WWF INFORMATION

An investigation into deep seabed mining and minerals

Commissioned by WWF

Elaborated by Christoph Weigl

Edited by Barney Jeffries

September 2020

Synthesis

The present study maps existing knowledge on the likely environmental and socioeconomic impacts of deep seabed mining in the context of global efforts to transition to a low-carbon and circular economy. It identifies knowledge gaps as well as bringing to light misconceptions around the necessity of deep seabed mining for enabling a move to a greener global economy.

This study acknowledges that the low-carbon transition will require large amounts of virgin materials and that deep seabed mining would have the potential to supply some of these materials. However, this argument needs to be balanced against the probable negative impacts of deep seabed mining on biodiversity, the functioning of the Earth's ecosystems and the sustainable production of metals and minerals. Carbon neutrality is not a target that can be achieved in isolation, and simply comparing the greenhouse gas intensity of different material extraction methods is misleading: carbon neutrality can only be achieved by taking appropriate action across the entire value chain of deploying low-carbon technologies. This includes reducing demand, avoiding the use of finite resources where possible, reducing the amount of materials used, as well as repurposing and recycling materials before disposing of them appropriately.

Deep seabed mining would support none of these critical steps. Claims for its potential climate benefits are highly uncertain and pay little consideration to its wider environmental and socioeconomic consequences. The short-term benefits from rushing to deep sea minerals should not be mistaken for the structural changes we need instead to accomplish long-term, low-carbon development.

The structure of this study follows a set of questions that are frequently presented by deep seabed mining stakeholders – but gives answers that consider the wider context of sustainable development and the latest knowledge and innovations affecting trends in mineral demand, recycling and utilization. A summary of the answers is provided here as a synthesis, while the detailed research is presented in the analysis below.

Why do we need more metals?

Material demand is expected to increase significantly over the coming decades. This will be driven largely by the rapid growth in electric vehicle (EV) deployment. A scenario analysis conducted by Dominish, Teske & Florin (2019), for instance, expects demand for cobalt, lithium and nickel to well exceed current mining reserves by 2050 – in the case of cobalt by around 420%. Similar results were found by various other studies (Månberger & Stenqvist, 2018; Olivetti *et al.*, 2017; World Bank, 2020), highlighting in particular the supply criticality of cobalt.

However, the studies also point out that these estimations are at the upper and rather unlikely end of the range and that mineral demand can indeed be kept within terrestrial limits. Demand reductions of as much as 60-90% for almost all minerals have been found possible under scenarios with basic assumptions on increased material efficiency and recycling.

Researchers also frequently emphasize the limited scope of their studies as a reason for overestimating future mineral demand. Rapid technological developments in material science or innovative modular and shared mobility business models, for instance, hold great potential to drastically reduce mineral demand. The EV sector in particular is young and rapidly evolving, with manufacturers regularly announcing innovations such as new solid-state battery technologies that could halve battery size (Samsung, 2020) and modular battery rental schemes that can optimize battery utilization. Acknowledging the difficulty in estimating such developments, almost none of the reviewed studies adequately incorporate these innovations in their scenarios, leaving their potential to reduce mineral demand largely unquantified.

Why can't we just recycle?

The long lifetime of solar cells and EV batteries (up to 30 years with various second-life applications) keeps metals in circulation for many years before being freed up for recycling purposes. This increases pressure on virgin mineral use as we seek to cover rapidly rising demand in the short-to-medium-term future. Recycling also has high labour costs (versus extensive automation and falling capital costs in mining), which is reducing its competitiveness (OECD, 2019). This is why most reviewed studies (Olivetti *et al.*, 2017; Månberger & Stenqvist, 2018; Dominish, Teske & Florin, 2019; World Bank, 2020) agree that recycling alone will be insufficient to meet immediate metal demand growth.

However, we need to appreciate the fundamental shifts that are happening in manufacturing as well as in consumer behaviour. Focusing excessively on recycling obscures the potential of previous life-cycle steps to reduce primary mineral demand to levels where recycling can fully replace virgin mineral demand. The aim must not be to feed enough material into the system to make recycling possible, but to reduce material demand at customer, design and production stages to levels where recycling can cope with the quantities.

Under current projections, producing copper through recycling in 2060 will still be around 15% more expensive than through mining, and other recycled non-ferrous metals will be up to 25% more expensive (OECD, 2019). Deep seabed mining would open up yet another low-cost pathway for minerals to enter supply chains, likely dampening mineral prices and hence undermining long-term incentives for producers and governments to scale recycling efforts, especially in emerging economies.

Why shouldn't we keep mining the land?

The extent to which deep seabed mining may replace land-based mining is highly uncertain. Deep seabed mining is a nascent technology that lacks scientific proof for its supposed environmental advantages over land-based mining. A lack of historical experience and limited scientific understanding of deep sea ecosystems make it impossible to compare the impacts of deep seabed mining against potentially avoided environmental impacts on land. In addition, mining operations on land have become ever more efficient (Arndt *et al.*, 2017) and, despite their often detrimental environmental impacts, they represent significant sources of income for some of the poorest countries and communities on the planet (ICMM, 2016).

Deep seabed mining, on the other hand, would be dominated by only a few operators who have the required technology and capital, and has the potential to fundamentally disrupt marine ecosystems. As well as being an ecological disaster, this could affect global fisheries, threatening the main protein source of around 1 billion people and the livelihoods of around 200 million people (FAO, 2018).

What is on the ocean floor?

Much of the deep sea remains yet to be explored and scientifically understood, but contrary to long-held beliefs it has been found to be teeming with life. In fact, the very minerals of interest to commercial exploitation are the foundation for the livelihood of deep sea organisms and ecosystems.

The main marine mineral resources are polymetallic nodules, seafloor massive sulphides and cobalt-rich crusts, which can be found at different locations and geographies at depths of up to 6,000 metres. The exploitation of seafloor massive sulphides and polymetallic nodules are considered the most economically feasible, while exploiting cobalt-rich crusts is currently not expected to be commercially profitable – despite demand for cobalt being one of the justifications for exploiting deep seabed mineral reserves (European Commission, 2014; Haeckel, 2019).

A wide variety of microbial life and other larger lifeforms exist in the deep and find habitat on the metal-rich geologies that are of interest to deep seabed mining. These organisms exert significant influence on the ocean's ability to cycle nutrients and carbon, balance metal contents and ocean chemistry, and stabilize atmospheric carbon dioxide concentrations over long time horizons. In the absence of sunlight, deep-sea microorganisms use the energy from chemical reactions to absorb carbon and form organic compounds through a process called chemosynthesis, which in turn build the bottom of the food chain for the wider marine ecosystem (FFI, 2020).

This interdependence goes far beyond the ocean floor. In fact, marine ecosystems have no obvious physical boundaries, which means that deep seabed mining cannot occur in isolation and its impacts would not be limited to the ocean floor. Disturbances can easily cross ecological and jurisdictional boundaries and thus lead to unexpected and unquantifiable consequences even on land.

How do deep seabed mining processes work?

While different mineral deposit types require different mining techniques, all involve the physical removal of sediments and the subsequent alteration of habitats. Seafloor massive sulphides and cobalt-rich crusts require the use of cutting and drilling tools to break up and extract the minerals. The extraction of polymetallic nodules, on the other hand, requires vacuum cleaner-like collection vehicles that suck the mineral-rich nodules from the ocean floor. All collection equipment is remotely operated, and the collected material is pumped as slurry through a piping system to a collection vessel at the water's surface. From there, the minerals are processed and transported to land, while excess sediments are released back into the water (BGR, n.d.; Sanderson, 2018; DeepGreen, 2020a).

Deep seabed mining is to some extent operationally similar to offshore oil and gas projects. Some project management standards from the industry could therefore be adapted to deep seabed mining operations. However, technical process standards in the oil and gas industry may not be applicable to every aspect of the nascent technology that is applied in deep seabed mining. The same applies to environmental standards: these draw on many years of research, but this is mostly limited to the waters of the shallow continental shelf or in relative proximity to land, with limited experience in deep sea environments (>3000m).

What is the environmental impact of ocean metal collection?

Up to now, deep sea ecosystems have experienced low levels of rapid and abrupt disturbance. They are, however, likely to have low levels of resilience. This results from a set of characteristics that reduce their capability to withstand and recover from disturbance, such as species' long lifespans, slow growth rates, late maturity and reproduction and low fertility, and high degrees of connectivity to other ecosystems.

A wide range of environmental impacts would have to be expected from deep seabed mining. Next to direct physical ecosystem destruction through mineral collection vehicles, major damage and disturbance would likely arise from light, noise and sediment pollution. It is particularly important to consider these risks not only at a project level but at a cumulative scale, since deep seabed mining would impact areas of continental scale. The most imminent impacts are:

1. Loss of habitat and life-supporting substrates, killing fauna and flora
2. Sediment plumes swirled up from mining, impacting species and habitats
3. Exposure of seabed life to toxic metals released during mining operations
4. Harm to genetic links between different populations of deep sea animals
5. Habitat alteration and fragmentation through sediment, light and noise
6. Impacts to primary production in the water column and food webs
7. Impacts to ecosystem functions through disruption of key processes
8. Alteration of large-scale ocean cycles including carbon, nutrients and trace metals.

For instance, a single polymetallic nodule mining operation is expected to directly impact an area the size of New York City each year. Operations on the ocean floor would suspend up to 45 million cubic metres of wet sediment or 15 million tonnes of dry matter – which is equivalent to 41 times the volume and weight of the Empire State Building – as fine powder into the water column. This suspended sediment would not only release already accumulated metal particles back into the water but would also cover and potentially destroy the habitat of deep sea organisms. Given the slow pace of deep sea processes, the recovery of destroyed habitats is likely to exceed human timescales (Volkman & Lehnen, 2018; Haeckel, 2020; FFI, 2020).

More data is needed to estimate the full scale of environmental impacts from deep seabed mining. Yet, while deep seabed mining as an industry is currently valued at US$2-20 billion (FFI, 2020), it threatens to disrupt a much wider ocean economy, valued at US$1.5-2.4 trillion annually (Hoegh-Guldberg *et al.*, 2015; OECD, 2016).

What happens if you discover unexpected consequences? What regulation is there around this?

Deep sea operations are extremely expensive, which impedes extensive auditing and the collection of evidence to prove misconduct or negative impacts. A single day of offshore research may cost up to US$80,000 (FFI, 2020). Standards and regulations on the management and funding of environmental monitoring and safeguarding are currently drafted by the International Seabed Authority (ISA), which regulates deep seabed mining operations in areas beyond national jurisdiction. The ISA is further tasked with the establishment of a benefit-sharing mechanism that will redistribute some of the financial benefits from deep seabed mining to projects for the global good.

In fact, the United Nations Convention on the Law of the Sea (UNCLOS) designates the deep sea and its resources as the Common Heritage of Humankind and deep seabed mining operations need to be sponsored by a state that is a signatory to UNCLOS. This, however, provokes conflicts of interests. In the case of the ISA, a single institution is tasked with regulating deep seabed mining while also having an interest in its financial benefits. A sponsoring state that promotes a deep sea operator, meanwhile, both benefits from its financial success and is ultimately responsible to execute liabilities against it in the case of misconduct or damages.

Both the benefit-sharing mechanism and liability regime remain vaguely defined by current regulation under the ISA.

Why are deep seabed mining operators often for-profit companies?

The main corporate and governmental actors involved in deep seabed mining include sponsoring states, international organizations such as the ISA, deep seabed mining operators and investors. Also, national research institutions and universities are heavily involved in establishing the scientific baseline around the potential impacts of deep seabed mining. Many international institutions, such as the EU, or multilateral development banks, such as the World Bank, do not yet have a common and clear official position on deep seabed mining.

While some operators claim to be profit-driven companies for the sake of efficiency and to be able to raise capital from investors quickly (DeepGreen, 2020), it is unclear how financial benefits are to be shared and redistributed in an equitable manner among commercial stakeholders and the wider global community. Benefits are further mostly viewed in financial terms, since other benefits, such as potentially avoided mining impacts on land, are difficult to quantify and still lack scientific evidence. The benefits of preserving functioning deep sea ecosystems now and for future generations are also largely unquantifiable and hence not adequately reflected in current regulation around deep seabed mining (FFI, 2020). Ultimately, high capital expenditure to start mining operations in the deep sea may lock-in companies to extract minerals for many years and at excessive rates.

How will deep seabed mining contribute towards a closed-loop economy?

The potential emergence of deep seabed mining runs counter to a closed-loop economy for five main reasons:

1. Deep seabed mining operations would create significant pollution and environmental destruction
2. Deep sea minerals are finite resources and essential to the functioning deep sea ecosystems
3. Deep seabed mining would compromise ocean carbon, metals and nutrients cycles
4. Deep seabed mining would undermine efforts to increase the recycling of minerals and metals
5. Deep seabed mining would undermine efforts to reduce material intensity in design and production.

Analysis

A knowledge stock-take on deep seabed mining

The structure of this study follows a set of questions that are frequently presented by deep seabed mining stakeholders – but gives answers that consider the wider context of sustainable development and the latest knowledge and innovations affecting trends in mineral demand, recycling and utilization.

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1. Why do we need more metals?

Do current material demand and emission scenarios justify deep seabed mining?

Answer:
Innovative business models, backstop technologies and recycling are sufficient to keep growing mineral demand within terrestrial limits. Aligning consumer convenience, business interests and technological change toward the common goal of reduced material intensity will be critical.

> ***Backstop technology:*** *a close substitute to the best-in-class technology that uses non-exhaustible or more abundant resources as inputs while producing almost identical results.*

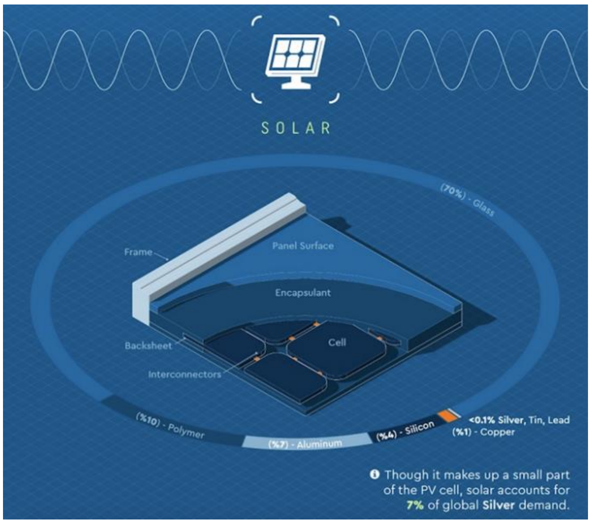
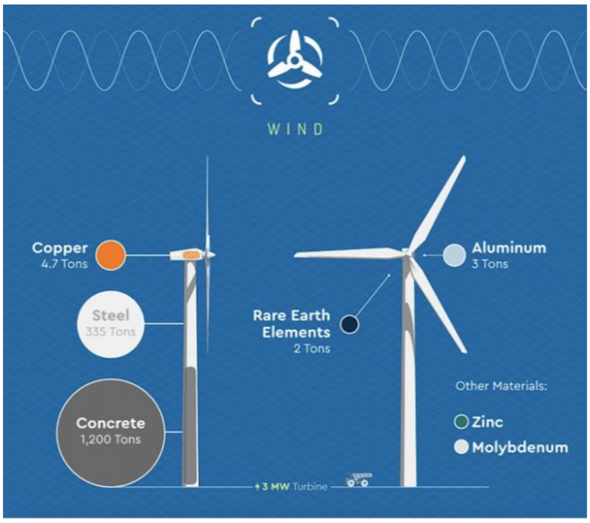
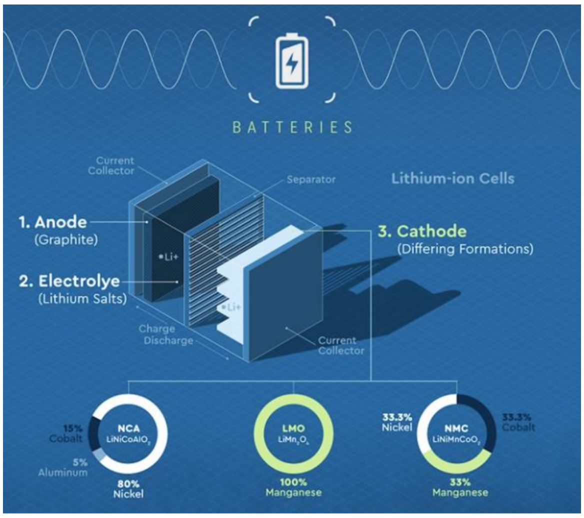
Knowledge gaps:

1. Current models do not account for business model innovation (e.g. modular batteries) in their estimations of future mineral demand.
2. The effect of improving mining efficiencies was not reflected in the mineral demand models studied for this analysis.
3. The speed of technological change might significantly decrease mineral demand. This, however, is difficult to represent in models.
4. Rapid material demand increase is expected over the next two decades, which might be too soon for deep seabed mining to make a significant contribution. Deep seabed mining might therefore only contribute substantial material amounts when demand has already peaked and new technologies and recycling take hold.

Background:
According to the Intergovernmental Panel on Climate Change (IPCC), the remaining carbon budget for limiting global warming to 1.5°C by 2100 amounts to 420Gt of CO_2 (66%-chance scenario). This represents approximately 10 years of current annual emissions (IPCC, 2018). Heat and electricity generation and the transportation sector are the dominant sources of annual global GHG emissions, contributing around 30% and 15% respectively (Statista, 2020; IRENA, 2019). The decarbonization of the energy and transport sectors is therefore essential to achieving current climate change targets. Increasing the share of renewables and electrifying the transport sector are expected to contribute 50% of potential emissions reduction targets in the near future (IRENA, 2019; Statista, 2020).

Under these assumptions, IRENA (2019) expects that between 2018 and 2050, the global stock of electrical vehicles (EVs) needs to jump from 6 million to 1.2 billion passenger cars and grid-battery storage capacity needs to climb from 0.5 gigawatt-hours (GWh) to 12,380GWh. Further, the amount of installed solar photovoltaic (PV) capacity must rise from around 486GW to more than 6,000GW and installed wind capacity from 564GW to 8,500GW (= 1.5°C scenario = 86% renewables in energy and 50% decarbonization of transport). The deployment of these technologies, however, requires substantial amounts of metal and mineral resources, as listed in Table 1. This demand ultimately drives efforts to explore and exploit deep sea mineral deposits.

Table 1 Low-carbon technologies and associated metals and minerals

<table>
<tr><th>Technology</th><th>Main minerals and metals used</th></tr>
<tr><td>
</td><td>Aluminium
Copper
Cadmium
Indium
Gallium
Selenium
Silver
Tellurium
Tin</td></tr>
<tr><td>
</td><td>Aluminium
Copper
Zinc
Molybdenum
Rare earth elements (REE):
–Neodymium
–Dysprosium</td></tr>
<tr><td>
</td><td>Aluminium
Cobalt
Lithium
Nickel
Manganese
Rare earth elements (REE):
–Neodymium
–Dysprosium</td></tr>
</table>

Sources: illustrations published and adapted from World Bank (2020); main minerals and metals compiled from various studies (Dominish, Teske & Florin, 2019; IISD, 2018; World Bank, 2020)

Currently, these metals and minerals are predominantly mined on land and differentiate themselves not only through distinct chemical properties, but also through their resource abundance (minable reserves and resources in the Earth's crust) as well as production economics. Most critical for determining the economic feasibility of deep seabed mining are therefore:

1. Currently available mineral reserves
2. Expected mineral demand
3. Expected growth in production
4. Geographic concentration of reserves
5. Geographic concentration of production.

For the main minerals needed for renewable energy technologies, Dominish, Teske & Florin (2019) present a coherent analysis for those five parameters. Assuming a climate and renewables demand scenario that would be consistent with limiting global warming to 1.5°C, they estimate the related mineral demand by 2050; their results are summarized in Table 2. In reality, governments are likely to fall short of meeting their climate goals and therefore the results summarized below may overestimate material demand.

Table 2 Metals and minerals demand expectations

	2050 demand in % of current mining reserves	2050 demand in % of known terrestrial resources	% production increase by 2050	Current production concentration	Current reserves concentration	% of 2050 demand from renewables	Criticality assessment
Aluminium	2%	1%	3%	54% - CN	20% - AU		Low
Cadmium	4%	0%	3%	36% - CN			Medium
Cobalt	423%	120%	1,788%	58% - CD	49% - CD	43%*	High
Copper	18%	4%	29%	27% - CL	22% - CL		Low
Dysprosium	19%	11%	640%	81% - CN	18% - RU/VN	32%	High
Gallium	2%	0%	28%			17%	High
Indium	51%	16%	38%	43% - CN		8%	High
Lithium	280%	85%	8,845%	43% -AU	18%* - AR	50%*	Low
Manganese	14%	0%	40%	33% - ZA	29% - ZA		Low
Neodymium	13%	7%	592%	81% - CN	18% - RU/VN	32%	High
Nickel	136%	77%	313%	19% - ID	16% - BR	3%	Low
Selenium	11%	7%	12%	28% - CN	26% - CN		Medium
Silver	52%	21%	40%	22% - MX	18% - PE	9%	High
Tellurium	75%	48%	199%	67% - CN	21% - CN	40%	Medium
	>100%		>500%	>50%	>33%	>25%	High
	>50%		>100%	>33%	>25%	>5%	Medium
					*resources	*2020 figure	

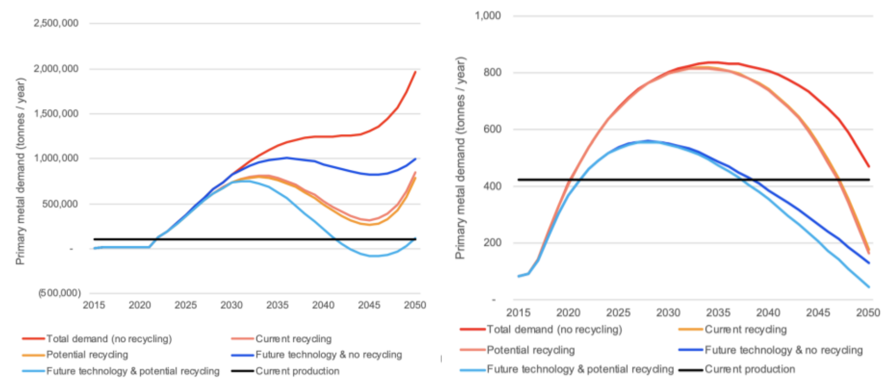
Country code: AU – Australia, AR – Argentina, BR – Brazil, CD – Democratic Republic of the Congo, CN – China, CL – Chile, ID – Indonesia, MX – Mexico, PE – Peru, RU – Russia, VN – Vietnam, ZA – South Africa

Source: based on Dominish, Teske & Florin (2019)

The results not only show the substantial increase in demand and production in the minerals sector, but they in particular highlight that demand for cobalt, lithium and nickel will substantially exceed current mining reserves in 2050. In the case of cobalt, demand is even expected to exceed known terrestrial resources. Similar results were found by various other studies (Månberger & Stenqvist, 2018; Olivetti *et al.*, 2017; World Bank, 2020), highlighting particularly the supply criticality of cobalt. For lithium, Olivetti *et al.* (2017) consider the supply bottleneck as being dependent not on the availability of resources but whether production can be ramped up quickly enough.

The demand for minerals is expected to grow particularly rapidly over the next two decades, correlating to the rapid expansion in the renewables and EV sectors. Figure 1 shows two examples of expected demand growth scenarios for cobalt and tellurium that exemplify the strong growth in demand until around 2035 and a levelling off towards the end of the first half of this century. In particular, demand for cobalt, lithium and nickel is most notably driven by the expected growth in the EV sector, since these three metals form the key elements of current EV battery chemistries. Since cobalt and nickel are also key minerals contained in ocean mineral deposits, these results highlight the importance of engaging car and battery manufacturers in the discussion around deep seabed mining.

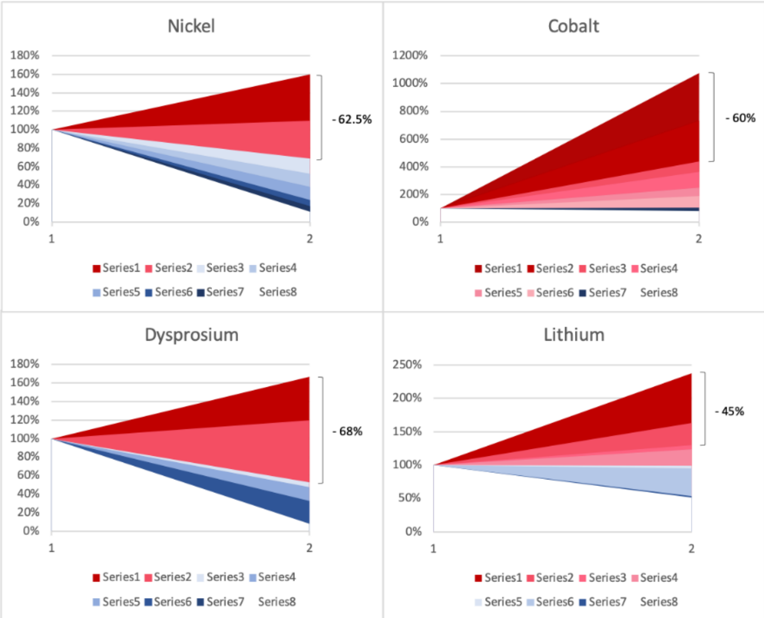
Figure 1 Annual primary demand from battery production for cobalt (left) and from solar PV for tellurium (right)



Source: Dominish, Teske & Florin (2019)

What also becomes clear from studied demand scenarios is the large extent of possible variation between scenarios. For instance, assumed recycling rates, assumptions on decreasing material intensity across technologies, the deployment of backstop technologies or the assumed average size of EV batteries had significant impact on a model's results. This points to high degrees of uncertainty in estimating future metals and mineral demand, but also points out potential avenues for significantly reducing material demand across almost all listed materials. Examples of the significant demand reduction potential for a selected set of materials is shown in Figure 2 below.

Figure 2 Demand scenario variations showing the potential for material demand reduction



Source: Månberger & Stenqvist (2018)

Månberger & Stenqvist (2018), for instance, argue that especially improvements in material intensity and the application of backstop technologies in the EV battery sector can yield significant demand reductions for materials like cobalt, nickel and lithium. The study further argues that the most effective measure to reduce material demand is to foster technological diversity, by supporting industries to move away from critical materials. For instance, in the battery industry a continued trend toward cobalt-free batteries is expected. Experts such as Ken Hoffman from McKinsey see the current concentration of cobalt production in the Democratic Republic of the Congo and the associated volatility in its price and supply as key drivers behind battery manufacturers' efforts to reduce cobalt content in batteries. However, it is also important to keep in mind that shifting demand away from one material may cause increasing demand for another (e.g. replacing cobalt with more lithium, nickel and manganese).

The expected potential for reducing demand through recycling is limited in the short to medium term. Various studies (Månberger & Stenqvist, 2018; Olivetti *et al.*, 2017; Dominish, Teske & Florin, 2019; World Bank, 2020) agree that recycling can limit primary material demand in the long term but cannot pick up fast enough to meet the rapid increase in demand that is expected over the next two decades.

In the EV battery sector, Månberger & Stenqvist (2018) see greater importance in reducing battery pack sizes and reducing the pressure on car manufacturers to produce high-range vehicles. Demand for higher driving ranges increases the size of batteries in EVs, critically influencing their material intensity. The introduction of shared-mobility services and establishing thorough charging networks can thus significantly reduce material demand from the transport sector.

Ultimately, it is important to consider the fast pace of change in technological developments, with new battery chemistries for instance capable of reshaping future demand completely. From this point of view, mining companies argue that deep seabed mining might be an enabler of technological change by providing scarce or inaccessible minerals that can be used in new technologies.

What is the state of global metal reserves and mining capacity on land and in the ocean?

Answer:
Mining on land is facing two major trends. On the one hand, technological efficiency and proficiency in exploring, extracting and producing minerals from ores are increasing, while on the other ore grades are decreasing as high-grade deposits become depleted. Deep seabed mining would be characterized by the opposite: high ore grades and mineral abundance, versus nascent and low-security exploration and extraction technologies. Nevertheless, oversupply of minerals through deep seabed mining and resulting price reductions may undermine the efficient exploitation of existing mining reserves on land.

Knowledge gaps:

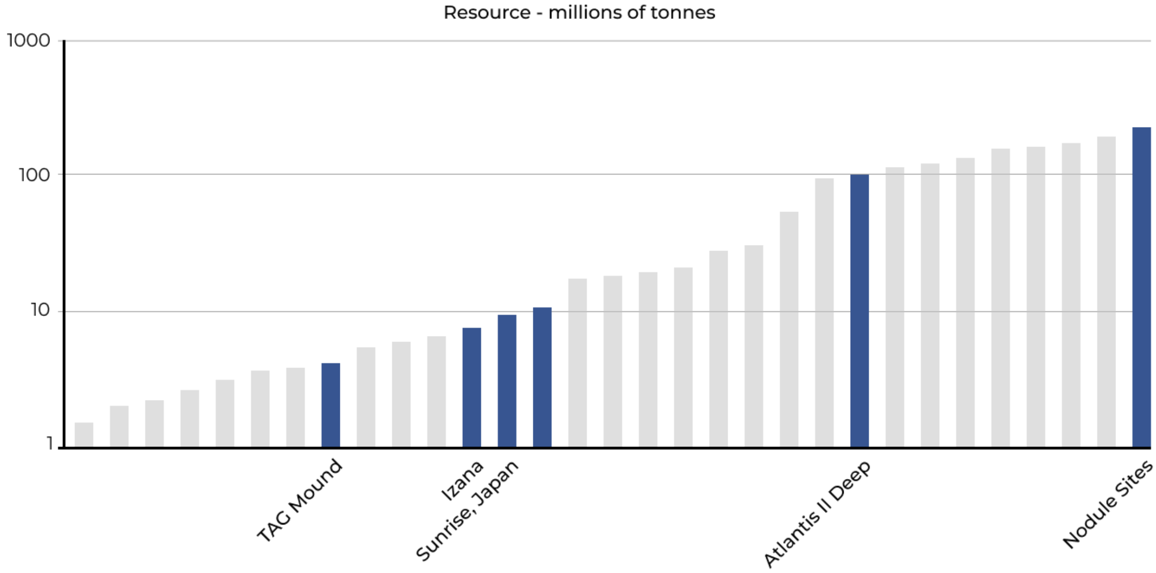
1. The impact of deep seabed mining on global metals and minerals prices is little understood and analysed. If oversupply through deep seabed mining outweighs mineral demand, price slumps may undermine the efficient exploitation of existing reserves on land.
2. Determining whether efficiency gains in mineral extraction will compensate for decreasing ore grades or vice versa is difficult, especially for a broader set of materials.
3. The potential mining capacity that can be added to current production levels is hard to estimate. Also, the amount that can be extracted from marine resources remains uncertain.
4. Resource estimates in the ocean but also on land remain highly uncertain, with large resources expected to be still discovered.
5. The definition of reserves and resources often leads to misunderstandings around the availability of critical minerals.

Background:
Manganese, nickel, copper, cobalt and molybdenum are found in great abundance in marine mineral deposits. Together with other rare earth elements, they present the economically most interesting minerals to be sourced from deep sea deposits.

On land, stark differences exist in the extraction and production processes for these minerals and technological improvements have significantly increased their efficiency. To date, most mineral exploration and discovery, and mining operations, have focused on the upper few hundred metres of the Earth's crust. However, a similar density of many deposit types is expected to be present in the upper few kilometres, becoming increasingly accessible through new technologies (Arndt *et al.*, 2017). Considering this reality, Arndt *et al.* (2017) argue that improved technologies and efficiency gains have kept the expected lifetime of existing mining reserves on land growing and well within the needs of industry and society. They not only expect this trend to continue for the foreseeable future, but also argue that under increasing prices even more, lower-grade deposits on land may be mined commercially. While it is true that this would lead to larger mining operations on land, an oversupply through deep seabed mining, on the other hand, would reduce mineral market prices and generally undermine the efficient exploitation of existing land mining reserves.

Marine mineral deposits are significantly more mineral-rich than terrestrial deposits (FFI, 2020). For instance, the discovery of a seamount in the Atlantic Ocean has revealed a crust of rock with concentrations of the scarce material tellurium 50,000 times higher than in deposits on land (Shukman, 2017). As shown in Figure 3 below, marine (sulphide) mineral deposits are among the largest known mineral resources in the world. In particular, polymetallic manganese nodule resources, of which the majority occur in the Clarion-Clipperton Zone (CCZ), are the largest known resource of minerals (Haeckel, 2019).

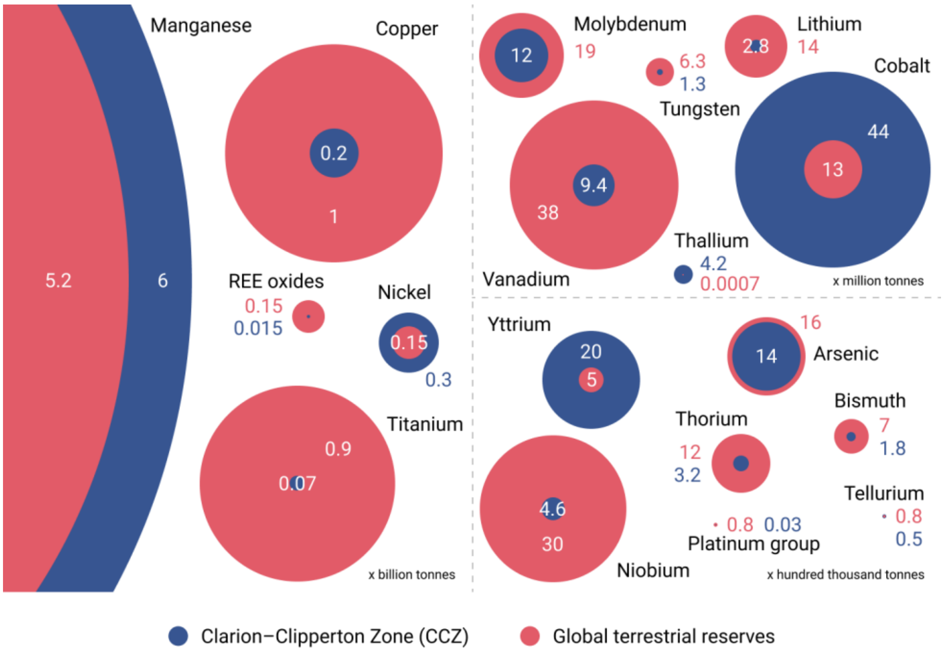
Figure 3 Size of seafloor (blue) and on-land (grey) mineral deposits



Source: based on Haeckel (2019)

The CCZ is a submarine fracture zone in the Pacific that stretches approximately 4.5 million km^2 and is characterized by the abundant occurrence of polymetallic nodules. The metal concentration in these nodules can vary significantly, but they are on average comprised of 27% manganese, 8% iron oxides, 1.4% nickel, 1.3% copper and 0.2% cobalt, alongside other elements. In comparison, typical land-based deposits contain concentrations of 1% copper, 1% nickel and less than 1% cobalt (Haeckel, 2019). In total, the available resource of minerals contained in polymetallic nodules in the CCZ surpasses land-based reserves, especially for cobalt, manganese, nickel, thallium and yttrium (Heffernan, 2019). The amount of the minerals that can be feasibly extracted from those resources, however, remains questionable, with estimates ranging around 20% (Haeckel, 2019). A comparison between the CCZ polymetallic nodule mineral resource and currently available terrestrial mining reserves is depicted in Figure 4 below.

Figure 4 Mineral reserves on land (red) compared to resources expected in polymetallic nodules in the CCZ



Source: adapted from Heffernan (2019)

In total, comprising all different kinds of marine mineral deposits, the projected possible value of seabed mining is estimated to be in the order of about US$2 billion a year (compared to US$100 billion for oil and gas) and may grow by an order of magnitude if exploitation ramps up (FFI, 2020).

What technology substitutes could make sea bed mining obsolete?

Answer:
Technological change, especially around new EV battery chemistries, evolves rapidly and erratically, with little certainty in predicting new developments and their commercialization. Nevertheless, promising developments in the solid-state battery space could drastically reduce mineral demand. Progress in the solar PV and wind sector has matured and developments are less rapid but are still leading to material intensity reductions of a few percent every year.

Knowledge gaps:

1. Shift in material demand through technological change is hard to anticipate. It may move one material out of the spotlight, while causing criticality for another (e.g. cobalt and nickel or manganese). The speed of technological change and its effect on the case for deep seabed mining is thus little understood.
2. The implications of technological change on global metal prices are difficult to anticipate, but crucial for determining the economic case for deep seabed mining.
3. Material costs are a major cost driver in EV and battery manufacturing. Producers therefore have an interest in cutting the material intensity of their products. This trend may be undermined if mineral prices drop due to a ramp up of deep seabed mining.
4. A hydrogen and fuel cell based economy is, in the long run, desired by many policy-makers and capable of reducing mineral demand significantly. The compatibility of deep seabed mining with this policy priority is little understood.

Background:
Solid-state battery technologies, which use solid electrodes and electrolytes instead of current liquid technologies, have the most immediate potential to drastically reduce and shift material demand in EV mobility. They are expected to not only increase battery safety, but also bring about significant increases in battery efficiency. This allows batteries to be cheaper and smaller, while providing larger driving ranges and faster charging cycles. It also simplifies battery construction and recycling.

In terms of materials, not only does the reduced size of solid-state batteries yields material reductions, but the material composition itself is less reliant on cobalt and graphite. On the other hand, evolving solid-state battery chemistries are even more reliant on lithium and manganese (Kurzweil & Garche, 2017; Chandler, 2020). Technological advances in this space are extremely fast. In March 2020, for instance, Samsung announced a new all solid-state battery using a silver-carbon anode instead of lithium (Samsung, 2020). The applied technology would reduce battery size by 50%, while allowing a vehicle to travel up to 800km. Solid-state battery technologies are further expected to cut battery prices by half, making EVs more affordable (Hoffman, 2018a).

In the longer term, the use of fuel cells to convert hydrogen into electricity to power EVs also presents a viable option. Using hydrogen as a source of energy would make batteries obsolete and thereby limit material demand to fuel cell (platinum) and engine (rare earth elements) components. Expected growth in the fuel cell electric vehicle sector, however, is far smaller than in the battery-EV market. The International Energy Agency (IEA) expects the current stock of fuel cell electric vehicles to increase from 11,200 to around 2.5 million in 2030, which is only a third of current battery-EV stocks (IEA, 2020, 2019a, 2019b). Nevertheless, targeted policy action such as the launch of the Clean Hydrogen Alliance by the European Commission is being put in place to include hydrogen and fuel cells in climate targets (European Commission, 2020a; FCH, 2020; di Paolo Emilio, 2020).

Other technological developments that can reduce material demand are advances in widespread charging infrastructure to increase the range of small-sized battery EVs as well as improved battery management systems and software to increase battery efficiency (Hoffman, 2019; Bland *et al.*, 2020).

In the renewables sector, thin film solar cells are an emerging technology that is significantly less materials intensive, but the materials required are rarer and found in lower concentrations. At current material intensities, a ramp up of thin film solar could lead to the rapid depletion of tellurium, gallium, selenium and indium reserves and increase demand for copper and cadmium. Nevertheless, the potential for reducing their metal intensity is significant (Månberger & Stenqvist, 2018).

With any of these technological developments, however, the timing will be critical. Given the rapid ramp up in material demand, new technologies need to be commercialized and deployed rapidly – limiting the potential contribution of deep seabed mining.

What business model innovations could reduce the need for minerals?

Answer:
Shared and micro mobility as well as vehicle and battery rental and modularization schemes are fast-evolving business areas with significant yet unquantified potential to reduce mineral demand in the transport sector. In the renewables sector, community and solar home schemes may increase mineral demand.

Knowledge gaps:

1. The adoption rate of new business models in the transport sector is difficult to anticipate and highly dependent on satisfying consumer demand for convenience.
2. The actual potential for mineral demand reduction from different business models has not yet been quantified.
3. Different business models may emerge and succeed in different countries and cultures. Assuming success on a global level is difficult.
4. The compatibility of deep seabed mining with many new business models has not yet been explored, but seems counterintuitive.

Background:
A great variety of emerging business models, especially in the transport sector, is affecting mineral demand. Some of the most promising and currently most rapidly evolving business sectors are listed below.

Car sharing – Services like ShareNow, a joint venture by Daimler AG and BMW, offer short-term car rentals via a membership card. They are currently being rolled out predominantly in urban and metropolitan areas. Ride hailing services like Uber, Lyft or Gojek also reduce demand for individual car ownership and therefore mineral demand.

Micro mobility – Services like (e-)scooter and bike rentals can be used for short distances that are otherwise often travelled in (electric) cars. In fact, around 60% of car trips are shorter than 8km and could be substituted by micro mobility services, thereby reducing the need for individual car ownership, especially in urban areas (Heineke *et al.*, 2019).

Vehicle subscriptions – Schemes like Access by BMW, cluno in Germany, evezy and elmo in the UK or Canoo in the US present new models of partial ownership of a vehicle. The aim is to allow users to subscribe to vehicle services on a monthly basis. The schemes are expected to decrease individual long-term car ownership and improve the efficiency of vehicle usage. Schemes may include not only the rental of the vehicle but also vehicle maintenance, home-charging stations and electricity packages. While it is true that customers of such schemes can request a new or different vehicle at any time, the schemes may still provide advantages in dispersing new technologies faster and improve material recyclability.

Modular batteries – Various car companies, such as Volkswagen, GM and FIAT, are actively working on the increased modularization of battery systems, allowing for more flexibility in car design as well as in meeting customer needs. For instance, if higher driving ranges are desired, for instance for a holiday trip, additional batteries can be built in or even rented. FIAT recently introduced the FIAT Centoventi with interchangeable battery packs for different situations. Car manufacturers may also look at using a wider spectrum of battery chemistries in their cars, providing for instance high-range/high-capacity batteries to customers in rural environments, and smaller ones to urban users. Overall, these concepts can optimize material use in vehicles by reducing standard battery size in the majority of vehicles.

Public transport – While public transport is not a new concept, offerings that increase people's flexibility not only in urban but also rural and interregional environments are heavily supported by local governments and public transport providers seeking new customer segments. For instance, Austrian Railways (ÖBB), like the Caledonian Sleeper in the UK, have increased their night train offerings due to increasing demand. Additional services that reduce the demand for cars have been introduced by Swiss Railways (SBB) and others, offering passengers for instance baggage delivery to and from their destination or rental car options after reaching a station by train. Also, new bus route offerings such as those by Flixbus in Europe are increasingly competing with individual, car-based mobility, especially among younger generations.

Autonomous vehicles – Reducing human interference in traffic can increase the efficiency of road networks. This can have beneficial effects on battery utilization and lead to an optimization of material intensity per distance travelled. Paired with shared mobility services it can further lower individual car ownership.

In the renewables sector, business models that may increase material demand are off-grid and community energy products and services. Those schemes incentivize the installation of solar home systems that may include home battery-based energy storage systems. While characterized by a higher degree of flexibility, they are also less material efficient than industrial-scale applications. Current examples of companies providing such products are the Tesla Roof and Powerwall and the sonnenBatterie and sonnenCommunity by Sonnen.

Other business models that reduce energy demand more generally and thus the amount of material used in its generation should also be considered, but a closer analysis exceeds the scope of this study.

How do potential material substitutes affect the business case for deep seabed mining?

Answer:
Ample options exist for most applications to shift demand for specific minerals to other minerals or materials. However, security, performance and cost aspects often prohibit the use of less critical materials in battery and renewable energy applications. Bringing innovations from the lab scale to a commercial scale, however, may take years to decades.

Knowledge gaps:

1. Knock-on effects from shifts in material demand are difficult to estimate.
2. Innovations in material science are hard to anticipate and the time it takes for those innovations to grow to commercial applications is even more uncertain for most presented solutions.
3. The supply and demand structure for minerals at different purities is little understood in the context of deep seabed mining. Given the demand for high-grade materials for EV manufacturing, this field is of growing importance.
4. The availability and abundance of materials has a strong influence on material science and research. The effect deep seabed mining may have on shifting research interests is little understood.

Background:
Shifting material demand is often closely linked to shifting to different sub-technologies. For instance, direct drive motors use rare earth elements (REEs) but are widely used in offshore wind turbines due to their reduced weight and lower maintenance intensity. Gear-drive motors, on the other hand, do not contain REEs but are also heavier and better suited for the varying wind speeds on land (Månberger & Stenqvist, 2018). A collection of possible solutions to use different materials instead of critical minerals in low-carbon energy technologies is presented in Table 3. These solutions include both direct material substitution and the application of different sub-technologies. Table 3 further includes potential knock-on demand for other materials from these shifts.

Table 3 Possibilities for material substitution in low-carbon energy technologies

Technology	Critical elements	Possible substitution	Knock-on demand
EV electric drive motors	REEs: Neodymium, praseodymium, dysprosium	REE-reduced/free motors – Induction motors – Transverse flux motors – Reluctance motors	Copper, ferrite (iron, nickel) and aluminium
Lithium-ion batteries	Cobalt	Cobalt-reduced/free chemistries: – Lithium-iron phosphate – Lithium-oxygen – Cobalt-manganese-nickel compounds	Aluminium, carbon, lithium, manganese, nickel, silver and sodium
	Lithium	Sodium, sulphur or magnesium-based batteries	Sodium, sulphur and magnesium
		Organic electroactive electrode materials	Carbon, hydrogen, oxygen, nitrogen and sulphur
Direct-drive offshore wind turbines	REEs: Neodymium, praseodymium, dysprosium	REE-reduced/free motors – Gear turbines – Improved cooling systems to avoid dysprosium sintering	Copper and ferrite (iron, nickel)
Crystalline solar cells	Silver	Nickel-copper platings	Arsenide, silicon, silver, cadmium, copper, nickel, tellurium and tin
Thin-film solar cells	Indium, gallium	Silicon-based cells, cadmium-tellurium-cells Carbon nanomaterials	

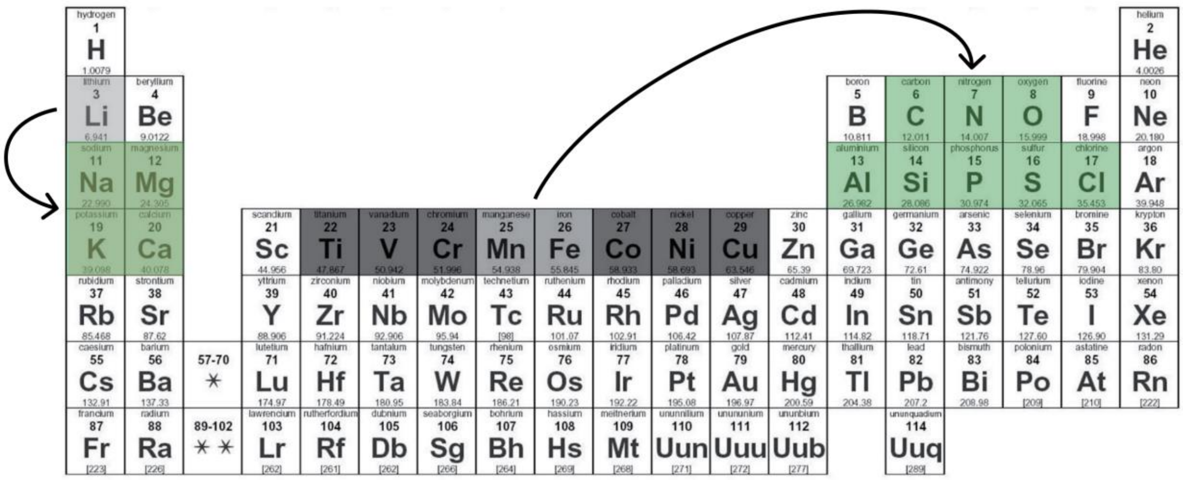
Source: based on Schüler (2015); European Commission (2017) and Månberger & Stenqvist (2018)

In the EV battery sector, the shift towards solid-state batteries has already been discussed as the most prominent trend that can currently be observed at a scientific scale. Replacing lithium with the widely available element sodium is seeing especially promising developments. Nevertheless, shifting away from critical minerals is also possible in already commercialized battery chemistries. In fact, experts (Hoffman, 2019) expect the current trend to shift away from cobalt to continue (Reuters, 2020). Developments are primarily looking at replacing cobalt with nickel and lithium, such as in chemistries where cobalt makes up only 10% of the used battery materials (8-1-1 chemistries).

Reaching commercialization for any kind of new material mix or new technology is a big hurdle, and must not be underestimated when assessing potential effects on material demand. For instance, bringing a new battery technology from the lab to the road will be determined by i) how many charging cycles a battery can deliver, ii) if it can be manufactured commercially, iii) if it works under real world weather, humidity and accident conditions, and iv) if the necessary materials can be provided in the long term, at scale and in the right purities. In the battery sector, in particular, high-grade/high-purity materials are needed, which might cause demand shortages even within a material class (Hoffman, 2020, 2018b).

Further down the horizon, a shift towards lithium-air, synthetic graphite and organic-based electroactive materials is possible. The latter shift towards organic materials is illustrated in Figure 5 below.

Figure 5 Shifting towards organic-based electroactive materials in battery chemistries



Source: based on Larcher & Tarascon (2015) and Lakraychi & Vlad (2018)

Last but not least, it is important to consider the interconnections between material research and the mining industry and materials supply. For instance, significant recent ramp-ups in lithium production signalled to car manufacturers to use as much lithium as possible in their chemistries. With such strategies, mineral producers take a so-called “long-term greedy” position, attracting long-term demand from battery and car manufacturers. On the other hand, mining projects are capital intensive and mining companies needs sufficient assurance from the market that it is worth ramping up production and investing in new reserves (Hoffman, 2018b).

2. Why can't we just recycle?

How much of expected mineral demand can be satisfied through recycling?

Answer:
Metals have the theoretical potential for almost infinite recovery and reuse through recycling. However, in light of the pace and scale of current and expected demand growth, recycling does not provide substantial potential to limit immediate primary mineral demand.

Knowledge gaps:

1. Metals and mineral prices are dictating the economic feasibility of recycling processes. Commodity price developments under deep seabed mining scenarios have not yet been modelled and the impact of deep seabed mining on the economics of recycling has not been estimated in the studies we analysed.
2. Cascaded product life-cycles of EV batteries and their influence on the economics of recycling and broader material demand are difficult to estimate.
3. The demand reduction potential of avoidance of material use in product design and production steps are hard to estimate and uncertain.

Background:
Recycling is not a viable option for reducing virgin metals demand in the short to medium term until 2040. Even in the longer term until 2060, recycling may only play a limited role in meeting mineral demand (Månberger & Stenqvist, 2018). Looking at the averages across different mineral demand scenarios modelled by Månberger & Stenqvist (2018) indicates that recycling may yield a reduction in primary demand of between 5% and 35% for most relevant elements by the year 2060. These findings are summarized in Table 4.

Table 4 Primary demand reduction potential through recycling by mineral (% of total demand until 2060)

Material	Demand reduction potential
Cobalt	20-25%
Copper	25-30%
Dysprosium	0-10%
Gallium	0-2%
Indium	0-3%
Lithium	5-35%
Neodymium	10-30%
Nickel	25%-37%
Platinum	30-50%
Selenium	0-5%
Tellurium	0-5%

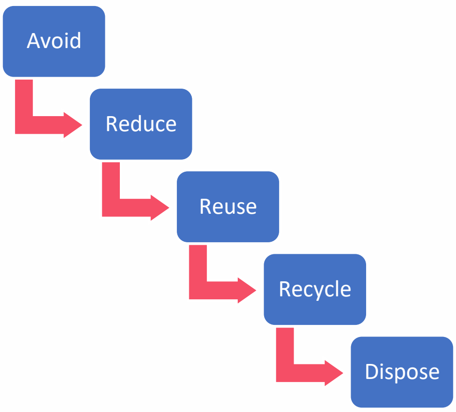
Source: calculated from Månberger & Stenqvist, 2018

A study conducted by Dominish, Teske & Florin (2019) presents more optimistic results in its scenario analyses, estimating the demand reduction potential of recycling to be as high as 50% for cobalt and nickel and even 75% for lithium by 2050. For other metals, such as indium and tellurium, however, their results match those of Månberger & Stenqvist (2018).

While different scenarios yield different long-term estimates, most reviewed studies (Olivetti *et al.*, 2017; Månberger & Stenqvist, 2018; Dominish, Teske & Florin, 2019; World Bank, 2020) agree that recycling will be insufficient to meet immediate metal demand growth. In particular long lifetimes for solar cells (30 years) and EV batteries keep metals in circulation for many years before they are freed up for recycling purposes (Olivetti *et al.*, 2017; Månberger & Stenqvist, 2018). Especially in the batteries sector, the cascaded use of batteries first in EVs and then in electricity storage prolongs battery material lifetime. For instance, EV batteries reach their end of life when their capacity has dropped to 80%, but they might still be used for grid or domestic electricity storage applications (Olivetti *et al.*, 2017). Nevertheless, rapid technological change could lead to faster growth in recycling, especially if the gap to old recycling technologies becomes too large or if recycling becomes economically more viable from a material price or cost point of view (Månberger & Stenqvist, 2018). Equally, the emergence of new mining capacity, whether on land or in the ocean, can have profound impacts on the economic feasibility of recycling.

Lastly, putting the focus on recycling obscures the potential of previous life-cycle steps to reduce primary mineral demand. Much potential to reduce material demand may lie already in the design and production phase of a product, where material use can be avoided or reduced. The typical life-cycle of a product in a non-circular economy is depicted in Figure 6, highlighting the fact that recycling should only the second-last resort for reducing material demand.

Figure 6 Non-circular hierarchy of material handling options



Source: own creation

Are current and emerging recycling technologies cost-competitive to deep seabed mining?

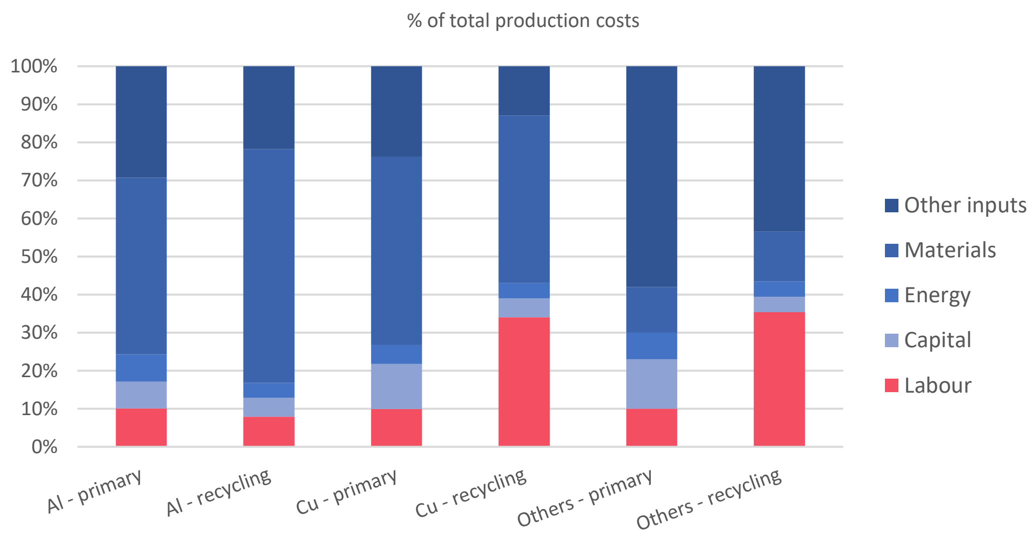
Answer:
Recycling currently cannot compete with mining on a cost-competitive basis. It is also not expected to do so by the year 2050, even considering reasonable advancements in recycling technologies and material availability.

Knowledge gaps:

1. With little understanding of the economics of deep seabed mining and the timing of its potential commercialization, it is unclear when and at what price deep sea minerals may compete with recycling.
2. With a high degree of automation and benefiting from low capital costs, deep seabed mining has the potential to present a low-cost solution to metals production. However, it may also undermine efforts to increase recycling and the development of new recycling technologies. These impacts are widely unexplored.
3. More granular data on current recycling rates for different materials in different regions is difficult to access.

Background:
The profitability of recycling is highly dependent on metal market prices, the amount of recyclable material available (economies of scale), labour and energy costs as well as on achieving sufficient material purities. There are a wide variety of recycling techniques available for solar cells, wind turbines and EV batteries, but most processes are labour intensive and require high energy input to separate materials. Solar cells, electric engines and battery packs are designed for longevity and performance under harsh conditions. This complicates the separation of materials and adds cost to recycling processes (OECD, 2019; Månberger & Stenqvist, 2018). The costs involved in producing primary metals through mining compared to secondary metals production through recycling are shown in Figure 7 below, highlighting in particular the high labour intensity of recycling.

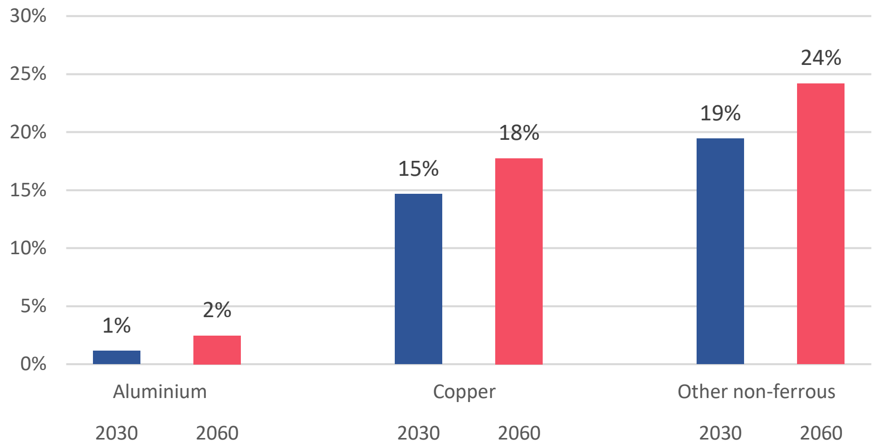
Figure 7 The cost structures of primary and secondary metals production (aluminum, copper and other metals)



Source: based on OECD (2019)

Over the next 40 years, the cost of recycling compared to mining is expected to fall. Nevertheless, an increase in global wages will prevent recycling from reaching a cost advantage over mining. The fact that recycling is labour intensive while mining is capital intensive decreases its competitiveness – now and in the long term. As further depicted in Figure 8 below, the production of recycled copper, for instance, is currently 15% more expensive than producing copper from virgin ore and is expected to become even less competitive until 2060. The same holds for the production of other non-ferrous metals, which are currently almost 20% more expensive to recycle than to mine. This gap is expected to increase to almost 25% in 2060 (OECD, 2019). Considering that deep seabed mining would be highly automated, it may profit from low capital costs even more, resulting in an even greater competitive advantage over recycling.

Figure 8 Comparison of relative prices of primary vs. secondary metals



Source: based on OECD (2019)

Considering the high labour costs, low material stocks compared to growing demand and the low cost for primary mineral production in mining, it becomes evident why recycling rates for many minerals are low. As shown in Table 5 below, across almost all metals and minerals, end-of-life recycling rates are far from their theoretical potentials of 90-95%. The share of recycled content compared to total material stock in circulation is even lower and in most cases below 35%. Table 5 presents global aggregated numbers; stark differences in these rates have to be expected across geographic regions.

Table 5 Recycling rates for selected materials, with those important for low-carbon technologies marked in red

Material	End-of-life recycling	Recycled content
Chromium	90	19
Cadmium*	80	n.a.
Tellurium*	77	n.a.
Tin	75	22
Platinum	70	20
Silver	65	30
Palladium	65	21
Nickel	60	35
Aluminium	55	35
Rhodium	55	40
Manganese	53	37
Niobium	53	22
Copper	50	30
Gold	50	30
Tungsten	46	40
Zinc	40	23
Magnesium	39	33
Cobalt	32	68
Molybdenum	30	33
Iridium	25	17
Antimony	20	5
Rhenium	17	60
Ruthenium	10	55
Tantalum	5	20
Lithium*	0	0
Gallium	0	n.a.
Indium	0	38
Dysprosium*	0	n.a.
Neodymium*	0	n.a.
Selenium*	0	n.a.

Source: OECD (2019); *Dominish, Teske & Florin (2019)

From a technological point of view, pyro-metallurgical and hydro-metallurgical processing dominate the recycling of lithium-ion batteries. Each of these processes has several different process routes and current research focuses on adaptations of these routes as well as on novel processes. Pyro-metallurgical processes make up most of currently installed capacity. This type of process prioritizes the recovery of the valuable cobalt and nickel while the less valuable metals such as lithium and manganese are usually not recovered. Lithium and manganese, however, may be recovered through hydro-metallurgical processes, where their separation requires the application of expensive organic reagents as solvents. Alternatively, the two materials can also be down-cycled for lower value applications. Copper and aluminium, on the other hand, can be recovered already during mechanical pre-processing at rates of approximately 70% or even higher. Neodymium and dysprosium are currently not recycled, although up to 95% is assumed to be technologically possible (Månberger & Stenqvist, 2018).

EV battery manufacturing requires high material purities, which might not always be achieved through recycling at a competitive price. In particular, recovering battery-grade manganese and lithium through recycling is more expensive than producing them in required purities from mined ores (Olivetti *et al.*, 2017; Dominish, Teske & Florin, 2019; Bernhart, 2019). In fact, the EV battery recycling market is expected to reach a value of only US$2 billion in the coming years. By contrast, the value of non-recycling market opportunities, such as second-life applications for EV batteries, may be ten times bigger; this is discussed further below (Engel, Hertzke & Siccardo, 2019; Olivetti *et al.*, 2017).

The recycling of solar panels is not a mature industry either. Owing to the typical long lifetime of most modules (30 years +), the volume of end-of-life panels is currently too low for recycling to be economically viable. At the moment, most solar panel recycling is happening in existing recycling plants using mechanical and manual processes. These processes focus on recycling the glass, aluminium and copper, while the small amounts of other metals are not recovered. Even silver is mostly not recovered, although it represents nearly 50% of the material value of a solar panel. The main challenge in recycling solar panels is the removal of the encapsulant layer that contains most metals, and which is designed to last for decades in harsh environments without losing its functional properties. Expensive thermal processes and organic solvents are needed for their removal (Dominish, Teske & Florin, 2019).

For wind turbines, recycling of the bulk materials, such as steel, aluminium and copper, which make up about 80-95% of the weight, is well established. However, similar to EV engines, there is currently no recycling of dysprosium or neodymium from permanent magnets in wind turbine generators, despite its technological feasibility (Dominish, Teske & Florin, 2019).

What recycling policy initiatives and regulations are being put in place in the metals sector?

Answer:
Recycling targets set by policy-makers are limitedly successful but prove effective especially in more advanced and institutionalized economies. There are positive examples from the EU with clear targets and from China with increasing scrutiny on battery manufacturers to assure adequate recycling of battery materials.

Knowledge gaps:

1. Recycling has largely been a policy-driven industry, but the material intensity of especially EV battery production is also increasing corporate-driven action to improve recycling rates. The scalability of such company-owned schemes is yet to be assessed and their influence on future mineral demand scenarios may be underestimated.
2. Policy responses to cascaded product life-cycles are yet to be refined and their effectiveness can only be assessed once sufficient data from large-scale implementation becomes available.

Background:
Lithium ion batteries have been found to be less toxic compared to lead acid and nickel cadmium batteries. Nevertheless, landfill prohibitions and strict recycling targets have been imposed by some jurisdictions, such as California, New York and the EU (Olivetti *et al.*, 2017). As part of the Strategic Energy Technology Plan, the European Commission has set out the goal for EV battery recycling to become economically viable by 2030, with a collection target of 85% and recycling efficiency rates reaching 50%. At the same time, the targets foresee an increase in domestic EV battery production to around 50GWh per year in 2030 (European Commission, 2016; Drabik & Rizos, 2018).

In China, the government is holding battery manufacturers responsible for setting up a collection network for lithium ion batteries. As a result, by 2025, China is expected to account for more than 35% of global lithium ion battery recycling, followed by the US at 29% and the EU at 24% (Anzai, 2019; Reuters, 2018a).

The recycling of solar panels and wind turbine engines in the EU is governed by the Waste Electrical & Electronic Equipment (WEEE) Directive, but no clear targets have been found by this study (European Commission, 2020b).

From an industry point of view, with more and more manufacturers being either held accountable for the collection and recycling of their EV batteries or seeing it as an attractive business and re-supply model, batteries are increasingly designed with disassembly in mind. This is expected to facilitate future recycling and material recovery processes. In fact, since materials are a large part of the cost of an EV, manufacturers have a self-interest in reducing material intensity (Olivetti *et al.*, 2017). Battery and vehicle manufacturers such as Northvolt, LG Chem, Tesla, Volkswagen and BYD have announced ambitious recycling and battery take-back schemes. Almost all of these companies are building or planning to build proprietary recycling facilities with process efficiencies at around 80-90% material recovery (Manthey, 2019; Reuters, 2018b; Umicore, 2019). Other car makers, like Renault, are experimenting with battery rental and leasing schemes not only to reduce vehicle prices but also to increase customer loyalty and assure the return of batteries to their supply chain at the end of a vehicle's lifetime (Renault, 2020).

Ultimately, while being unfit for use in EVs soon as their capacity drops below 80%, EV batteries are expected to find use in second-life applications such as grid and home electricity storage. According to Engel, Hertzke & Siccardo (2019), the potential market for second-life batteries will amount to US$30 billion globally by 2030. While such business models prolong battery lifetimes and keep material out of recycling streams, they also significantly reduce primary material demand from other storage applications.

3. Why shouldn't we keep mining the land?

How could the emergence of deep seabed mining affect the geopolitics around critical minerals?

Answer:
The potential emergence of deep seabed mining may shift worldwide minerals production away from low- and middle-income countries to developed economies. It may thereby increase global dependence on China and Russia as suppliers of almost all critical minerals, while bringing the opportunity for the EU to also adopt a major role in their global production.

Knowledge gaps:
1. Shifting mineral production through deep seabed mining to industrialized nations and away from developing countries may reduce income for vulnerable communities and exacerbate geopolitical tensions.
2. Industrialized nations have the technological, financial and institutional capacities to engage in deep seabed mining ventures. A lack of competencies may prohibit weaker economies from participating.
3. Geopolitical shifts primarily depend on the scalability of deep seabed mining, but also need to be discussed on a more granular level, considering for instance aspects around mineral purities and battery manufacturing.
4. The role of mining companies in geopolitical developments is often obscure. Depending on the actors gaining access to deep seabed mining licences, different effects may evolve.

Background:
Until now, 30 contractors have been granted 15-year contracts for deep sea mineral exploration outside national jurisdictions. These contracts are granted and governed by the International Seabed Authority (ISA), a dedicated and specialized UN body. Companies have to apply for a licence through a sponsoring state that is signatory to United Nations Convention on the Law of the Sea (UNCLOS). The countries that have sponsored most concessions are China (5), Russia (4), South Korea (3), UK, Germany, France and Japan (2 each). A full list of concession holders is available here.

When considering deep seabed mining and its impact on global geopolitics, it is important to again summarize the minerals that are of interest in this context. Polymetallic nodules, found on the abyssal plains and particularly in CCZ, yield manganese, nickel, copper, cobalt, REEs and traces of platinum as the commercially most relevant minerals. The exploitation of polymetallic sulphides, which are found around active and inactive hydrothermal vents, yields mainly copper, zinc, lead, silver and gold. Lastly, cobalt-rich crusts found on the flanks of seamounts mainly contain cobalt, platinum, REEs, nickel and manganese (Miller *et al.*, 2018; ISA, n.d.).

Given the current centralization of production of most of these minerals to a few geographical areas and countries, securing access to mineral deposits is an important political driver for other countries to support deep seabed mining and apply for concessions. Actors such as Germany, Belgium, the UK and South Korea seek to be self-sufficient in sourcing strategic minerals and to decouple from countries that may hold monopolies on certain minerals, such as China on REEs or the DRC on cobalt (FFI, 2020). Small island states, on the other hand, may promote deep seabed mining in the search for new opportunities for economic diversification and new revenue streams in the face of declining fish stocks (World Bank, 2016). Nevertheless, China and Russia emergence as the dominant driving forces behind deep seabed mining considering the number of licences held. As summarized in Table 6, this may lead to a major shift of production of many minerals to China, Russia and the EU. This also highlights a shift from mineral production in developing economies towards industrialized economies. In the right-hand column, Table 6 presents potential geopolitical developments that may occur in relation to shifting production of a specific mineral.

Table 6 Shifting mineral production through deep seabed mining and potential geopolitical consequences

Mineral	Land mining: production today	Deep seabed mining: exploration contracts	Potential powershifts
Cobalt	DRC (58%) Russia (5%) Australia (5%) China is global leader in processed cobalt (sourcing 90% in DRC)	China (4) Russia (3) EU (3) UK, South Korea, Japan (2 each)	China and Russia may strengthen their role as global leaders in cobalt production. DRC may lose importance as source country. Opportunity for market participation for the EU.
Copper	Chile (27%) Peru (12%) China (9%)	EU (6) China (4) Russia (3) South Korea, UK, India (2 each)	China and Russia may gain market share, diminishing importance of Chile and Peru as supplier countries. EU has the potential to become a core supplier.
Gold*	China (12%) Australia (10%) Russia (9%) Argentina (6%)	EU (3) China, Russia, South Korea, India (1 each)	Currently largely non-existent in gold production, the EU could establish itself as a gold supplier.
Manganese	South Africa (33%) China (16%) Australia (14%)	China (4) Russia (3) EU (3) UK, South Korea, Japan (2 each)	No concessions given to South Africa or Australia yet, reducing their chance of future market participation.
Nickel	Indonesia (19%) Philippines (11%) New Caledonia (10%)	China (4) Russia (3) EU (3) UK, South Korea, Japan (2 each)	Possible substantial shift away from current production leaders (low- and middle-income countries) to the advantage of developed economies like China, Russia and the EU.
Platinum*	South Africa (72%) Russia (12%) Zimbabwe (8%) Canada (4%)	China (4) Russia (3) EU (3)	China has no significant platinum production and may establish a major stake though

	USA (2%)	UK, South Korea, Japan (2 each)	deep seabed mining. This is equally true for the EU.
REEs	China (81%) Australia (15%) Russia (2%) Brazil (2%)	China (4) Russia (3) EU (3) UK, South Korea, Japan (2 each)	Australia's market share may diminish. However, the granted concessions may bring more equally distributed supply, reducing China's 81% share and increasing the shares of Russia, EU, UK.
Silver	Mexico (22%) Peru (18%) China (10%)	EU (3) China, Russia, South Korea, India (1 each).	No concessions held by Mexico or Peru, reducing their chance of future market participation. Production shift may advantage developed economies.
Zinc*	China (33%) Peru (11%) Australia (10%) USA (6%)	EU (3) China, Russia, South Korea, India (1 each)	The EU has no significant zinc production and may establish a major stake though deep seabed mining and shift its dependence away from China.
Sources	Dominish, Teske & Florin (2019); *USGS (2020)	ISA (2020a), EU countries summarized	Own argumentations

Given the fact that deep sea mineral deposits are polymetallic, i.e. they contain a variety of minerals in high concentrations in a concentrated location, access to those deposits means access to a range of minerals. Dominating the number of deep seabed mining concessions can therefore also shift production for a broad range of minerals. While a low number of concessions might be enough to satisfy domestic demand for markets such as the EU, countries not owning deep sea exploitation contracts may grow increasingly dependent on dominant players like China and Russia.

Mining is an important source of income for many developing countries like Indonesia, Zimbabwe or Peru and supports large parts of the population either through employment or tax revenue. Shifting mineral production to industrialized nations with the technological, financial and institutional capabilities to engage in deep seabed mining could lead to significant income reductions for communities in developing countries, exacerbating geopolitical tensions (see below).

Does deep seabed mining undermine opportunities for socioeconomic development on land?

Answer:
While this is a heavily unexplored area in terms of economic modelling, deep seabed mining may lead to development issues in economies with a particularly high dependence on mineral production, which will likely be exacerbated by weak national institutions.

Knowledge gaps:

1. Income shifts resulting from deep seabed mining are little understood, as is the shift in negotiation power away from developing countries. The extent to which deep seabed mining may replace land-based mining is highly uncertain.
2. The performance of redistribution mechanisms under the ISA is yet to be elaborated in detail and operationalized. At their current stage, they hold much potential for disputes and inequalities.
3. The potential devastating impact of deep seabed mining on global fisheries may yield new socioeconomic development threats that have not yet been studied.

Background:

The commercialization of deep seabed mining and the resulting increase in minerals supply is likely to have effects on market prices as well as on the demand for land-mined minerals. In fact, while deep sea minerals are not expected to fully substitute land-mined minerals right away, they represent additional supply, pressuring mineral prices and altering the negotiation power of current producing countries. In many cases, current producers are low-income countries which heavily depend on the mining sector (ICMM, 2016). For instance, 23% of the DRC's GDP is generated by the mining sector (ICMM, 2018).

Divesting from land mining is likely to thwart economic and social development in already struggling countries. In particular, deep seabed mining tends to advantage the technologically advanced while excluding the poor from participating in technological advancement. Nevertheless, increased pressure on price and negotiation power triggered by deep seabed mining can also represent an opportunity for economic diversification. Whether a country will suffer further impoverishment or diversify its revenue landscape will largely depend on the quality of local institutions (Acemoglu & Robinson, 2012). In any case, investors and stakeholders should acknowledge the strategic value and consequences of shifts in the mining industry (ICMM, 2016).

Under UNCLOS Article 140, it is stipulated that any activities, including resource extraction, in the deep sea "*shall (...) be carried out for the benefit of mankind as a whole, irrespective of the geographical location of States, whether coastal or land-locked, and taking into particular consideration the interests and needs of developing States and of peoples who have not attained full independence or other self-governing status recognized by the United Nations (...)*" (UNCLOS, 1982). Further, the responsible authority (the ISA) shall "*provide for the equitable sharing of financial and other economic benefits derived from activities in the Area through any appropriate mechanism, on a non-discriminatory basis (...)*" (UNCLOS, 1982). While these provisions point towards an equitable handling and sharing of mining proceeds, their practical implementation and detailed elaboration is highly controversial and difficult (German Environment Agency, 2019). Issues pertain not only to the percentage of net proceeds that are to be contributed to the benefit of humankind via the ISA, but also to accounting standards, tax regulations, auditing as well as the subsequent use of collected funds for income redistribution. All of these aspects are much disputed and susceptible to be influenced by the dominant player(s), threatening weaker economies to accept suboptimal results.

Ultimately, with deep sea organisms building the bottom of the food chain for many marine species and being responsible for essential biological and chemical cycles in the global oceans, deep seabed mining may have a detrimental impact on global fish stocks and ocean health (Miller *et al.*, 2018; FFI, 2020). Scientists have limited understanding of these processes, but the connectedness of deep and shallow ocean organisms is certain. There are numerous examples of fish species depending on nutrient cycles passing through the deep sea or even migrating through the deep sea themselves (Evans, 2020). The intended scale of deep seabed mining operations may lead to a collapse of ocean cycles and fish stocks (FFI, 2020). This would not only be an ecological disaster, but also threatens the main protein source of around 1 billion people and the livelihoods of around 200 million people (FAO, 2018), largely in developing countries.

Does the avoidance of environmental impacts on land justify the impacts of deep seabed mining?

Answer:
It is uncertain to what extent deep seabed mining could substitute for or replace land-based mining, so estimating its potential to avoid environmental impacts on land is highly speculative. A lack of research or benchmarks to properly understand the impacts of deep seabed mining makes it easier for its advocates to argue that impacts will be less significant than those caused by mining on land. But not being able to measure an impact does not mean that there is none: deep seabed mining is highly likely to cause profound negative impacts on marine ecosystems.

Knowledge gaps:

1. Direct and holistic comparisons and scenario analyses of the costs and benefits of deep seabed mining vs. those of land-mining are difficult to elaborate and are yet to be compiled.
2. The amount of land-based mining that may be avoided through deep seabed mining is difficult to estimate, considering the lack of adequate economic models. Estimating avoided environmental impacts is therefore equally difficult. Current analyses do not support this argument with a sufficient degree of certainty and scientific backing.

Background:
Land-related environmental impacts have been researched significantly more than those related to mining in deep sea environments. The global community lacks clear understanding of the habitats and interdependencies of deep sea ecosystems as well as their relation to life on land. This limits our ability to develop adequate benchmarks for measuring the impact of deep seabed mining and comparing it to land mining (Miller *et al.*, 2018).

In addition to global disagreements on how to quantify ecosystem services in general, the imbalance of knowledge on land versus sea mining further sows confusion. Advocates of deep seabed mining can present clear figures on the negative impacts of mining on land, such as areas of deforestation, and use this to build a seemingly coherent case for the environmental benefits of deep seabed mining. Meanwhile, those who fear vast but unknown environmental impacts from deep seabed mining struggle to back their arguments with scientific research, let alone numbers. However, the inability to quantify the impacts and consequences from deep seabed mining will not stop them coming into effect.

Last but not least, with rapidly rising mineral demand, deep seabed mining may not replace or avoid impacts from land-based mining but may simply come in addition.

What benchmarks can be applied to compare land and deep seabed mining?

Answer:
Objective comparison of land and sea mining requires benchmarks which can be equally applied to both types. Benchmarks that by nature are not based on the same underlying units

for comparison may easily benefit one extraction technology over the other and should be avoided.

Knowledge gaps:

1. Socioeconomic impact benchmarks are hard to define and apply to deep seabed mining projects, especially since benefit-sharing mechanisms are not yet sufficiently elaborated.
2. Even if existing benchmarks are applied, quantifying and weighting their components is difficult.

Background:
A non-exhaustive collection of sensible benchmarks that use equal comparators for land-based and deep seabed mining is provided in Table 7. Benchmarks have been sorted according to the three pillars of inclusive growth, namely environmental, social and economic performance.

Table 7 Potential benchmarks for the comparison of deep sea and land-based mining

Environmental	Social	Economic
GHG emissions from mining process: – CO2 – Methane – Other gasses – Use of global warming potential **Water pollution:** – Wastewater amounts – Sediment and toxicity levels – Water and sediment dispersion – Temperature pollution **Other environmental impacts:** – Uncertainty levels in % – Proximity to areas of environmental importance – Extracted minerals compared to created solid waste in % – Extracted minerals compared to created liquid waste in % – Number of species impacted – Area impacted **Ecosystem services** – Provisioning services – Regulating services – Cultural services – Supporting services	**Human development indicators:** – Gain/loss of physical assets – Gain/loss of cultural assets – Gain/loss of income – Impact on safety – Impact on happiness indicators – Settlement indicators **Community engagement:** – Collective and transparent decision-making processes – Reduction of inequalities among stakeholders – Fair distribution of social and economic benefits – Equal opportunities for participating in extraction – Innovation indicators, such as new businesses created – Education indicators, such as schooling or training rates	**Contribution to GDP** – Nominal – Real **Employment** – Jobs created/destroyed – Direct employment – Indirect employment **Infrastructure investments** – Amount invested – Secondary benefits – Grievances **Taxation** – Tax revenue created – Tax revenue destroyed – Tax evasion **Return on investment** – Net present value – Secondary returns **Process efficiencies** – Inputs vs. outputs

Source: based on IFC (2012)

Examples for benchmarks that should not be used include, for instance, avoided deforestation or land-use change. Deforestation is an inappropriate benchmark, since deep seabed mining cannot lead to deforestation by nature and avoided deforestation through avoided mining on land is speculative. In addition, while vegetation on the deep seabed may not resemble trees, it might still be of equal importance to biodiversity and the ecosystem (Hein, Koschinsky & Kuhn, 2020). Measuring and comparing the area impacted by an activity would yield a better and more neutral comparison. Similarly, land-use change is an inappropriate comparator since seabed areas do not count as “land”. Nevertheless, they represent areas of environmental and economic importance, and even areas untouched by humans may yield economic benefits.

4. What is on the ocean floor?

What are the different minable mineral resources in the deep sea?

Answer:
The main resources of interest are polymetallic nodules, seafloor massive sulphides and cobalt-rich crusts.

Knowledge gaps:

1. The formation of these resources takes millions of years and its influence on ocean chemical cycles are yet little understood.
2. Resource estimates for the three named deposit types are vague and characterized by high degrees of uncertainty (also see next section).

Background:
Areas covered with more than 200m depth of seawater are considered as the deep sea – an area that covers around 50% of the Earth's surface or around 360 million km^2. Much of the deep sea is abyssal plain at depths below 3,000 m, which is interrupted by topographic features such as canyons, trenches and ridges as well as hydrothermal vents and seamounts. Most of these deep sea environments remain as yet uncharted and unexplored, with little understanding of the existing biodiversity (Miller *et al.*, 2018; FFI, 2020).

The extraction of minerals is of particular commercial interest for three main deposit types:

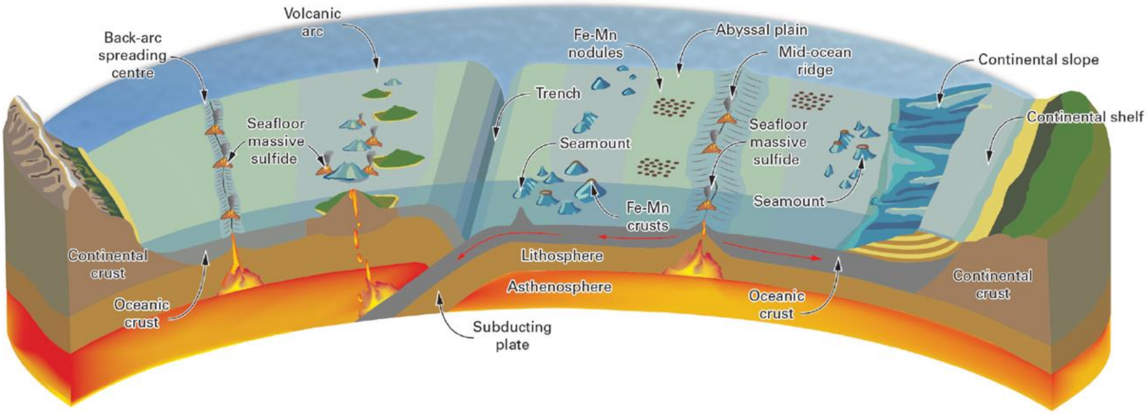
I. Manganese or polymetallic nodules (MN) on the abyssal plains

II. Seafloor massive sulphides (SMS) at active or inactive hydrothermal vents

III. Cobalt-rich crusts (CRC) along the slopes of seamounts

Substantial deposits for all of these three types have been discovered in particular in the Pacific Ocean. It is believed they are formed from minerals suspended in the sea water, which are deposited through geological and chemosynthetic processes by bacteria and other organisms over millions of years. As such, these deposits are expected to stabilize and regulate chemical cycles in the oceans (FFI, 2020; Miller *et al.*, 2018).

Table 8 A cross section of the Earth's crust, showing different deep sea environments and mineral deposits



Source: Lusty & Murton (2018)

What are the metal contents, purities and production costs for these reserves?

Answer:
The exploitation of seafloor massive sulphides is considered the most economically feasible according to some estimates, assuming sufficiently large deposits are available for 15+ years of operation. Polymetallic nodules are also expected to present a positive business case, with more certainty around resource availability for long-term operations. Exploiting cobalt-rich crusts is currently not expected to be economically feasible.

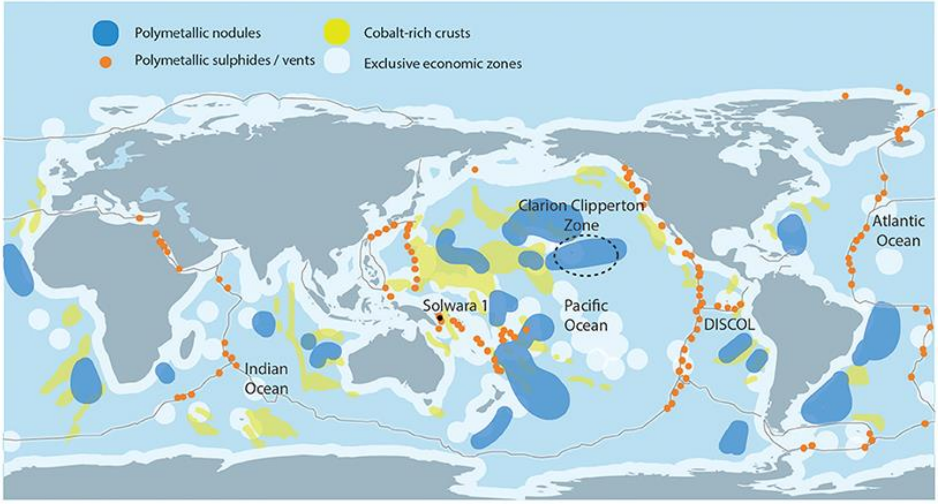
Knowledge gaps:

1. Resource estimates are highly uncertain and often use different measures, such as wet or dry weight.
2. Resource estimates for the three named deposit types are vague and characterized by high degrees of uncertainty.
3. Resource availability over the entire project period may vary or even cease.
4. Production cost estimates vary but are expected to fall with technological advancement.

Background:

According to the results compiled by the European Commission (2014), the exploitation of seafloor massive sulphides yields the highest returns at the lowest production costs. These results assume that manganese is not of economic interest. Other experts (Haeckel, 2019), however, argue that many deep seabed mining ventures do factor-in revenues from manganese extraction in their economic modelling. This would strongly increase the business case for polymetallic nodule mining but may in reality not be feasible due to resulting large oversupply of manganese to global markets (Haeckel, 2019).

Figure 9 A world map showing the location of the three main marine mineral deposits: polymetallic nodules (blue); polymetallic or seafloor massive sulphides (orange); and cobalt-rich ferromanganese crusts (yellow)



Source: Miller *et al.* (2018)

Table 9 Mineral concentrations and resource estimates for major deep sea deposit types

Deposit type	Mineral concentrations	Resource estimate
Polymetallic nodules	**North pacific averages:** Manganese: 22-27% Nickel: 1.2-1.4% Copper: 0.9-1.1% Cobalt: 0.15-0.25% Iron: 5-9% Traces of molybdenum, REEs, lithium	**Nodule densities:** Range: 0-75 kg/m² Average: 10-15kg/m² **CCZ resource:** 21 billion dry tonnes
Seafloor massive sulphides	**Ranges across locations:** Arsenic: 200-10,600 ppm Copper: 1-14% Iron: 7-27% Gold: 0.5-13 ppm Lead: 0-10% Silver: 90-900ppm Zinc: 4-19%	**Significant deposits:** Atlantis II: 90 Mt Middle Valley: 15 Mt TAG: 4 Mt Izena: 3.4 Mt Solwara 1: 2.3 Mt
Cobalt-rich crusts	**Ranges across locations:** Iron: 17-22% Manganese: 17-23% Nickel: 0.26-0.42% Copper: 0.1% Cobalt: 0.3-07% Tellurium: 0-205 ppm REEs: 0.16-0.25% Platinum: 0.7-3 ppm	**Occurrence:** Crust thickness: 1-260mm Coverage: 6.35 million km² (= 1.7% of the ocean floor) Translates into 1 billion t of cobalt

Note: high uncertainties surround all of these estimates, with significant variations across geographies. Source: own creation based on various studies (European Commission, 2014; ISA, n.d.; Lusty & Murton, 2018; Hein, Koschinsky & Kuhn, 2020; Miller *et al.*, 2018; Heffernan, 2019)

Table 10 The business case for deep sea mineral extraction by deposit type

	Polymetallic nodules	Seafloor massive sulphides	Cobalt-rich crusts
Production volume (dry)	2 million t/year	1.3 million t/year	0.8 million t/year
Capital expenditure	US$1.2 billion	US$1 billion	US$0.6 billion
Operational expenditure	US$ 175 /t	US$ 170 /t	US$200 /t
Revenue (exl. manganese)	US$ 306 /t	US$ 718 /t	US$ 216 /t
Years of operation	20	15	20
Internal rate of return	2%	68%	No positive cash flow

Source: European Commission (2014), who analysed various studies

Which ecosystems and species may be affected by deep seabed mining operations?

Answer:
Most of the species potentially affected are yet to be discovered. Marine ecosystems are highly connected and impacts from deep seabed mining may cross ecological and jurisdictional boundaries. Most directly affected may be the highly specialized organisms living on and around mineral deposits, which include predominantly microbial organisms, but also larger invertebrates and, more remotely, larger megafauna.

Knowledge gaps:
1. The importance of deep sea biodiversity for the chemical balancing of the oceans is assumed, but little understood.
2. Affected ecosystems hold great potential for genetic discoveries and new biomaterials and are highly endemic. Most species, their characteristics and potential importance for marine ecosystems remain yet to be discovered.
3. Deep sea organisms threatened by mining form the basis of the food chain in deep sea environments and for the wider marine ecosystem. The dependence of coastal fisheries and ocean-roaming megafauna on these organisms is not fully understood.

Background:
Marine environments contain a variety of habitats, ranging from surface and intertidal waters to the deepest trenches of the deep ocean. These habitats and ecosystems are highly connected, which may amplify environmental impacts from deep seabed mining operations. The below section has been complied and shortened from FFI (2020):

Polymetallic nodules on abyssal plains

Contrary to long-held believes, abyssal plains are teeming with life. While optically resembling vast, desert-like environments, a wide variety of microbial life and other larger lifeforms exists on those plains and inhabits the metal-rich nodules. As such, this habitat exerts significant influence on the ocean's ability to cycle nutrients and carbon, dissolute calcium carbonate, and stabilize atmospheric carbon dioxide concentrations over long time horizons.

Microbes living on and around polymetallic nodules fix trace metals onto the nodules as part of a process called chemosynthesis. These processes are still poorly understood but are expected to stabilize ocean chemistry. The extraction of trace metals from the sea water through these microbes is likely to balance the concentration of metal elements in the oceans and can thereby also reduce the presence of toxic metal compounds.

The chemosynthetic microbial communities thriving on nodules form the basis of life on the abyssal plains and potentially the wider ocean ecosystem. They are also found within the seafloor sediment, as so-called bacterial mats. By being responsible for the main part of primary production in these habitats, the microbes living on polymetallic nodules thus act as the base of the food chain for an extensive and unique collection of organisms.

Polymetallic sulphides on hydrothermal vents and seeps

Deep-sea vents and seeps are one of the most physically and chemically diverse biomes on Earth. Their particular environment is characterized by chemical reactions that can fuel abundant chemosynthesis-driven microbial life. Similar to polymetallic nodules, these microbial communities form the basis of life around these systems and thereby support highly specialized and endemic organisms.

In addition, hydrothermal vents and seeps are important carbon sinks. Microorganisms specifically adapted to these environments consume and sequester carbon and methane, a greenhouse gas with roughly 25 to 50 times the potency of carbon dioxide. As such, these ecosystems are also a vast genomic repository of unique value to screen for highly specific metabolic pathways and processes. Vent and seep biota hold unmapped potential for the provision of new biomaterials, medicines and genetic resources.

Cobalt-rich crusts around seamounts

Seamount systems support deep-sea corals that thrive on and around seamounts. They are expected to host more than 1,300 different species of animals with high degrees of endemism. Seamounts rise from the seafloor and create obstacles that shape ocean currents and reflect deep, nutrient-rich waters to the ocean surface. These factors make seamounts fertile habitats for diverse communities of marine life, including sponges, crabs, sea anemones, commercially important fish and deep-sea corals. They support important fisheries and a diverse range of marine megafauna. Marine mammals, sea turtles and large predators rely on seamounts to feed and rest during migrations.

The chemosynthetic and biochemical processes through which cobalt-rich crusts form on these seamounts help to maintain the balance of the ocean's chemistry and its ability to regulate the climate and ocean metal concentrations.

Ocean processes, currents and connectivity

Deep-sea ecosystems are globally important for Earth system regulation. They are central to the global climate, fisheries, genetic and evolutionary processes as well as to the maintenance of ocean chemistry and primary productivity – thereby supporting life on Earth.

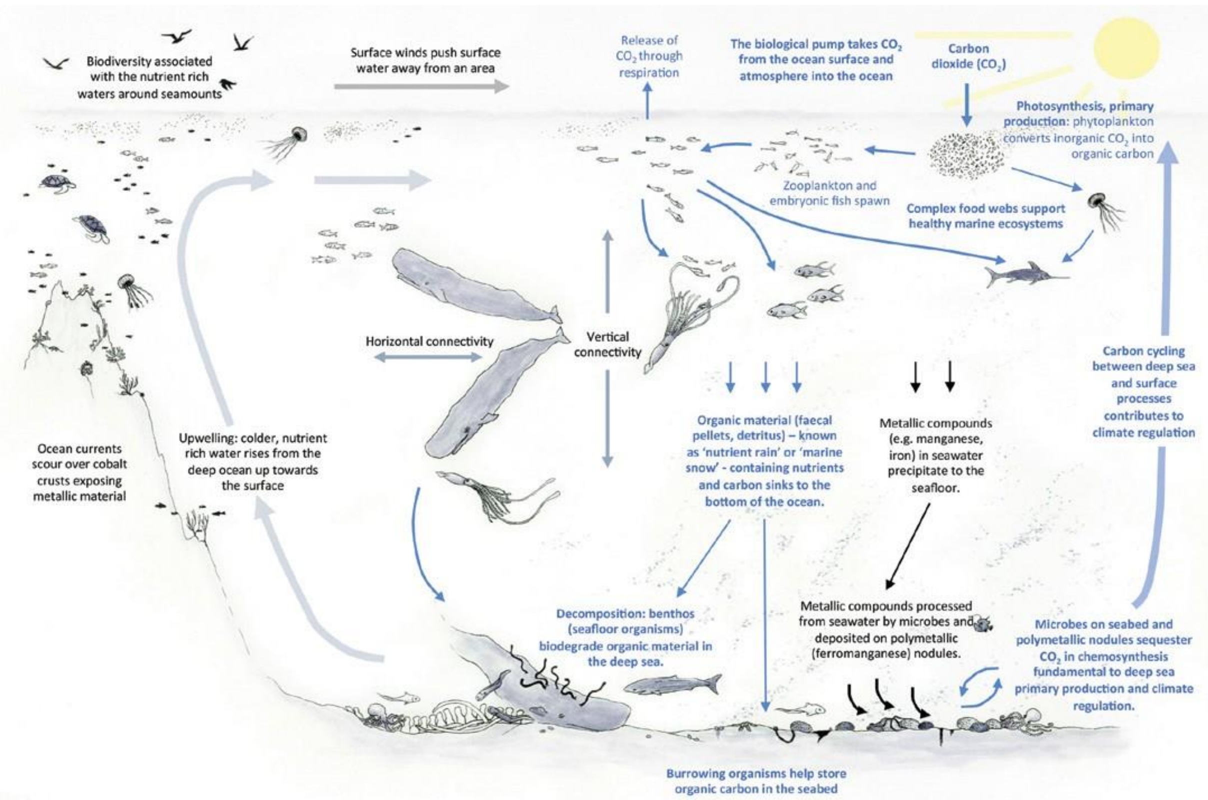
The oceans are responsible for the storage of more carbon than the terrestrial biosphere. In a process referred to as the "biological pump", organic matter sinks into the ocean interior where it is decomposed by bacteria to inorganic carbon and nutrients. We are yet to fully understand the fundamental biological, geophysical and biochemical functioning of these processes.

There is a relationship between the geophysical and biogeological processes that drive trace metal budgets on the planet. Trace metals are fundamental to a wide range of biological processes (including ion and nutrient transport, reproduction, respiration and photosynthesis). These are not only essential to the formation of microbes in the deep sea but are also the same metals that are of interest to deep seabed mining.

The interconnected nature of the oceans also means that ecosystems have no obvious physical boundaries. They are defined by powerful currents that transport nutrients and small marine organisms. Highly mobile species migrate across ocean basins for feeding and reproduction. This horizontal and vertical movement connects the open ocean, coastal waters and the deep ocean and similarly links national waters to areas beyond national jurisdiction.

This interconnectedness means deep seabed mining cannot occur in isolation. Impacts in one place can have consequences elsewhere, easily cross ecological and jurisdictional boundaries and thus lead to unexpected and unquantifiable consequences. The implications of disrupting these biological, geophysical and biochemical processes through deep seabed mining require very precautionary consideration.

Figure 10 The ocean biological pump and dependent ecosystems



Source: FFI (2020)

What do we know about the deep sea ecosystems most at risk?

Answer:
Deep sea ecosystem are low-disturbance, low-resilience regimes. Up to now, they have experienced low levels of rapid and abrupt disturbance and are characterised by low levels of resilience. This results from a set of characteristics that reduce their capability to withstand and recover from disturbance: species' long lifespans, slow growth rates, late maturity and reproduction and low fecundity; high degree of connectivity to other ecosystems; and step-like vulnerability thresholds. Our scientific understanding of these species and ecosystems is limited.

Knowledge gaps:
1. Knowledge gaps on deep sea ecosystems are substantial since deep sea exploration and science has only emerged in the second half of the 20^{th} century.
2. The scale of potential damage is hard to predict because our understanding of deep sea marine biota remains limited.
3. Also unknown is the extent to which an ecosystem may recover when mining ceases and especially over what timescales such a recovery would take place.

Background:
A collection of the most important characteristics of deep sea ecosystems is presented in Table 11 below.

Table 11 The characteristics of deep sea ecosystems and species

Characteristic	Type of ecosystem or species
Undiscovered	Many species remain uncharted and unstudied; new species discoveries occur at almost every sampling exercise. These discoveries range from microbes and small invertebrates to larger vertebrates and even mammals.
Slow growth and long lifespans	Deep sea ecosystems are defined by slow growth rates and long lifespans, being particularly vulnerable to physical disturbance. Examples include the Greenland shark (*Somniosus microcephalus*) that dives to around 1,200m. It is described as the longest-living vertebrate, reaching maturity at 156 ± 22 years and has a lifespan of at least 392 ± 120 years. Black coral (*Leiopathese* spp.) is a deep ocean species found off the Azores. It is known to have a colony lifespan of up to 2,320 ± 90 years, arguably one of the longest-living organisms on Earth (Miller *et al.*, 2018).

Step-like vulnerability thresholds	The relationship between impact intensity and vulnerability is not linear or proportional for most marine ecosystems and particularly for fish stocks. Abrupt changes may occur once a threshold is crossed (FAO, 2020).
High degree of connectivity	Ocean systems and ecosystems are highly connected through currents, chemical and atmospheric cycles and the movement of highly mobile species.
Reproduction late in life and low fecundity	Deep sea species are known to reach maturity late in life (e.g. Greenland shark) and to have a low natural capability to produce offspring.
Vulnerability and slow recovery	Increased longevity, slow growth rates, reproduction late in life, low fecundity and the high degree of connectedness make deep sea species highly vulnerable to environmental impacts and reduce their capability to recover quickly. Deep sea ecosystems are low-disturbance, low-resilience regimes (Miller *et al.*, 2018).
	Source: FFI (2020) if not stated otherwise

According to a growing number of marine scientists, any scale of seabed mining may systematically deplete resources, disturb, damage or remove structural elements of ecosystems, cause irreversible biodiversity loss and impact ecosystem services. At our current level of understanding, the scale of potential damage is hard to predict because our understanding of deep sea marine biota remains limited. To address this knowledge gap, a consortium of 32 European universities, research institutes and mining companies called MIDAS (Managing Impacts of Deep Sea Resource Exploitation) is conducting extensive scientific investigation into the potential consequences of deep seabed mining (FFI, 2020).

5. How do deep seabed mining processes work?

What are the nascent deep seabed mining processes and what environmental risks are involved?

Answer:
Deep seabed mining equipment is currently in the prototyping stage and involves rock cutting and mineral collection vehicles that operate on the ocean floor, as well as surface mineral collection and processing vessels. Technology is nascent and still highly prone to technical failures.

Knowledge gaps:

1. Current prototypes are at a scale that is a fraction of the commercial vehicles ultimately envisioned. There is much uncertainty around the final shape, size and functionality of deep seabed mining equipment.
2. Not all technological developments may currently be known to the public, with deep seabed mining actors hiding their technology from competitors.
3. This study focused primarily on technological developments of players in the western hemisphere. Little insights were gained into current Chinese, Russian, Korean or Japanese technologies.

Background:
First designs for deep seabed mining were already drawn up more than 40 years ago. The latest equipment being developed for deep seabed mining activities can be divided into three main groups:

(I)
Rock cutting and collection tools

Source: Doherty (2019)

Used for polymetallic sulphides and cobalt-rich crusts

(II)
Nodule collector ROVs

Used for polymetallic nodules

Source: DSM Observer (2019)

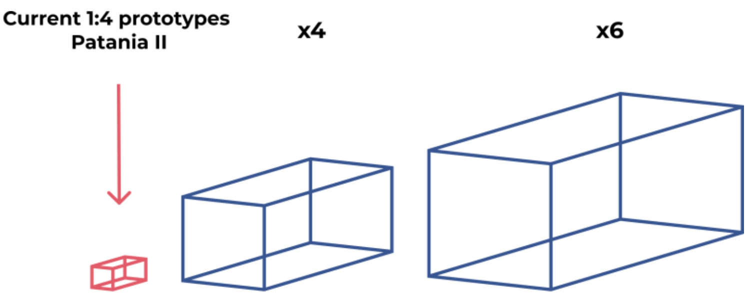
(III)
Mineral riser and collection vessel

Source: DeepGreen (2020a)

Surface support infrastructure for all mining types

One of the most advanced module collector prototypes in the western hemisphere has been developed by DEME group and is called the Patania II, as pictured above under (II). Padania II is a nodule collector remotely operated vehicle (ROV) that is around 4m wide, 4m tall and 12m long and weighs approximately 30 tonnes. It is a 1:4 scale prototype; fully developed commercial collectors may be 4-6 times larger, as illustrated in Figure 11 below. The Patania II has four front suction heads, each 1m wide, and two track drives that allow it to move forward, while nodules are sucked in through the suction heads (BGR, n.d.). This type of collector vehicle is connected to the mining vessel above with an umbilical, which contains the electric wiring for hydraulics and telemetry as well as optic fibres for communication. Next to the umbilical, a riser tube is used to transport the collected minerals to the collection vessel, as illustrated in Figure 12. A discharge tube is used to release excess water back into the ocean.

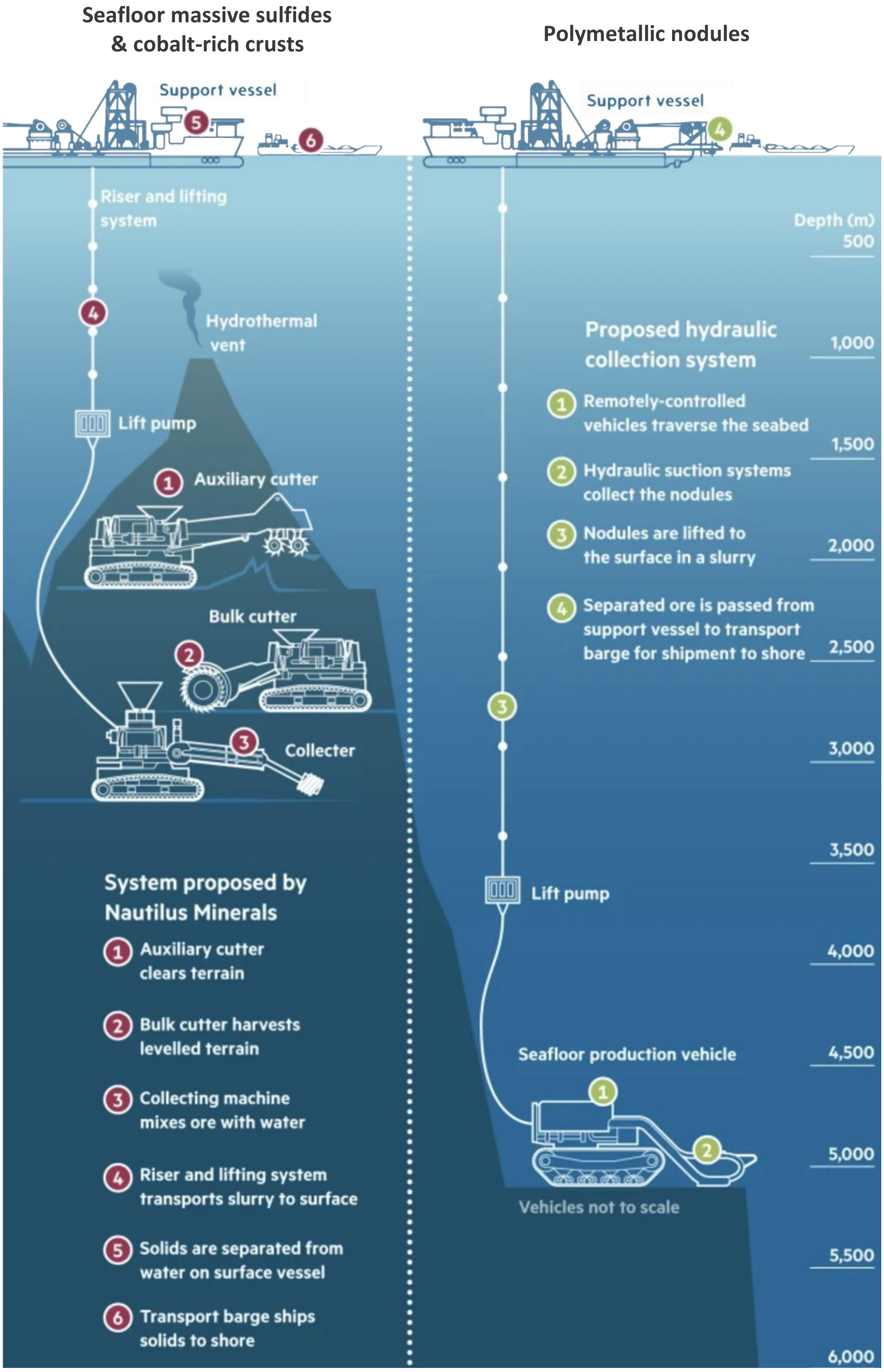
Figure 11 Size comparison of current nodule collector prototypes and commercial-sized applications



Source: self-creation, based on information from BGR (n.d.); Haeckel (2019)

For use as a collection and processing vessel, large ship types are required and will need to be serviced by bulk carriers to transport processed minerals to the land. Most recently the deep seabed mining company DeepGreen, together with the oil and gas engineering company Allseas, has acquired the former ultra-deep-water drill ship "Vitoria 10000" (pictured at (III) above) for conversion to a polymetallic nodule collection vessel. The ship is 228m long, 42m wide, can accommodate 200 people and will be converted to accommodate a pilot nodule collection system currently engineered by Allseas. As a former drill ship, the Victoria 10000 is well suited for modifications necessary to deploy the 4.5km-long riser system, which is also currently developed by Allseas (DeepGreen, 2020a). An overview of the deep seabed mining process and involved equipment is given in Figure 12.

Figure 12 Deep seabed mining technology comparison



Source: Sanderson (2018)

How applicable are existing ESG and project management frameworks (e.g. IFC standards)?

Answer:
There is little precedent for applying or adapting existing environmental, social and governance (ESG) standards to deep seabed mining.

Knowledge gaps:

1. The baseline scenario against which to measure or build ESG standards and assessments for deep seabed mining is currently unclear due to a lack of scientific data.
2. The technology and capital intensiveness of operating in the deep sea may prohibit sufficient access for auditors to assess compliance with ESG standards.

Background:
Deep seabed mining is to some extent operationally similar to oil and gas projects off shore. Some project management standards from the industry could be adapted to deep seabed mining operations. However, technical process standards in the oil and gas industry may not be applicable in every aspect to deep seabed mining. The same holds for environmental standards, which rely on many years of research and experience in waters and depths mostly limited to the continental shelf or in relative proximity to land. Lastly, well-developed social and governance standards exist for the oil and gas or even the mining industry. These, however, take footing in well-established national or international jurisdictions and legal frameworks. Deep seabed mining is pursued in areas beyond such frameworks but is still likely to have social and governance implications for individual nations as well as for humanity as a whole. For shaping adequate and fair standards to address these issues, there is little precedent.

Taking the above into account, an interview was conducted to assess how one of the most prominent ESG project management standards, the International Finance Corporation (IFC) Performance Standards, may be applied to deep seabed mining. The interview was conducted with a mining industry expert, who particularly specializes on social issues along mining project life-cycles and who has deep knowledge of the IFC Performance Standards. It is important to note that the IFC Performance Standards present a framework that leaves sufficient room for individual companies and operators to adapt and set their own standards or management thresholds and processes. This might also be useful for deep seabed mining operators. The interview results are summarized in Table 12 below, discussing each IFC standard and its meaning for deep seabed mining operations.

Table 12 The IFC Performance Standards and their implications for deep seabed mining

IFC Performance Standard	Implications for deep seabed mining
1. Assessment and management of environmental and social risks and impacts	The operator has to adapt measures and processes to its particular situation and environment. This means that the operator must prove sufficient capabilities to adequately assess and manage environmental and social risks. An important part of the above is the establishment of effective grievance mechanisms that involve all necessary stakeholders, accept anonymity and

	effective communication on grievances between the management and the operations. In deep seabed mining, the following is questionable: - Who are the potentially affected communities? - How can affected communities prove grievances? - To whom can affected communities report grievances and how can they defend their case? - What are the applicable jurisdictions? - How can a particular company be addressed or would deep seabed mining operators deal with grievances collectively?
2. Labour and working conditions	Precedents may be taken from the offshore industry, since deck work is similar. Important to clarify the jurisdiction under which labour laws and employee grievances are handled.
3. Resource efficiency and pollution prevention	Capabilities to measure resource efficiency and assess the effectiveness of pollution prevention usually require detailed baseline assessments against which measurements are taken. Such baseline assessments do not yet exist for deep seabed mining operations. A lack of scientific data may currently prevent assessing a baseline scenario with sufficient level of detail and certainty.
4. Community health, safety, and security **5. Land acquisition and involuntary resettlement**	Wider considerations for deep seabed mining: - How may new port side infrastructure, needed to handle deep sea minerals, affect communities (e.g. in small island states that have interest in developing such infrastructure)? - Does the influx of new labour lead to worker towns and resettlement of native communities? - How do you compensate fishing communities for potential negative impacts from mining? - What is the community value of fisheries?

	- What gender dimensions are involved? - How do you include communities in deep seabed mining decision-making processes and profit-sharing mechanisms?
6. Biodiversity conservation and sustainable management of living natural resources	Similar to Standard 3. There is a lack of understanding of the baseline scenario and no experience in managing deep sea ecosystems and resources sustainably. - Would there be a way for deep seabed mining to enhance biodiversity? Deep seabed mining would be highly technology and capital intensive and may therefore exclude stakeholders from monitoring, auditing or participating in the conservation and management of deep sea resources. - How may equal access be assured or compensated?
7. Indigenous peoples	Management of impacts of deep seabed mining on indigenous peoples: - How may deep seabed mining affect indigenous communities in small island states or in surrounding geographies? - Would deep seabed mining compete with or undermine income streams of particular importance to indigenous peoples, such as fisheries or artisanal and small-scale mining? - How can indigenous peoples participate in grievance mechanisms?
8. Cultural heritage	The cultural value of the deep sea is a little-explored concept. We might not be able to fully anticipate the cultural benefits of intact deep sea ecosystems for our lives as well as for future generations. Also, the deep sea's archaeological and geological heritage has to be considered.

Other practices or standards that may be applied:

- Corruption monitoring mechanisms such as the Extractive Industries Transparency Initiative (EITI)
- Base erosion and profit-shifting frameworks (OECD/G20 Inclusive Framework on BEPS)
- Natural Resource Charter
- International Petroleum Industry Environmental Conservation Association (IPIECA) standards

6. What is the environmental impact of ocean metal collection?

What are the known potential impacts of deep seabed mining and how can they be quantified?

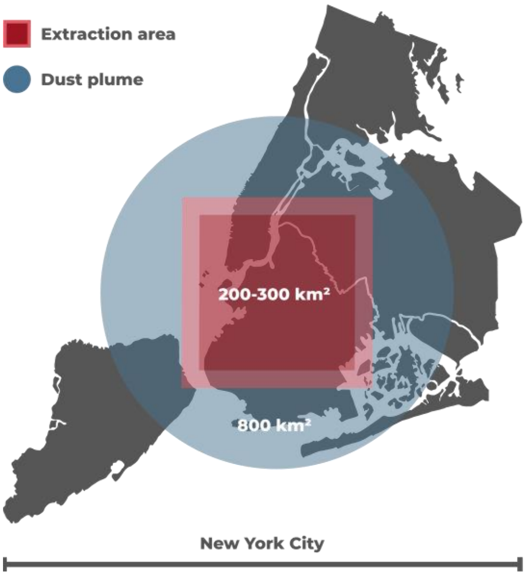
Answer:
A wide range of environmental impacts are expected. Next to direct physical ecosystem destruction through mineral collection vehicles, major damage and disturbance can arise from light, noise and sediment pollution. It is particularly important to consider these risks not just at a project level but at a cumulative scale, since deep seabed mining would impact areas of continental scale.

Knowledge gaps:

1. The cumulative impacts of deep seabed mining across large areas in the deep sea are difficult to estimate.
2. Different risks arise at different project stages. Current prototyping and small-scale studies may not provide sufficient data for estimating all impacts of each project stage at full commercial scale.
3. Many impacts may not be known, considering the lack of scientific understanding in many areas of deep sea research.
4. Quantification of impacts would be difficult due to a lack of long-term scientific data and no sufficient understanding of environmental baseline scenarios.

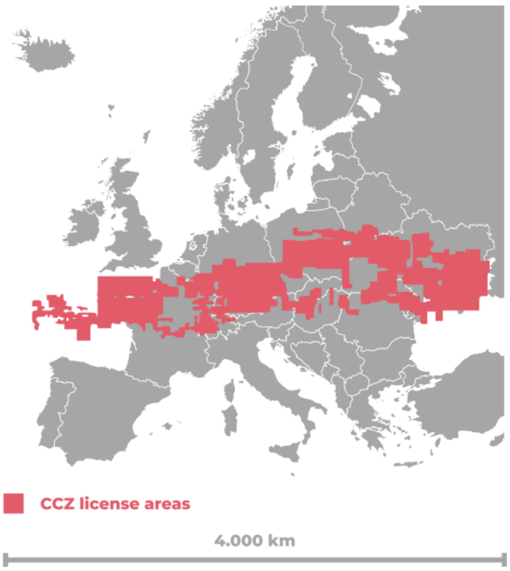
Background:
Major environmental risks from deep seabed mining arise from the physical force used by collection vehicles as well as from the sheer scale at which operations are likely to impact deep sea ecosystems. For the collection of polymetallic nodules, for instance, a single commercial-scale operation is expected to mobilize up to 45 million m^3 of wet sediment or 15Mt of dry matter in the course of one year (BGR, n.d.). This is equivalent to moving 41 times the Empire State Building and dispersing great parts of it as powder into the deep sea environment. Of these 15 Mt of sediment, around 30% is collected nodules of which 3% is made up of the valuable minerals nickel, copper and cobalt (Volkmann & Lehnen, 2018; Haeckel, 2019). In total, this equates to a mining efficiency of 1% (low boundary), compared to 2.6% efficiency of land mining (DeepGreen, 2020b). Not only is the efficiency lower, but also only achieved while consuming much more space. In fact, a single contractor is expected to harvest nodules from an area of 200-300km^2 each year. The sediment plume that would be dispersed through the operations would likely affect an area of 800km^2 each year. In cumulative terms, this means that polymetallic nodule collection operations are likely to impact areas of continental scale, as illustrated in Figures 13 and 14.

Figure 13 The area impacted each year by a single contractor for the collection of polymetallic nodules



Source: self-creation, based on Haeckel (2019)

Figure 14 Licence areas in the Clarion-Clipperton Fracture Zone compared to the size of Europe



Source: based on Geomar map data, accessed through KDM (n.d.)

Environmental impacts from deep seabed mining are similar across deposit types. At the project level, however, they are diverse and therefore best graphically summarized by Figures 15-17 below. The illustrations not only show the large range of potential impacts, but also highlight the great variety of risks that still require engineering solutions and the many weak points for technical failure. It is also important to consider that these risks may arise at different scales across the entire project cycle, ranging from exploration and extraction to project closure and rehabilitation.

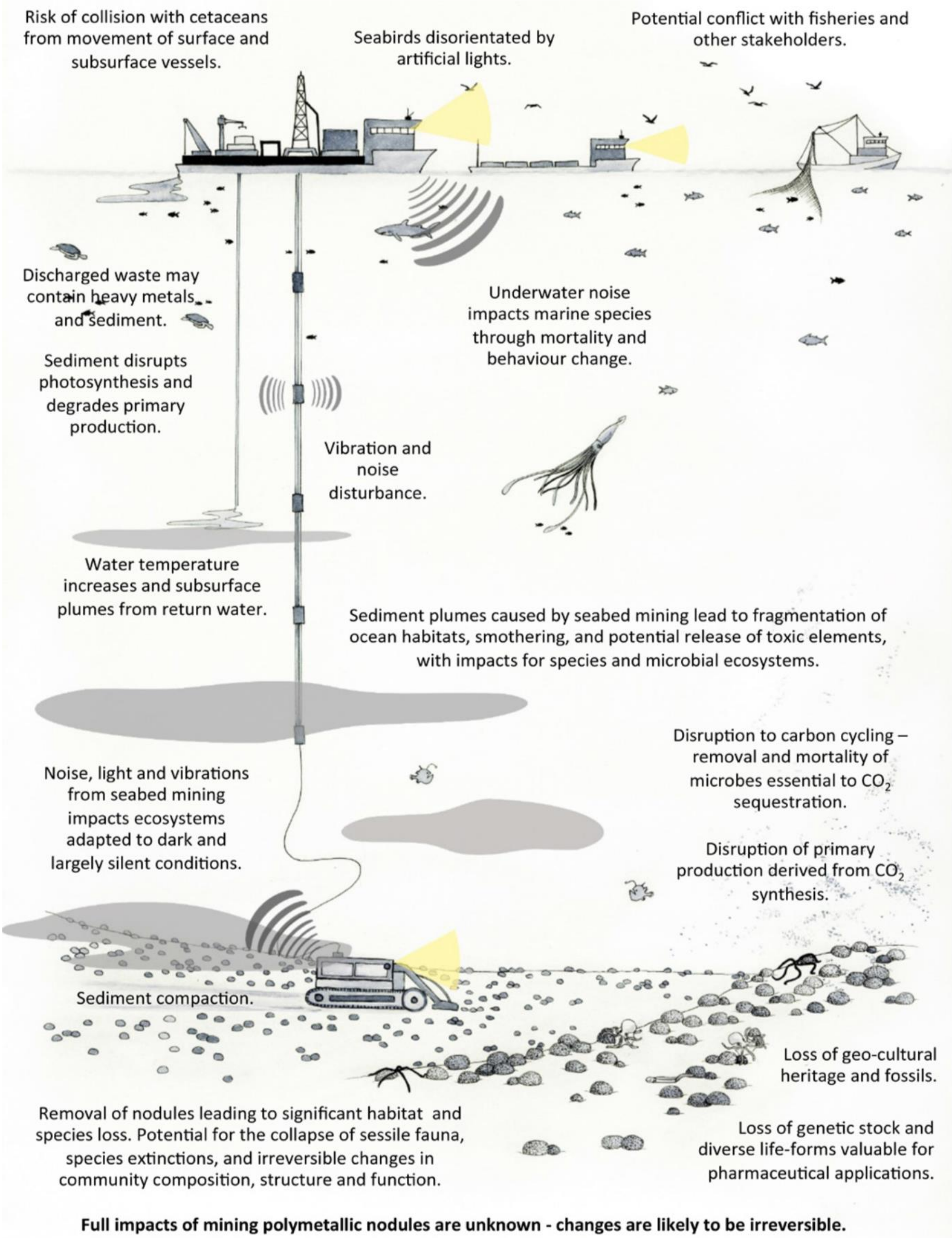
The most notable environmental impacts from deep seabed mining that were identified by the MIDAS consortium are presented in Table 13 together with the factors needed to quantify them (FFI, 2020):

Table 13 Likely environmental impacts from deep seabed mining and factors for their quantification.

Environmental impacts	• Loss of habitat and life-supporting substrates resulting in mortality of fauna and flora • Sediment plumes swirled up from mining impacting species and habitats • Exposure of seabed life to toxic metals released during mining operations • Harm to genetic links between different populations of deep-sea animals • Habitat alteration and fragmentation through sediment, light and noise • Impacts to primary production in the water column and food webs • Impacts to ecosystem functions through disruption of key processes • Alteration of large-scale cycles including carbon, nutrients and trace metals
Quantification factors	• Intensity and severity of impacts • Spatial extent of impacts relative to habitat size • Timing and duration of impacts • Probability of impacts occurring • Sensitivity and vulnerability of the ecosystem • Ecosystem's ability to recover • Extent of ecosystem alteration • Cumulative effects of impacts • Scientific uncertainty related to impacts

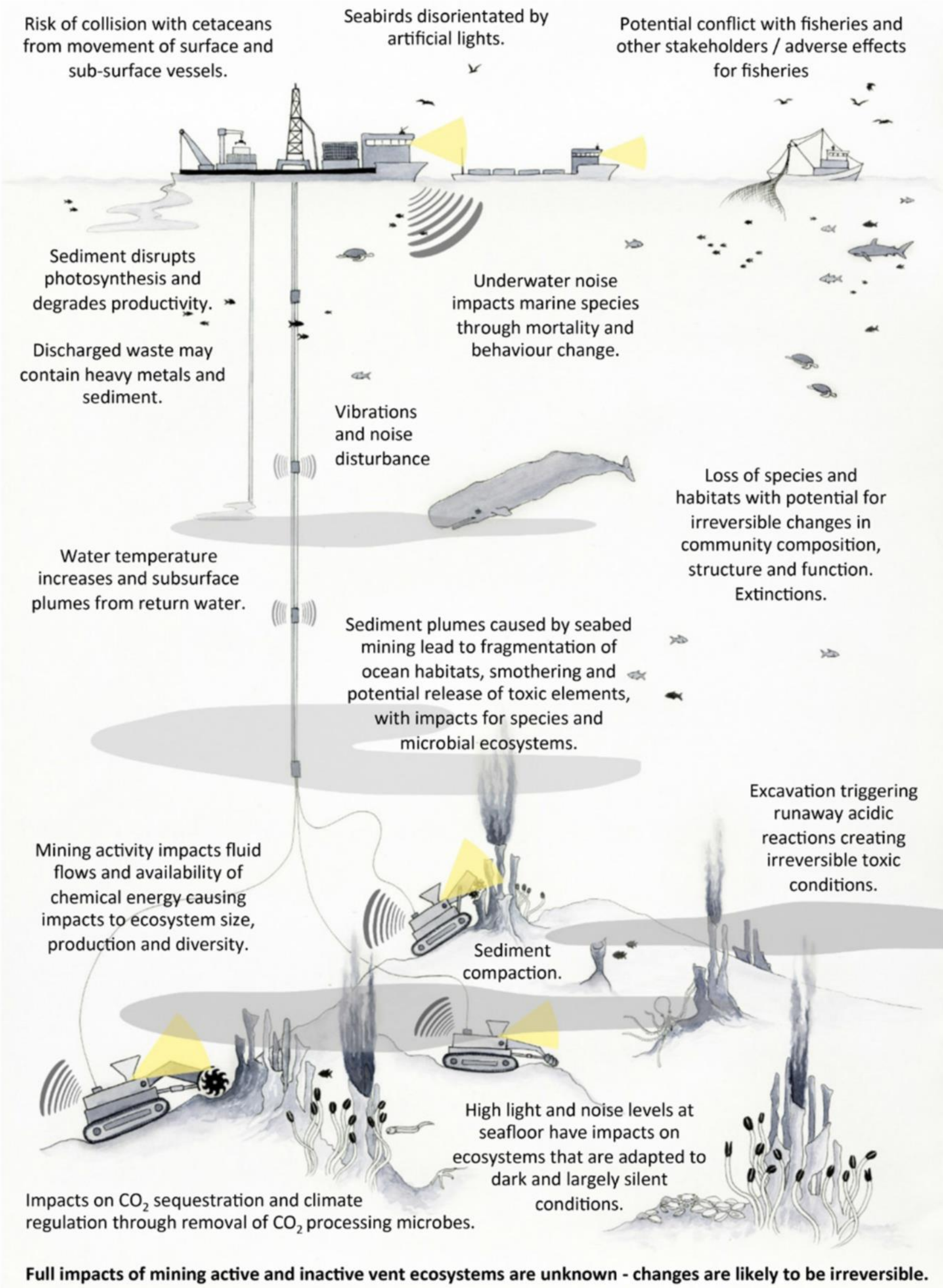
Source: FFI (2020)

Figure 15 Potential environmental impacts from polymetallic nodule extraction



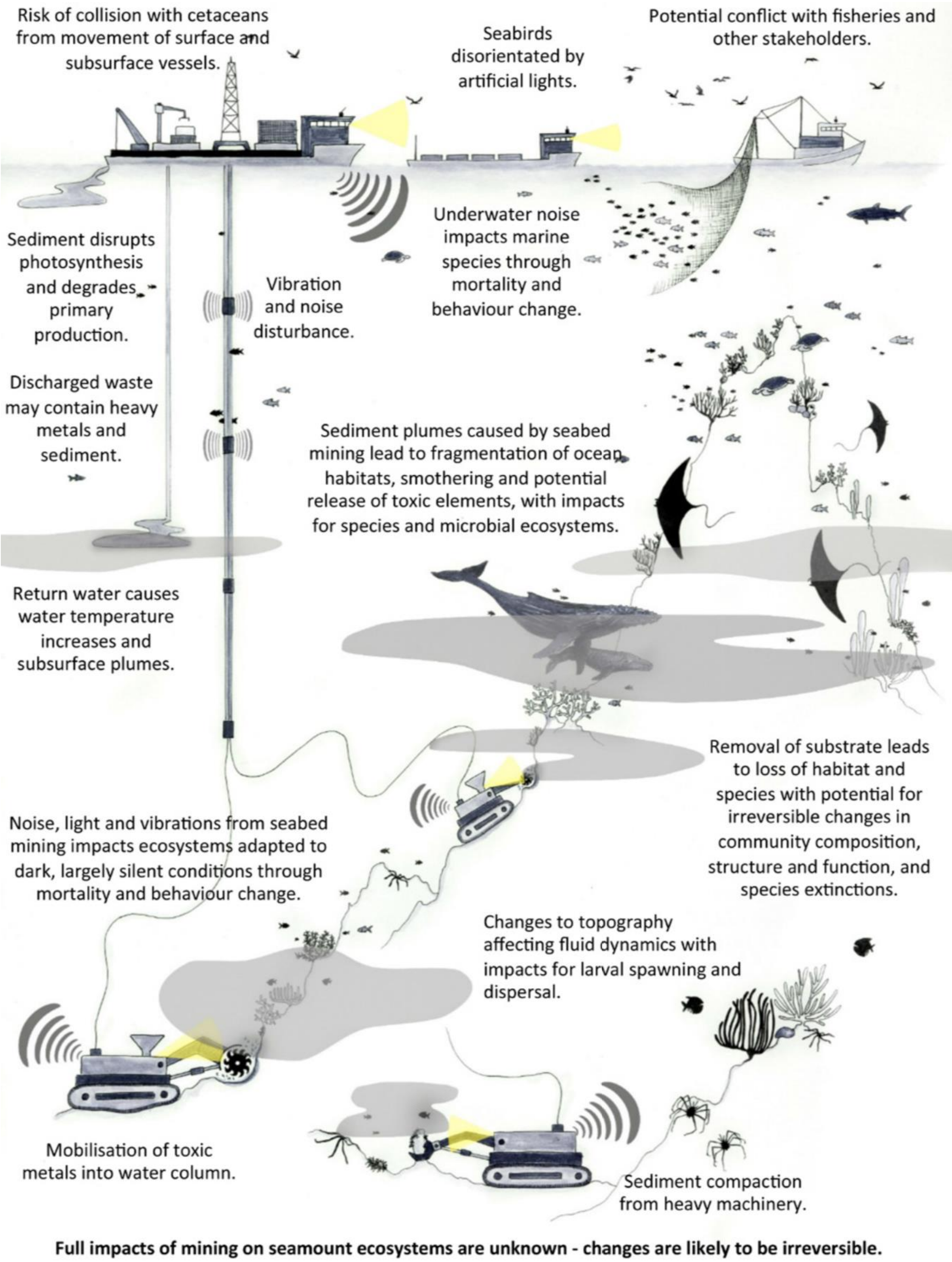
Source: FFI (2020)

Figure 16 Potential environmental impacts from mining seafloor massive sulphides



Source: FFI (2020)

Figure 17 Potential environmental impacts from mining cobalt-rich crusts

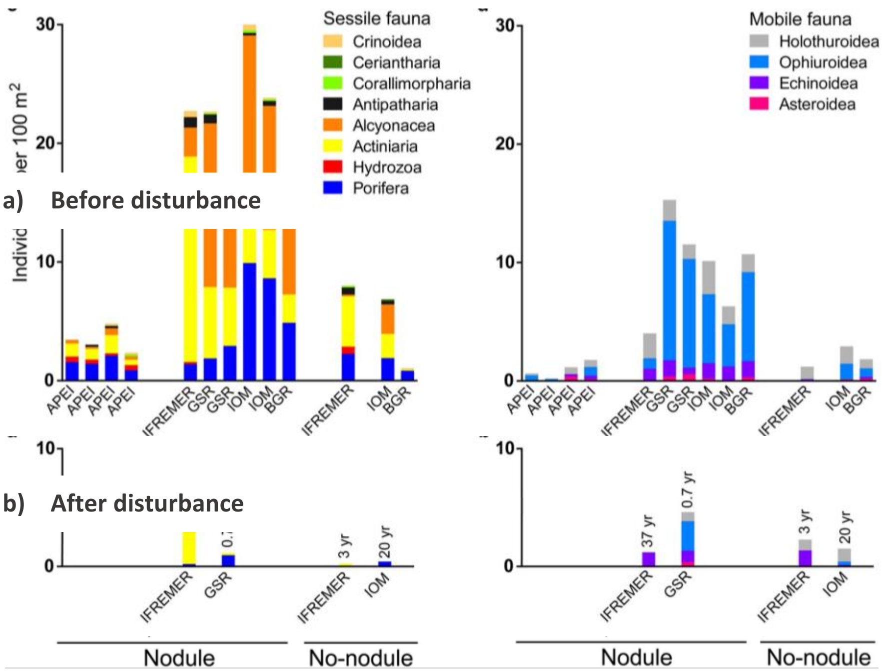


Source: FFI (2020)

Much of the deep sea remains to be explored and scientifically understood. Only a limited number of studies have been conducted to assess the potential impacts of deep seabed mining. While it is true that efforts have been significantly ramped up with the current interest in exploiting deep sea mineral resources, there is a particular lack of long-time data. Since deep sea ecosystems are characterized by extremely slow growth rates and that mineral formation processes span thousands and millions of years, long-term data is essential in assessing environmental impacts.

One of the most important studies in this area was conducted by Vanreusel *et al.* (2016). They have revisited polymetallic nodule fields that were disturbed by dredging between 40 and 25 years ago to assess ecosystem and species recovery rates. Their results, presented in Figure 18, show not only clear signs of species abundance on nodule fields before the disturbance occurred, but even more strikingly the significantly reduced species count decades after. Long-lasting time series of such data would ultimately be needed to infer the long-term impact of deep seabed mining at a single project site. Assessing cumulative impacts over large areas and long timeframes would be even more difficult.

Figure 18 Comparison of species count a) before dredging disturbance and b) more than 25 years after disturbance



Source: adapted from Vanreusel *et al.* (2016) according to Haeckel (2019)

How is the precautionary principle applicable to deep seabed mining?

Answer:
There are different legal, scientific and commercial interpretations of how and when the precautionary principle should be applied. This calls for a globally articulated decision-making process on whether deep seabed mining should be pursued for the benefit of all humankind.

Knowledge gaps:

1. While the topic of deep seabed mining is gaining more and more media attention, the global debate around deep seabed mining still has very limited resonance in the general population. The general public therefore has little influence on if and how the precautionary principle is applied.
2. There is a debate around whether the ISA is acting in the interest of protecting deep sea ecosystems for the benefit of humankind, or whether it is mandated by UNCLOS to actively promote the pursuit of deep seabed mining with environmental protection as a secondary mandate.

Background:

Definition: Precautionary principle: "*When human activities may lead to morally unacceptable harm that is scientifically plausible but uncertain, actions shall be taken to avoid or diminish that harm. Morally unacceptable harm refers to harm to humans or the environment that is*

- *threatening to human life or health,*
- *or serious and effectively irreversible,*
- *or inequitable to present or future generations,*
- *or imposed without adequate consideration of the human rights of those affected.*

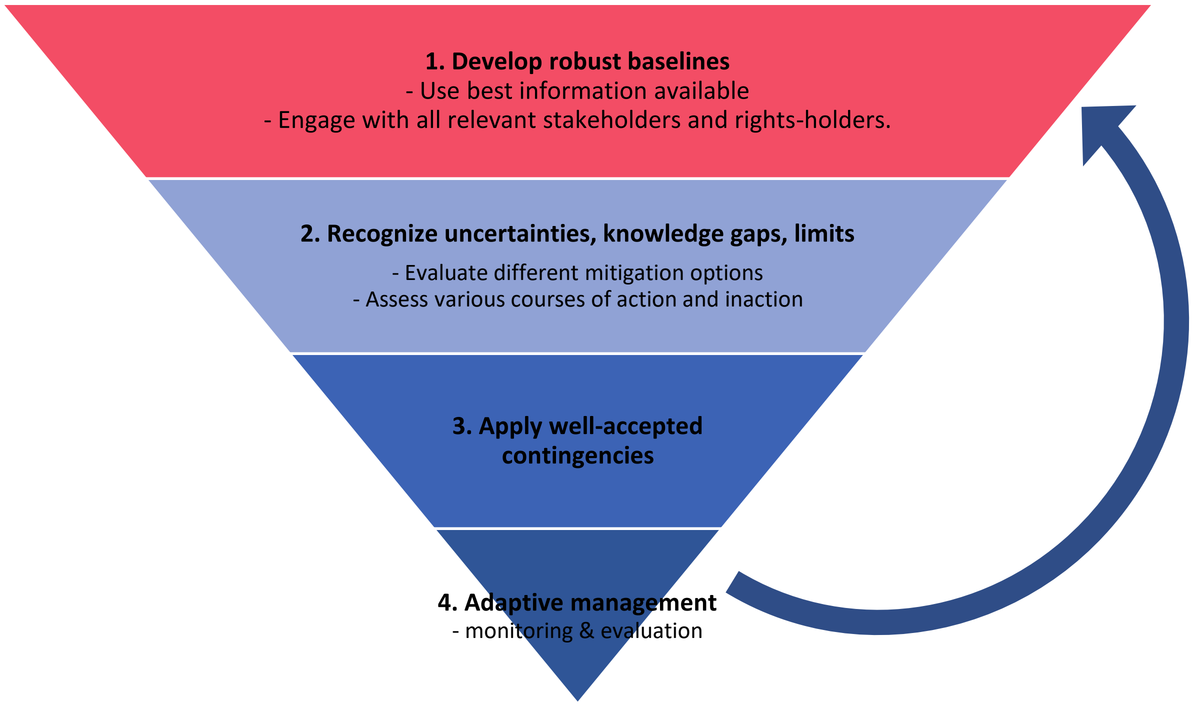
The judgement of plausibility should be grounded in scientific analysis. Analysis should be ongoing so that chosen actions are subject to review.

Uncertainty may apply to, but need not be limited to, causality or the bounds of the possible harm.

Actions are interventions that are undertaken before harm occurs that seek to avoid or diminish the harm. Actions should be chosen that are proportional to the seriousness of the potential harm, with consideration of their positive and negative consequences, and with an assessment of the moral implications of both action and inaction. The choice of action should be the result of a participatory process." (UNESCO, 2005:p.14)

Considering the above definition, where there is uncertainty, the threat of environmental damage and the potential of threats to lead to serious or irreversible harm, a precautionary approach to deep seabed mining must be applied. A lack of certainty regarding the threat of environmental harm is no excuse for not taking action, since the cost of inaction may only become apparent once sufficient information becomes available (FFI, 2020). Applying the precautionary principle should include the steps summarized in Figure 19.

Figure 19 Essential steps when applying the precautionary principle



Source: based on FFI (2020)

Even proceeding with deep seabed mining in its infancy must be approached in a precautionary and step-wise manner. This can allow new and developing knowledge to be integrated, environmental management goals and monitoring protocols to be applied to different development stages, and adequate standards to be established (FFI, 2020; Niner *et al.*, 2018).

Since deep sea resources are considered the common heritage of humankind, it is also important to sufficiently involve the global community in the deep seabed mining debate. All relevant voices need to heard and considered, and a basis must be established for regular and thorough supervision of deep seabed mining exploration and potential exploitation processes. Greater civil society participation can also increase scrutiny of the established Legal and Technical Commission, which advises the ISA, specifically on decisions in the absence of scientific evidence regarding the potential for serious harm to the marine environment (FFI, 2020). Transparency and global participation are key in this process.

What ecosystem services does the deep sea provide and which ones are at risk?

Answer:
The deep sea provides a variety of ecosystem services ranging from providing food, regulating global climate processes, holding cultural and scientific value to supporting other marine and terrestrial ecosystems with nutrients.

Knowledge gaps:

1. Little is understood about the dependencies of other ecosystems on the services provided by the deep sea.
2. The extent to which ecosystem services are at risk is difficult to estimate since resilience thresholds are unknown.

Background:

Table 14 Summary of ecosystem services provided by the deep sea

Ecosystem service type	Type description	Ecosystem service
Provisioning services	Goods or products obtained from ecosystems (including biological raw materials and food).	I. Some deep sea organisms are directly consumed by people (e.g. clams and oysters). II. Some are used as bait (e.g. worms and clams) or in other processes. III. Genetic material may be extracted from organisms for pharmaceutical and research use. IV. Proteins or chemical compounds may be extracted from organisms for pharmaceutical and industrial use.
Regulating services	Benefits obtained from the regulation of ecosystem processes such as flood attenuation, climate regulation and waste attenuation.	V. Deep sea organisms (benthic as well as sediment-dwelling organisms and bacteria) influence climate processes through organic decomposition processes and sedimentation. VI. Organisms influence water purification and pollution attenuation processes. Burying the sediment itself may reduce the bioavailability of pollutants. VII. Sediment structure and the accumulation of sediment regulates accretion and erosion processes as well as storm surge and flood control.
Cultural services	Non-material benefits from ecosystems such as recreation and sense of place.	VIII. Deep sea organisms can be used in the process of generating human well-being, education, or scientific understanding. IX. Well-being may be derived by individuals simply because they know a healthy deep sea community exists.

Supporting services	Natural processes that maintain other services such as primary production and nutrient cycling.	X. Sediment dwelling organisms cycle energy, nutrients, organic matter and genetic information within and between ecosystems. XI. Energy cycling facilitates the production of future ecosystem services across multiple ecosystems. XII. Three dimensional deep sea structures (e.g. sea mounts, nodules and vents) represent a feature around which organisms may aggregate while feeding and/or reproducing.

Ecosystem service examples:

- 50% of global primary production occurs in the oceans
- 35 million jobs are directly linked to ocean fisheries
- 300 million livelihoods are directly linked to ocean fisheries
- 500 million people depend economically on coral reef ecosystems
- Coastal communities have deep cultural and spiritual connections with the oceans
- Deep sea species have been observed in the stomach contents of commercially important fishes
- Approximately 5-15 billion tonnes of carbon are moved to the ocean interior and deep sea per year
- A giant sponge collected at 1,110m depth is thought to be the oldest animal on Earth at 11,300 years of age (Danovaro *et al.*, 2017).

Source: based on FFI (2020)

How may the natural capital and economic value of ecosystems in the deep sea, and potential losses, be captured?

Answer:
The economic value derived from the oceans is estimated to range between US$1.5 trillion and US$2.4 trillion annually. Maritime and coastal tourism, according to one estimate, is expected to become the biggest ocean-based industry by 2030, valued at almost US$800 million. Deep sea-specific estimates have not been identified.

Knowledge gaps:

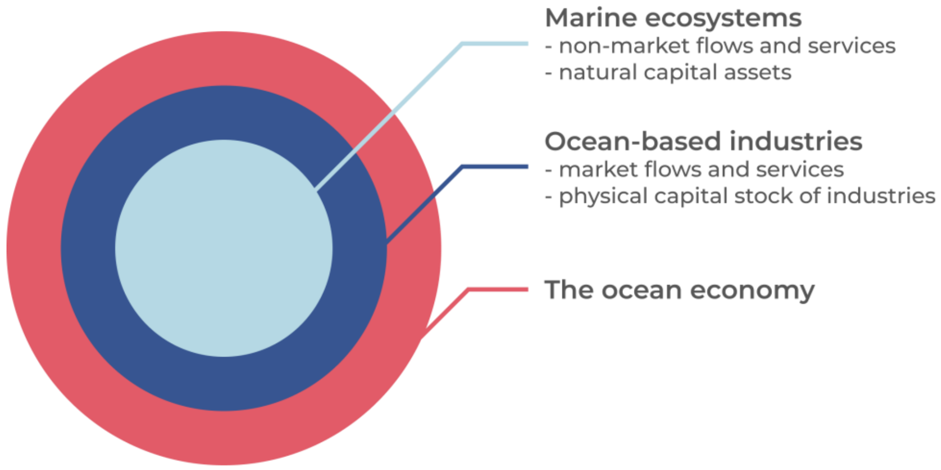
1. The high value addition generated by marine and coastal tourism industries attributes high cultural relevance to ocean ecosystems. To what extent these industries could be

affected by deep seabed mining is highly uncertain, but may have knock-on effects on health and socioeconomic development.
2. There are different approaches to valuing natural capital and the loss of ecosystem services. A common framework to value the deep sea has not been found in the course of this study.
3. Ocean-based industries are highly interconnected and one industry suffering from negative impacts from deep seabed mining may influence economic performance in another (non-)ocean-based industry.

Background:
A wide variety of industries is dependent on healthy and functioning ocean ecosystems, as illustrated in Figure 20. Those industries range from fisheries to coastal tourism. Estimating their value is a difficult econometric exercise. Estimating the total, commercial and non-commercial value added from our oceans is an even more daunting task. Difficulties already arise when deciding what types of industries should be included in the ocean economy. For instance, estimates on the value of the ocean published by WWF (Hoegh-Guldberg *et al.*, 2015), which are presented in Figure 21, do not include the value of the offshore oil and gas industry. Fossil fuel extraction is not considered to be an output generated by the oceans and thus not included. For comparison, Figure 22 presents estimates calculated by the OECD which do include the oil and gas industry.

On the other hand, the study published by WWF (Hoegh-Guldberg *et al.*, 2015) includes the value of ecosystem services, such as carbon absorption, in its estimate, while the OECD (2016) does not. These examples not only shed light on the methodological difficulties involved, but also provide interesting approximative values for the commercial benefits we derive from the oceans. For instance, WWF estimates the economic value for ocean carbon sequestration at US$4.3 trillion (Hoegh-Guldberg et al., 2015). From the OECD estimate, an approximate value for the cultural services provided by the ocean may be inferred, considering that the maritime and coastal tourism industry is valued at around US$800 million (OECD, 2016). Ultimately, these numbers also show us that both ocean ecosystems and the derived industries are highly interconnected. A collapse of one may thus significantly influence the economic performance of another.

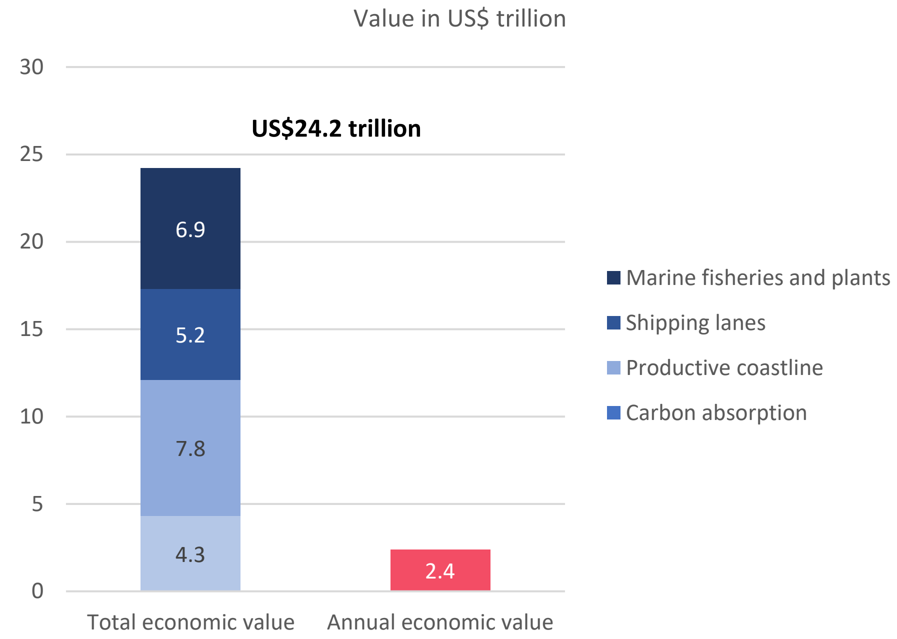
Figure 20 Marine ecosystems are at the heart of the ocean economy



Ocean-based industries	
Established industries	**Emerging industries**
Capture fisheries	Marine aquaculture
Seafood processing	Deep- and ultra-deep water oil and gas
Shipping	Offshore wind energy
Ports	Ocean renewable energy
Shipbuilding and repair	Marine and (deep) seabed mining
Offshore oil and gas	Maritime safety and surveillance
Marine manufacturing and construction	Maritime biotechnology
Maritime and coastal tourism	High-tech marine products and services
Marine business services	
Marine R&D and education	
Dredging	

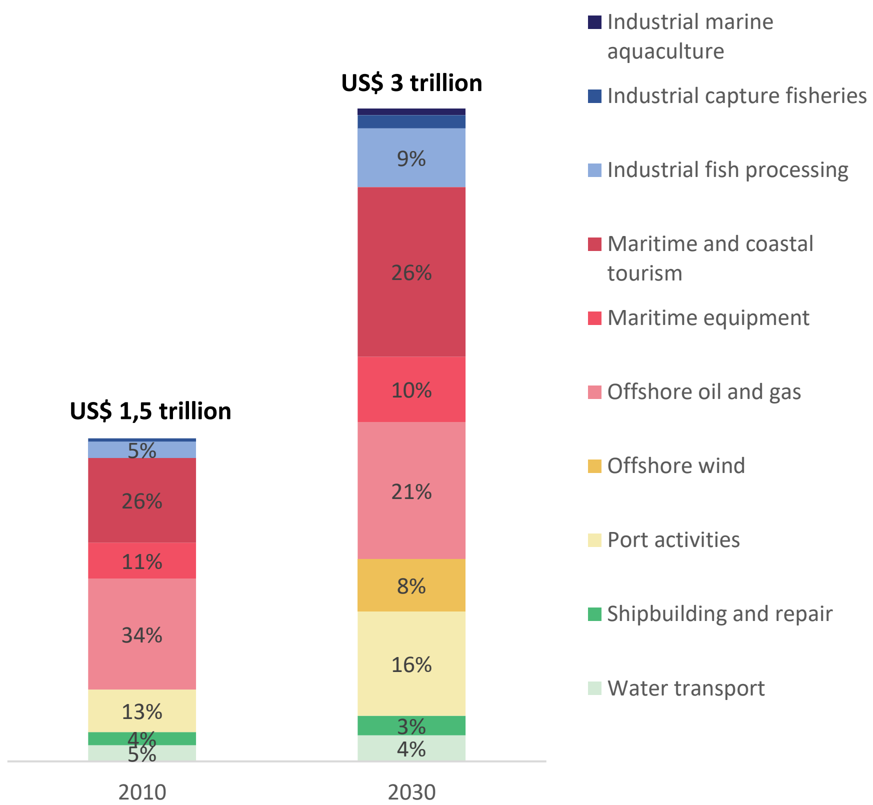
Source: created and adapted based on OECD (2016)

Figure 21 WWF estimate of the economic value of the ocean in 2015 (excl. oil and gas industry)



Source: Hoegh-Guldberg *et al.* (2015)

Figure 22 OECD estimate of annual ocean value-added output (2010 & 2030)



Source: OECD (2016)

7. **What happens if unexpected consequences are discovered?**
8. **What regulation is there around deep seabed mining?**

Are effective checks, balances and audits feasible for deep seabed mining operations?

Answer:
Deep sea operations are extremely expensive. This impedes extensive auditing and the collection of evidence to prove misconduct. In addition, appointing independent auditors with sufficient powers to report on deep seabed mining processes and incidents would be critical. The ISA is tasked with setting up a so-called Seabed Mining Directorate or Mining Inspectorate.

Knowledge gaps:
1. This study has found little insight into current possibilities and processes to monitor and audit deep seabed mining operations.
2. How independent monitoring and auditing activities would be financed is unclear.

Background:
The auditing and monitoring of deep seabed mining activities may prove to be extremely costly, with estimates of around US$80,000 per day for offshore research. Scholars have therefore called for the establishment of a separate and independent fund to be established under the auspices of the UN to fund auditing and monitoring activities (FFI, 2020).

The ISA is currently developing the regulations and standard contract terms, under which procedures will also be elaborated for site-specific environmental management and monitoring plans. These will also include emergency orders to prevent operations from causing serious harm as well as closure plans. Contained environmental regulations will also place on the ISA the requirement to develop regional-scale environmental management plans (also strategic environmental management plans) and a Seabed Mining Directorate or Mining Inspectorate. A draft of these regulations is expected in the course of 2020 (FFI, 2020).

What liability frameworks govern incidents of environmental damage in the deep sea?

Answer:
In the absence of a clear baseline and instruments and frameworks to quantify damages, liability claims against deep seabed mining companies may be difficult to prove. Up to now, no liability regime for deep seabed mining exists.

Knowledge gaps:
1. Frameworks to assess and quantify liability claims are yet to be developed.
2. Given the high degrees of uncertainty surrounding deep seabed mining, gaps in liability coverage are to be expected.
3. National legislation of sponsoring states may vary and be inadequate or incapable of handling deep seabed mining liability claims, bringing operators to justice and executing damage claims against them. In case of financial default by mining

operators, liabilities may ultimately be borne by the sponsoring states. Whether they themselves have the financial means to pay liability claims is questionable, in particular in the case of small (island) states with limited financial resources.

Background:
In the absence of a scientifically established baseline and accurate instruments and frameworks to measure potential impacts, assessing damages inflicted by deep seabed mining may be difficult if not impossible (FFI, 2020).

While a detailed liability regime for deep seabed mining operations has yet to be established, current legislation under UNCLOS suggests that any liabilities caused by deep seabed mining operators (companies) may ultimately fall back to the sponsoring state that supports the operator. In this case, it is up to the sponsoring state to have regulation in place to execute liabilities (Craik, 2018; Lily, 2018). A detailed explanation of this legal condition is provided below:

> *"In the case of mining in the Area, mining companies need a State sponsor. The State sponsor has to exercise due diligence to ensure that the mining company complies with International Seabed Authority rules, regulations, standards and procedures. There is no specific guidance for this and at present relationships are developed on a case-by-case basis. There is a requirement, though, to follow Best Environmental Practice and for the sponsor to exercise a high degree of due diligence following a ruling in 2011 by the Seabed Disputes Chamber of International Tribunal for the Law of the Sea (ITLOS). The ruling is detailed in The Advisory Opinion of the ITLOS Seabed Disputes Chamber on the responsibilities and obligations of States sponsoring entities with respect to activities in the Area. The ruling stressed that "due diligence" includes the need for all States to ensure they have the administrative capacity to monitor, supervise and enforce their laws. No State is exempt from this requirement due to the need to avoid the potential rise of 'sponsoring States of convenience' applying weaker regulatory measures. This means that States may need to introduce new laws, administrative procedures and resources to regulate their enterprises to meet the expected standard. If laws are not enacted and enforced States may be held liable for damage including to the marine environment."*
> (FFI, 2020)

What conflicts of interest does the sponsoring states mechanism of the ISA provoke?

Answer:
Under existing and envisaged legal instruments, the organ (the ISA) governing and policing deep seabed mining is ultimately also the one financially profiting from deep seabed mining. This provokes a conflict of interest at a regulatory level.

Knowledge gaps:
1. Liability regimes are unclear, as are investor-state arbitration proceedings under existing investment treaties and benefit-sharing mechanisms.
2. No legal instruments have been identified in the course of this study that warrant that individual sponsoring states or contractors are acting in the interest of humanity, while benefiting from exploiting a resource dedicated as the common heritage of humankind.

Background:
In the course of this study, the following conflicts of interest have been identified:

1. Becoming a sponsoring state may be lucrative for governments and states, because individual royalty-sharing terms can be negotiated with mining contractors.

2. The ISA is drafting the regulations governing deep seabed mining. At the same time, the ISA would also be responsible for collecting royalties from deep seabed mining and for their redistribution. Regulation may thus be biased towards maximizing royalty generation from deep seabed mining, with environmental concerns being of secondary importance (Aldred, 2019).

3. The ISA has recently opened its databases to the public. Data and technology sharing, however, remains an issue, while being essential to allowing for equal access and thorough monitoring (Woody, 2019).

4. UNCLOS requires the sponsoring state to supervise an operator's deep seabed mining activities, but:
   - It might not be in the interest of a sponsoring state to halt operations in case of misconduct, as this might mean losing out on royalties for the sponsoring state; or
   - Should a sponsoring state sanction a business for violations, such as by suspending its sponsorship, it might come under scrutiny from investors who may resort to investor–state arbitration to file liability claims.

5. Liability and investor-state arbitrations may ultimately weigh most heavily on small sponsoring states, which may struggle to pay out compensation awards and cover the cost of legal bills (Cotula & Berger, 2020).

6. The EU parliament has urged the European Commission to not support deep seabed mining, but member states may still act on their own in sponsoring deep seabed mining activities. The role of the EU and its member states in supporting deep seabed mining is unclear (European Parliament, 2018; Seas at Risk, 2018).

How can the international community participate in the decision-making process?

Answer:
Currently, scientific, legal and economic expert advisory bodies and diplomatic participation dominate the ISA's policy-making. Public engagement is limited, suffering in particular from an almost non-existent debate around deep seabed mining in the wider global population, on whose behalf the ISA ultimately acts.

Knowledge gaps:
1. Mechanisms for the wider global population to actively engage in the decision-making process around deep seabed mining are weak. This study has not identified ongoing actions by the ISA to significantly increase global public engagement.
2. In light of potential impacts that might span various generations, the ISA appears to have made little effort to represent the interests of future generations in current decision-making processes.

Background:
While UNCLOS designates the deep sea as Common Heritage of Humankind, the ISA interprets 'benefits' primarily in economic terms and has not addressed if and how those

benefits would be shared globally and equitably among all of humankind. Similarly, the ISA has not addressed how adequate public participation in decisions concerning all of humanity may be organized (Kim, 2017).

In the same way as technical and scientific advisory bodies are essential to taking decisions on deep seabed mining, so is the process of public participation. Scientific and economic expert views only represent a relatively small range of opinions among all of humanity, which is made up of heterogenous viewpoints. Public participation therefore plays a key role in allowing administrative bodies to capture a wide range of concerns and perceptions of risk and acceptability. As such, public participation is also important for applying the precautionary principle (Jaeckel, 2017). Public participation may involve the following elements (Jaeckel, 2017):

- The media
- Open discussion events
- Stakeholder surveys
- Election of an ombudsperson
- Establishment of an advisory body representing public groups or NGOs

Apart from growing awareness on seabed mining among the scientific community and communities of engaged small island states, public awareness of the debates around deep seabed mining and the ISA in the wider global population is minimal, if not non-existent. This represents a major challenge for the ISA in ensuring adequate public engagement (Jaeckel, 2017).

As an example for promoting public participation, the SPC-EU Deep Sea Minerals Project, supported by the EU and the Secretariat of the Pacific, has focused on promoting public consultation and participation (EU & SPC, 2014). Between 2011 and 2014, the project, among other achievements, has:

- Supported 15 in-country national stakeholder consultation workshops.
- Supported 6 countries to establish multi-stakeholder national offshore mineral committees.
- Supported 3 countries to run public awareness and consultation programmes.
- Produced a wealth of user-friendly information materials, including 15 themed information brochures and two 25-minute documentaries.

Ultimately, potential impacts of deep seabed mining are expected to span timeframes of generations. The question of how inter-generational interests are reflected in public participation has, however, not been addressed by this study.

9. Why are deep seabed mining operators often for-profit companies?

Who are the main corporate and governmental actors behind current deep seabed mining efforts?

Answer:
The main corporate and governmental actors involved in deep seabed mining are sponsoring states, international organizations such as the ISA and deep seabed mining contractors and investors, but national research institutions and universities are also heavily involved.

Knowledge gaps:

1. The mechanisms under which large multinational enterprises from developed countries currently engage with developing countries, and especially small island states, are vague. Investment offerings may put substantial financial pressure on them, in terms of both potential revenues as well as potential liabilities.
2. To what extent deep seabed mining is promoted by small island states in the search for new revenue sources is a complex issue. These states are potentially most affected by deep seabed mining impacts, but at the same time they are currently facing limited other opportunities for economic development.
3. The role and position of the EU in the promotion of deep seabed mining is currently unclear.

Background:
A list of current contract holders across different deposit types and associated sponsoring states is collected in Table 15 below. The table also shows the state of development of the mining technology developed by each contractor or state.

Table 15 Deep seabed mining contractors, sponsoring states and the status of developed mining technology

Contractor	Associated country	Associated companies or subcontractors	Developed mining technology
Polymetallic nodules/CCZ			
China Minmetals Corporation China Ocean Mineral Resources Research and Development Association	China China		• Rigid riser with self-propelled miner. • Tried different concepts of collector and lifting mechanisms.
Cook Islands Investment Corporation	Cook Islands		
Deep Ocean Resources Development Co Ltd	Japan		• Passive nodule collector tested at 2,200m depth. • Conducted field pilots.
Federal Institute for Geosciences and Natural Resources of Germany	Germany		• Scientifically accompanying Belgium and DEME Group in their trials.
Global Sea Mineral Resources (GSMR) NV	Belgium	DEME Group	• Development of Patania II nodule collector (crawler with riser). • Tested at 4,500m depth in the CCZ.
Government of the Republic of Korea	South Korea		• Design includes flexible riser system with self-propelled miner. • Developed 1/20 scale test miner. • Field trials conducted.
Institut francaise de recherche pour l'exploitation de la mer (Ifremer)	France		• Model studies on self-propelled miner with hydraulic recovery system.
Interoceanmetal Joint Organization (IOM)	Bulgaria, Cuba, Czech Republic, Poland, Russian Federation and Slovakia		• Conceptual design includes nodule collector, buffer, vertical lift system.

Marawa Research and Exploration Ltd Nauru Ocean Resources Inc Tonga Offshore Mining Limited	Kiribati Nauru Tonga	DeepGreen (Canada), Allseas (Switzerland, Netherlands)	• Minerals production vessel acquired by Allseas. • Collection, riser and offshore technology to be developed by Allseas. • Zero-tailings, onshore production process developed by Deep Green.
Ocean Mineral Singapore Pte Ltd	Singapore		
UK Seabed Resources Ltd (I and II)	UK	Lockheed Martin (US)	• Designs conceptualized. • Building on early work from Lockheed Martin.
Yuzhmorgeologiya	Russian Federation		
Polymetallic nodules/Indian Ocean			
Government of India	India		• Design includes flexible riser and multiple crawlers. • Crawler tested at 1,000m depth.
Polymetallic nodules/Pacific Ocean			
Beijing Pioneer Hi-Tech Development Corporation	China		• Includes rigid riser with self-propelled miner. • Tried different concepts of collector and lifting mechanisms.
Polymetallic sulphides/Indian Ocean			
China Ocean Mineral Resources Research and Development Association	China		• Includes rigid riser with self-propelled miner. • Tried different concepts of collector and lifting mechanisms.
Federal Institute for Geosciences and Natural Resources of Germany	Germany		
Government of India	India		

Government of the Republic of Kore	South Korea	• Design includes flexible riser system with self-propelled miner. • Developed 1/20 scale test miner. • Field trials conducted
Polymetallic sulphides/Mid-Atlantic Ridge		
Government of the Russian Federation	Russian Federation	• Collector and mining subsystems in trial stage.
Government of Republic of Poland	Poland	
Institut francaise de recherche pour l'exploitation de la mer (Ifremer)	France	
Cobalt-rich ferromanganese crusts/Pacific Ocean		
China Ocean Mineral Resources Research and Development Association	China	• Includes rigid riser with self-propelled miner. • Tried different concepts of collector and lifting mechanisms.
Japan Oil, Gas and Metals National Corporation	Japan	
Ministry of Natural Resources and Environment of the Russian Federation	Russian Federation	• Collector and mining subsystems in trial stage.
Republic of Korea	South Korea	
Cobalt-rich ferromanganese crusts/South Atlantic Ocean		
Companhia De Pesquisa de Recursos Minerais	Brazil	

Sources: self-compiled (ISA, 2020b; FFI, 2020)

A comprehensive list of further subcontractors in the field, such as equipment providers, consultancies and mining companies has been compiled by the Deep Sea Conservation Coalition in 2017 and can be accessed here.

In addition, the roles of the EU, other intergovernmental organizations and (industry) alliances need to be considered. For now, their roles remain vaguely understood. International renewable industry alliances, such as the Global Battery Alliance hosted by the World Economic Forum, may also play a key role in influencing future minerals demand and therefore the economic case behind deep seabed mining.

Who are the main financiers and insurers of deep seabed mining activities?

Answer:
Currently there are no standards or regulations actively prohibiting financiers and insurers from engaging in financing deep seabed mining. Also, many "green finance" principles do not yet cover deep seabed mining. This is why mainstream financiers and insurers such as Macquire or Allianz currently engage or consider engaging in deep seabed mining.

Knowledge gaps:

1. Deep seabed mining investments by large corporations such as Glencore or Maersk do not reach the attention of the general public. Nevertheless, pension funds and banks, which administer funds from the general public, may well be shareholders of these companies. They thereby indirectly engage money provided by the general public in deep seabed mining activities. Shedding light on these connections requires thorough research.
2. The future financing needs of the deep seabed mining sector are difficult to estimate.
3. The traditional insurance sector may well provide deep seabed mining companies with insurance against physical damages to their equipment. Insuring against ecosystem impacts, however, requires innovative and tailored products, often structured with the support of governments. How such instruments can be applied to deep seabed mining is still unclear.

Background:
Two expert views have been collected through interviews on the topic of financing deep seabed mining in the course of this analysis. The main points raised are summarized below:

- Deep seabed mining is currently still in the venture stage, not requiring huge amounts of capital. This means it can be very well financed by corporations themselves and their own financial means.

- Potentially large fees from mining operations are attractive for banks and insurers and there is interest in gaining deep seabed mining contractors as clients.

- There is not much strategic thinking among large mining corporations on deep seabed mining. Financing is often provided as venture capital, keeping them the option to engage in deep seabed mining more actively in the future. This venture capital is relatively small compared to the usual capital expenditures of mining corporations, but still supports deep seabed mining to take hold.

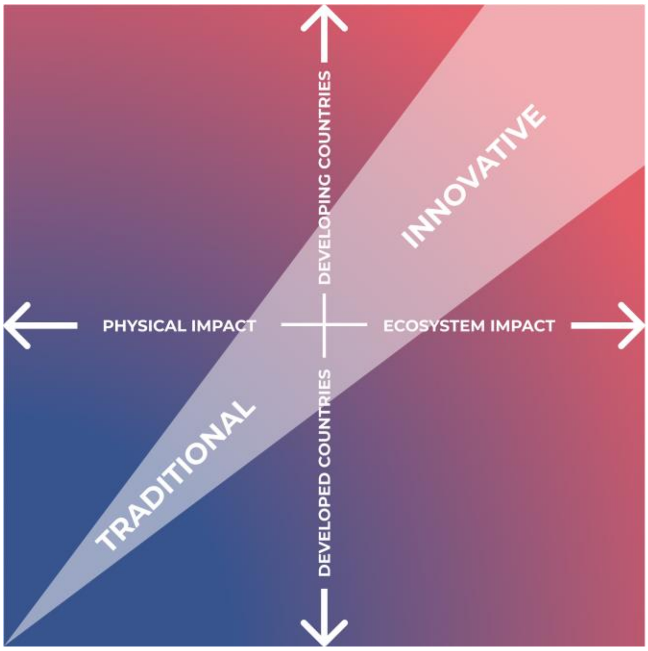
- Many international institutions, such as the World Bank or the EU, do not yet have a common and clear official position on deep seabed mining, leaving a vacuum for other investors to engage.

– ESG rankings are often superficial and do not represent the conditions on the ground, especially if grievance mechanisms and monitoring are weak or hard to achieve, as in the case of deep seabed mining. This, in combination with targeted marketing, can portray a wrong image about deep seabed mining being a "green industry". Financiers or insurers with little knowledge about deep seabed mining may thus consider it as a sustainable investment.

While the financing environment around deep seabed mining remains obscure and state-driven, public information from listed companies can yield early insights. For instance, public information is available on the financial support that the deep seabed mining start-up DeepGreen has received so far. Its current feasibility study is supported through Macquarie Capital and Fearnley Securities, which have led the latest US$150 million investment round. Strategic investors in this and other rounds include the Swiss-based marine engineering company Allseas (majority investor), which joins Glencore PLC and Maersk Supply Services A/S as previous investors in a US$77 million investment round (Sanderson, 2019; Barich, 2019).

With regards to insurance, there are many traditional insurance companies providing physical risk insurance for ocean-going equipment, including equipment used for deep seabed mining (Allianz, 2019; Niehörster & Murnane, 2018). However, insuring against the loss of ecosystem services is a nascent or rather non-existent field, often relying on governments or intergovernmental organizations to provide guarantees or recovery funds. The relationship between traditional insurance instruments and innovative insurance mechanisms regarding ecosystem service impacts is depicted in Figure 23. It becomes evident that effective insurance is also dependent on strong institutional frameworks, currently mostly limited to developed economies. Insurance protection for potential impacts on ecosystem services from deep seabed mining is currently not covered in traditional insurance mechanisms.

Figure 23 Traditional vs. innovative insurance solutions



Source: based on Niehörster & Murnane (2018)

What longer-term business models are pursued by involved companies?

Answer:
Little insight has been gained in the course of this study on the business models of different deep seabed mining operators. Nevertheless, rising metals demand and the economics around recycling, in tandem with high capital expenditure needed to commercialize deep seabed mining, hint that companies may be locked into deep seabed mining in the long term. For operators to switch to recycling does not appear to be a realistic option.

Knowledge gaps:

1. A lock-in may occur where deep seabed mining companies need to continue mining to recover capital, even if mineral demand and availability on land may change or new (recycling) technologies are developed.

Background:
The commercial models around deep seabed mining heavily depend on developments of the metals and minerals markets and actual future demand. While companies may vary the amount of minerals collected from the seafloor each year, there is still much uncertainty around the profitability of these operations, with current models often involving the sale of manganese to reach profitability. This would, however, provide substantial excess material to current manganese markets and may in reality not be feasible. Also, the number of deep seabed mining companies operating is critical, since more than two or three may already bring excess supply to a wide range of mineral segments and deteriorate profitability (Haeckel, 2019).

Whether it is realistic for companies, as stated for instance by DeepGreen, to move into the recycling industry and only engage in deep seabed mining for 15-20 years is highly uncertain (DeepGreen, 2020b). This would again heavily depend on the economics and associated costs. As we have established above, recycling may even in the long term not become price-competitive with deep seabed mining. Actors may focus on building their technological advantage in different fields of deep seabed mining, such as seafloor equipment or nodule and mineral processing. The latter may allow for an easier pivot towards recycling. Nevertheless, capital expenditure on mining equipment and technical and environmental research would be substantial until commercialization is achieved. The need to recover this capital would potentially lock companies into deep seabed mining for the long term.

How are expected business models governed under UNCLOS and how do they contribute to the global good?

Answer:
While UNCLOS prescribes the financial contributions that have to be paid by contractors to the ISA, no concrete mechanisms for the redistribution of these funds towards humanity have yet been defined. Deep seabed mining may contribute in various forms to the global good, such as through generating economic growth and funding deep sea and marine research.

Knowledge gaps:

1. The equitable redistribution among all of humanity and future generations has yet to be defined and adequate mechanisms need to be set up.
2. Varying accounting methods may yield opportunities for contractors to minimize financial contributions to the ISA and the common good.

3. Like the uncertainties surrounding the negative impacts of deep seabed mining, positive contributions to the global good are difficult to estimate. Despite the attempts of some researchers, no comprehensive cost-benefit analysis of deep seabed mining has been identified in the course of this study.
4. How benefit- sharing mechanisms would be applied to communities of UNCLOS non-member states has not been researched, but it is clear that they too form part of humanity.

Background:
UNCLOS has defined the financial contribution that a contractor has to pay to the ISA in Annex III, Article 13 as summarized in Table 16. However, UNCLOS does not prescribe the financial mechanism through which the collected benefits of seafloor mineral exploitation are to be redistributed, other than in an "equitable" manner (UNCLOS, 1982; FFI, 2020). This not only raises questions around the interpretation of "equitable distribution" among humanity to date, but also about intergenerational equity. In addition, the provisions defining the financial contributions to be made to the ISA leave leeway for different accounting practices to be applied and may well be prone to corruption, as may be the mechanisms for redistributing the contributions.

Table 16 Financial contributions to be paid by licence holders to the ISA

Type of financial contribution payable	Amount or calculation scheme
Administrative application fee	US$500,000 per licence application
Annual fee for commercial licence	US$1,000,000 per year per licence
Variable financial contribution (two options):	
A) Paying a production charge	**Production charge** Years 1-10: 5% Years 11-end: 12% As % of the market value of the processed metals
B) Paying a combination of a production charge and a share of net proceeds	**Production charge:** Phase I: 2% Phase II: 2-4% (depending on ROI) As % of the market value of the processed metals **Share of net proceeds:** (Period I / Period II) ROI 0-10%: 35% / 40% ROI 10-20%: 42.5% / 50% ROI >20%: 50% / 70% As calculated on the basis of "attributable net proceeds" from mining in the area.

Source: UNCLOS (1982)

Apart from financial contributions being paid to the ISA, potential benefits of deep seabed mining may include (FFI, 2020):

- Driving and supporting global economic growth
- Mineral supply security and independence for states
- Funding and advancing deep sea and marine research and science
- Channelling of funds towards developing countries and the social good
- Minerals supporting "green" technologies
- Enabling emerging mineral-based appliances and markets
- Deep seabed mining yields various metals at once and is hence not so sensitive to price fluctuations
- Inexpensive transportation by sea can be utilized compared to mining on land
- Existing port facilities can become supply hubs and drive local economic growth
- Onshore processing can be performed at favourable locations regarding cost and proximity to market.

What investor regulations and guidelines apply to the financiers of deep seabed mining?

Answer:
Specific investor regulations or guidance on deep seabed mining have not been identified in the course of this study. Investors may take guidance from more general ESG investing guidelines. Knowledge about deep seabed mining remains limited among investors.

Knowledge gaps:

1. Investor regulations would have to take project-level as well as the cumulative impacts of deep seabed mining into account.
2. Little information is available on the public opinion of large investment banks or public investment bodies supporting deep seabed mining.
3. Current investment in deep seabed mining can be considered venture capital and may fall under special investment regimes or regulations.

Background:
Few opinion pieces by investment or asset management companies have been found on the topic of deep seabed mining. Nevertheless, an opinion published by Amundi, one of the ten biggest asset managers measured by assets under management (AUM) in the world, is reproduced below:

> *"Despite the opportunity presented by deep-sea mining, the sector faces several challenges. In addition to economic, technological and regulatory obstacles, there is also a lack of knowledge on the ecosystems in these environments, and on the disruptions that will be caused by mining. Because of these uncertainties, it is difficult to accurately assess underlying ESG risks. In order to preserve this unique environment, we recommend using a precautionary approach when rating companies involved in these activities and to not invest in those that produce no serious studies on their environmental and social impact.*

Lastly, it is important to continue to further develop mineral recycling, which ultimately should reduce the need to mine new resources. We encourage companies to adhere to this rationale." (Amundi, 2017)

Among the United Nations-supported Principles for Responsible Investment, the principles with the most potential relevance for investments in deep seabed mining are the following (PRI Association, 2020):

Principle 1: We will incorporate ESG issues into investment analysis and decision-making processes.

- Support development of ESG-related tools, metrics, and analyses.
- Assess the capabilities of internal investment managers to incorporate ESG issues.
- Advocate ESG training for investment professionals.

Principle 2: We will be active owners and incorporate ESG issues into our ownership policies and practices.

- Develop and disclose an active ownership policy consistent with the Principles.
- Exercise voting rights or monitor compliance with voting policy if outsourced.
- Develop an engagement capability either directly or through outsourcing.
- File shareholder resolutions consistent with long-term ESG considerations.
- Engage with companies on ESG issues.
- Participate in collaborative engagement initiatives.

Principle 3: We will seek appropriate disclosure on ESG issues by the entities in which we invest.

- Ask for standardized reporting on ESG issues using tools such as the Global Reporting Initiative.
- Ask for ESG issues to be integrated within annual financial reports.
- Ask for information from companies regarding adoption of and adherence to relevant norms, standards, codes of conduct or international initiatives such as the UN Global Compact.
- Support shareholder initiatives and resolutions promoting ESG disclosure.

10. How will deep seabed mining contribute towards a closed loop economy?

What is the expected timeline for the extraction of deep sea mineral resources?

Answer:
Commercialization of deep seabed mining may occur in the next 5-20 years, with single deep seabed mining licences expected to last for up to 40 years of extraction. Economic shocks may delay these timelines, while technological advancements may accelerate them.

Knowledge gaps:

1. The technological and economic readiness of deep seabed mining contractors is difficult to estimate.
2. The impact of the current economic downturn on the timeline for deep seabed mining is uncertain.
3. Whether commercial and environmental timelines and research agendas are aligned remains disputed.

Background:
Different estimates exist around when deep seabed mining could reach commercialization, ranging from 2025 to 2040+. The World Economic Forum, for instance, assumes deep sea minerals will be established as a resource by 2030 (WEF, 2019). Estimates on how long deep seabed mining could persist once established depend on mineral availability and demand. Some resources, and in particular polymetallic nodule collection licences in the CCZ, are expected to provide enough minerals for 20-40 years of extraction each (Volkmann & Lehnen, 2018). While these timeframes do not match those of deep sea ecosystem life-cycles, they are still significant and potentially new technological or environmental findings may need to be considered with time passing (WEF, 2019).

It is also important to revisit earlier estimates of the timeline of deep seabed mining, such as the one below provided by the MIT (2011), and assess if estimates match actual progress:

2012-2020: Exploratory mines and extraction technologies developed

2020-2025: Strict restrictions established to protect environment and minimize impacts

2025-2035: New technologies developed matching latest scientific insights

2035-2040: Implementation of those technologies occurs at a more rapid pace

2040+: Further expansion of deep sea mines across the oceans

Current exploration licences held by contractors and issued by the ISA are limited to 15 years (ISA, 2020b).

How do deep sea ecosystem life-cycles compare to expected extraction timelines?

Answer:
Deep sea ecosystems function at timescales of hundreds to thousands to millions of years. Deep seabed mining operations may "only" last decades but can bring significant impact on those ecosystems, disrupting biological and chemical cycles and processes of planetary scale and evolutionary timeframes.

Knowledge gaps:

1. The time and geographical scales at which deep sea ecosystems function are not yet fully understood.
2. Knowledge gaps regarding the impact of deep seabed mining will persist, since scientific studies cannot be conducted over timeframes at which deep sea ecosystems usually function.

Background:
As discussed above, deep seabed mining operations may last up to 40 years under a single production licence and may impact between 200-800km² per year (in the case of polymetallic nodule collection). An overview of the scales and timeframes at which deep sea ecosystems function is presented in Table 17 below:

Table 17 Scales at which deep sea ecosystems function and their implications for deep seabed mining

Observations concerning the scales at which deep sea ecosystems function
Species life-cycles: – Some deep sea species can live several hundred years. – Cold temperatures and little available energy create metabolic constraints that slow down organisms. – Reproduction is metabolically expensive, which is why some species take many years to reproduce. – Only some deep sea organisms exhibit metabolic rates similar to shallow water organisms. – Smaller organisms can tolerate temperature shifts better than larger organisms. – Thermal energy strongly influences biological assemblages at microscopic scales. – Chemical energy affects processes at macroscopic scales.
Ocean cycles: – The atmosphere's CO_2 concentration is determined by the chemistry of the oceans over timescales of thousands of years. – A carbon atom spends about 5 years in the atmosphere, 10 years in terrestrial vegetation, and 380 years in intermediate and deep ocean waters. – Over timescales of hundreds to thousands of years, polymetallic nodules influence the ocean's carbon cycle, dissolution of calcium carbonate, and atmospheric carbon dioxide concentrations. – Carbon can remain locked up in ocean sediments or fossil fuel deposits for millions of years. – It takes 1,000 – 1,200 years for a drop of water to circulate the world's oceans.
Geologic cycles: – Polymetallic nodules take >10 million years to form.

Ecosystem services:

- Some ecosystem functions may only occur on the scale of microns to metres and timescales up to years, with the derived services becoming useful only after centuries of integrated activity.
- Small and slow processes over vast areas can create massive services.
- Large and fast processes on small spatial scales can equally create massive, often far detached, services.

Implications for deep seabed mining:

- Environmental management is dependent on the ability to recognize and act on deep sea characteristics.
- The timing of baseline and monitoring data collection must be scientifically relevant to deep sea ecosystems.
- Timelines for detecting and monitoring the impacts on deep sea processes may conflict with the timelines for deep seabed mining and individual project progression.

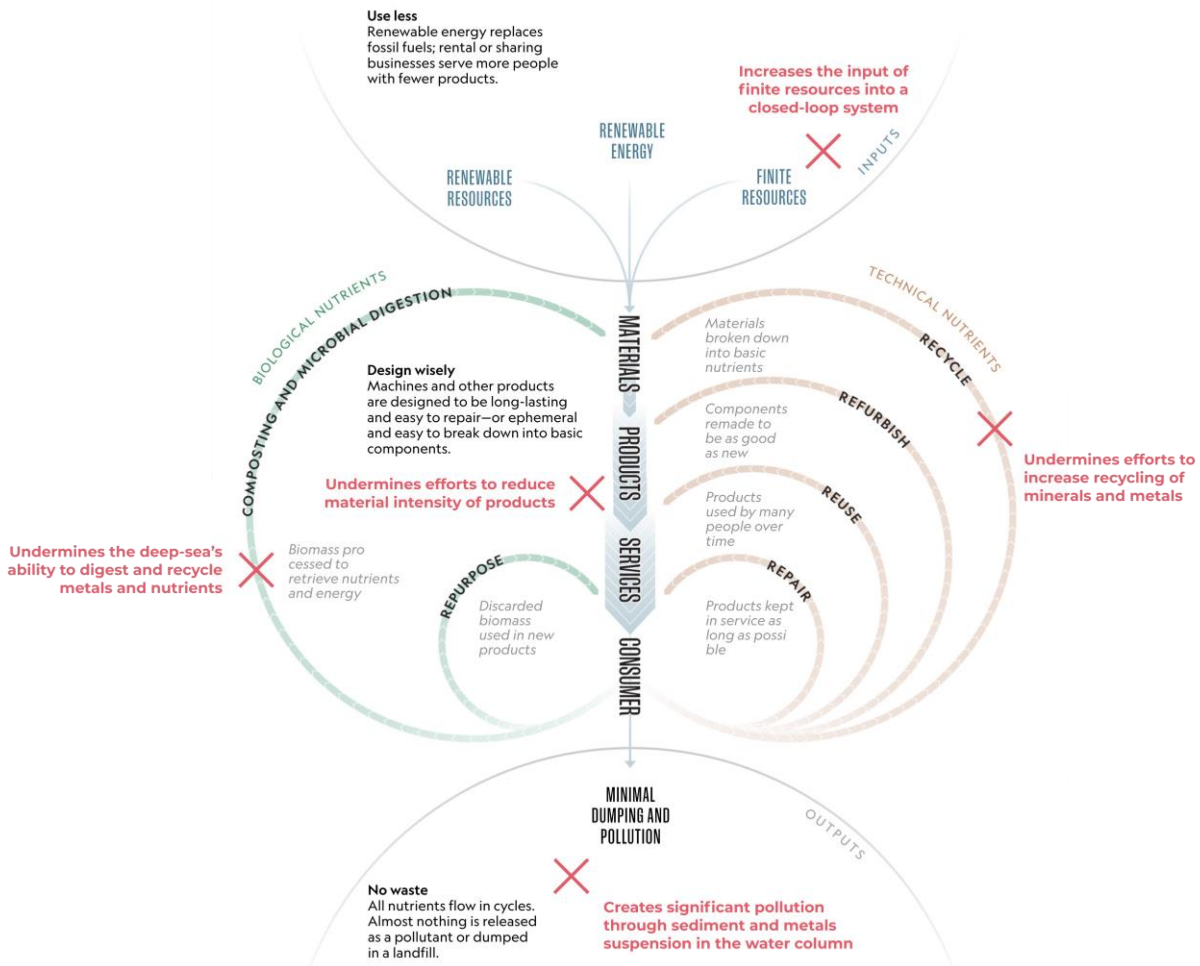
Sources: own compilation based on various studies (Danovaro *et al.*, 2017; Thurber *et al.*, 2014; FFI, 2020)

Conclusion

The depletion of land-based resources caused by rising demand for minerals and metals for low-carbon energy technologies, such as renewables and electric mobility, is currently boosting interest in marine mineral resources. While some commercial operations are already taking place on shallow seabed deposits and within national jurisdictions, much richer mineral deposits in the deep sea are only now moving into the realm of commercial and technical feasibility. Governed by the ISA, exploration contracts have been issued to a variety of countries for the mining of the three main deep sea deposits: (i) seafloor massive sulphides, (ii) ferromanganese cobalt-rich crusts, and (iii) polymetallic nodules.

The exploitation of these deposits carries significant environmental, social and economic risks. Not only at a project level, but in particular at the intended scale of impacting millions of square kilometres, deep seabed mining would negatively and irreversibly affect biodiversity and alter global chemical cycles. The arising consequences are likely to disrupt the entire ocean ecosystem together with the livelihoods depending on it. Providing political and financial support to deep seabed mining ventures therefore contradicts current efforts to move towards a sustainable, carbon-neutral and circular global economy. The rationale behind this argument is visualized in Figure 24 and discussed in more detail below.

Figure 24 Deep seabed mining and its implications for a closed-loop economy



Source: adaptations introduced into original illustration from Kunzig (2020)

I. Deep sea minerals accumulate over millions of years and are essential to deep sea ecosystems

Deep sea mineral deposits are not only finite resources, like fossil fuels, but also essential building blocks for the functioning of marine ecosystems. Whether polymetallic nodules, seafloor massive sulphides or cobalt-rich crusts, deep sea mineral deposits accumulate over millions of years and support unique forms of life in the most unexplored regions of our planet. Bacteria and other, larger organisms thriving on these deposits form an important part of global food chains (FFI, 2020). The removal of deep sea mineral deposits may thus lead to the collapse of marine ecosystems, global fisheries and coastal economic activities. This is further exacerbated by the fact that deep sea organisms are characterized by particularly low levels of resilience against external shocks (Miller *et al.*, 2018). Once disturbed, they are unlikely to recover within human timescales. Overall, this means that by extracting finite mineral resources from the deep sea, we would in fact negatively impact the availability of other, more essential and above all renewable ocean resources.

II. Deep seabed mining would undermine efforts to increase recycling of minerals and metals

Recycling will likely not be sufficient to significantly reduce primary mineral demand in the short- to medium-term future. Considering the rapid rise in demand for minerals from renewable energy and electric mobility technologies, the recycling sector is required to grow rapidly. However, currently low metal stocks in circulation, the long lifetime of batteries and solar cells, and low-cost competition from the mining sector prohibit recycling from rapidly increasing in scale. At present, recycling is particularly labour intensive, compared to the capital-intensive mining sector. With labour costs expected to rise and capital costs expected to fall over the coming years, recycling is likely to remain the less price-competitive method to produce metals (OECD, 2019). While it is true that recycling efforts are being stepped up due to increasing policy action and the desire by companies to secure stable material supplies, major technological and societal shifts would be needed to close the loop in mineral supply chains.

Not underestimating the possible speed of technological change in this area, deep seabed mining, however, could be characterized by an even higher degree of automation and capital intensity. Being labour-lean, it would compete in the lower-cost segment of mining operations and has the potential to provide cheap minerals at large quantities to global markets. This would not only undermine efforts in the land-based mining sector to become more efficient (by for instance extracting higher-cost ores from existing reserves) but would also impede efforts in the recycling industries to recover metals from already produced products at a competitive price.

III. A cheap supply of minerals would undermine efforts to reduce material intensity in production

Similar to the case of recycling, reducing material intensity in the production of EV batteries, solar panels or wind turbines is mostly driven by the desire to minimize cost. Raw material input is a major cost factor, particularly in the production of EV batteries. In the desire to make EVs affordable to a wide range of customers and threatened by rising metal prices, manufacturers seek to reduce production costs by reducing the material intensity of their products. With large quantities of minerals potentially becoming available through deep seabed mining and fuelling competition from land-based mining operators, metal prices may drop significantly and a major incentive to reduce material intensity in manufacturing industries would be diminished.

IV. Impacts from deep seabed mining would threaten ocean carbon, metals and nutrient cycles

The formation of deep sea mineral deposits through sedimentation and chemosynthesis balances ocean chemistry. Metals reach the ocean through a number of pathways, including volcanic activity or erosion and sediment run-off from land. They are vital to almost all forms of life as so-called trace metals, regulating biochemical processes in organisms and even within humans. At high concentrations, however, they are prohibitive to life and turn toxic. This also holds true for ocean ecosystems and ultimately the fish we eat and cherish. The accumulation of metal deposits in the deep sea plays an essential part in keeping ocean metal concentrations at a balanced and life-supporting level (FFI, 2020). Reaching this balance has taken millions of years. Removing minerals from the deep sea would not only release already accumulated metal particles back into the water through sediment dispersion but would also destroy the habitat of bacteria that digest and remove metals from the ocean waters. As a consequence, the ocean's ability to recycle metals and keep ocean chemistry balanced could be irreversibly compromised.

Similar impacts are expected on global carbon and nutrient cycles. As part of the ocean biological pump, the deep sea is removing and storing 5-15 billion tonnes of carbon each year from the atmosphere. A carbon atom spends about 5 years in the atmosphere, 10 years in terrestrial vegetation, but almost 400 years in intermediate and deep ocean waters (Danovaro *et al.,* 2017; Thurber *et al.*, 2014; FFI, 2020). Responsible for this are ocean currents, created by the Earth's rotation and powerful winds that move carbon-rich water to the ocean floor. There, productivity of life itself is responsible for removing and storing carbon away from the atmosphere. In the absence of sunlight but benefiting from the presence of metal elements, deep sea organisms perform chemosynthesis. They form organic compounds from carbon dioxide that is dissolved in the sea water. This process is called primary production and the formed organic compounds become the basis of the food chain. Deep seabed mining could impact large areas where these processes take place and thereby compromise the ocean's ability to cycle nutrients and carbon on the planet.

V. Deep seabed mining operations would create significant pollution

Removing minerals from deep sea deposits involves the use of heavy equipment, over large areas and over extended periods of time. A single mining operation for polymetallic nodule collection is expected to adversely impact an area of up to 800km^2 per year. This would be equivalent to the size of New York City and within a few years, with various contractors operating, an area half the size of Europe could be impacted. High degrees of uncertainty surround these estimates and especially the impacts of the sediment plumes that would be created by the equipment operating on the ocean floor. While 200-300km^2 would be impacted directly by the equipment of a single operator each year, swirled-up sediments may travel even further and may take years to settle completely. Deep sea sediments are particularly light and deep sea currents are particularly slow, making these environments vulnerable to rapid disturbances. Over the course of a single year, a polymetallic nodule operation would suspend up to 45 million m^3 of wet sediment or 15 million tonnes of dry matter – which is equivalent to 41 times the Empire State Building – as fine powder into the water column. This suspended sediment would not only release large quantities of metal particles back into the water but would also cover and potentially destroy the habitat of deep sea organisms that perform the life-supporting processes described above (Volkman & Lehnen, 2018; Haeckel, 2020; FFI, 2020).

It is the cumulative impact of numerous deep seabed mining operations over the years and over very large areas that has the potential to profoundly disrupt the ocean ecosystem. Similar to fishing or pollution from land, where the ocean may be able to absorb and counterbalance single incidents, it is persistence over time and scale that would compromise life in the ocean. Ocean ecosystems are closely interconnected through currents and nutrient flows. This would amplify and disperse impacts from deep seabed mining, with effects being possibly felt far away from the operations. Disrupting fish larvae dispersion in the deep sea through the suspension of sediments, for instance, may cause the collapse of a faraway costal fishery and ultimately threaten the livelihoods of communities on land.

Providing ocean minerals for the low-carbon transition and arguing for potential benefits needs to be balanced against the backdrop of the full picture of these effects. While benefits may be realized in the short term, deep seabed mining may undermine the long-term functioning of our ecosystems at an irreparable scale.

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