 77', ensured support for the proposal, which was also backed by the US, and in 1968 it was decided to set up a Seabed Committee to continue deliberations on the issue.

Box 3: The Cold War impact and 'Glomar Explorer'

In March 1968, the K-129, a Soviet nuclear submarine of the Golf-II class, sank in the Pacific at a depth of 5,000 m. US intelligence, alerted by the extensive but fruitless search by the Soviet Navy, managed to locate the sunken vessel in May the same year and, in 1970, the US Intelligence Board decided to launch an operation to salvage the submarine—a plan with high potential rewards, such as access to a Soviet nuclear warhead and secret communication equipment and codes, but also exceptional technical challenges (to reach and raise a 2,000-tonne vessel had never been attempted before), not to mention serious political risks during this period of the Cold War. It therefore had to be carried out under maximum secrecy.



'Golf II class SSB 629A project', by Mike1979 Russia, under CC BY 3.0, via Wikimedia Commons

DSM, so much in political and economic focus at the time, was the perfect disguise. It took four years to design and build the unique salvage vessel, called 'Glomar Explorer'. To make the cover as perfect as possible, the CIA made a deal with the eccentric billionaire Howard Hughes, who would front as the ship's owner. In early August 1974, parts of the Soviet vessel were salvaged, though exactly how much remains classified. In the spring of 1975, news of the operation somehow leaked to the press and a follow-up secret operation to raise more of the sunken vessel was stopped. The US authorities and the Soviets buried the incident, and it was only in 2014 that additional details of the plot were made public.

This spectacular operation increased interest not only in the nodules on the Pacific seafloor but also in seabed mining generally, in two ways. First, the story that a private investor was willing to invest more than US$300 million in the DSM sector made its viability seem credible. Second, the successful results showed that the technical problems of working at such extreme depths could be solved. Looking back, it can be asked: how much of the hype around DSM during the 1970s was actually created by the US intelligence organizations and how much was based on solid economic and technical facts? (Todd Bennett 2018).

'Hughes Glomar Explorer', by Tequask, under CC BY-SA 3.0, via Wikimedia Commons

There were, however, differences of opinion between the Group of 77, the US and other industrialized countries, and the Soviet bloc. With growing economic and military interest in the high seas, the Third UN Conference on the Law of the Sea was convened in Caracas in 1974. This eventually resulted in a Convention of the Law of the Sea, established in 1982. That convention was ratified by the prescribed number of countries in 1994 and entered into force in 1996.

The final convention had partly been watered down but still contained the basic principle that the oceans beyond national jurisdictions should be considered part of the common good of humankind and be governed by designated international authorities, including ISA, the International Maritime Organization (IMO), and the International Whaling Commission. The International Tribunal for the Law of the Sea (ITLOS) was also set up as an independent judicial body with jurisdiction over any dispute concerning the interpretation or application of the Convention, and special rules were made to facilitate the access of developing countries to the resources of the seas (Nandan et al. 2002).

The DSM industry has experienced two major boom periods, the first in the late 1970s and early 1980s and the second around 2010. During the first boom several international joint ventures were set up with participants from both the traditional mining industry and companies from the oil industry with a focus on the nodules located in the Pacific. The oil majors had made enormous profits during the OPEC oil shocks and were trying to diversify into mining. The Kennecott Consortium, with Kennecott Copper, Rio Tinto, BP Consolidated Goldfields, Mitsubishi, and Noranda as shareholders, was set up in 1974. The Association française pour l'étude et la recherche des nodules (AFERNOD) was also founded in 1974 by the private companies Société Le Nickel and the Empain-Schneider group, together with state organizations BGRM (the French geological survey), CEA (the nuclear energy organization), and CNEXO (a government-owned ocean research organization), as well as Ocean Mining Associates (OMA), whose partners were US Steel, Union Minière, and Sun Oil. The following year, Ocean Management was set up by Canadian transnational mining giant Inco, a German JV, mining and metal companies Metallgesellschaft, Preussag, Salzgitter, and Rheinische Braunkohlenwerke, and the government organization BGR (the Federal German geological survey), along with a large group of Japanese participants including Sumitomo, Nippon Mining, Dow Mining, and Marubeni, and the US oil-drilling company Sedco. Other, smaller national projects were set up in several countries, of which Japan was among the most active.

All these projects slowly faded away and died during the long decline in metal prices from the 1980s to the early 2000s, by which time it was widely realized that the supposed lack of metals on land was actually a chimera (Ericsson 2008). A number of technical advances were made but DSM remained unprofitable and technically unproven.

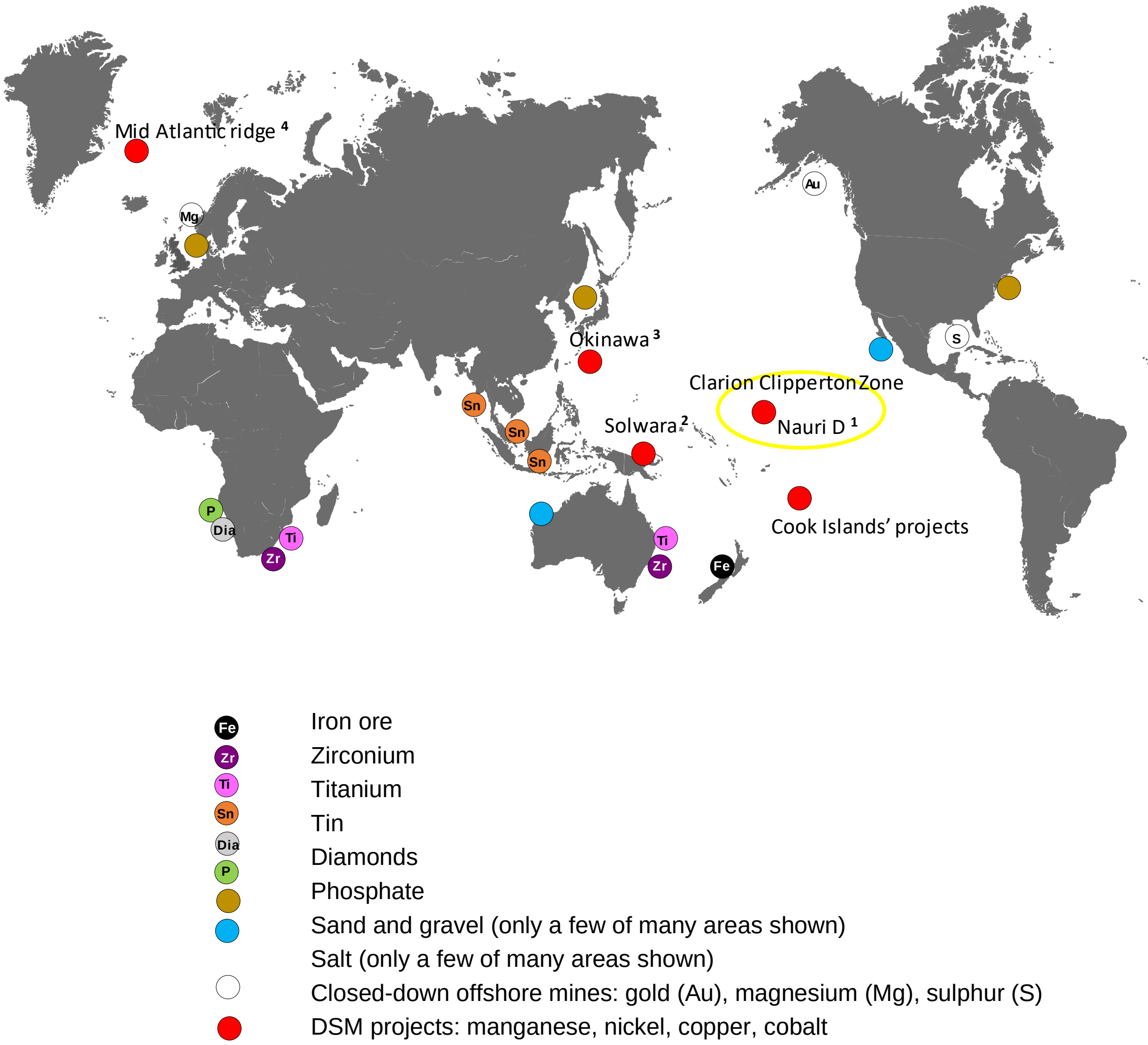
In the late 2000s, during the so-called super cycle, there was a metals price rally and DSM once again came into focus. This time, attention was focused not only on the Pacific nodules but also on the massive sulphide stocks on the sea floor.

The following section presents a number of specific current exploration and exploitation activities from seawater, offshore, and in the deep seabed.

4 Current seabed exploration and exploitation

A number of companies are or have been involved in exploration and exploitation offshore (Figure 2). In the deep seabed no commercial mining venture has yet been started, only exploration.

Figure 2: Present and previous offshore mining and DSM projects



Note: 1 = The Metals Company; 2 = Nautilus (closed down); 3 = JOGMEC; 4 = early-stage Norwegian projects.

Source: authors' updated illustration based on Borgese (1985).

Offshore exploration/mining

In territorial waters there are limited exploration activities in spite of EEZs holding around half of the massive sulphides and the cobalt-rich crusts (Petersen et al. 2016). Japanese companies have been active off the coast of Okinawa and the state-backed organization JOGMEC was reported to have excavated some 649 kg of material from cobalt-rich crusts in 2020 (Guthrie 2020). The Cook Islands granted exploration licences to three companies in early 2022 (Cook Islands 2022) and there have recently been reports of nascent activities in the Arctic north of Russia's long coast (Economist 2021).

In New Zealand, on the west coast of North Island, iron-bearing beach sand is mined in the Waikato North Head and Tahoroa mines; the iron is then used in a local steel plant or exported to China. Production has been quite stable, at 3–4 Mt/a during the last decade (Löf and Löf 2021; UNCTAD 2016). Trans-Tasman Resources have also applied for a 50 Mt/a iron sand mining permit, the South Taranaki Bight Project, some 22–36 km offshore. The company plans to use a sub-sea crawler vacuuming up sand to a custom-built processing ship (Trans-Tasman Resources 2022).

In Namibia, an extensive marine diamond industry is currently active (see Box 1). In 2020, some 1,181,000 ca were produced by two companies, Debmarine Namibia (a joint venture between DeBeers and the Namibian government) and the Sakawe Mining Corporation through its subsidiary Omicor (Chamber of Mines of Namibia 2021). Sakawe also owns Namibian Marine Phosphate, which plans offshore phosphorites mining for fertilizer production. Meanwhile, Debmarine Namibia announced in 2019 that it would commission the world's first custom-built diamond recovery vessel. On 18 March 2022, the company announced that MV 'Benguela Gem' was ready to start operating, with a production capacity of 500,000 ca annually (Debmarine 2022).

Also in Namibia, the Sandpiper marine phosphate project operated by Namibia Marine Phosphate has established a resource and conducted a feasibility study. The project is estimated to produce 3.0 Mt/a of phosphate concentrate over an initial mine life of 20 years (NamPhos 2022).

Tin mining in Thailand, Malaysia, and Indonesia has been carried out for a long time, both on land and offshore by dredging, using both small-scale privately operated vessels and high-tech industrial equipment. In recent years, the depletion of on-land resources has led to an increase in offshore operations in Indonesia, while production in Malaysia and Thailand, which was previously considerable, has fallen.

In Norway, new legislation specific to seabed mining/minerals in EEZ waters was promulgated in 2019 and projects to exploit deposits on the Mid-Atlantic Ridge within its EEZ are now advanced, with a focus on sulphides in the seabed and manganese crusts at a depth of 2,500–3000 m.

Offshore dredging of sand and gravel is the most economically important offshore mining activity. There is a lack of relevant statistics, but it is estimated that 4–5 billion tons are extracted annually around the world. Dredging is particularly important in Europe and the USA, as well as around Japan and Singapore. In Singapore much of the material is used for constructing new land areas. In other countries the sand and gravel is used for general construction purposes including the production of concrete. It seems that the demand for sand and gravel from the sea will grow as the need of land for other purposes than gravel pits increases. It is possible to transport huge quantities of sand directly to customers more cheaply by barge than by lorry. However, the environmental effects are not fully understood and there is much criticism of this type of mining.

Deep-seabed exploration

Oceans and seas cover 71 per cent of the Earth. The seafloor beyond the continental slopes (i.e. in the Area) is around 55 per cent of this (Scott 2001). Within the Area there are, as of March 2022, 31 exploration contracts under the ISA regime: PMN (19), PMS (7), and CRC (5) (Tables 4 and 5).

Table 4: Total area of the high seas covered by exploration contracts, 2022

		Exploration area (km^2)	Total area (km^2)	%
Total area of the seas			362,000,000	100
Contracted exploration areas (ISA)				
19	PMN	75,000	1,425,000	0.4
7	PMS/SMS	3,000	21,000	neg.
5	CRC	10,000	50,000	neg.
	Sum		1,496,000	0.4
	Reserved area (ISA)		1,165,000	0.3
	Total seabed under exploration contract with the ISA		2,661,000	0.7

Note: neg. = negligible. A reserved area is an area of the deep seabed that has been explored and is being reserved by ISA for LICs and MICs. The exact area under the control of ISA is not possible to calculate, as the boundaries of the areas under national jurisdictions are not fully determined.

Source: ISA (https://www.isa.org.jm/minerals/exploration-areas; https://www.isa.org.jm/files/files/documents/statusofreservedareas-01-2019-a.pdf; https://www.isa.org.jm/exploration-contracts).

Table 5: Contracts between ISA and contractors

Contract no.	Contractor	No. of contracts				Type of contractor
		PMN	PMS/SMS	CRC	Total	
1	Interoceanmetal Joint Organization	1			1	Governmental
2	JSC Yuzhmorgeologiya	1			1	Governmental
3	Government of the Republic of Korea	1	1	1	3	Governmental
4	China Ocean Mineral Resources Research and Development Association	1	1	1	3	Governmental
5	Deep Ocean Resources Development Co. Ltd	1			1	Governmental
6	Institut français de recherche pour l'exploitation de la mer	1	1		2	Governmental
7	Government of India	1	1		2	Governmental
8	Federal Institute for Geosciences and Natural Resources	1	1		2	Governmental
9	Nauru Ocean Resources Inc.	1			1	Private
10	Tonga Offshore Mining Limited	1			1	Private
11	Global Sea Mineral Resources NV	1			1	Technology co.
12	UK Seabed Resources Ltd	2			2	Private
13	Marawa Research and Exploration Ltd	1			1	Private
14	Ocean Mineral Singapore Pte. Ltd	1			1	Private
15	Cook Islands Investment Corporation	1			1	Governmental
16	China Minmetals Corporation	1			1	State owned
17	Beijing Pioneer Hi-Tech Development Corporation	1			1	State owned
18	Ministry of Natural Resources and Environment of the Russian Federation		1	1	2	Governmental
19	Government of Poland		1		1	Governmental
20	Japan Oil, Gas and Metals National Corporation			1	1	Governmental

21	Companhia de Pesquisa de Recursos Minerais S.A.			1	1	Governmental
22	Blue Minerals Jamaica Ltd	1			1	Governmental
	Total	**19**	**7**	**5**	**31**	

Source: ISA (https://www.isa.org.jm/exploration-contracts).

Current sponsoring states are Belgium, Brazil, China, Cook Islands, France, Germany, India, Jamaica, Japan, Kiribati, Korea, Nauru, Poland, Russian Fed., Singapore, Tonga, and the UK.

Deep-seabed mining

One of the most promising DSM ventures was Nautilus Minerals' Solwara project within PNG EEZ waters. The company was set up in Canada by an international group of owners comprising the three major transnational mining companies, Anglo American, Barrick, and Teck, and Russian oligarch Alisher Usmanov. (A few years later, in 2011, Teck was replaced by an Omani oil field service provider.) In the early 2010s, Nautilus secured an exploitation licence and an environmental permit to start mining at a depth of 1,600 m, but the technical problems had not yet been solved and the project continuously needed additional capital injections. In 2019, the company filed for bankruptcy and the PNG government, which had enthusiastically taken a 15 per cent share in the project, lost both its investment and its interest in DSM—at least for the time being.

The remaining parts of Nautilus have been taken over by Deep Sea Mining Finance, which is co-owned by the above-mentioned Omani group, controlled by Mohammed Al Barwani Hamdi, together with USM Holdings, controlled by Alisher Usmanov, one of the founding partners of Nautilus (Deep Sea Mining Finance 2022).

After Nautilus went bankrupt in 2019, there was no company with a DSM project approaching commercial production. Given the projected huge demand increase for some of the metals found on the deep seabed, however, new projects and actors have sprung up in the past few years. The Metals Company has already been mentioned. Belgian Global Sea Mineral Resources is another venture testing nodule mining technologies with plans to mine the CCZ (IEEE Spectrum 2022).

Norway's economy is founded on hydrocarbons and it has built extensive knowledge and technologies concerning seabed mining from the offshore oil and gas industries during more than 50 years. With the climate situation gradually declining values in oil & gas and/or declining production volumes, however, the country, is looking to develop DSM operations. A national impact assessment of the environmental, economic, and social consequences of the mining of seabed deposits started in 2021 and, according to some projections, commercial DSM operations could start in 2023 (Lunde Trellevik forthcoming; Olje- og Energidepartementet 2021). However, given that the national impact assessment must be completed before any applications for permits can be made, this time schedule seems over-optimistic.

5 The future of marine mining

In this section, we assess the effects that marine mining might have on LICs and MICs and on land-based mining, since concerns have been raised that DSM will have adverse effects on the latter. First, however, it is important to have an idea of future demand for metals as well as a fundamental understanding of the economics of DSM, which will be examined in the following sub-sections. We then discuss the potential for DSM and offshore mining and assess their possible environmental impacts and their relation to the blue economy.

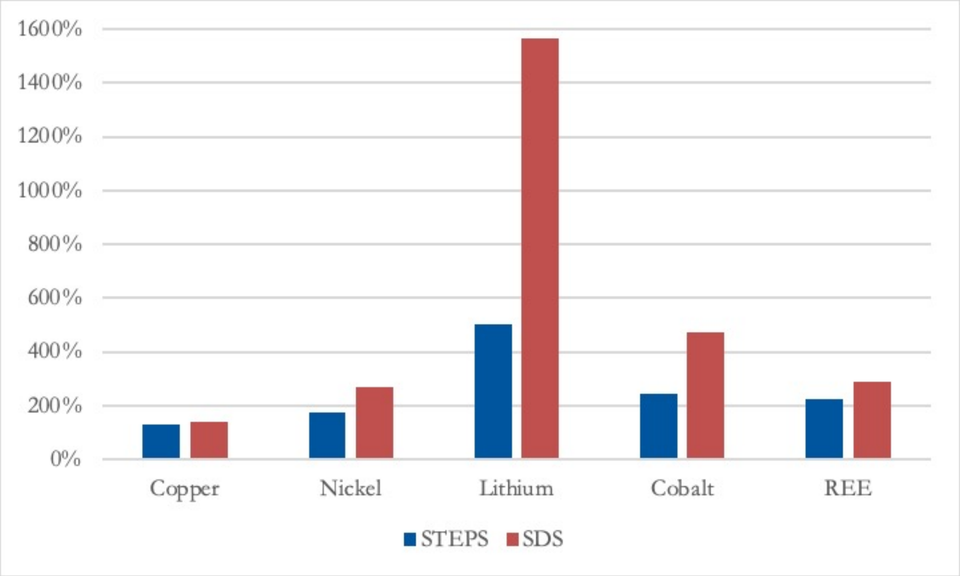
5.1 Demand for copper, nickel, lithium, cobalt, and REE

Demand for metals is forecast to increase as: (i) the global population increases and GDP per capita grows in LICs and MICs[5] and (ii) the transition to a carbon-free economy progresses (Hund et al. 2020).[6] The International Energy Agency (IEA) has calculated total demand for various metals according to two scenarios for the transition to a fossil-free future:

- Stated Policies Scenario (STEPS): an indication of where the energy system is heading based on a sector-by-sector analysis of today's policies and policy announcements;
- Sustainable Development Scenario (SDS): indicating what would be required in a trajectory consistent with meeting the Paris Agreement goals.

According to IEA forecasts, mineral and metal demand will increase, in some cases dramatically, between 2020 and 2040. For example, copper demand in 2040 will be 1.3–1.4 times the demand in 2020, nickel 1.7–2.7, lithium 5.0–15.7, cobalt 2.4–4.7, and REE 2.2–2.9 times (Figure 3).

Figure 3: Growth in total demand for selected minerals 2040 relative to 2020 (%)



Source: authors' illustration based on IEA (2021).

It should be noted that the growth in demand for copper and nickel as estimated by the IEA is broadly in line with historical growth rates. Between 2000 and 2020, for example, demand for copper increased by 165 per cent (ICSG 2002, 2022) and for nickel by 212 per cent (Löf and Löf 2021). While the three other metals—lithium, cobalt, and REE—have recently shown considerably higher demand increases, the absolute volumes concerned are much smaller than for copper and nickel. Annual global production of lithium, cobalt, and REE is in the order of a few hundred thousand tonnes, while nickel production is ten times higher (2 Mt) and copper production a

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[5] See, for example, Halland et al. (2015) and Radetzki and Wårell (2021) for a discussion of the demand for minerals and metals based on population growth and income per capita.

[6] The IEA predicts that the energy sector will become a leading consumer of minerals as the energy transition accelerates. As an example, in 2040, depending on the scenario, demand for lithium from clean energy technologies will be between 74 and 92 per cent of total demand, for cobalt 40–69 per cent, for nickel 31–61 per cent, for copper 32–45 per cent, and for REE 24–41 per cent (IEA 2021).

hundred times higher (20 Mt). The number of mines, and the size of the mines, needed to satisfy this demand is thus much lower, as would be the scale of investment required.

5.2 Economics and technology

For any investment in new mining capacity to go ahead a number of legal and technical issues need to be dealt with, as any project must have a commercially satisfactory rate of return. If demand for the raw material proposed for mining is stable, any new mine also needs to produce the raw material at a lower cost than the highest-cost mine that it would displace. Even this might not be enough, as any older mine will continue to produce as long as it can cover its variable costs. Thus, a new mine must have not only lower initial costs but also lower operating costs for long enough to displace higher-cost production.

The short-term price is dependent on supply and demand. As has been discussed above, demand is set to increase for most mineral raw materials and especially those potentially mined in the deep seabed. With increased demand, prices will increase until enough capacity is available to fulfil demand, at which time prices will fall to the marginal price of the highest-cost producer. It is also worth noting that the new marginal cost could very well be higher than the earlier marginal cost of production due to, for example, lower ore grades, increased environmental and post-closure costs, and costlier production for the highest-cost producer. For DSM to happen, the cost of production must be lower than the highest cost of potential future production on land. Estimates of costs for DSM have been made and the profitability is often projected to be marginal (see, for example, Volkmann et al. 2017). Furthermore, the costs linked to offsetting environmental degradation in the deep seabed including post-closure are largely unknown. This means that the risks for an investor are very high.

The advantage of DSM compared with land-based mining is the ore grades. The average grades in, for example, polymetallic nodules are for each mineral comparable to the average grades in land-based mines (Priester et al. 2019). However, in PMNs, as the name suggests, there is an abundance of various metals, and the total metal content is roughly 50 per cent (ISA a). Nonetheless, there are currently no available technologies to exploit the deep seabed commercially at a profit. Whereas land-based mining has been going on for thousands of years and billions upon billions have been invested in exploration, R&D, new technology, etc., DSM technology is still in its infancy.

Thus, seabed mining should not be seen as a separate industry but as a part of the larger extractive industry, including the land-based mining with which it will have to compete. Land-based mines currently have a technological advantage but, should DSM technology become cheaper and more readily available, such that operating costs are equal to or lower than for land-based mines, a shift towards seabed mining will take place. Nevertheless, operating land-based mines will obviously retain a fixed cost advantage as the investments have already been made.

UNCLOS defines the objectives and principles that should underpin the financial terms of contracts between ISA and DSM mining companies. In particular, the system of payments to ISA shall be fair both to the contractor and to ISA. The rates of payments under this system shall be within the range of those prevailing for land-based mining of the same or similar minerals in order to avoid giving deep-seabed miners an artificial competitive advantage or imposing on them a competitive disadvantage. ISA has studied the tax regimes for land-based mining of the four most important metals (cobalt, copper, manganese, nickel) in all of the most important producing countries (RMG Consulting 2020). No decisions on details of a proposed tax regime for the Area, such as royalty rates, have yet been made, but it seems likely that the most recent and applicable regimes for land-based and offshore mining will be used as a starting point.

5.3 Location

From the list of contractors engaged in the industry (Table 5) it can be seen that these are mostly research organizations—often governmental bodies or state-controlled companies—that have applied for exploration permits in the Area. Most of these companies are not yet planning to begin DSM but are working to increase their understanding of the environment where the extraction is supposed to take place and to establish the technologies for exploration and exploitation. Only one has published any sort of plan to actually commence DSM. The Metals Company is planning to start mining as soon as ISA has made available regulations for exploitation (The Metals Company 2022). The company was instrumental in the demand from Nauru to ISA that mining should commence, thus forcing ISA to fulfil its obligation to finalize an exploitation regulation, and is planning to start mining in its NAURI-D resource sponsored by Nauru. The Metals Company has through joint ventures and mergers and acquisitions been able to gather three of the current exploration contracts in the Area linked to the CCZ into its business plans (contracts 9, 10, and 13 in Table 5).

The plan is to commence trial mining of 1.3 Mt (wet weight) in 2024 and expand it to 11.3 Mt/a (wet) from 2025. This could be further expanded to 54.5 Mt (wet) should the entire resource be available for exploitation. According to the company, the initial mining of the resource, estimated at 357 Mt (wet), would yield a total revenue of US$95.1 billion (The Metals Company 2021a).[7] Considering the 357 Mt resource and an extraction rate of 11.3 Mt/a, the resource would be exhausted in roughly 32 years. That equals US$3 billion in revenues each year. The company further estimates operating costs at US$37.5 billion, or US$1.2 billion per year; hence a profit before tax and other costs, such as capital costs, of US$1.8 billion per year.

While the entity responsible for the mining in NAURI-D may have to pay tax in Nauru, processing is planned to take place in the United States. Thus, the bulk of the value-added production will take place in the USA, close to the intended market, which is the US electrical vehicle battery industry. The actual income allocated to Nauru is thus difficult to assess at the present time. The Metals Company has made public that it will pay an administrative fee each year to Nauru and Tonga. The fee is subject to review and increase in the event that the exploration contracts become exploitation contracts. Further, The Metals Company has agreed to make a seabed mineral recovery payment of an undisclosed amount. In total The Metals Company has, however, assumed that ISA and state royalties will amount to US$33/dry ton.

According to a Greenpeace study (Greenpeace International 2020), Nautilus (which was taken over by DeepGreen, which later merged to form The Metals Company) disclosed some of the terms of its financial relationship with Tonga. The Tongan government was supposed to receive a royalty of US$1.25/dry ton of nodules for the first 3 million dry tons of nodules mined in any one year and US$0.75/dry ton for all dry tons mined thereafter in that same year. Applying these figures to the NAURI-D annual production, the total amount awarded to Nauru would be US$7.9 million in seabed mineral recovery payments per year.[8] However, the above calculations use the figures of a previous company linked to another exploration contract (contract number 10 in Table 5), while

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[7] This is calculated using the following prices: nickel US$16,106/t, copper US$6,787/t, cobalt US$46,416/t, and manganese silicate US$4.53/dmtu (dry metric ton unit).

[8] At an annual production rate of 11.3 Mt/a (wet) and with a moisture content of 24 per cent (the assumed moisture content of the NAURI resource (The Metals Company 2021b)), the production would be roughly 8.6 Mt (dry)/a. The total volume of 3 Mt times the royalty of US$1.25 equals US$3.75 million, while the remaining 5.6 Mt at US$0.75 equals roughly US$4.2 million. The sum is of these is US$7.95.

The Metals Company plans to start production at the NAURI-D resource (part of contract number 9 in Table 5), so the actual likely seabed mineral recovery payment is not currently known.

The projected annual profits for The Metals Company before tax are US$1,800 million and the royalty income for Nauru is US$7.9 million. There could certainly be additional income streams from other taxes and salaries paid by the company but, even with these, the total income for Nauru seems relatively small, especially if other intangible potential costs such as environmental impact are taken into account.

Going forward, should the plans of The Metals Company work out and profitable production start, DSM might also become feasible elsewhere. However, considering the lead-times—including formalizing partnerships, continuing and expanding exploration activities, and carrying out all necessary environmental baseline studies—this would most likely not be before 2030.

In contrast, given that exploration and preparations for exploitation are already well under way in its EEZ, Norway may very well turn out to be the first country with a commercially viable DSM operation.

5.4 Marine mining and the environment

All mining activity, whether it is based on land or in a marine environment, will have certain negative impacts on the environment. However, metals—and hence mineral extraction—have always been and remain necessary for building societies. The questions for policy-makers with regard to mining are thus whether it can be pursued without causing unacceptable environmental impacts, and whether it will create sufficiently positive economic and social effects to offset any negative environmental impacts.[9] The purpose of this study is to focus on the economic, technological, and legal aspects of marine mining for LICs and MICS, but a brief review of the environmental aspects follows.

The main possible negative impacts of seabed mining include introduction of light (depending on depth), waste disposal and associated turbidity and/or toxicity effects, underwater noise, and loss of (largely unknown) biodiversity (Drazen et al. 2020; Koschinsky et al. 2017; Miller et al. 2018; Muñoz-Royo et al. 2020; Volz et al. 2020). As on land, it has been suggested that certain particularly sensitive areas should be set aside and protected from mining activities in so-called Marine Protected Areas (Oxford Department of International Development n.d.).

The ecosystems closer to shore at shallower depths are less affected by these impacts, which often occur above or near the wave base, where the environment is naturally dynamic and prone to extensive and constant change (Tarras-Wahlberg 1998). Offshore mining, which is governed by national jurisdictions, operates in much the same ecosystems as offshore oil and gas exploitation, fishing, and tourism, so that there already exists some understanding of the consequences of exploitation in shallow waters.

Nevertheless, serious problems arising from sand and gravel dredging have been observed around the world, such as habitat burial and resulting extinction of benthic life, as well as coastal erosion, changing currents, etc. (Beiser 2018; Bonne 2008; Charlier 2002; Griffith et al. 2009; UNEP 2019).

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[9] For a reflection on the value of nature see the report by Professor Partha Dasgupta commissioned by the British Government: https://www.gov.uk/government/publications/final-report-the-economics-of-biodiversity-the-dasgupta-review.

Both fishing and tourism have been affected. When dredging technologies permit working at greater depths, the problems will spread to larger areas.

In contrast, the natural conditions in the deep sea are rather stable and unchanging, and the organisms that live there are often long-lived and slow to reach reproductive age, with low fertility rates. Given the slow pace of deep-sea processes, disturbed habitats would likely recover slowly (Glover and Smith 2003). Some observers even argue that DSM will cause irreparable damage to marine ecosystems (Thompson et al. 2018).

DSM outside territorial waters is governed by UNCLOS (and ISA), which stipulates that DSM in the Area should be done using the best available environmental technology, and that a precautionary approach should be employed (UNCLOS Part XI Article 145; Jaeckel 2017).[10] Impacts will also vary depending on the resource that is being mined. It is thus widely believed that DSM of CRC will be more environmentally damaging than that of PMN and/or PMS/SMS (Rademaekers et al. 2015). Furthermore, as there has yet not been any commercial exploitation in the Area, but only exploration activities, understanding of the possible impacts of DSM is preliminary and considerably more research is necessary (Koschinsky et al. 2017; Rademaekers et al. 2015). A consequence of this uncertainty is that many environmental NGOs have called for a moratorium on deep-seabed exploration and exploitation (Greenpeace USA 2021; IUCN[11]; WWF[12]). In May 2022, the European Parliament adopted a resolution for member states and the European Commission to support an international moratorium on DSM (European Parliament 2022). Concerns have also been expressed by Chile and Fiji, among others (Bloomberg News 2022), and companies including car manufacturers BMW, Renault, Volkswagen, and Volvo have pledged not to source metals from DSM (Mining.com 2021). There have also been calls for particularly sensitive areas to be set aside and protected from mining activities in so called Marine Protected Areas (Oxford Department of International Development n.d.).

Opposing views have also been heard. It has been argued, for example, that an 'absolutist opposition' can lead to industrial research stagnation (Ali 2020), and ISA maintains that current knowledge of the deep sea, gathered over more than 40 years, is enough to warrant exploration and exploitation.

To put these issues into perspective, at present only 0.7 per cent of the seabed is covered by an exploration contract, including reserved areas, through ISA (see Table 4), and the areas that might actually be exploited in the near to mid term will cover only a fraction of the reserved areas. Thus, the areas where DSM could impact the environment are limited.

5.4 The blue economy

The blue economy can be defined as all economic activities related to oceans, seas, and coasts (European Commission 2018). It therefore involves, for example, aquaculture, fishing, shipping, tourism, and the extraction of oil and gas, as well as other minerals. Most commonly, the concept includes a sustainability aspect as well as an economic one (World Bank & United Nations 2017). The global blue economy is estimated to have a value of at least US$2.5 trillion (Hoegh-Guldberg

[10] The precautionary principle states that if an action or a policy could constitute a risk of harm to the public or the environment, protective action should be taken pending scientific proof of a risk.

[11] See Motion 069 of the IUCN Congress 2020, Protection of Deep-Ocean Ecosystems and Biodiversity through a Moratorium on Seabed Mining (https://www.iucncongress2020.org/motion/069).

[12] See 'No Deep Seabed Mining' at:
https://wwf.panda.org/discover/our_focus/oceans_practice/no_deep_seabed_mining/

et al. 2015) and employs hundreds of millions of people (Hudson 2018). Marine mining would, at least in the short to mid term, be a relatively small part of the total blue economy. Yet, various intergovernmental organizations have acknowledged the importance of marine mining (AU-IBAR 2019a, 2019b; European Commission 2021). One reason for this interest might be the fact that many countries and regions are discussing security of supply and have been looking to DSM for a potential new source of strategic metals. Another reason is the potential for additional jobs and incomes. But it is also the case that the blue economy and its parts are all interlinked (European Commission 2018). Thus, investments in the blue economy would create synergies across ocean industries (Sepponen et al. 2021).

5.5 Effects on LICs and MICs

DSM has so far only been a mirage in spite of the many hopes and plans presented over the past 50 years. The failure of the Solwara 1 project in PNG clearly demonstrates the risks associated with new DSM projects, in particular for LICs and MICs with limited resources. When optimistic voices are heard again, it is probably wise to remain cautious, particularly in view of the widespread concerns about the environmental impacts of DSM (European Parliament 2022). The cost of limiting these impacts to an acceptable level is unknown and might be rising. Given the many uncertainties, it is unlikely that DSM production will get going before the end of the present decade. Recent developments in Norway and Japan also suggest that the first DSM projects will start in high-income countries. Among LICs and MICs, island states in the Pacific such as Nauru and Cook Islands seem most likely to be among the early starters.

If and when DSM does start, royalties levied on production are, according to UNCLOS, to be distributed to the benefit of humankind. ISA has developed models to show how this can be done in an equitable way. These models attempt to ensure that the share of proceeds received by lower-income states is higher than the share received by higher-income states. First, however, the costs of operating ISA and the control of DSM operations and their environmental impact must be covered (ISA 2022). How much of what remains after these costs have been covered will in the end be allotted to LICs and MICs is mainly dependent on the volumes of production and the prices of the metals produced, and is therefore impossible to estimate today.

Sponsoring states could also require the contractors they are supporting to give them additional income on top of the allotment from ISA. The contract between Nauru and The Metals Company is an example of such an agreement, although it does not seem to produce any significant economic advantages to the host country.

The chances of success for marine mining in LICs or MICS are probably better in the realm of offshore mining, as Namibia and Indonesia have demonstrated. But even in this field the road to success is long and winding (Hannington et al. 2017).

A third possibility is to start building national competence and skills around DSM without necessarily getting directly involved in physical operations. If DSM does develop the need for engineers, environmental specialists, legal experts, resource economists, geologists, etc., it will grow quickly. Mauritius is an example of an MIC that has started to build national skills in order to be able to participate in a future DSM boom independently of where in the world this might take place.

Regardless of how the markets for metals potentially mined from marine deposits develop and the extent of future technological progress, a key question for LICs and MICs is: which fiscal regime will be optimal for them to secure maximum economic benefits? The income from DSM could come both from exploitation in these countries' EEZs and from operations in the Area through

ISA. All developing economies with ambitions in marine mining should actively follow the process running under the ISA umbrella to set the fiscal regime for DSM in the Area. In their EEZs LICs and MICs should be observant and create a regime which secures a reasonable share of future profits. If the share for the country is too high, it might deter investors. If it is too low, the investor will make super profits at the expense of the citizens of the country.

Competition with land-based mining

There are concerns about the future competitiveness of land-based mining if DSM becomes operative among LICs and MICs with existing mines producing any of the four key metals (cobalt, copper, manganese, nickel). Land-based mines currently have a technological advantage but, should DSM technology become cheaper and more readily available, such that operating costs are equal to or lower than for land-based mines, a shift towards seabed mining will take place.

However, given the many technical, economic, and environmental problems that remain to be solved before commercial DSM can start, as described above, it seems unlikely that land-based mining will be seriously affected in the near- to mid-term future. Land-based mining has so far proven capable of meeting increasing global metal demands and these mining companies will, of course, do their best to maintain their production shares and profits. Besides, operating land-based mines will obviously retain a fixed cost advantage as the investments have already been made.

Additionally, if ISA and national authorities are serious about assuring that the environmental impact of DSM is acceptable and fully internalized in the operating costs of DSM, production costs might increase relative to land-based mining. Thus, a transition from land-based to DSM, even when the technology might become available, would still take a long time.

It is nevertheless clear that seabed mining should not be seen as a separate industry but as a part of the larger extractive industry, including the land-based mining with which it will have to compete. Both are parts of the same competitive global market.

6 Discussion

The total value in 2018 of marine mineral extraction is estimated at US$634 billion, 95 per cent of this value being attributed to extraction of offshore oil and gas. That ratio was of the same order of magnitude in 1972.[13] The 2018 figure is around 2 per cent of the total value of all non-fuel minerals produced (excluding sand and gravel and limestone). It is likely that the relatively slow increase since 1972 will continue in both the short and long term. While there are certain other offshore industries that have experienced rapid growth, in both relative and absolute terms, such as sand and gravel, tin, and the Namibian offshore diamond industry, there are others, like sulphur and magnesium, that have disappeared more or less completely. Salt has maintained its relative share and more than doubled in volume.

The future of offshore oil and gas extraction is, however, fraught. In part this is because new technological developments have decreased the cost of fracking on land to such a level that shale gas is now competing successfully with offshore oil and gas. This has made investments in offshore oil and gas less attractive than they were only 10 years ago (Aguilera et al. 2015). Furthermore, the green transition will make investments in oil and gas in general more costly, either because of a

[13] If anything, there has been a slight increase of the share non-fuel marine production in the period up to 2018.

perceived and/or real increased financial risk or in actual costs of offshore operations compared with fracking and exploiting onshore deposits.

It is not likely that the value of marine minerals other than fossil fuels can equal the value of oil and gas, at least not in the short to medium term. Thus, overall, marine extraction may even see a decrease in value terms over the coming years. However, marine extraction of all minerals other than oil and gas (i.e. marine mining) is likely to increase in importance and value globally in both the short and long term. Marine mining could become an important part of some coastal countries' economies. Sand and gravel is a good example of a mineral resource that can easily be extracted and both used locally and to some extent exported. The marine extraction of diamonds in Namibia is another interesting example. While the resource is unique, and the chances of finding similar resources in other locations must be considered slim, the model of the Namibian marine diamond industry is undoubtedly a success. From the first discovery of diamonds in the seabed to actual mining a whole set of technologies had to be developed, and today the industry is a vibrant and important part of the Namibian economy. While the technology is specialized for diamond mining, there is nothing to suggest that the same kind of development cannot also take place in the mining of other marine minerals such as phosphorite nodules, as is already under way. It is also clear that it will take decades to develop a high-tech offshore mining sector whatever the deposits available. Indeed, the Namibian experience is unique and so should be studied in order to provide lessons for possible offshore mining in other locations.

In the case of seawater mining, the extraction of minerals dissolved in seawater has largely been reduced to salt extraction. While this is an important industry, the further growth potential seems to be primarily connected to an increase in the global population. However, new technologies to desalinate seawater, and the growing importance of desalination to secure access to fresh water in many parts of the world, may transform this industry. The waste product would be a salt solution containing all the various minerals soluble in seawater; thus, it would be a concentrate ready for processing. While research is ongoing, further R&D is needed for that industry fully to exploit the value of the concentrate.

Another possible area of development is the mining of beach sand. The iron-bearing beach sand in New Zealand, the tin in Indonesia, and the titanium-containing sands in Mozambique, South Africa, and other countries, are all of interest, and similar resources can be found in other parts of the world. In this case, too, however, resources and reserves still need to be developed and technology adapted.

Deep-seabed mining technology is still in its infancy. It will be necessary to continue to develop new technologies and improve existing technologies if the DSM industry is to have a chance to finally become profitable without damaging the environment. Some researchers claim that the huge demand for metals created by the necessary transition to a fossil-free world is an argument to speed up development (Toro et al. 2022).

The economic benefits to LICs and MICs from DSM in the form of royalties seem to be limited, at least as measured by the figures obtained from the NAURI-D project run by The Metals Company in Nauru. There could be additional economic flows, such as other taxes, higher salaries, and increased employment, but the total revenues will probably also be limited. There is therefore an obvious need for each host country to carefully weigh up the costs and benefits of DSM projects before they are given the go-ahead.

DSM, like other mining, both onshore and in the sea, demands considerable investment but creates a limited number of jobs. Furthermore, the processing of seabed minerals is often planned for countries close to the customer. In these cases, the potential is open mainly to HICs with a developed battery- and electric vehicle-producing industry and the value added in the processing stage seems to be predestined to go to industrialized countries, with LICs and MICs finding it difficult to develop a downstream industry—a problem already well known for host countries in the developing world with land-based mining.

Considering all of the above, offshore mining looks like a more interesting option for LICs and MICs than DSM. The technology is readily available, experiences can be disseminated, and some MICs, such as Namibia and Indonesia, have already grown their own offshore mining industry, which could serve as a model for other countries, while others, like Mauritius, are preparing by creating a pool of the requisite skills and revising their legislation to cater for a growing marine sector—whether offshore or from the deep seabed.

In order to be accepted and successful, new marine mining technologies will probably have to make a much smaller ecological footprint than methods used so far. The potential environmental damage and problems caused by all marine mining activities, and in particular DSM, have been the subject of strong criticism in recent years and there have been calls for a moratorium on DSM. Such an 'absolutist' approach might, however, stop or seriously limit most of the present research and preparatory activities aimed at expanding metal supply to meet the demands of a growing population in the LICs and the MICs (Ali 2020). A more sensible way forward could be to strengthen ISA and keep up the momentum of exploring the deep seas and developing new technologies to exploit the resources of the seas—to balance the pros and cons of both marine and land-based mining in an optimal way to the benefit of humankind. Metal demand, after maximum recycling, will always have to be met by either land-based mines or marine operations. The environmental problems caused by marine mining must always be compared with the effects of land-based mining. It is clear that in some respects marine mining is advantageous to land-based mining.

In the short to mid term, both offshore mining and DSM should be considered from a blue economy perspective. The blue economy is a substantial part of the national and regional economy in coastal states. Any marine mining activity, be it DSM or offshore projects, can also become a vital part of infrastructure developments such as ports, railways, and energy supplies. Increasing knowledge of the riches of each country's territorial waters and its seabed will be important to optimize fishing and tourism today and potentially mining in the future. All activities in the blue economy will create employment, tax income, and general economic and social development. Benefits from marine mining must be weighed against the potential loss of income from disturbances these activities might cause for other parts of the blue economy. To facilitate the growth of the entire blue economy, education and R&D efforts will be useful and important. In which directions these efforts should be directed and exactly what must be done is, however, not at all obvious, and each country will have to develop its own pathway and select R&D focus and goals for training efforts, etc. Comprehensive and thorough policies as a means to maximize utility should be a valuable tool in the development of the blue economy.[14] As a consequence, marine mining should not be seen as an industry on its own, but as a part of the bigger blue economy. Engaging with ISA could be a fruitful first step to increase knowledge of the seabed and related issues as ISA actively engages in knowledge sharing and knowledge building through various educational programmes.

It is also important to acknowledge UNCLOS and the work by ISA as an attempt to bring peace and order to the high seas. For the first time in history, the exploitation of minerals is not only a

[14] See, for example, Economic Commission for Africa (2016).

matter between investors and individual national governments but for all countries which have signed the convention. The convention also gives all developing countries, whether low or lower-middle or upper-middle income, special rights and possibilities to participate in the exploitation of the mineral riches of the seas. Many problems remain for ISA and its member states to solve but a foundation has been laid (Lodge et al. 2017).

7 Conclusions

The economic importance of marine mining has increased during the past 50 years. Its total value is, however, relatively limited at around US$15 billion (excluding sand and gravel) in 2018, compared with less than half a billion in 1972.

DSM is an industry that has not managed to fulfil the optimistic prophecies of the 1970s in spite of 50 years of gradual but slow development. Considering that there are as yet no deep-seabed reserves, i.e. commercially mineable deposits, there will be no DSM in the short term. In the mid term it is uncertain whether proposed technologies can be used commercially and profitably and with acceptable environmental impact. Exploration is, however, ongoing and plans for commercial operation have been presented.

While marine mining may contribute to national and regional economies, it will also compete with land-based mining. The existence of minerals in/on the seabed does not necessarily make these minerals the optimal solution to satisfy future demand for minerals. It will always be the lowest-cost producer that will provide minerals and metals to the market. Considering the amount of R&D invested in land-based mining, it seems likely that marine mining, and particularly DSM – if it will start—will not take over the market completely but rather remain as a niche market, at least in the short to mid term. The concern that DSM will force land-based mines to close seems premature.

Moreover, mineral reserves that can be exploited economically do not yet exist in the deep seabed. Until such reserves have been identified, no DSM will take place. Potentially, new investments in land-based mines may be diverted to DSM in the longer term. However, all existing land-based mines will have a clear cost advantage over DSM at least until reserves are mined out, since investments have already been made in these. In the mid term it is uncertain whether proposed, but not yet tested, DSM technologies can be used commercially and profitably and with acceptable environmental impact.

Offshore mining looks like a more interesting option for LICs and MICs than DSM. The technology is readily available, and there are MICs that have extensive experiences from offshore operations that can be relatively easy shared with other countries.

The processing of the minerals obtained by DSM seems most likely to take place in industrialized countries or established mining countries close to the main markets for the metals, which are the end product. Emerging countries with potential DSM deposits should therefore seek to secure the establishment of processing and refining of marine minerals for themselves.

UNCLOS is a unique ex-ante attempt to create a regime for mineral extraction which benefits humankind—not only by the metals produced but also in that part of the profits shall be shared equitably by humankind. The process to operationalize UNCLOS is a democratic experiment with all its attendant problems and slow progress, but it is not only the mining companies or mineral-rich countries that have all the decision-making power.

LICs and MICs that want to participate in the future of marine mining should build a cadre of knowledgeable and experienced persons from all professions of importance to the sector. Their mineral legislation should be aligned to UNCLOS. Participation in the work of ISA is the first step in these preparations.

Alternatively, linkages to existing offshore oil and gas industries may serve as a starting point, although resources and reserves still need to be developed. Here, policy interventions could become an important tool by, for example, increasing the activities of local geological surveys to reduce the risks associated with mining projects and facilitate investments from private companies. Policies to facilitate the introduction of new specific legislation and promote local skills development would also be useful.

A range of serious environmental problems created by marine mining are still unresolved. It will be important to find a sensible way forward to be able to study the environmental problems of marine mining and not to stop such work completely. ISA could play an important role in this respect.

Any marine mining should also be considered from a blue economy perspective. The blue economy and its parts are all interlinked and investments into the blue economy would create synergies across marine industries. The blue economy can become a substantial part of the national and regional economy in coastal states where it can promote infrastructure developments like ports, railroads, and energy supplies. Further, increasing the knowledge of the riches of each country's territorial waters and its seabed will be important to optimize fishing and tourism today and potentially mining in the future. All activities in the blue economy will create employment, tax income, and general economic and social development. Revenues from fisheries and tourism could well exceed those from marine mining, and so care must be exercised in containing the environmental impact of the latter.

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