

Study to investigate the state of knowledge of deep-sea mining

Final Report under FWC MARE/2012/06 - SC E1/2013/04

Client: European Commission - DG Maritime Affairs and Fisheries

Rotterdam/Brussels, 28 August 2014

ECORYS 



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List of abbreviations

ABNJ	Areas Beyond National Jurisdiction
Ag	Silver
Au	Gold
AUV	Autonomous underwater vehicles
BGR	Federal Institute for Geosciences and Natural Resources of Germany
CAPEX	Capital Expenditure
CBD	Convention on Biological Diversity, 1992
CCZ	Clarion-Clipperton Zone
CLCS	Commission on the Limits of the Continental Shelf
CNMI	Commonwealth of the Northern Marina Islands
Co	Cobalt
Cu	Copper
DRC	Democratic Republic of Congo
DSHMRA	Deep Seabed Hard Minerals Resources Act
EEZ	Exclusive Economic Zone
EIA	Environmental impact assessment
EIP	European Innovation Partnerships
EITI	Extractive Industries Transparency Initiative
EOL-RR	end-of-life recycling rate
ESA	European Space Agency
EU	European Union
Eurometaux	European Association of Metals
FP7	7th Framework Program
IMMS	International Marine Minerals Society
IMO	International Maritime Organization
IODP	International Ocean Discovery Program
IRR	Rate of Return
ISA	International Seabed Authority
ITLOS	International Tribunal for the Law of the Sea
Li	Lithium
LME	London Metal Exchange
LTC	Legal and Technical Commission
MAR	Mid Atlantic Ridge
Mn	Manganese
MPA	Marine Protected Area
MSFD	Marine Strategy Framework Directive
MSP	Marine spatial planning
Mt	Million ton
NASA	National Aeronautics and Space Administration

Ni	Nickle
NIOT	National Institute of Ocean Technology
nm	Nautical mile
NOAA	National Oceanic and Atmospheric Administration
NORA	Nordic Ocean Resources AS
NPV	Net present value
OCSLA	Outer Continental Shelf Lands Act
OCT	Overseas countries and territories
OMZ	Oxygen Minimum Zone
Part XI Deep Sea Mining Agreement	Agreement relating to the Implementation of Part XI of the United Nations Convention on the Law of the Sea of 10 December 1982, 1994
PGE	platinum-group elements
PGM	platinum group metal
PNG	Papua New Guinea
Pt	Platinum
RALS	Riser and Lifting System
RC	Recycled content
REE	Rare Earth Element
ROV	Remotely operated vehicles
SAC	Special Area of Conservation
SEA	Strategic environmental assessment
SMD	Soil Machine Dynamics
SPA	Special Protected Area
SPC	Secretariat of the Pacific Community
Te	Tellurium
Th	Thorium
TRL	technology readiness level
UNCLOS	United Nations Convention on the Law of the Sea, 1982
UNEP	United Nations Environment Program
WEEE	waste of electrical and electronic equipment
Zn	Zinc



Preface

This report gives an overview on the current and latest state of knowledge of deep-sea mining, with a focus on the potential from a geological perspective, the relevant technologies, the economic viability, environmental implications, the legal regime under which seabed mining operates, and an inventory of ongoing exploration and exploitation projects.

The report is based on an extensive desk-based research, literature review, interviews with stakeholders and expert workshops. We would like to express our sincere thanks to all who have contributed to this study. The study is not aimed to produce new knowledge or innovations but rather to bring together all available information and data currently present on the matter.

The main report presents the overall findings in a coherent storyline. Detailed information on the various aspects of deep-sea mining as well as more detailed description of underlying data and figures is presented in of the annexes attached.

It should be noted that this study has been carried out by an independent team of consultants and researchers and that the report represents the views of the consultant, which do not necessarily coincide with those of the Commission.

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Executive Summary

Deep-sea mining is part of the EU's Blue Growth strategy under the thematic area of marine mineral resources. Deep-sea mining is part of the wider activity of marine mining which also includes mining of aggregates and other materials such as phosphates, tin, diamonds and tin in shallower waters.

Deep-sea mining has become particularly important in recent years as, after many decades of research and interest into seabed mineral reserves, technological developments have allowed us to exploit previously unreachable deposits and increasing demand and resulting price increases in combination with a scarcity of some materials have triggered a renewed attention for the possibilities of exploiting deep sea resources. At the same time, concerns have been raised concerning the potential impacts of these activities.

At this stage, the Commission is preparing a position vis-à-vis the development of this activity. To this end, this scoping study was commissioned. The aim is to provide the European Commission with a coherent set of information on the current state of knowledge of the legal framework, economic feasibility and environmental impact of accessing and extracting relevant and strategic deep sea minerals, as well creating an overview of ongoing exploration and exploitation efforts and the potential competitive position of European industry. Whether or not deep-sea mining will become an important commercial activity, and to which extent EU stakeholders will be able to play a role, depends on a large number of factors.

First an overview is given of the key issues and parameters the three different deposit types that are currently considered for deep-sea mining.

Table 1.1 Key factors related to the three deposit types

Deposit type	Polymetallic sulphides	Polymetallic nodules	Cobalt-rich crusts
Main metal contents ¹	Copper, Silver, Zinc	, Cobalt, Copper, Nickel, traces of molybdenum and REE (rare earth elements (commercial viability of Manganese processing debatable)	Cobalt, Nickel, Copper, Platinum Group metals, Thorium, Tellurium, Lithium, other REE
Demand	Increasing demand for metals across the board, with some variations, driven by global economic growth and a growing intensity of electronics and high-tech in daily life. Different price ranges depending on abundance, annual consumption and role of each metal.		
Security of supply relevance	No, metals abundantly present in terrestrial sources	Yes (Cobalt and REE, Democratic Republic Congo as main source for cobalt, role of China in REE)	Yes (Cobalt and several other minerals incl REE). See nodules.

¹ See list of abbreviations

Deposit type	Polymetallic sulphides	Polymetallic nodules	Cobalt-rich crusts
Seabed potential	Only small deposits identified, resource definition so far limited	High potential for Co	High potential for Co (seabed potential larger than terrestrial resource)
(Technical) ability	Concrete first exploitation attempts. Nautilus, Atlantis II Deep No full scale rising system proven yet (addressed in Blue Mining project)	Cook islands Seabed system (collector) concept designed. No full scale tested rising system available yet (addressed in Blue Mining project) Mineral processing to get out trace elements and REE from anoxide ores. Scientific research by China and Japan (?)	Interests shown/ exploration by China, Russia, Japan, Brazil, but technology development still pending. The EU-funded (Blue Mining project also addresses this deposit category (as well as the others) Mineral processing issues idem as for nodules
Environmental issues	<p>The main environmental impacts for all three deposits concern:</p> <ol style="list-style-type: none"> 1. loss of substrate, 2. effects of mining on the seabed, the operational plume and re-sedimentation and 3. discharge plume and its effects on pelagic and/or benthic fauna depending on the depth of discharge, <p>One of the most important impacts is the actual removal of the minerals, which can severely damage the sea bed eco-system. Another impact will be the spread of sediments which depending on the depth, technology, currents and the types of deposits mined can have varying levels of impacts. Potential pollution from ships onto the surface water and noise pollution from the vessels as well as the underwater equipment can potentially have negative impacts, but the largest effects relate to the activities on the sea bed itself. As for all mining activities the disposal of tailings² on land or sea can also have long term impacts. Key issue that deep-sea ecosystems are largely unexplored and their resilience to human interference in some cases is still unknown.</p>		

The key metals listed in the table can be also be related to the review of critical raw materials³ as carried out by the European Commission as well as to the implementation of the Raw Materials Initiative. Sufficient access to critical raw materials as found in deep sea deposits is crucial for the European manufacturing sector and subsequently for maintaining the competitiveness of Europe's Member States. The EU is increasingly dependent on imports for some of these raw materials, with 49% of the critical raw materials⁴ being resourced from China. But also the dominant position of the

² waste and refuse remaining after the ore has been processed

³ http://ec.europa.eu/enterprise/policies/raw-materials/critical/index_en.htm

⁴ Antimony, Beryllium, Borates, Chromium, Cobalt, Coking Coal, Fluorspar, Gallium, Germanium, Indium, Magnetite, Magnesium, Natural Graphite, Niobium, Platinum Group Metals, Phosphate Rock, REE (Heavy), REE (Light), Silicon Metal, Tungsten have been identified as critical raw materials as per the study in 2014
http://ec.europa.eu/enterprise/policies/raw-materials/files/docs/crm-report-on-critical-raw-materials_en.pdf

Democratic Republic of Congo in the production of cobalt is relevant in this respect.. Having one country exert such influence over the accessibility of certain resources can result in price and/or access fluctuations which in turn can have a negative impact on planning, forecasting as well as – in case of lack of access to resources – production for European enterprises. The importance of deep-sea mining lies partially in the fact that it would allow access to new deposits and hence supply sources for these critical metals.

The seabed potential

Polymetallic sulphides (also known as seafloor massive sulphides – SMS) are occurrences of metal-bearing minerals that form on and below the seabed as a consequence of the interaction of seawater with a heat source (magma) in the sub-seafloor region of volcanic ridges and along volcanic arcs. They are typically found on and around mid-ocean and back arc ridges where they are formed in the process of tectonic movements. The total number of such vent sites that exists on the modern sea floor is not known, although several hypotheses have been used to infer their abundance.

Based on our review, we assess that the size of an individual sea floor massive sulphide deposit varies from a few tonnes to >15 million tons (Mt) of ore material. However, reliable size estimates are very rare since drilling information is needed to accurately infer the tonnage of polymetallic sulphide occurrences. This information is only present for very few sites. For most occurrences information on their size relies on visual estimates of the surface area that is covered by hydrothermal precipitates. Most of the explored polymetallic seafloor sulphide occurrences are small⁵. The exceptions to this are the brine pool deposits in the Red Sea, including the Atlantis II Deep deposit, which is by far the largest known metal deposit (90 Mt) on the modern seafloor⁶.

Polymetallic nodules occur widely on the vast, sediment-covered plains of the abyssal ocean at depths of about 4 000 to 6 500 m. They are mineral concretions made up of manganese and iron oxides that can be found in sizes as small as golf balls or as big as large potatoes. The greatest concentrations of metal-rich nodules occur in the Clarion-Clipperton Zone (CCZ), which extends from off the west coast of Mexico to as far west as Hawaii. Nodules are also concentrated in the Peru Basin, near the Cook Islands, and at abyssal depths in the Indian and Atlantic oceans.

Manganese and iron are the principal metals in polymetallic nodules. The metals of greatest economic interest, however, are nickel, copper, cobalt, and possibly manganese if this can be extracted and processed in a commercially viable manner. In addition, there are traces of other valuable metals, such as molybdenum, rare-earth elements (REE), and lithium that have industrial importance in many high-tech and green-tech applications and can possibly be recovered as by-products once appropriate extraction and processing techniques have been developed.

Cobalt-rich **polymetallic crusts** precipitate onto nearly all rock surfaces in the deep ocean that are free of sediment. Here, they form pavements of manganese and iron oxides. Polymetallic crusts may also coat rock pebbles and cobbles. Their thickness varies from less than 1 millimetre to about 260 millimetres. They form at water depths of 600 to 7 000 m on the flanks of volcanic seamounts, ridges, and plateaus.

Many seamounts are within the Exclusive Economic Zones (EEZs) of Pacific Island states. The Atlantic Ocean has fewer seamounts. Cobalt-rich polymetallic crusts are often associated with

⁵ Less than one million tonnes

⁶ We distinguish between modern and ancient seafloor. Copper, zinc, lead, silver, and gold are often mined from ancient black smoker deposits (co-called VMS deposits) that were transferred from the ancient seafloor onto land through geological processes (obduction). They occur in various countries e.g. Spain and Portugal, Russia and Cyprus or Germany.

hydrothermal activity at seafloor-spreading centres, with the exceptions of the northeast and northwest continental margin areas. Cobalt is one of the trace metal of greatest economic interest and commonly shows values greater than 0.5 weight % Cobalt. Another metal of great interest is Tellurium (Te), which globally averages about 50 ppm (parts per million) in crusts, with a maximum value found of 205 ppm⁷.

Legal conditions

The legal framework for deep-sea mining derives from multiple levels of law.

In terms of **international law**, the basic legal framework for deep-sea mining is set out in the United Nations Convention on the Law of the Sea ('UNCLOS') as modified by the Part XI Implementation Agreement. UNCLOS distinguishes between maritime zones under the jurisdiction of coastal States (internal and archipelagic waters, territorial sea, exclusive economic zone and continental shelf) and areas beyond national jurisdiction, namely the high seas and the seabed beyond the continental shelves of coastal States (called the "Area" in Part XI of UNCLOS).

All rights in the mineral resources of the Area, which comprises the international seabed, ocean floor and subsoil, are 'vested in mankind as a whole'. The International Seabed Authority (ISA), an international organisation based in Kingston, Jamaica, is responsible for regulating deep-sea mining in the Area. The EU and Member States are members of ISA. The regulatory regime for deep-sea mining in the Area is not yet complete. Regulations on exploration have been adopted, while regulations on exploitation are currently being developed. Outstanding issues include the basis on which ISA will levy royalties for deep-sea mining, environmental standards and, in due course, benefit sharing. In its Advisory Opinion the Seabed Disputes Chamber of the International Tribunal for the Law of the Sea, a specialised court created under UNCLOS, provided guidance on the notion of 'sponsorship' of contractors engaged in deep-sea mining in the Area, and the need for such States to adopt laws, regulations and administrative measures to ensure compliance by such contractors.

As regards deep-sea mining in areas under national jurisdiction, coastal States clearly have regulatory jurisdiction in terms of international law and can design and adopt their own legislation accordingly. There are no international standards for deep-sea mining in areas under national jurisdiction and consequently there is a risk that different, stricter standards may in due course apply in the Area than in areas under the coastal State jurisdiction. States are subject to a number of obligations in terms of international agreements of global or regional application which tend to be of a rather general nature and the extent to which they may affect and deep-sea mining is not entirely clear. In due course there may be a need for the establishment of specific standards for vessels or platforms engaged in deep-sea mining;

EU law applies to deep-sea mining in the waters under the jurisdiction of the Member States. Unlike marine hydrocarbon extraction, however, the topic of deep-sea mining is not (yet) specifically addressed in EU legislation. Although plans or programmes that relate to deep-sea mining would be subject to strategic environmental assessment, deep-sea mining projects are not subject to the Environmental Impact Assessment Directive. Environmental data relating to deep-sea mining is currently subject to the Environmental Information Directive. Existing general EU waste legislation would apply to deep-sea mining but the specific directive on mining waste does not and while EU environmental liability legislation is potentially applicable to deep-sea mining its effectiveness might be reduced due to the need to prove fault on the part of an operator before liability can be established. Other environmental legislation may impact on how deep-sea mining is undertaken in

⁷ Hein et al., 2013

European waters but will not prevent it taking place. Finally European companies engaged in deep-sea mining both in European waters and elsewhere in the world are subject to the specific reporting requirements of extractive industries under the Accounting Directive.

As regards **national legislation** that governs deep-sea mining in the Area many EU Member States have yet to adopt the necessary laws. Out of the eight Member States considered in this Study, only two, Germany and the UK have legislation on deep-sea mining in the Area in place although France has informed ISA that the preparation of such legislation is under way. The third countries considered in this study that have adopted legislation on deep-sea mining in the Area were party to the interim agreements that preceded UNCLOS. Most, but not all of these States, have updated their laws following the entry into force of UNCLOS. One exception in this respect is the USA which is not party to UNCLOS but which has retained its original legislation on deep-sea mining in the Area.

As regards national legislation to regulate deep-sea mining in areas under national jurisdiction, more often it is the case that terrestrial mining legislation applies to the continental shelf or EEZ, rather than specific deep-sea mining legislation. In a number of cases, terrestrial mining legislation has been modified so as to include specific reference to deep-sea mining. Only the USA has specific legislation in place on deep-sea mining in areas under its national jurisdiction. Although deep-sea mining and terrestrial mining are both concerned with the extraction of mineral ores from the ground the extent to which terrestrial mining legislation is really suitable for application to the sea is surely questionable as shown by a number of practical questions raised in connection with deep-sea mining in the waters of Papua New Guinea. Also noteworthy, given that the nearby seabed appears to offer some of the most promising possibilities for deep-sea mining in European waters, is the fact that the Administration of the Azores took the decision to develop specific legislation for deep-sea mining, even though this was subsequently ruled unconstitutional.

Technical feasibility of deep-sea mining

Whether deep-sea mining will become viable in the near future depends to a large extent on the ability of industry and technology developers to provide systems capable of efficient operation in real life environments. Until date there is no commercial seabed mining of any of the three deposits taking place which means there is no proven equipment directly available. The majority of current activities are associated to exploration rather than exploitation.

In order to assess the technical state of play and identify the main barriers/bottlenecks to be tackled, a deep-sea mining value chain has been composed and its components assessed in terms of their technology readiness level (TRL). Furthermore, for each component the role that EU industries take is estimated.

Typically, the process of deep-sea mining, following exploration, will consist of a seabed remotely operated vehicle to collect (nodules) or excavate the deposit (sulphides, crusts), which is connected to a vertical transport system to lift the material to the sea surface, where it is collected in a ship or platform, dewatered and then transferred in a carrier and transported to shore for further processing.

A schematic presentation of the value chain for deep-sea mining is given in the figure below.

Figure 1.1 Schematic overview of deep-sea mining value chain



Typically, exploration involves locating, sampling and drilling, using technologies such as echosounders, sonars, camera's and sampling techniques. The resource assessment phase concerns the analysis of exploration data as regards the feasibility of a possible mining project.

Extraction, lifting and surface operations, the core part of the exploitation phase, encompass the excavation of the sea bed minerals, their transportation to the surface and eventual processing and handling operations taking place offshore. For the sea bed excavation, cutters (for sulphides and crusts) or collectors (for nodules) and rising systems are being developed. For the vertical transport, various concepts of lifting systems are being studied.

Logistics involves technologies similar to those found in 'traditional' land-originating minerals. For processing this is also the case although mineral composition differences call for development of advanced separation techniques.

For polymetallic crusts, the requirements of the seabed ROV differ from those related to sulphides and crusts due to the different nature of the deposit layers (hardness, composition, structure). Apart from these differences also the surface differences between sites define the requirements of the seabed equipment (e.g. steepness of slopes, curves to be made) as well as the water depth (pressure and temperature) in which to operate.

Typically, TRL levels are lower (range 1-4) for technologies required on the sea bed and for vertical transport, whereas technologies required at sea level (ship/platform and associated equipment) and onshore are more mature as they have similarity to applications in other sectors already existing. The role of EU industries in deep-sea mining has mainly focused on developing technologies – for the sub-sea part – and providing services (e.g. for construction of project sites and for exploration work). Typically the high technology capabilities of EU companies give them a competitive advantage over suppliers from elsewhere. When looking more downstream to surface and shore operations, this is less the case and competition from across the world can be expected.

Ongoing and planned activity

So far only exploration licences have been issued by the ISA. Up until May 2014, 19 applications have been approved out of which:

- 13 concern the exploration of polymetallic nodules, four for polymetallic sulphides and two the exploration of cobalt-rich polymetallic crusts;
- 12 of the exploration projects are located in the CCZ. This area is located in international waters of the Pacific Ocean. The remaining projects are located in the Indian Ocean (3), the Atlantic Ocean (2) and the north-western Pacific Ocean (2);
- These 19 approved projects cover an area of 1 million km². Six of these licenses will expire in 2016.

In 2013, seven additional applications, covering an area of around 234.000 km², were made to the ISA for exploration projects. These were discussed at the ISA's 20th annual session in July 2014, and were approved, but still need to be contracted out.. This means that by the end of 2014/beginning of 2015 there will be 26 approved projects by the ISA with a total covered area of around 1.2 million km². This is an area as big as Portugal, Spain and France together.

Generally applications can be submitted by national governments (e.g. China, India, Korea and Russia) as well as private enterprises.

Creating an overview of the licences granted within the national jurisdiction area of individual states' EEZ is more difficult as there is not a single source or database where this information can be gathered from. Extensive desk-research and interviews have been carried out to collect the relevant information, and we have identified 26 projects in EEZ areas. At the same time it must be stated that due to unavailability of data and information, specific projects in South America, Africa and Russia could not be identified. It is estimated however that the number of projects in the EEZ of these countries is limited since the two private companies that hold the majority of (exploration) licenses within EEZ zones (Nautilus Minerals and Neptune Minerals) do not hold any license in the EEZ zones of these two continents and Russia.

National governments have until now issued two deep sea marine exploitation (or mining) licenses: one by the government of Papua New Guinea (Solwara 1 project in the Bismarck Sea) and one by the governments of both Saudi Arabia and Sudan (Atlantis II project in the Red Sea). In both projects mining has not yet started. All other issued deep sea licenses by national governments concern exploration projects⁸.

The sizes of the areas granted for mining, exploration or areas under application in EEZs are not always known. Based on the information available we estimate the total area licensed or under application in EEZ areas of countries to be around 800 000 – 900 000 km². All EEZ licenses are for polymetallic sulphides deposits only.

Environmental impacts

A considerable amount of scientific information has been generated on the physical attributes of sea-floor massive sulphides, manganese nodules, and cobalt-rich ferromanganese crusts. However the habitats, biodiversity, ecosystem structure, and resilience associated with these types of mineral deposits are less well-understood. If deep-sea mining is developed, environmental policies will need to be adjusted as new information, technologies and working practices emerge. This will require an on-going, collaborative approach involving industry representatives, policy makers, field scientists and subject matter experts, environmental managers, government authorities, international agencies, civil society and the general public. As deep-sea mining activities will, for the most part, be carried out in remote locations which may make independent observation difficult, transparency will need to be a key consideration in developing such approaches.

The major impacts from mining will be similar for the three types of mineral deposits considered here, namely:

1. loss of substrate,
2. effects of mining on the seabed, the operational plume and re-sedimentation and
3. discharge plume and its effects on pelagic and/or benthic fauna depending on the depth of discharge,

it is important to note that there are differences in impacts depending on the deposit type as well as the geomorphological setting, physical conditions, the scale of operations, and the technology used for extraction. The extraction processes that are expected to have strongest environmental impacts are the following:

- Disaggregation
- Lifting
- Dewatering.

⁸ Other mining licenses have been issued but these cannot be characterized as deep-sea mining licenses since the depth of these locations does not exceed 500 meters. This is for example the case for Sandpiper Marine Phosphate project off the coast of Namibia (depth of 180-300 meters) and the location Chatham Rise within the EEZ zone of New Zealand (depth of 350-450 meters).

The three mineral deposit types are expected to return different environmental results when it comes to the:

- duration of the impact;
- size of the area impacted;
- nature of the impacts and the
- potential for recovery.

One of the most important drivers behind the impacts is the actual removal of the minerals which often hosts a number of species. Seafloor massive sulphides based in active hydrothermal vents are expected to recover relatively quickly (months to years) while inactive sites will take considerably longer ranging from tens to hundreds of years. Nodules will likely take the longest time when it comes to recovery after the removal of the elements and may take tens to hundreds of years or even longer in heavily mined areas (nodule faunas may take millions of years to recover). Similarly crusts are expected to recover slowly meaning tens to hundreds of years.

Another impact will be the spread of sediments which depending on the depth, technology, currents and the types of deposits mined can have varying levels of impacts. For all three elements the spread of sediment laden plumes near the seabed can go various kilometres beyond the mining site and can potentially smother seabed animals. Sediment in the water column can cause a reduction in light penetration and in temperature. These factors are likely to reduce plankton growth with knock-on impacts to the whole food chain. Additionally, ecosystems as a whole can be impacted by the shift on sediment grain size (sediments may change towards sandier or finer composition).

Pollution from ships onto the surface water and noise pollution from the vessels as well as the underwater equipment can potentially have negative impacts; however as to date no extraction has taken place the extent of these impacts cannot be measured. With regard to noise pollution short-term masking effects on marine mammals are likely. As for all mining activities the disposal of tailings⁹ on land or sea can also have long term impacts.

Finally, it is important to caution that although coastal marine mining in shallow waters (e.g. aggregates, diamond, placer gold) has a relatively long history, no actual commercial scale deep-sea mining operation (i.e. beyond 500m water depth) has ever been conducted. Only scientific mineral extraction and limited technological testing has taken place (as early as the 1970s). A cautious approach is thus a vital consideration when considering the topic of deep-sea mining, in order to avoid repeating destructive practices evident in the deep sea from, for instance, bottom trawling.

The social aspect

Embedded within the environmental and economic impacts there are important social implications that need to be considered. For the local population, the sea and the minerals it contains are often considered a property and the minerals under the sea can in some cases have cultural value associated with them. Therefore, it is important that stakeholders are sufficiently involved regarding the different aspects of the mining operations including safety and sharing of its benefits. Furthermore, transparency and continuous communication is necessary in order to ensure there is a common understanding on the principles of the operations and on the conduct of the mining company. Communication would preferably involve topics related to the entire value chain (from exploration through processing to decommissioning).

⁹ waste and refuse remaining after the ore has been processed

Supply and demand for metals

Market conditions vary significantly between minerals and metals, but some common characteristics in metals markets and terrestrial mining can be observed. The common “flaw” of the (land-based) mining industry is its boom-and-bust cycles: mining operations are inflexible in the short and medium term and therefore the market often fluctuates between states of oversupply and supply shortage, as could also be observed recently. Following a demand surge starting in the early 2000s, prices increased substantially. In search of an increasing quantity of ores, companies have turned to lower ore grades, thus increasing costs which in the current situation of a moderate demand outlook may already be too high. Another development that most materials have in common is that we observe an increase in state-owned mining (mainly driven by China) or attempts of the state to secure mining rents. Deep sea mining can be seen as part of the move towards more difficult ores..

Despite these general observations, market conditions and main players differ strongly per material or material group. Precious metals (gold, silver) are characterised by low production concentration and existing market exchanges, which however are only marginally influenced by physical demand and supply (due to the role of these metals as investment and hedging vehicles). Therefore additional supply from deep-sea mining is not expected to have an influence on the price. The markets for base metals (copper, nickel, zinc) are functioning well, but deep-sea operations would not produce the quantities to make a difference on the market. In markets for minor metals (cobalt) deep-sea mining could make a difference because they are traded in relatively low quantities and with a low elasticity of supply; in the case of cobalt, deep-sea mining has a role to play as this material has a high supply risk and expected tonnages from deep-sea mining are comparatively high in comparison to global production.

Looking at the economic viability of deep sea mining in this context, a basic economic model was developed and tentative commercial viability calculations were made for each deposit based on assumptions on capital expenditure, operational costs and revenues. Assumptions regarding these costs have been based on a range of available sources, but should be treated with caution as no actual operations have yet taken place, and technologies have not yet been fully developed and proven. The results show that polymetallic sulphides are expected to show the highest commercial viability, whereas nodules and crust are only marginally or not commercially feasible. Key uncertainty regarding polymetallic sulphides is that it assumes an operation of 15 years to generate returns on investment, whereas most resources and proven reserves seem to point to smaller sizes and a strain of operations on different locations needs to be established.

Apart from the overall uncertainty within the assumptions, a specific uncertainty exists regarding potential revenue streams for manganese, which is abundantly present in these latter two types of deposits, but for which the commercial viability of the additional processing costs are highly uncertain. This directly points to the importance of further efficiency increases not only in mining itself but in particular in processing as this would allow additional revenue streams (also potentially including REEs). Finally obviously, scarcity and increasing prices will have a direct impact on the commercial viability of deep sea mining operations, although this will obviously also trigger further terrestrial (including recycling) developments. Deep sea mining operations in itself are not expected to directly influence global prices of most metals, except for cobalt. This will limit the number of operations that can be exploited in parallel in crust and nodules to avoid boom and bust developments.

Security of supply policies

In addition to the rising demand for metals, geo-political issues can also limit the availability of metal resources. With China claiming ownership over a large quantity of terrestrial mineral reserves for specific critical raw materials, ensuring access to ores of sufficient quality and maintaining a predictable price level with acceptable ranges of volatility becomes a challenge. Exploration into new resources takes time and the bargaining power is on the side of the – relatively few - suppliers who are confronted with a large demand.

This may be further influenced by the phenomenon where metals are pledged in as collateral to obtain financing from banks. Anecdotal evidence suggests that in China copper and aluminium were used to raise capital (Yuan) on a secured basis¹⁰. If the same stock of metal is used as collateral for different loans, banks could ask to freeze this inventory and even seize the collateral which in return (depending on the quantity) which can have a direct impact on global prices¹¹. A further consequence could be increasing control of specific countries over commodity prices¹². These aspects carry the risk of monopolistic behaviour (prices) but also may pose a supply risk (strategic behaviour and impact on critical industries and sectors in Europe's economies). Bringing in a new source for metal supply, particularly if located in international waters, may alleviate the price competition and provide more security for Europe.

Comparison with land-based mining and recycling

Currently land-based mining is the main source of metals used. As demand increases and high-grade deposits are getting depleted, industry is driven towards lower-grade sites as well as towards more “remote and challenging environments”. For terrestrial sites, this implies larger areas need to be excavated to deliver the required demand volumes, potentially in more vulnerable eco-systems with longer rehabilitation times, resulting in large land disturbance, large waste generation and large biodiversity losses.

Many aspects of the proposed deep-sea mining involve the same steps used in conventional mining. Hence a number of impacts is facing the same direction, although of course the detailed nature varies as marine eco-systems differ substantially from terrestrial ones.

In addition to land-based and deep-sea mining, an alternative source of supply for raw materials would be recycling. According to UNEP, recycling rates of metals are in many cases far lower than their potential for reuse. Less than one-third of the 60 most common metals have end-of-life recycling rate above 50%; 34 are under 1%.¹³ In Europe, recycling rates of critical metals show strong differences. This is partially due to lack of adequate technology, or sub-optimal pre-processing techniques, but also to insufficient collection or illegal exports of e.g. waste of electrical and electronic equipment (WEEE)¹⁴.

The analysis of recycling has shown that despite high end-of-life recycling rates for the relevant deep-sea mining metals (with the exception of rare earth elements), recycled content remains rather low. This means that a significant amount of metal content is lost during the recycling process. This suggests that even by elevating recycling rates to 100% recycling content this would still not be sufficient to substitute r mining operations and fully cater demand. Nonetheless, it is

¹⁰ The Wall Street Journal (2014): BHP Calms China Commodity Fears, <http://online.wsj.com/articles/bhp-calms-china-commodity-fears-1404296229>.

¹¹ Financial Times (2014): China probe sparks metals stocks scramble, <http://www.ft.com/cms/s/0/7928cdaa-f07e-11e3-8f3d-00144feabdc0.html#axzz36sQePuul>.

¹² Ke Tang, Haoxiang Zhu (2014): Commodities as collateral, http://www.mit.edu/~zhuh/TangZhu_CommodityCollateral.pdf.

¹³ Journal of Industrial Ecology, What Do We Know About Metal Recycling Rates, Volume 15, Issue 3, pp 355–366, June 2011.

¹⁴ ECSIP consortium (2013): Treating waste as a resource for the EU industry. http://ec.europa.eu/enterprise/newsroom/cf/itemdetail.cfm?item_type=254&lang=en&item_id=7100

possible that increased recycling could cover a share of new metals arriving to the market from mining (deep-sea or terrestrial). In order to identify the extent to which recycling could cover demand for new metals a number of variables would have to be analysed, including:

- reserves available from current and soon-to-be-opened land-based mines;
- prices of commodities;
- global demand for metals;
- quantity of cost-efficiently extractable high concentration ores from seabed reserves;
- expected changes in European metal demand for commodities that can also be sourced from the seabed; and
- price implications of metals sourced from seabed minerals.

The cumulative impacts of such a focused exercise could lead Europe closer to a circular economy by closing the loop on the recycling systems and at the same time could facilitate research into innovative technologies for recycling.

Standards and transparency

Currently there are no internationally approved and applied standards for deep-sea mining performance, technology and environmental impact assessments (see also the legal section). Furthermore, there are no internationally recognised practices for managing communication with stakeholder groups and ensuring transparency of operations. These factors are seen as barriers for the future development of the industry as they lead to misinformation and ultimately can harm relations with stakeholder groups, particularly NGOs and the local population.

There are a number of ongoing initiatives when it comes to performance and environmental standards for the industry, however these are not harmonised and coordination has not been rolled-out to involve a wide stakeholder base. As the starting date for commercial practices is getting closer, even if it applies so far only to the EEZ areas of the Pacific Island States, an international agreement to clarify technical, environmental, reporting and transparency criteria is ever more pressing.

Conclusions and recommendations

It is very likely that explorations onto the compositions and quantity of minerals on the seabed will continue both on international waters (ABNJ) and in the EEZ of various countries. On the short-term these activities will concentrate primarily around the waters of Pacific Island States, where most of the exploration activities within EEZ areas are taking place.

It is also expected that at the short term the extraction licensed project, Solwara I from Nautilus will go-ahead and mining will commence sometime around 2015-2016. Another operation with strong potential is Atlantis II Deep in the Red-Sea which has also been granted an exploitation license. Several other on-going exploration projects may also be successful on the medium to long-term however currently there is not enough information and data on their findings and readiness levels to evaluate or forecast future potential. It is clear that while for some countries extraction of deep-sea minerals in their EEZ area can bring financial and economic benefits, the operations can also serve wider purposes, such as:

- understanding the deep-sea environment;
- facilitating further research and innovation for exploration and exploitation technologies including increasing seafloor drilling performance, gravity gradiometer¹⁵, acoustic corer¹⁶,

¹⁵ Measuring the Earth's density needed to identify the more significant subsurface metal accumulations that would not be seen from surface or water column mapping. Gravity gradiometers already exist for terrestrial exploration and they require miniaturisation to be fit onto an AUV.

¹⁶ Seafloor imaging (Pan Geo Subsea tool) for hard rock environment

subsea gliders as well as increased use of Prompt Gamma Neutron Activation Analysis for grade control etc.;

- ensuring security of supply for raw materials.

Since the Exclusive Economic Zones of EU Member States – apart from the Azores islands – will unlikely to be subjected to deep-sea mining due to the lack of mineral reserves, the role of European stakeholders in the sector can be two-fold:

- On the one hand the European Commission and the individual Member States are expected to remain an important player in financing research and innovation in exploration, extraction and monitoring devices that may be used for seabed mining;
- On the other hand European private enterprises are likely to continue their involvement as technology and service providers.

Based on the research and interviews carried out in the study the following recommendations are made:

1. Increasing the intensity of bilateral and multilateral communication with Pacific Island States with specific focus on deep-sea mining and possible criteria or standards for environmental assessment and minimum standards for technological requirements (as a way to ensure conformity of requirements across countries);
2. Setting up focused research projects – via available mechanisms such as Horizon 2020 - for issues identified as of primary gaps in the industry (increased performance of seafloor drilling, subsea AUV mounted gravimeter/gradiometer¹⁷, sub-sea laser imaging, material handling, dewatering, alternative fuels etc.);
3. Training and advisory services for the Pacific Island States through the SOPAC office or other initiatives;
4. Expanding communication with the International Seabed Authority involving EU directorates with direct and relatable experience with stakeholders in the field (DG MARE, DG ENTR);
5. Communication between relevant DGs and the International Marine Minerals Society on expanding and integrating their seabed mining code of conduct into EU guidelines.

In relation to the environmental impacts, based on the analysis carried out, it is our understanding that future research should narrow its focus towards the most relevant and pressing technology needs related to ocean observation (remote sensing as well as in-situ monitoring) and potentially draw on the approach set out by the Marine Strategy Framework Directive (MSFD) to monitor/evaluate environmental status. Technology and methodological advancements could be accommodated into an evolving precautionary approach. Indeed some observational technology could be built directly into industry infrastructures, something already under consideration with oil and gas infrastructures. Ultimately, impact-related research should lead to a better understanding of deep-seabed ecosystems around the world.

¹⁷ Gravity gradiometer is required to identify the more significant subsurface metal accumulations of economic significance. While gravity gradiometers currently exist they need to be miniaturised to fit on an AUV.



1 Introduction

1.1 Background and objective

Interest in deep-sea mining operations has been developing since the mid-1960s when it was determined as an alternative way for accessing minerals, primarily for polymetallic nodules. However, as knowledge and technology progressed it became clear that real costs of this kind of exploration and extraction might go beyond what had been initially forecasted. At the same time, additional land-based deposits of minerals have been discovered which have redirected efforts and led to a decrease in market price.

Nevertheless, over the past ten years access to raw materials has once again become a focal point for the European Union (EU). Currently, the EU is increasingly dependent on imports for some strategically important raw materials, while exploration and extraction of these materials is facing increased competition and a strongly regulated market environment. According to the recently updated list of EU critical raw materials¹⁸ 49% of these materials are resourced from China.

Table 1.1 Percentage of primary supply of critical raw materials from the 20 most significant producing countries¹⁹

Critical Raw Material	% of supply	Major supplier >20%
Antimony	93%	China (87%)
Beryllium	99%	USA (90%)
Borates	88%	Turkey (38%), USA (30%)
Chromium	88%	South Africa (43%), Kazakhstan (20%)
Cobalt	82%	DRC (56%)
Coking Coal	94%	China (51%)
Fluorspar	84%	China (56%)
Gallium	90%	China (69%)
Germanium	94%	China (59%)
Indium	81%	China (58%)
Magnesite	86%	China (69%)
Magnesium	96%	China (86%)
Natural Graphite	93%	China (69%)
Niobium	99%	Brazil (92%)
Platinum Group Metals	93%	South Africa (61%), Russia (27%)
Phosphate Rock	66%	China (38%)
REE (Heavy)	100%	China (99%)
REE (Light)	100%	China (87%)
Silicon Metal	79%	China (56%)
Tungsten	91%	China (85%)

¹⁸ Antimony, Beryllium, Borates, Chromium, Cobalt, Coking Coal, Fluorspar, Gallium, Germanium, Indium, Magnesite, Magnesium, Natural Graphite, Niobium, Platinum Group Metals, Phosphate Rock, REE (Heavy), REE (Light), Silicon Metal, Tungsten have been identified as critical raw materials as per the study in 2013
http://ec.europa.eu/enterprise/policies/raw-materials/files/docs/crm-report-on-critical-raw-materials_en.pdf

¹⁹ European Commission (2014): Report on critical raw materials for the EU, http://ec.europa.eu/enterprise/policies/raw-materials/files/docs/crm-report-on-critical-raw-materials_en.pdf.

Critical Raw Material	% of supply	Major supplier >20%
Total	90%	China (49%)

Availability of these resources might become more challenging in the future as well since increasing demand from emerging countries can drive prices along an upward curve which can potentially make forecasting and planning difficult and can have a negative impact on small and medium sized enterprises that seek secure the raw materials necessary for production.

Strong reliance and limited current access coupled with uncertainty regarding the future availability of these minerals for the EU have led to a revitalised interest to identify alternative deposits, including on the seabed. While it is presumed that seabed deposits of minerals can provide significant quantities of raw materials (please see the geology analysis), technologies to exploit these resources are not yet fully developed. Additionally, there are strong environmental concerns related to exploration and exploitation activities even though the extent of environmental impacts are presumed to vary to a large extent based on the types of ores and their locations. While the same is true for many land-based mining operations, the levels of uncertainty are far superior with regard to deep-sea mining. It is important to define tools which would allow comparing and rating the extent of impacts that the different mining operations might have.

1.2 Main drivers for deep-sea mining

As indicated above, several main drivers can be identified that are at the cause of an increased interest in the possibilities of deep-sea mining:

- A growing demand for metals, including rare earth elements, driven by global economic growth and a growing intensity of electronics and high-tech in daily life. This trend is clearly reflected in increasing commodity prices for many metals and other elements. To some extent the worry about reducing availability of terrestrial resources is related although in several segments it is seen that as prices go up, new deposits may become commercially attractive extending the resource base;

Securing supply of raw materials that are critical for European manufacturing industries and consequently for ensuring competitiveness for Europe as a whole. As their main deposits are now to be found outside the territorial borders of the EU, and for some metals only at a small number of supplier countries sometimes located in politically unstable regions, ensuring access to these is of primary importance. The European Commission has recently reviewed its list of critical raw materials²⁰, please see table 1.1 above for the list and the primary locations of the reserves.

In addition to these market related factors, other drivers may be added to this, such as:

- The potential of a new export market for technology that deep-sea mining can offer for European and other manufacturing industries;
- The last frontier: an interest of mankind to explore an area that as has been stated 'we know less of than of them moon'. One may argue that the search for seabed deposits may also a 'gold rush' character, with companies and countries competing to be the first to succeed. Another factor influencing this drive is the fact that as far as we know now, many potentially attractive deposits are located in territorial waters of Small Island Development States in the Pacific, for which a new income source would be a welcome addition.

²⁰ European Commission (2014): Report on critical raw materials for the EU, http://ec.europa.eu/enterprise/policies/raw-materials/files/docs/crm-report-on-critical-raw-materials_en.pdf

Finally, from the Blue Growth policy perspective, the development of deep-sea mining may be attractive as a new generator of economic value added and employment, needed in the current time of high unemployment levels across Europe.

The validity of all these drivers and the extent to which they are to a larger or smaller extent influencing the viability of deep-sea mining is being investigated in the subsequent chapters of this report.

1.3 Study objective and scope

Study purpose

The main purpose of this study is to feed information, data and specific examples that will serve the European Commission to prepare a position vis-à-vis the development of deep-sea mining.

This study looks to collect all available information – as accessible – on the technology, the economic, legal, geological, environmental and social factors that are relevant for deep-sea mining operations. Consequently, the study focuses on the operations that are being planned or are being carried out as opposed to presenting general discussions on deep-sea mining.

This study versus other (research) projects

The main objective of the study is to gather and integrate information and knowledge already accessible on deep-sea mining. There are a number of research projects - ongoing or in preparation - that aim to raise awareness in the field and develop new means, applications or technologies. As these projects are expected to continue for several years, at this moment no research results are available yet. Rather, this present study is likely to feed information for projects such as MIDAS or Blue Mining, both co-funded by the European Commission's 7th Framework Program (FP7), by setting the scene and helping to focus research work on the areas where key knowledge gaps are found.

Scope: three deposit types

The study addresses three different types of deposit that are identified as potential sites for seabed mining:

- polymetallic nodules;
- polymetallic sulphides (or seafloor massive sulphides,); and
- cobalt-rich crusts.

These deposits contain a number of metals in concentrations suitable to extract and relevant in view of commodity prices, global demand or because of their critical function in applications. In addition there are other categories of sediments on the seabed, such as mud layers that are believed to contain traces of REE, although so far no licensed exploration activities have been seen there.

2 Geology

2.1 Summary

Polymetallic sulphides (also known as seafloor massive sulphides – SMS) are occurrences of metal-bearing minerals that form on and below the seabed as a consequence of the interaction of seawater with a heat source (magma) in the sub-seafloor region of volcanic ridges and along volcanic arcs. They are typically found on and around mid-ocean and back arc ridges where they are formed in the process of tectonic movements. The total number of such vent sites that exists on the modern sea floor is not known, although several hypotheses have been used to infer their abundance.

Based on our review, we assess that the size of an individual sea floor massive sulphide deposit varies from a few tonnes to >15 million tons (Mt) of ore material. However, reliable size estimates are very rare since drilling information is needed to accurately infer the tonnage of polymetallic sulphide occurrences. This information is only present for very few sites. For most occurrences information on their size relies on visual estimates of the surface area that is covered by hydrothermal precipitates. Most of the explored polymetallic seafloor sulphide occurrences are small²¹. The exceptions to this are the brine pool deposits in the Red Sea, including the Atlantis II Deep deposit, which is by far the largest known metal deposit (90 Mt) on the modern seafloor²².

Polymetallic nodules occur widely on the vast, sediment-covered plains of the abyssal ocean at depths of about 4 000 to 6 500 m. They are mineral concretions made up of manganese and iron oxides that can be found in sizes as small as golf balls or as big as large potatoes. The greatest concentrations of metal-rich nodules occur in the Clarion-Clipperton Zone (CCZ), which extends from off the west coast of Mexico to as far west as Hawaii. Nodules are also concentrated in the Peru Basin, near the Cook Islands, and at abyssal depths in the Indian and Atlantic oceans.

Manganese and iron are the principal metals in polymetallic nodules. The metals of greatest economic interest, however, are nickel, copper, cobalt, and possibly manganese if this can be extracted and processed in a commercially viable manner. In addition, there are traces of other valuable metals, such as molybdenum, rare-earth elements (REE), and lithium that have industrial importance in many high-tech and green-tech applications and can possibly be recovered as by-products once appropriate extraction and processing techniques have been developed.

Cobalt-rich **polymetallic crusts** precipitate onto nearly all rock surfaces in the deep ocean that are free of sediment. Here, they form pavements of manganese and iron oxides. Polymetallic crusts may also coat rock pebbles and cobbles. Their thickness varies from less than 1 millimetre to about 260 millimetres. They form at water depths of 600 to 7 000 m on the flanks of volcanic seamounts, ridges, and plateaus.

Many seamounts are within the Exclusive Economic Zones (EEZs) of Pacific Island states. The Atlantic Ocean has fewer seamounts. Cobalt-rich polymetallic crusts are often associated with hydrothermal activity at seafloor-spreading centres, with the exceptions of the northeast and

²¹ Less than one million tonnes

²² We distinguish between modern and ancient seafloor. Copper, zinc, lead, silver, and gold are often mined from ancient black smoker deposits (co-called VMS deposits) that were transferred from the ancient seafloor onto land through geological processes (obduction). They occur in various countries e.g. Spain and Portugal, Russia and Cyprus or Germany.

northwest continental margin areas. Cobalt is one of the trace metal of greatest economic interest and commonly shows values greater than 0.5 weight % Cobalt. Another metal of great interest is Tellurium (Te), which globally averages about 50 ppm (parts per million) in crusts, with a maximum value found of 205 ppm²³.

2.2 Types of deposits found on the seabed

Three main types of deposits are being explored for their metal contents. These are:

- Polymetallic sulphides (also known as sea floor massive sulphides –SMS);
- polymetallic nodules;
- polymetallic (cobalt-rich) crusts.

2.2.1 Seafloor Massive Sulphides

Polymetallic or seafloor massive sulphides are occurrences of metal-bearing minerals that form on and below the seabed as a consequence of the interaction of seawater with a heat source (magma) in the sub-seafloor region²⁴ of volcanic ridges and along volcanic arcs. During this process, cold seawater penetrates through cracks in the sea floor, reaching depths of several kilometres below the seafloor surface, and is heated to temperatures above 400°C. The heated seawater leaches out metals from the surrounding rock. The chemical reactions that take place in this process result in a fluid that is hot, slightly acidic, reduced, and enriched in dissolved metals and sulphur. Due to the lower density of this evolved seawater, it rises rapidly to the seafloor, where most of it is expelled into the overlying water column as focused flow at chimney vent sites. The minerals forming the chimneys and sulphide mounds include iron sulphides, such as pyrite, as well as the main minerals of economic interest such as chalcopyrite (copper sulphide) and sphalerite (zinc sulphide). Precious metals such as gold and silver also occur, together with non-sulphide (gangue) minerals, which are predominantly sulphates and silicates.

The total number of vent sites that exist on the modern seafloor is not known, although several hypotheses have been used to infer their abundance. Estimates based on Earth's heat flow indicate that approximately one black smoker per kilometre of ridge axis is necessary to explain the heat flux through the oceanic crust²⁵. The distribution of hydrothermal plumes along the spreading axis and over volcanic arcs has also been used to infer similar values. It should be noted, however, that the latter approach only considers active hydrothermal fields. Evidence suggests that there are many more inactive sites than active sites²⁶.

²³ Hein et al., 2013

²⁴ Hannington, M.D., de Ronde, C.D., Petersen, S. (2005). Sea-floor tectonics and submarine hydrothermal systems. *Economic Geology 100th Anniversary Volume* 111–141

²⁵ Mottl, M.J. (2003) Partitioning of energy and mass fluxes between mid-ocean ridge axes and flanks at high and low temperature, in: Halbach, P.E., et al., eds., *Energy and mass transfer in marine hydrothermal systems: Dahlem Workshop Report 89*: Berlin, Dahlem University Press, p. 271–286.

²⁶ Hannington, M., Jamieson, J., Monecke, T., Petersen, S., Beaulieu, S. (2011): The abundance of seafloor massive sulfide deposits. *Geology* 39, 1155–1158

Figure 2.1 Location of seafloor massive sulphide occurrences investigated for this report (306 sites)

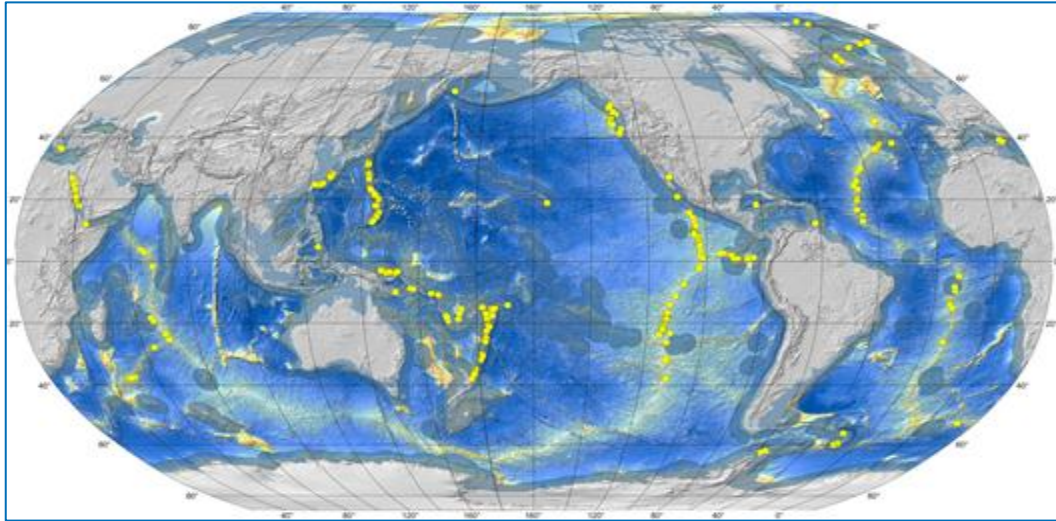


Table 2.1 The mean metal content of seafloor massive sulphides with respect to their tectonic setting

Setting	N	Cu %	Zn %	Pb %	Fe %	Au ppm	Ag ppm	As ppm
sediment-free MOR*	2302	4.9	8.0	0.2	26.9	1.2	93	365
ultramafic-hosted MOR	556	13.6	9.8	0.1	27.0	8.5	84	212
sediment-hosted MOR	173	1.1	3.6	0.5	24.7	0.5	84	1692
intraoceanic back arc	898	3.5	15.7	0.7	13.5	6.1	226	885
transitional back-arcs	789	5.6	18.4	1.5	7.1	12.0	312	10573
intracontinental rifted arc	136	3.3	19.0	9.7	7.1	5.3	916	4950
volcanic arcs	178	3.8	12.7	2.0	9.8	12.6	328	2010

(source GEOMAR) Note that the trace metals gold, silver and arsenic are in parts per million (ppm)

* MOR = mid oceanic ridge

While the number of discoveries of seafloor massive sulphides occurrences is steadily rising, most deposits are small in size and tonnage of contained sulphide. Hydrothermal vent systems do not generally incorporate metals into sulphide deposits efficiently. Much of the metal is lost to the hydrothermal plume and dispersed away from the vent sites. Large deposits form only where sediments allow for efficient trapping of the metals due to metal-precipitation below the sea floor (as in Middle Valley and Okinawa Trough)^{27 28} or where hydrothermal activity occurs for long periods of time, as with sulphide mineralization related to large detachment faults. Based on information about the age of the sulphides and the underlying volcanic crust, it appears that tens of thousands of years are needed to form the largest known deposits.

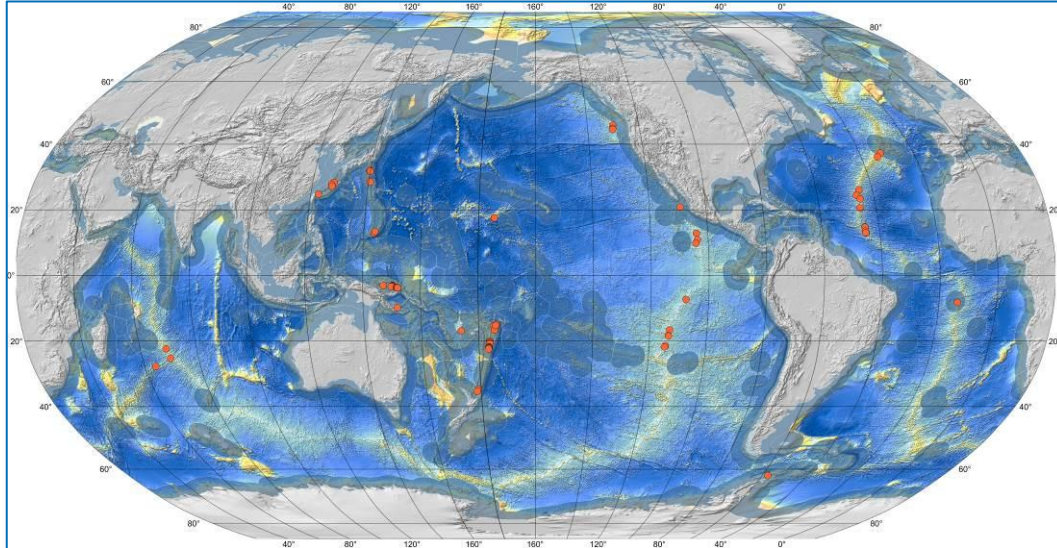
From the known vent sites geochemical data is only available for 130 occurrences. However, as stated above, a number of these occurrences contain little metals of economic interest. Since most deposits have only been sampled at the surface we used thresholds of 5 wt.% Cu, 15 wt.% Zn and 5 grams/tonne gold (Au) to indicate a base (Cu, Zn) or precious metal potential for the occurrences. Based on these criteria 82 occurrences show enrichments of one or more of these metals (figure below). It needs to be emphasized that geochemistry is not the only important parameter; size does

²⁷ Zierenberg, R.A., Fouquet, Y., Miller, D.J., Bahr, J.M., Baker, P.A., Bjerkgård, T., Brunner, C.A., Duckworth, R.C., Gable, R., Gieskes, J., Goodfellow, W.D., Gröschel-Becker, H.M., Guerin, G., Ishibashi, J., Iturrino, G.J., James, R.H., Lackschewitz, K.S., Marquez, L.L., Nehlig, P., Peter, J.M., Rigsby, C.A., Schultheiss, P., Shanks, W.C., III, Simoneit, B.R.T., Summit, M., Teagle, D.A.H., Urdat, M., Zuffa, G.G. (1998): The deep structure of a sea-floor hydrothermal deposit. *Nature* 392, 485–488.

²⁸ Takai, K., Mottl, M.J., Nielsen, S.H.H., the IODP Expedition 331 Scientists (2012): IODP Expedition 331: Strong and Expansive Subseafloor Hydrothermal Activities in the Okinawa Trough. *Scientific Drilling* 13, 19–27.

matter (see below). A number of other elements may occur in large quantities in single samples, however, on a regional scale these elements do not seem to be economically important (Tab. 2.2). Certain deposits may contain sufficient concentrations of one or more of these elements to improve economic viability, however, sufficient data is currently lacking to prove the case.

Figure 2.2 Location of seafloor massive sulphide occurrences with base and/or precious metal enrichment (source GEOMAR; N=82)



Based on our review, the size of a sea floor massive sulphide deposit varies from a few tonnes to >15 million tons (Mt) of ore material, however, reliable size estimates are very rare since drilling information is needed to accurately infer the tonnage of massive sulphide occurrences. This information is only present for very few sites (table below). For most occurrences information on their size relies on visual estimates of the surface area that is covered by hydrothermal precipitates. By far most seafloor sulphide occurrences are small! The exceptions to this are the brine pool deposits in the Red Sea, including the Atlantis II Deep, by far the largest metal deposit (90 Mt) on the modern seafloor. Here, the ore material is deposited as unconsolidated metal-bearing muds instead of massive sulphide²⁹.

Table 2.2 Seafloor Sulphide Occurrences for which size information is available based on drilling information

Deposit	Location	Size	drilling tool / vessel	Reference
Atlantis II	Red Sea	90 Mt	Coring	Nawab, 1984
TAG	Mid-Atlantic Ridge	4 Mt	ODP-drill ship	Hannington et al., 1998
Middle Valley	Juan de Fuca Ridge	10–15 Mt	ODP-drill ship	Zierenberg et al., 1998
PacManus	Bismarck Sea	small	ODP-drill ship	Binns et al., 2002
PacManus	Bismarck Sea	small	lander-type	Petersen et al., 2005
Solwara 1	Bismarck Sea	2.3 Mt	ROV-based	Lipton et al., 2012
Suiyo	Izu-Bonin Arc	small	lander-type	Marumo et al., 2008
Iheya North	Okinawa Trough	small	IODP-drill ship	Takai et al., 2012
Izena	Okinawa Trough	3.4 Mt	lander-type	Masuda et al., 2014
Fryer, Pika	Mariana Trough	small	lander-type	Kakegawa et al., 2008
Logatchev	Mid-Atlantic Ridge	small	lander-type	Petersen et al., 2009

²⁹ Nawab, Z.A. (1984): Red Sea mining: a new era. Deep Sea Research Part A. Oceanographic Research Papers 31, 813–822.

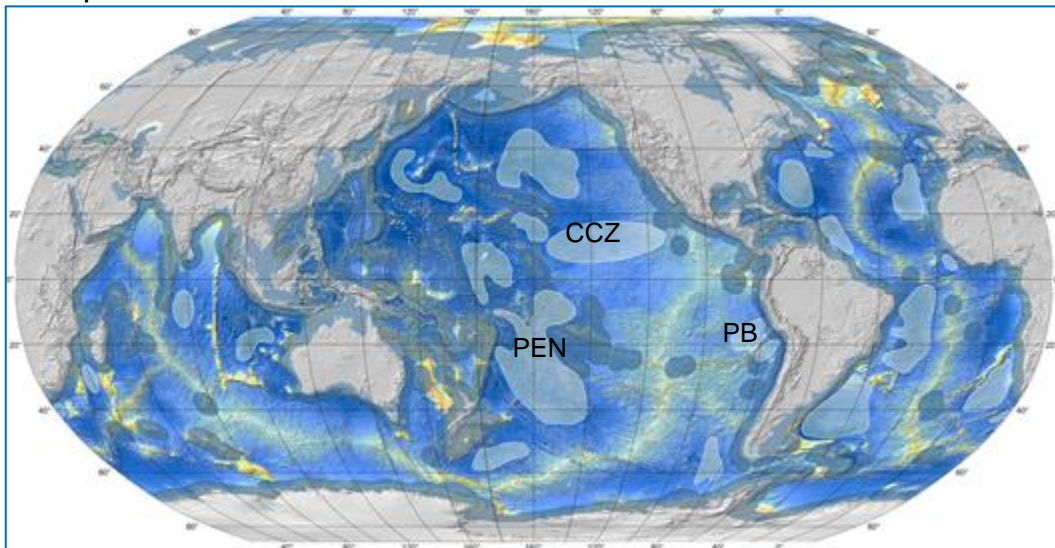
The largest deposits currently known are all at least 100,000 years old, implying that sustained hydrothermal venting over long periods is required to produce significant accumulations of massive sulphide at the seafloor. The growth rate for the main massive sulphide lens (2.7 million tonnes) at the TAG site on the Mid-Atlantic Ridge is about 500 to 1,000 tonnes/yr. Similar growth rates have been estimated for other large deposits on the Mid-Atlantic Ridge (Logatchev, Ashadze, and Krasnov), based on the maximum ages and estimated tonnages of the deposits.

2.2.2 Polymetallic nodules

Manganese nodules occur widely on the vast, sediment-covered, plains of the abyssal ocean at depths of about 4,000 to 6,500 m. They are mineral concretions made up of manganese and iron oxides that can be as small as golf balls or as big as large potatoes.

The greatest concentrations of metal-rich nodules occur in the CCZ, which extends from off the west coast of Mexico to as far west as Hawaii (below). Nodules are also concentrated in the Peru Basin, near the Cook Islands, and at abyssal depths in the Indian and Atlantic oceans. In the CCZ, the manganese nodules lie on abyssal sediments covering an area of at least 9 million square kilometres. Nodule densities can be as high as 75 kg per m² of seabed within this area, but more commonly average less than 15 kg per m². The highest percentages of seafloor covered by nodules are found in water depths between 4,100 – 4,200 m, and the highest abundance values are found between 12° to 16° N latitude³⁰.

Figure 2.3 Area with highest polymetallic nodule potential based on morphology, age of the crust, and metal input³¹



Abbreviations: CCZ = Clarion-Clipperton Zone, PB = Peru Basin, PEN = Penrhyn Basin near the Cook Islands

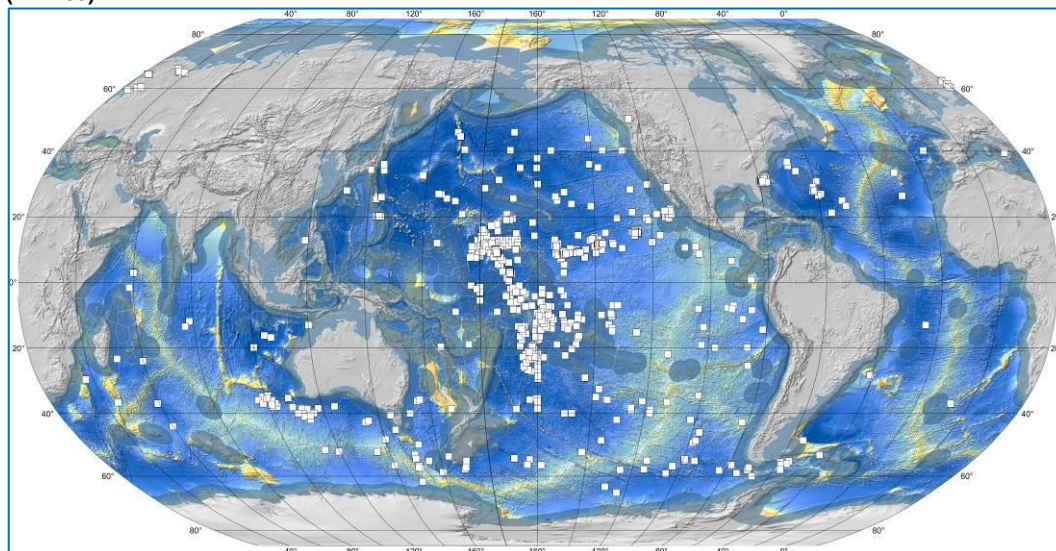
Manganese and iron are the principal metals in manganese nodules. The metals of greatest economic interest, however, are nickel, copper, cobalt, and maybe manganese. In addition, there are traces of other valuable metals, such as molybdenum, rare-earth elements, and lithium that have industrial importance in many high-tech and green-tech applications and can possibly be recovered as by-products). The market for Li is growing rapidly due to its use in batteries, including those in electric and hybrid cars. Lithium in CCZ nodules averages 131 ppm and is especially high

³⁰ ISA (2010): Technical Study No. 6: A Geological Model of Polymetallic Nodule Deposits in the Clarion-Clipperton Fracture Zone. International Seabed Authority.

³¹ after Hein et al., 2013

in diagenetic nodules of the Peru Basin (mean of 311 ppm³²). This is at the lower end of typical Li-bearing salty brines that are exploited on land and contain between 200 and 1 400 ppm Li or pegmatite rocks that contain about 1 % Li³³. REE concentrations in nodules are smaller than in ferromanganese crusts, so investigations of possible exploitation of marine resources for REE will likely focus on ferromanganese crusts. Platinum concentrations are much lower in manganese nodules than in ferromanganese crusts, therefore investigations to secure metal supply for this element should also focus on ferromanganese crusts.

Figure 2.4 Location of polymetallic nodule samples in the ISA database investigated for this report (N=2753)



Conservative resource estimates, e.g. neglecting the recovery of trace elements as valuable components, commonly use a combined Cu+Ni+Co grade of >2.5 wt.% as a cut-off grade for economically feasible future mining operations. Based on this, only few areas of interest remain, mainly in the CCZ (figure below). However, the manganese nodules around the Cook Islands are still considered to be a viable resource based on their high Co-content, commonly exceeding 0.5 wt. % Co in individual samples. These concentrations are some of the most Co-rich in the oceans (figure below).

2.2.3 Polymetallic crusts

Cobalt-rich ferromanganese crusts precipitate onto nearly all rock surfaces in the deep ocean that are free of sediment (Figure 2.5 Seamounts, guyots, and oceanic plateaus important for the formation of polymetallic crust (based on morphological features identified by GRID Arendal; Harris et al., 2014)). Here, they form pavements of manganese and iron oxides. Ferromanganese crusts may also coat rock pebbles and cobbles. Their thickness varies from less than 1 millimetre to about 260 millimetres. They form at water depths of 600 to 7 000 m on the flanks of volcanic seamounts, ridges, and plateaus. Crusts with sufficient mineral content to be of economic interest commonly occur at depths of about 800 to 2 500 m³⁴. In the Pacific Ocean, there are more than 11 000

³² Hein, J.R. and Koschinsky, A. (2013): Deep-ocean ferromanganese crusts and nodules. In: *Treatise on Geochemistry*, 273-291

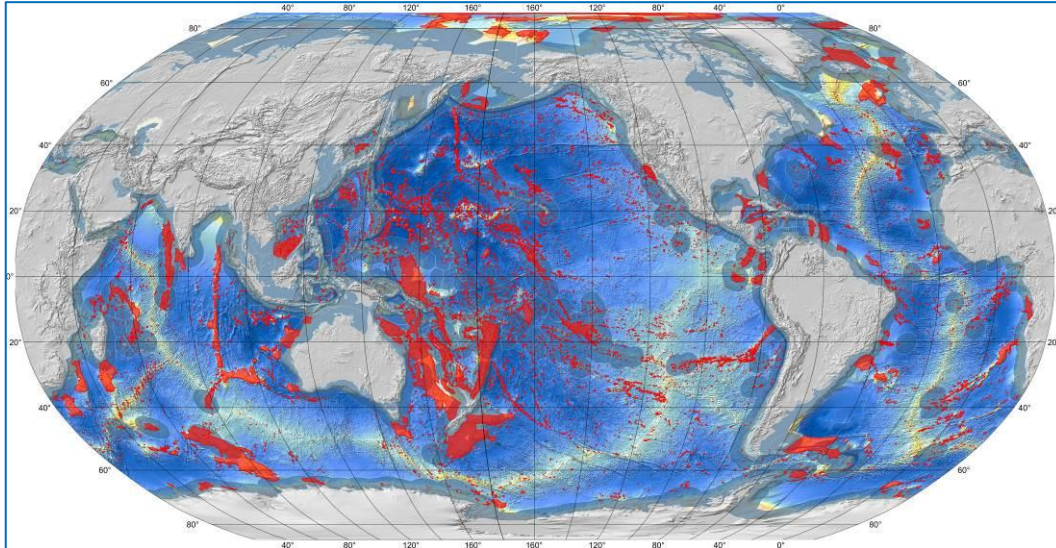
³³ Kesler, S.E., Gruber, P.W., Medina, P.A., Keoleian, G.A. Everson, M.P., and Wallington, T.J. (2011). Global lithium resources: relative importance of pegmatite, brine and other deposits *Ore Geology Reviews* 4, 55-69.

³⁴ Hein, J.R. and Koschinsky, A. (2013): Deep-ocean ferromanganese crusts and nodules. In: *Treatise on Geochemistry*, 273-291

seamounts (57 % of the global total) and 41 000 knolls³⁵ (estimated from the latest global bathymetry), and many more might exist in uncharted waters³⁶.

Many seamounts are within the EEZs of Pacific Island states (below). The Atlantic Ocean has fewer seamounts, and their cobalt-rich crusts are often associated with hydrothermal activity at seafloor-spreading centres, with the exceptions of the northeast and northwest continental margin areas.

Figure 2.5 Seamounts, guyots, and oceanic plateaus important for the formation of polymetallic crust (based on morphological features identified by GRID Arendal; Harris et al., 2014)



Ferromanganese crusts have a simple mineralogy and are composed predominantly of the manganese oxide vernadite and a variety of non-crystalline iron oxyhydroxides. The crusts also contain minor amounts of detrital minerals, such as quartz and feldspar. Ferromanganese crusts vary in thickness from <1 to 260 mm and are generally thicker on older seamounts. Most thick crusts (greater than about 60 mm) also contain a layer enriched in phosphorous that formed long after the crusts have precipitated from seawater.

Iron and manganese occur in approximately equal amounts in crusts. Cobalt is the trace metal of greatest economic interest and commonly shows values greater than 0.5 wt. % Co. Another metal of great interest is Tellurium (Te), which globally averages about 50 ppm in crusts, with a maximum value of 205 ppm³⁷. The REEs are of great interest because China currently produces about 95% of the total world production. Total REEs average about 0.16% to 0.25% over large regions of the global ocean). However, localized areas can yield total REE concentrations as high as 0.7% and individual samples over 1% total REEs. The trace element platinum may occur with concentrations up to 3 ppm³⁸, however, even on a local scale, Pt does not average more than about 0.7 ppm. Other platinum-group elements (PGEs) are much less concentrated in the crusts. Further metals of interest as potential by-products of Co-Ni-(Mn) mining include Bi, Nb, and Zr (Table below).

³⁵ Yesson, C., Clark, M.R., Taylor, M.L., Rogers, A.D. (2011): The global distribution of seamounts based on 30 arc seconds bathymetry data. *Deep-Sea Research Part I* 58, 442–453.

³⁶ Kim, S.-S., Wessel, P. (2011) New global seamount census from altimetry-derived gravity data. *Geophysical Journal International* 186, 615–631.

³⁷ Hein, J.R. and Koschinsky, A. (2013): Deep-ocean ferromanganese crusts and nodules. In: *Treatise on Geochemistry*, 273-291

³⁸ Halbach et al., 1989; Hein et al., 2000

Table 2.3 Mean content of selected elements of polymetallic crusts in various regions

	NW Pacific	S Pacific	Atlantic	Indic
Fe (%)	16.8	18.1	20.9	22.3
Mn (%)	22.8	21.7	14.5	17.0
Ni (%)	0.42	0.46	0.26	0.26
Cu (%)	0.10	0.11	0.09	0.11
Co (%)	0.67	0.62	0.36	0.33
Bi (ppm)	42	22	19	30
Nb (ppm)	54	59	51	61
Pt (ppm)	0.5	0.5	0.6	0.2
REE+Y (ppm)	2454	1634	2402	2541
Te (ppm)	60	30	43	31
Y (ppm)	222	177	181	178
Zr (ppm)	559	754	362	535

(source Hein et al., 2013).

Numerous ferromanganese crust samples have been collected, however, many of the results are not publically available. We used the sample database of ISA and the distribution of the samples clearly shows a bias to Pacific samples which is related to their overall higher resource potential (figure below). Future resource-related research should focus on the Pacific Ocean based on the higher Co content in ferromanganese crusts from the Pacific when compared to other areas of the global oceans.

Figure 2.6 Location of polymetallic crust samples in the ISA database investigated for this report (N=1224)

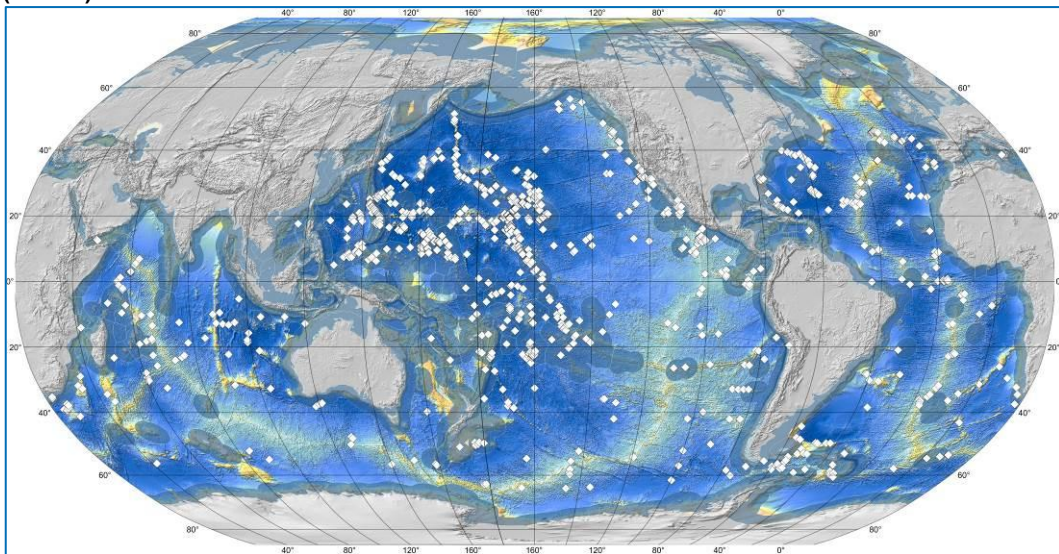
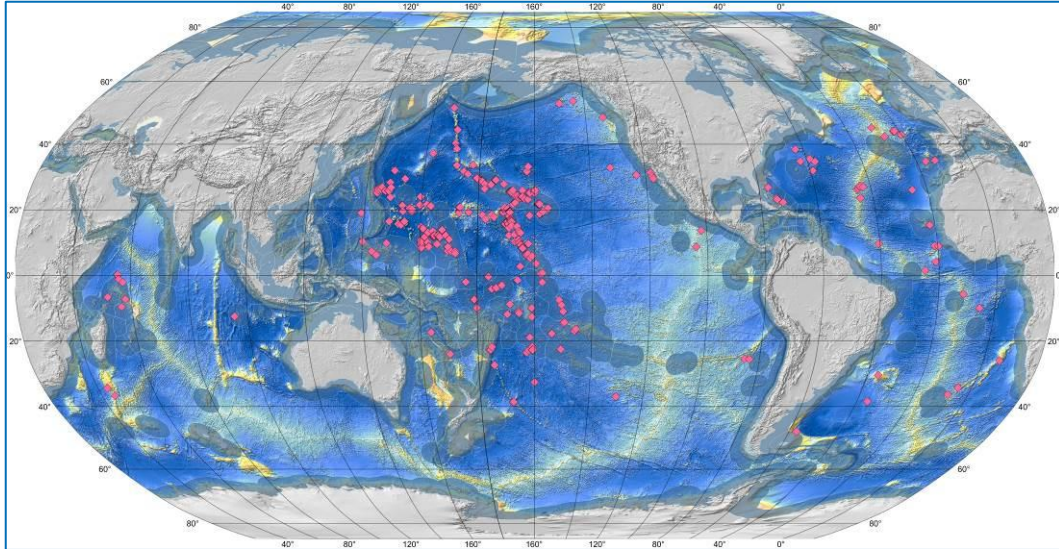
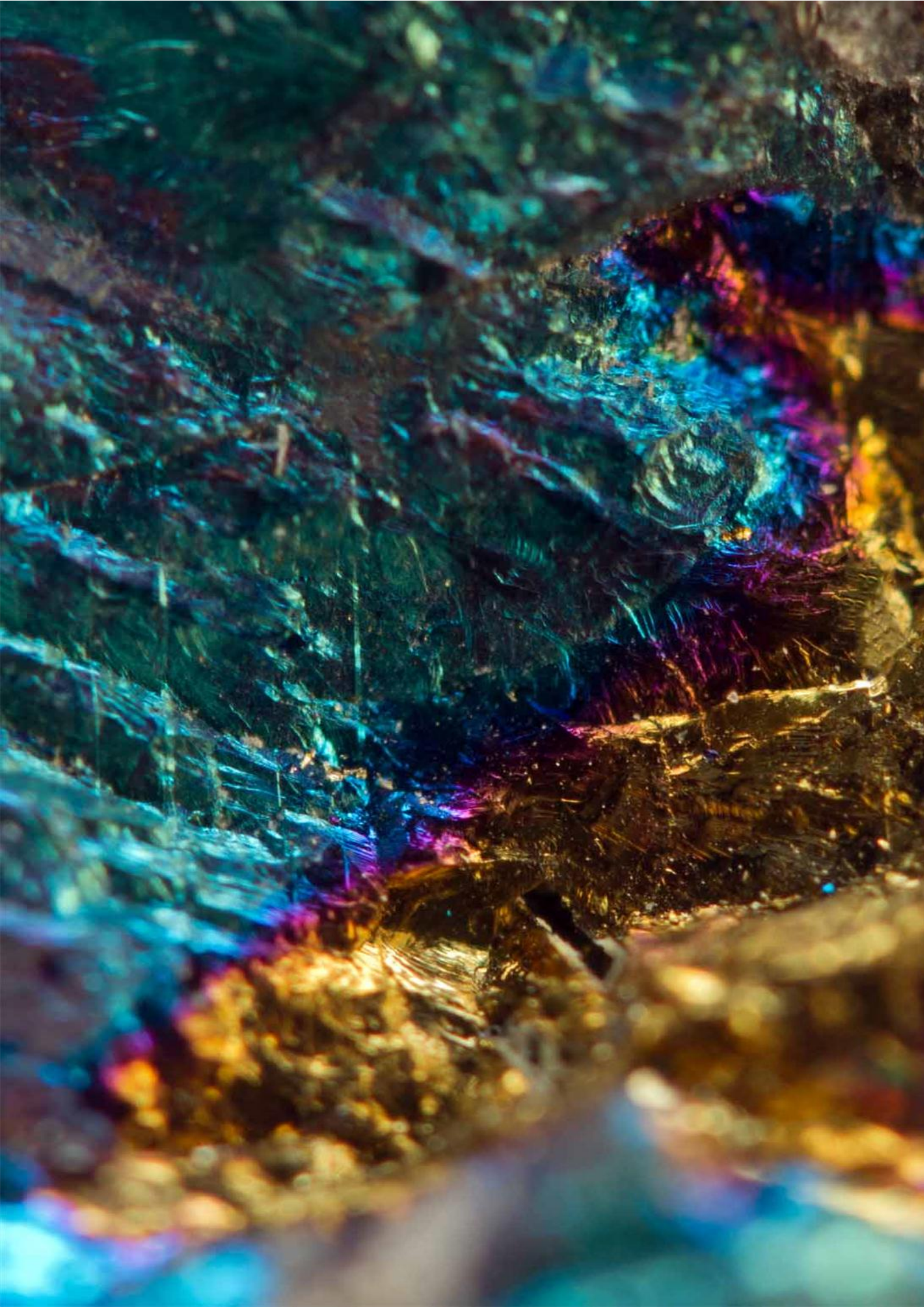


Figure 2.7 Location of polymetallic crust samples in the ISA database with Co concentrations above 0.5 wt. % (N=465). Note that most samples lie in the western Pacific.





3 Legal aspects

3.1 Summary

The legal framework for deep-sea mining derives from multiple levels of law.

In terms of **international law**, the basic legal framework for deep-sea mining is set out in the United Nations Convention on the Law of the Sea ('UNCLOS') as modified by the Part XI Implementation Agreement. UNCLOS distinguishes between maritime zones under the jurisdiction of coastal States (internal and archipelagic waters, territorial sea, exclusive economic zone and continental shelf) and areas beyond national jurisdiction, namely the high seas and the seabed beyond the continental shelves of coastal States (called the "Area" in Part XI of UNCLOS).

All rights in the mineral resources of the Area, which comprises the international seabed, ocean floor and subsoil, are 'vested in mankind as a whole'. The International Seabed Authority (ISA), an international organisation based in Kingston, Jamaica, is responsible for regulating deep-sea mining in the Area. The EU and Member States are members of ISA. The regulatory regime for deep-sea mining in the Area is not yet complete. Regulations on exploration have been adopted, while regulations on exploitation are currently being developed. Outstanding issues include the basis on which ISA will levy royalties for deep-sea mining, environmental standards and, in due course, benefit sharing. In its Advisory Opinion the Seabed Disputes Chamber of the International Tribunal for the Law of the Sea, a specialised court created under UNCLOS, provided guidance on the notion of 'sponsorship' of contractors engaged in deep-sea mining in the Area, and the need for such States to adopt laws, regulations and administrative measures to ensure compliance by such contractors.

As regards deep-sea mining in areas under national jurisdiction, coastal States clearly have regulatory jurisdiction in terms of international law and can design and adopt their own legislation accordingly. There are no international standards for deep-sea mining in areas under national jurisdiction and consequently there is a risk that different, stricter standards may in due course apply in the Area than in areas under the coastal State jurisdiction. States are subject to a number of obligations in terms of international agreements of global or regional application which tend to be of a rather general nature and the extent to which they may affect and deep-sea mining is not entirely clear. In due course there may be a need for the establishment of specific standards for vessels or platforms engaged in deep-sea mining;

EU law applies to deep-sea mining in the waters under the jurisdiction of the Member States. Unlike marine hydrocarbon extraction, however, the topic of deep-sea mining is not (yet) specifically addressed in EU legislation. Although plans or programmes that relate to deep-sea mining would be subject to strategic environmental assessment, deep-sea mining projects are not subject to the Environmental Impact Assessment Directive. Environmental data relating to deep-sea mining is currently subject to the Environmental Information Directive. Existing general EU waste legislation would apply to deep-sea mining but the specific directive on mining waste does not and while EU environmental liability legislation is potentially applicable to deep-sea mining its effectiveness might be reduced due to the need to prove fault on the part of an operator before liability can be established. Other environmental legislation may impact on how deep-sea mining is undertaken in European waters but will not prevent it taking place. Finally European companies engaged in deep-sea mining both in European waters and elsewhere in the world are subject to the specific reporting requirements of extractive industries under the Accounting Directive.

As regards **national legislation** that governs deep-sea mining in the Area many EU Member States have yet to adopt the necessary laws. Out of the eight Member States considered in this Study, only two, Germany and the UK have legislation on deep-sea mining in the Area in place although France has informed ISA that the preparation of such legislation is under way. The third countries considered in this study that have adopted legislation on deep-sea mining in the Area were party to the interim agreements that preceded UNCLOS. Most, but not all of these States, have updated their laws following the entry into force of UNCLOS. One exception in this respect is the USA which is not party to UNCLOS but which has retained its original legislation on deep-sea mining in the Area.

As regards national legislation to regulate deep-sea mining in areas under national jurisdiction, more often it is the case that terrestrial mining legislation applies to the continental shelf or EEZ, rather than specific deep-sea mining legislation. In a number of cases, terrestrial mining legislation has been modified so as to include specific reference to deep-sea mining. Only the USA has specific legislation in place on deep-sea mining in areas under its national jurisdiction. Although deep-sea mining and terrestrial mining are both concerned with the extraction of mineral ores from the ground the extent to which terrestrial mining legislation is really suitable for application to the sea is surely questionable as shown by a number of practical questions raised in connection with deep-sea mining in the waters of Papua New Guinea. Also noteworthy, given that the nearby seabed appears to offer some of the most promising possibilities for deep-sea mining in European waters, is the fact that the Administration of the Azores took the decision to develop specific legislation for deep-sea mining, even though this was subsequently ruled unconstitutional.

3.2 Introduction

The terms of reference call for a description of the legal framework governing deep-sea minerals exploration and extraction and exploitation in four different, yet inter-linked, spatial and jurisdictional contexts:

- maritime areas under the jurisdiction of selected EU Member States;
- maritime areas under the jurisdiction of the overseas countries and territories (OCTs) of the Member States;
- maritime areas of at least five other countries in which mining activity is already taking place or the results of underwater surveys have been promising;
- areas beyond the national jurisdiction of any country.

The legal framework for deep-sea mining derives from multiple levels of law. The foundation of the framework is provided by international law, the body of law that regulates the rights and duties of States and other actors, such as international organisations, recognised by international law. EU law applies to the Member States of the EU and in certain circumstances may also apply to their OCTs. Finally, maritime areas under the jurisdiction of States are subject to the national legislation of those States as shaped by international law and, in the case of the EU Member States, EU law. Moreover, as will be seen national law also has an important role to play in terms of deep-sea mining in maritime areas beyond the jurisdiction of the State concerned.

3.3 International law

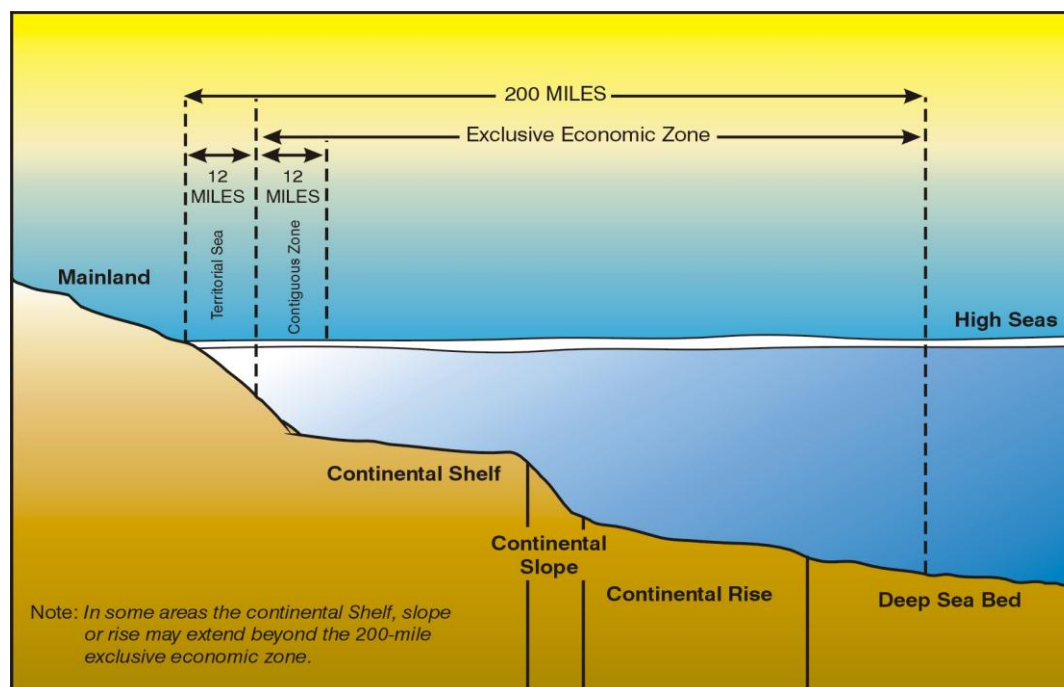
The starting point for examining international law relating to deep-sea mining is the law of the sea, the branch of international law that is concerned with all uses and resources of the sea. The cornerstone of the law of the sea is the United Nations Convention on the Law of the Sea (UNCLOS) which was adopted in 1982. At present there are 166 parties to UNCLOS including the EU and its Member States.³⁹ It is, however, important to note that around 30 States are not party to UNCLOS, including the United States of America (USA), Colombia, Israel, Libya, Peru, Syria, Turkey and Venezuela.

The sources of the law of the sea are identical to those of international law in general, namely agreements (treaties) and customary international law. Apart from UNCLOS a number of other international agreements are also potentially relevant to deep-sea mining and these are considered below.

Part of the balance eventually achieved by UNCLOS was through the system of maritime zones that it provides for, including those that pertain to coastal States. These zones, which determine the spatial competence and jurisdiction of States, and thus which specific legal regime applies to deep-sea mining.

The sovereignty of a coastal State extends beyond its land territory and internal waters to an adjacent belt of sea described as the **territorial sea** that may extend up to twelve nautical miles (nm)⁴⁰ measured from the baseline (usually the low water mark⁴¹). Within its territorial sea the authority of a coastal State is in principle absolute except as restricted by UNCLOS and other rules of international law⁴².

Figure 3.1 Maritime zones under UNCLOS



³⁹ http://www.un.org/Depts/los/reference_files/status2010.pdf.

⁴⁰ 1 nm = 1,852 metres.

⁴¹ In some circumstances a coastal State may draw a straight baseline for example on heavily indented coasts and over the mouths of bays and estuaries.

⁴² The most important restriction is the right of 'innocent passage' through the territorial sea, which is enjoyed by ships of all States (article 17).

Beyond its territorial sea a coastal State may claim a contiguous zone, which is not relevant to deep-sea mining, and an exclusive economic zone (EEZ) which potentially is. The **EEZ** can extend up to 200 nm from the baseline. Within its EEZ a coastal State does not enjoy sovereignty as such but a more limited set of “sovereign rights” relating to living and non-living resources and with regard to other activities for the economic exploitation and exploration of its EEZ, such as the production of energy, as well as deep-sea mining.

UNCLOS also recognises the rights of a coastal State over its adjacent **continental shelf**, which comprises the seabed and subsoil of the ‘submarine areas’ beyond the territorial sea. The continental shelf may extend as far the natural prolongation of the land territory to the outer edge of the continental margin as adjusted by a complex formula or to a distance of 200 nm from the baseline in cases where the outer edge of the continental margin does not extend that far. In other words some, but not all, coastal States may be entitled to an **outer continental shelf** that extends beyond 200 nm from the baseline and thus beyond the outer edge of the EEZ (although the final outer limit cannot exceed either 350 nm from the baseline or 100 nm from the 2,500 m isobath (depending on the criteria chosen⁴³). With regard to its continental shelf, Article 77 provides that a coastal State exercises ‘sovereign rights for the purpose of exploring it and exploiting its natural resources’.

Beyond the outer edge of the continental shelf (of 200 nm or more if the conditions for this are satisfied) lies the Area, defined by UNCLOS as the ‘seabed and ocean floor and subsoil thereof, beyond the limits of national jurisdiction’, and which is the subject of Part XI of UNCLOS. No State may claim sovereignty or sovereign rights over any part of the Area or its resources. Instead, all rights in the ‘resources’ of the Area are ‘vested in mankind as a whole’ on whose behalf the International Seabed Authority (ISA), established pursuant to UNCLOS, is to act.⁴⁴

The water column and the surface waters of the sea directly above the Area (and any part of the continental shelf that extends beyond 200 nm from the baseline) are the **high seas** which include all parts of the sea that do not form part of the EEZ, territorial sea or other maritime zones of coastal States.⁴⁵

While UNCLOS clearly confers the necessary jurisdiction on each coastal State to regulate deep-sea mining in areas under its national jurisdiction (in other words within its territorial sea, EEZ and continental shelf including its outer continental shelf if any) in accordance with its own legislation, it offers very little guidance as to how this is to be done. In other words just as there is no comprehensive international legal framework for the regulation of land based mining, precisely how coastal States are to regulate deep-sea mining is not specified in international law. Nevertheless, the rights of coastal States are not absolute. In regulating deep-sea mining in areas under its national jurisdiction, a coastal State may be subject to other more generally applicable rules of international law, including those contained in UNCLOS and other international agreements, in particular as regards environmental matters. The potential scope of such obligations is considered in more detail below.

In contrast to the relatively sparse legal framework for deep-sea mining in areas under national jurisdiction, UNCLOS, supplemented by the Part XI Implementation Agreement⁴⁶, established a

⁴³ UNCLOS Article 76(5) and (6).

⁴⁴ Article 137.

⁴⁵ In other words if a coastal State does not claim an EEZ or some form of derivative zone the surface waters and water column above its continental shelf may also be considered to form part of the high seas.

⁴⁶ Agreement relating to the Implementation of Part XI of the United Nations Convention on the Law of the Sea of 10 December 1982 New York, 28 July 1996, 33 *International Legal Materials* 1309 (1994); <www.un.org/Depts/los>.

relatively detailed although, as will be seen, as yet incomplete legal framework for deep-sea mining in the Area.

Part XI of UNCLOS establishes a number of generally applicable principles with regard to the conduct of States in relation to the Area including peace, security international cooperation and mutual understanding, the responsibility to ensure compliance and liability for damage, the use of the Area for exclusively peaceful purposes. The main focus of Part XI, however, is on the exploration and exploitation of the resources of the Area.

Other parts of UNCLOS that are potentially relevant to deep-sea mining are Part XII on the protection and preservation of the marine environment, Part XIII on marine scientific research and Part XIV on technology transfer.

Many industrialized countries were dis-satisfied with the provisions included in Part XI of the final version of UNCLOS. In order to address those concerns, following lengthy negotiations the Part XI Implementation Agreement was concluded on 28 July 1994, paving the way for the entry force of UNCLOS later that year. Although it did not alter the basic principle that the resources of the Area are the common heritage of mankind, it dis-applied the detailed production policies, systems of assistance to land-based producers and provisions on the mandatory transfer of technology. Instead it takes a more market-oriented approach that combined a reduction in the size of the institutions foreseen for ISA and broader representation in its decision-making bodies.

With the entry into force of UNCLOS in 1994, ISA formally came into existence as an international organisation (and thus a body recognized by international law). The members of ISA are *ipso facto* the parties to UNCLOS and therefore include the EU and its Member States. Each member of ISA is represented in the Assembly which is the supreme organ of the organisation and responsible for policy making. The Council, which consists of 36 members of the Authority elected by the Assembly on the basis of a complex set of rules so as to provide a balanced composition, is the executive organ of ISA and establishes the specific policies to be followed by the organisation as well as approving applications for exploration/exploitation rights. A number of EU Member States are members of the Council and have played a prominent role in its activities over the years. The Council is assisted by the Legal and Technical Committee, which is made up of elected experts. The ISA Secretariat, which is headed by the Secretary General, is located in Kingston Jamaica and currently has around 40 technical and non-technical staff.

The regulatory regime for deep-sea mining in the Area is set out principally in Annex III of UNCLOS, as modified by the Part XI Implementation Agreement and supplemented by a series of rules, regulations and procedures adopted by ISA that together make up the 'Mining Code'. To date three sets of regulations describe the regimes for exploration for nodules, crusts and sulphides respectively.

Exploration activities may only be carried out in areas specified in detailed and approved plans of work by suitably qualified applicants in terms of financial and technical capabilities and on the basis of authorizations issue by ISA. The regulations specify how an application is to be made for an approved plan of work as well as the form and content of the contracts for exploration. Some 16 contracts for exploration have been concluded to date.

ISA has begun work on the development of regulations on exploitation which will comprise the exploitation code. This will inevitably be a very complex and challenging task that will need to address *inter alia* the applicable financial and environmental regimes. In terms of the financial arrangements key issues that will need to be addressed include the approach to royalties payable

to ISA, the method of calculating such royalties and the relationship with national taxation regimes. There some time pressure here given that the first exploration contracts will end in 2016: the Part XI Implementation Agreement specifies that the Council must thereafter consider and provisionally approve an application for a plan of work for exploitation even if the rules, regulations and procedures for exploitation are not in place.

As regards the issue of benefit sharing, ISA proposes to focus on the exploitation code and to leave the issue of benefit sharing until a later stage, by which time a clearer picture of the benefits of deep-sea mining in the Area should emerge.

UNCLOS provides that activities in the Area may be carried out by *inter alia* States Parties, or state enterprises or natural or juridical persons which possess the nationality of States Parties or are effectively controlled by them or their nationals, when sponsored by such States. At the request of ISA, the precise nature of the obligations of sponsoring States were examined by the Seabed Disputes Chamber of the International Tribunal for the Law of the Sea established under UNCLOS. In its advisory opinion, the Chamber clarified that the obligation of a State to ensure compliance by a sponsored contractor is an obligation of 'due diligence'. However, States also have their own direct obligations including the obligation to assist ISA. As to liability the Chamber held that the liability of the sponsoring State arises only from its failure to fulfil its own obligations under the relevant legal framework and does not automatically arise from the failure of the contractor to comply with its own obligations. In other words the notion of sponsorship under the deep-sea mining regime does not envisage a system of strict or 'no-fault' liability on the part of sponsoring States. Finally the Chamber held that UNCLOS requires a sponsoring State to adopt within its legal system laws, regulations and administrative measures that have two distinct functions, namely to ensure compliance by the contractors with its obligations and to exempt the sponsoring State from liability: a contractual arrangement between a sponsoring State and a contractor is not sufficient.

Once the exploitation regulations are adopted a further question will arise as to the extent to which the provisions on environmental protection are applicable with regard to deep-sea mining in areas under national jurisdiction. More specifically while ISA is required to develop a robust legal regime for deep-sea mining in terms of the protection of the marine environment the same may not be the case for deep-sea mining in areas under national jurisdiction, either because less strict rules will apply or because the necessary mechanisms for the enforcement of such rules may be lacking. In short there is a risk of different standards being applied: stricter standards in the Area applied by ISA and less strict standards in areas under the national jurisdiction of, for example, developing countries.

Other international instruments of potential relevance to deep-sea mining include the Convention on Biological Diversity,⁴⁷ to which the EU and the Member States are Contracting Parties, in terms of the protection of the marine environment. In contrast the London Convention⁴⁸ and Protocol⁴⁹, which are concerned with the disposal of wastes at sea both expressly exclude waste generated by deep-sea mining from their ambit. A range of legal instruments adopted under the auspices of the International Maritime Organization are of potential relevance to deep-sea mining, although their focus is primarily on merchant shipping. In due course new standards may be necessary to address the specific requirements of vessels and platforms used for deep-sea mining. Finally deep-sea mining activities may be affected by regional environmental agreements such as the OSPAR Convention⁵⁰ that applies to the North East Atlantic Ocean, the Barcelona Convention⁵¹ which

⁴⁷ 31 ILM (1992), 822.

⁴⁸ London, Mexico City, Moscow and Washington, 29 December 1972; 1046 UNTS 120.

⁴⁹ London, 7 November 1996; (1997) 36 ILM 1.

⁵⁰ Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR), Paris, 22 September 1992; 2354 UNTS 67.

applies to the Mediterranean Sea and the Noumea Convention⁵² which applies to part of the Pacific Ocean.

3.4 European Union law

EU law applies to maritime areas over which EU Member States have jurisdiction⁵³. In other words EU law will apply to deep-sea mining and related activities conducted in maritime zones under the jurisdiction of Member States. Unlike marine hydrocarbon extraction, which is subject to the regulatory framework created by the Hydrocarbons Directive⁵⁴, the topic of deep-sea mining is not directly addressed in EU law. This is not really surprising given that deep-sea mining does not yet take place in EU waters and its prospects in this respect are not entirely clear. The seabed in many areas within European waters is simply not suitable for deep-sea mining. The instruments of EU law that are potentially of most relevance to deep-sea mining, should it take place in areas under the jurisdiction of the Member States, are concerned with environmental protection.

The **Environmental Impact Assessment Directive**⁵⁵ requires the environmental consequences of certain public and private projects that are likely to have significant effects on environment by virtue, *inter alia*, of their nature, size or location to be assessed before authorisation. For certain projects, listed in Annex I of the directive, an environmental impact assessment (EIA) is mandatory. However as regards projects listed in Annex II of the directive, Member State authorities are required to determine through a case-by-case examination or general thresholds or criteria whether the project is to be made subject to an assessment. However while the directive includes quarries and open cast mining under Annex I and dredging in Annex II, it does not explicitly refer to deep-sea mining..

On the other hand the **Strategic Environmental Assessment Directive**⁵⁶ (the SEA Directive), which requires a formal environmental assessment of certain plans and programmes which are likely to have significant effects on the environment, most likely would apply to comprehensive plans or programs that relate to deep-sea mining.

The **Marine Strategy Framework Directive**⁵⁷ the **Birds Directive**⁵⁸ and the **Habitats Directive**⁵⁹ would not prevent deep-sea mining in European waters but may impact on how it is undertaken so as, in broad terms, to minimise negative environmental impacts.

The **Mining Waste Directive**⁶⁰ does not apply to waste generated from deep-sea mining meaning that such waste would fall to be regulated on the basis of the general regime for waste

⁵¹ Convention for the Protection of the Marine Environment and Coastal Regions of the Mediterranean. Originally the Convention for the Protection of the Mediterranean Sea against Pollution, Barcelona, 16 February 1976; 1102 UNTS 27.

⁵² The Convention for the Protection of Natural Resources and the Environment of the South Pacific Region, 24 November 1986, www.sprep.org/legal/noumea-convention

⁵³ See, for example, Case 61/77 Commission v Ireland [1978] ECR 417, paragraphs 45 to 51.

⁵⁴ Directive 94/22/EC of the European Parliament and of the Council of 30 May 1994 on the conditions for granting and using authorizations for the prospecting, exploration and production of hydrocarbons (OJ L 79, 29.3.1996). See also the recently adopted Directive 2013/30/EU of the European Parliament and of the Council of 12 June 2013 on safety of offshore oil and gas operations and amending Directive 2004/35/EC (OJ L 178 28.6.2013, p. 66) which was adopted to improve the safety of offshore oil and gas installations following the Deepwater Horizon oil spill in the Gulf of Mexico.

⁵⁵ Directive 2011/92/EU of the European Parliament and of the Council of 13 December 2011 on the assessment of the effects of certain public and private projects on the environment (OJ L 26, 28.1.2012, p. 1).

⁵⁶ Directive 2001/42/EC of the European Parliament and of the Council of 27 June 2001 on the assessment of the effects of certain plans and programmes on the environment (OJ L 197, 21.7.2001, p. 30).

⁵⁷ Directive 2008/56/EC of the European Parliament and of the Council of 17 June 2008 establishing a framework for Community action in the field of marine environmental policy (OJ L 240, 10.7.2004, p. 17).

⁵⁸ Council Directive 79/409/EEC of 2 April 1979 on the conservation of wild birds (OJ L 103, 25.4.1979, p. 1.).

⁵⁹ Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora (OJ L 206, 22.7.1992, p. 7.)

management created by the **Waste Framework Directive**⁶¹. The problem with this situation is that the overall approach of the Waste Framework Directive is designed for waste in general and as such may be considered less than fully appropriate for the management of waste generated by deep-sea mining.

The recently adopted **Directive on maritime spatial planning** will require Member States to develop maritime spatial plans covering activities taking place in their 'marine waters' as defined in the MSFD and including the water column, seabed and subsoil. Although it does not contain any explicit reference to deep-sea mining, this topic would be expected to be addressed in any assessment of activities taking place within the Areas covered by a Maritime Spatial Plan.

While the **Environmental Liability Directive**⁶² could potentially be of relevance to deep-sea mining undertaken in European waters, because it does not expressly refer to deep-sea mining, its effectiveness might be reduced due to the need to prove fault on the part of an operator before liability can be established.

Finally European companies engaged in deep-sea mining both in European waters and elsewhere in the world are subject to the specific reporting requirements of extractive industries under the **Accounting Directive**⁶³. This means that they must prepare and make public an annual report on payments made to governments thus including the level of royalty and other licensing payments made.

3.5 National legislation

In examining national legislation applicable to deep-sea mining it is necessary to distinguish between the legislation that regulates deep-sea mining in areas under national jurisdiction and that which regulates deep-sea mining in the Area. For the purpose of the study, deep-sea mining legislation was taken to mean legislation applicable to mining on the seabed at a depth of 200 metres or more so as to clearly separate mining legislation from the extraction of aggregates.

With regard to legislation that regulates deep-sea mining in the Area, because of the special nature of the specific regime of the Area, there are two basic scenarios. Either a country has adopted specific legislation on deep-sea mining in the Area or it has not. More specifically no jurisdiction considered has sought to adapt existing legislation, such as terrestrial mining legislation, to apply to the Area. This observation applies to Member States, Overseas Countries and Territories of the Member States and the Third Countries considered.

As regards the Member States considered in this Study, namely France, Germany, Greece, Italy, the Netherlands, Portugal, Spain, and the UK, only Germany and the UK have adopted legislation on deep-sea mining in the Area. The instruments concerned are the Seabed Mining Act, 1995 and the Deep-sea Mining Act 2001 respectively. In the case of both countries the current legislation either replaces earlier legislation (in the case of Germany the 1995 Act replaced and updated the

⁶⁰ Directive 2006/21/EC of the European Parliament and of the Council of 15 March 2006 on the management of waste from extractive industries and amending Directive 2004/35/EC (*OJ L 102, 11.4.2006, p. 15*).

⁶¹ Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives (*OJ L 312, 22/11/2008, p. 3*).

⁶² Directive 2004/35/CE of the European Parliament and of the Council of 21 April 2004 on environmental liability with regard to the prevention and remedying of environmental damage (*OJ L 143, 30.4.2004, p. 56*).

⁶³ Directive 2013/34/EU of the European Parliament and of the Council of 26 June 2013 on the annual financial statements, consolidated financial statements and related reports of certain types of undertakings, amending Directive 2006/43/EC of the European Parliament and of the Council and repealing Council Directives 78/660/EEC and 83/349/EEC (...).

earlier Interim Regulation of Deep Seabed Mining 1980) or has been updated by subsequent legislation (the Deep-sea Mining Act 2001 was substantially amended (and renamed) by the Deep-sea Mining Act, 2014). In both cases the earlier legislation was adopted in the early 1980s before the entry into force of UNCLOS and the new texts reflect the current legal framework for deep-sea mining in the Area under international law. Other Member States that have specific legislation on deep-sea mining in the Area are Belgium and the Czech Republic.

The fact that Member States have yet to adopt legislation is perhaps surprising for two reasons. First of all the Seabed Disputes Chamber was extremely clear in its advisory opinion about the need for a sponsor to adopt legislation on deep-sea mining in the Area. Second there is the fact that most of these countries, with the exception of Greece, are relatively active in terms of ISA and deep-sea mining in general. In this connection it is to be noted that France informed ISA in 2013 that work is under way to prepare legislation on this topic.

As regards the OTCs which are linked with Denmark (Greenland), France (New Caledonia and Dependencies, French Polynesia, French Southern and Antarctic Territories, Wallis and Futuna Islands, Mayotte, Saint Pierre and Miquelon), the Netherlands (Aruba, Bonaire, Curaçao, Saba, Sint Eustatius, Sint Maarten) and the UK (Anguilla British Antarctic Territory, Bermuda, British Indian Ocean Territory, Cayman Islands, Falkland Islands, Montserrat, Pitcairn, Saint Helena and Dependencies, South Georgia and the South Sandwich Islands, Turks and Caicos Islands, British Virgin Islands), the position is clear. None have legislation in place to regulate deep-sea mining in the Area. However as regards the UK a ministerial commitment was given in the course of debates in the UK Parliament on the Deep-sea Mining Bill 2014 to consult with the UK's overseas territories with a view to possibly extending the (then) Bill to them.

Of the third country legislation reviewed, Canada, China and Papua New Guinea do not have legislation in place on deep-sea mining in the Area although the development of such legislation has been placed on the agenda of the Chinese legislature.

As regards Japan, the Act on Interim Measures for Deep Seabed Mining provides for the regulation of mining activities by Japanese persons in the Area. The Act was enacted in 1982 and lastly amended in 2011 (which entered into force in 2012) although the amendments were not substantial. In the case of the USA, which is not party to UNCLOS, the Deep Seabed Hard Minerals Resources Act (DSHMRA) governs deep seabed mining in areas beyond national jurisdiction. The law was designed to apply in the aftermath of the U.S. decision not to join UNCLOS, and only until such time as the nation joined a comprehensive international treaty governing the oceans. Consequently, the DSHMRA continues to govern U.S. nationals (citizens, vessels, and others subject to U.S. jurisdiction) that engage in exploration for, and commercial recovery of, hard mineral resources on the deep seabed outside of areas of U.S. jurisdiction. The United States has rather limited practice in the application of the National Oceanic and Atmospheric Administration (NOAA) regulations that give effect to the DSHMRA. In 1984, the US issued four exploration licences under the DSHMRA, which were processed and approved by NOAA.⁶⁴ These exploration licences were for seabed areas in the CCZ of the North Pacific Ocean. The licences did not confer any security of title internationally, and only carry security of title as against U.S. citizens and companies. Two of the licenses have expired, although NOAA recently renewed the other two.

⁶⁴ The companies involved were Ocean Management, Inc., Ocean Mining Associates, and Ocean Minerals Company for five-year extensions of their exploration licenses.

On the other hand, Fiji's legislation on deep-sea mining in the Area in the form of the International Seabed Mineral Management Decree was adopted more recently, in 2013. This instrument creates a comprehensive legal framework to enable Fiji to act as a sponsor.

As regards national legislation on deep-sea mining in areas under national jurisdiction, analysis is to some extent complicated by the fact that in reality commercial deep-sea mining has yet to take place anywhere in the world. Again there are two basic scenarios: either a country has legislation in place or it does not.

However, in most of the countries considered in the case studies, the situation is often less the case that a country has adopted specific deep-sea mining legislation and more often the case that terrestrial mining legislation applies to the continental shelf or EEZ on the basis of specific wording in the relevant maritime zone legislation and the mining legislation itself (in the case of Portugal there is a reference to the ownership of mineral resources in the Constitutions). In terms of the EU Member States this is the case for France, Italy, the Netherlands, Portugal and Spain. In a number of cases, terrestrial mining legislation has been modified so as to include specific reference to deep-sea mining (such as the case of France where specific provisions on deep-sea mining have been added to the Mining Code).

As regards Greece, legislation that previously would have applied to deep-sea mining in the form of Decree 142 of 13 March 1969, 'On exploration and exploitation of submarine and shallow water minerals' has been amended to apply only to dredging. In the case of the UK, however, unlike the other Member States deep-sea mining is potentially subject to regulation not on the basis of a general mining act, as such does not exist under UK law, but rather on the basis of the Marine and Coastal Access Act, 2009 which created a new and comprehensive system of marine management for the UK marine area that *inter alia* includes a marine planning system, a comprehensive licensing system for marine activities and the designation of conservation zones.

Similar observations apply to the OCTs. In the case of Greenland and the OCTs linked to France and the Netherlands, terrestrial mining legislation theoretically applies. In the case of the overseas territories of the UK the position is a little more complicated because in most cases, the territories concerned do not have EEZ or continental shelf legislation but have instead sought to claim exclusive fishery zones (which are of little relevance to deep-sea mining). Moreover such territories do not, in most cases, have terrestrial mining legislation.

As regards the third countries considered, the picture is rather similar. For example, while Canada clearly has jurisdiction over the mineral resources on its continental shelf as a matter of Canadian law, there is no legislation in place that would provide for the regulation of deep-sea mining. In the cases of China, Fiji, Japan the scope of terrestrial mining legislation has been extended to maritime areas and the legislation amended accordingly.

Perhaps the most interesting case in this respect is Papua New Guinea, the first country in the world where commercial deep-sea mining is due to take place in the coming years in waters under national jurisdiction, in this case in the territorial sea. However, as set out in the case study, the existing legal basis for this is the terrestrial mining legislation and this raises a number of potential legal problems: (a) a lack of clarity over benefit sharing with local communities, the local level governments and provincial governments; (b) a lack of clarity over the relationship with customary law; (c) questions with regard to mine closure and remediation at sea; (d) the lack of waste management legislation and major question marks as to how mining waste under deep-sea mining would be dealt with; (e) the lack of appropriate legislation on mine safety issues; (f) the rights of communities affected by deep-sea mining; (g) no clear guidance in the legislation with regard to

royalty payments including as to how they are to be calculated or applied. In order to seek to provide answers to these questions draft offshore mining legislation is currently in the early stages of preparation.

Some of these issues may be specific to Papua New Guinea. However, a larger point arises. Although deep-sea mining and terrestrial mining are both concerned with the extraction of mineral ores the extent to which terrestrial mining legislation is really suitable for application to the sea is surely questionable.

In this connection too it is noticeable that the USA has specific legislation in place for deep-sea mining in areas under national jurisdiction in the form of the Outer Continental Shelf Lands Act, 1953 (OCSLA) which authorizes the U.S. Secretary of the Interior to approve leases for the exploration, development and production of seabed minerals in areas under U.S. jurisdiction. In part this may be a constitutional issue (in that the Federal Government has jurisdiction over the continental shelf whereas terrestrial mining is a state competence). Also noteworthy is the fact that the Azores Administration took the decision to develop specific legislation for deep-sea mining, even though this was subsequently ruled unconstitutional. And of course the seabed around the Azores appears to offer the most promising possibilities for deep-sea mining in European waters.

Table 3.1 National legislation on deep-sea mining

	Legislation on deep-sea mining in the Area	Legislation on deep-sea mining in areas under national jurisdiction			
		Specific legislation on deep-sea mining	Legislation on land based mining applies by implication	Specific references in legislation on land based mining	Deep-sea mining addressed in other legislation
Canada	-	-	-	-	-
China	-	-	-	□	-
Fiji	□	-	□	-	-
France & French OCTs	-	-	-	□	-
Germany	□	-	NA	NA	NA
Greece	-	-	-	-	-
Greenland	-	-	□	-	-
Italy	-	-	-	□	-
Japan	□	-	-	□	-
Netherlands	-	-	-	□	-
Netherlands OCTs	-	-	-	□	-
Papua New Guinea	-	-	□	-	-
Portugal	-	-	□	-	-
UK	□	-	-	-	□
UK OCTs	-	-	-	-	-
USA	□	□	-	-	-



4 Technology

4.1 Summary

Whether deep-sea mining will become viable in the near future depends to a large extent on the ability of industry and technology developers to provide systems capable of efficient operation in real life environments. Until date there is no commercial seabed mining of any of the three deposits taking place which means there is no proven equipment directly available. The majority of current activities are associated to exploration rather than exploitation.

In order to assess the technical state of play and identify the main barriers/bottlenecks to be tackled, a deep-sea mining value chain has been composed and its components assessed in terms of their technology readiness level (TRL). Furthermore, for each component the role that EU industries take is estimated.

Typically, the process of deep-sea mining, following exploration, will consist of a seabed remotely operated vehicle to collect (nodules) or excavate the deposit (sulphides, crusts), which is connected to a vertical transport system to lift the material to the sea surface, where it is collected in a ship or platform, dewatered and then transferred in a carrier and transported to shore for further processing.

A schematic presentation of the value chain for deep-sea mining is given in the figure below.

Figure 4.1 Schematic overview of deep-sea mining value chain



Typically, exploration involves locating, sampling and drilling, using technologies such as echosounders, sonars, camera's and sampling techniques. The resource assessment phase concerns the analysis of exploration data as regards the feasibility of a possible mining project.

Extraction, lifting and surface operations, the core part of the exploitation phase, encompass the excavation of the sea bed minerals, their transportation to the surface and eventual processing and handling operations taking place offshore. For the sea bed excavation, cutters (for sulphides and crusts) or collectors (for nodules) and rising systems are being developed. For the vertical transport, various concepts of lifting systems are being studied.

Logistics involves technologies similar to those found in 'traditional' land-originating minerals. For processing this is also the case although mineral composition differences call for development of advanced separation techniques.

For polymetallic crusts, the requirements of the seabed ROV differ from those related to sulphides and crusts due to the different nature of the deposit layers (hardness, composition, structure). Apart from these differences also the surface differences between sites define the requirements of the seabed equipment (e.g. steepness of slopes, curves to be made) as well as the water depth (pressure and temperature) in which to operate.

Typically, TRL levels are lower (range 1-4) for technologies required on the sea bed and for vertical transport, whereas technologies required at sea level (ship/platform and associated equipment) and onshore are more mature as they have similarity to applications in other sectors already existing. The role of EU industries in deep-sea mining has mainly focused on developing technologies – for the sub-sea part – and providing services (e.g. for construction of project sites and for exploration work). Typically the high technology capabilities of EU companies give them a competitive advantage over suppliers from elsewhere. When looking more downstream to surface and shore operations, this is less the case and competition from across the world can be expected.

4.2 Deep-sea mining value chain

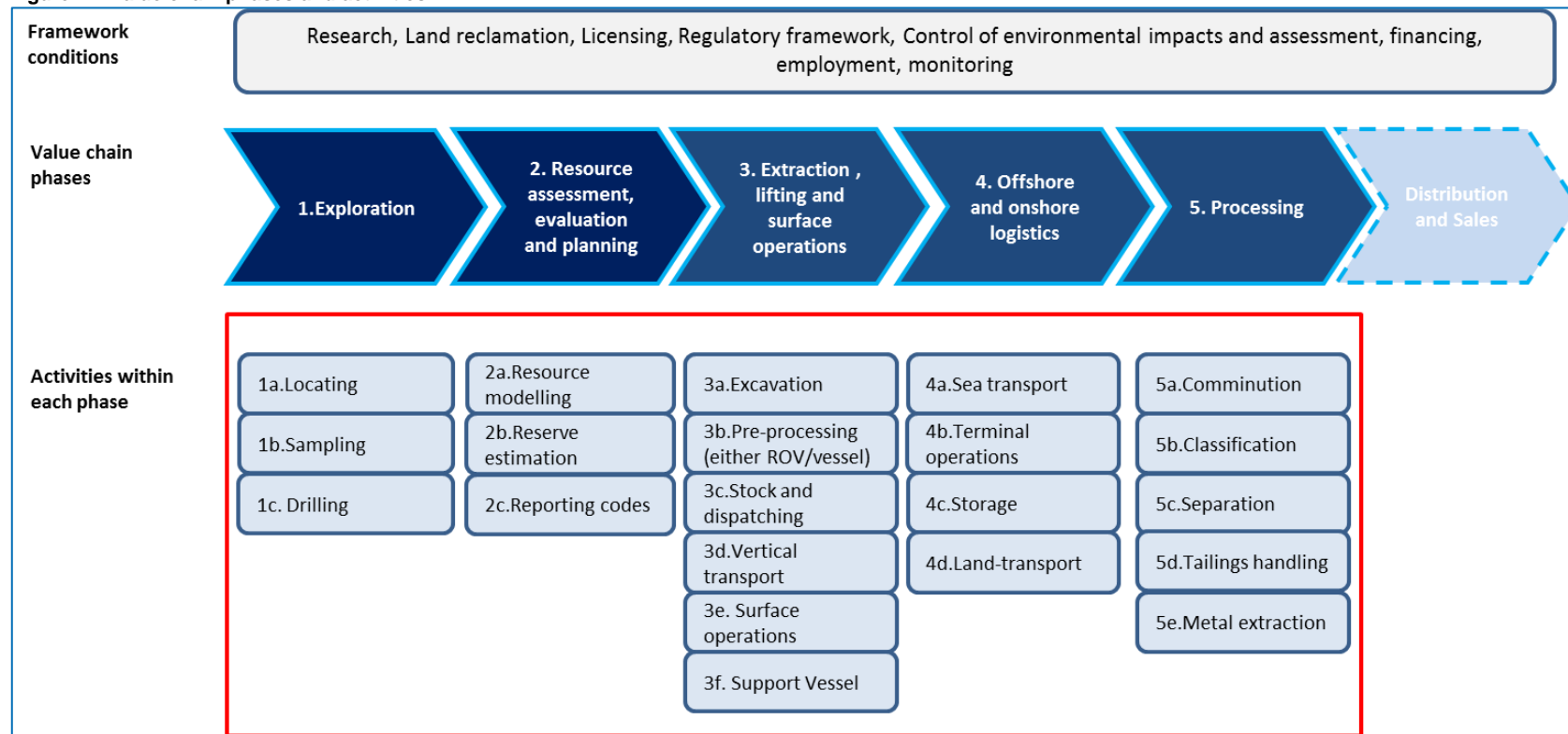
Within the value chain concept of deep-sea mining, six main stages from exploration to sales are identified, that apply independent from the type of ores to be mined:

1. Exploration;
2. Resource assessment, evaluation and mine planning;
3. Extraction, lifting and surface operations;
4. Offshore and onshore logistics;
5. Processing stage;
6. *Distribution and sales* (this stage is not included in this study's analysis).

As project plans of various industry players have shown, it depends on each project how the exact components and stages are shaped within a deep-sea mining project. So far, there has not yet been one system fully proven to be operational. The current focus of mining projects is therefore aimed at exploration, evaluation and planning rather than at exploitation. In these stages, the extraction, lifting and surface operation techniques, needed for exploitation, are also tested on a small scale. The development of these techniques is therefore merely part of the exploration phase.

The value chain and its main components can be visualised as follows.

Figure 4.2 Value chain phases and activities



Exploration

In the exploration stage, a variety of techniques are used to locate mineral deposits and assess their characteristics. After mapping areas of deposits e.g. using multi-beam echo sounders (side-sonars) and deep-tow sonars⁶⁵, camera surveys, gravimetry and other sampling techniques are used to gather samples and assess their composition and density of materials.

Resource assessment, evaluation and mine planning

This phase assesses the feasibility of a possible mining project in terms of technological and metallurgical, economic, marketing, legal, environmental, social and governmental factors. In the end a quantitative assessment of recoverable reserves will be made. The result should also serve as a bankability proposal.

Extraction, lifting and surface operations

This stage, which is a core part of the exploitation phase, encompasses the excavation of the deep-sea minerals, their transportation to the surface and eventual processing and handling operations taking place offshore. For the seabed excavation and lifting, cutter (for seafloor massive sulphides and crusts) or collectors (for nodules) and rising systems are identified. Possibly also pre-processing can take place at the seabed. The vertical transport system is a critical part as well. The support vessel, or platform, is a crucial component for the operations on the surface. The vessel may function as dispatching system, storage facility, should have dewatering systems and may act as an on-board processing facility. Depending on the extraction technologies used, distance to shore and volumes, the sediment may be dewatered at the ship or platform and the fines can be recovered by cyclones. The lifted water can be returned into the water column, which requires proper filtering/cleaning facilities and monitoring devices. When the extraction sites are located at a large distance from shore, adequate storage on a platform is required as to manage the logistics process.

Offshore and onshore logistics

The (raw or partially processed) commodities must be shipped to a processing location on shore. It depends on the type of commodities, quantities and distances to cover what type of ships are required for ocean transport. Those vessels might be 'traditional' bulk carriers used for the shipment of minerals mined on land, or alternatively they could be the same vessels also used to extract the ores, in such case Hayden argues that price for shipping will be a key condition for where mining activities will first take place⁶⁶. Like all commodities being shipped, also deep-sea minerals need to be unloaded from the vessels and (temporarily) stored at the same location as the processing site or maybe within strategic depots in ports.

Processing

Due to the large quantities of ore, and – in some cases – complex chemical process involved, the final processing will most likely take place on-shore⁶⁷, following one or more steps of pre-processing on the seabed and/or on board of the support vessel. Several techniques for processing e.g. polymetallic nodules have been suggested. In general two techniques have been tested: hydrometallurgy, where the metals are separated with acids (hydrochloric or sulphuric) or basic reagents (ammonia), and smelting.⁶⁸ The extent to which these processes differ from the

⁶⁵ ISA (2006a): Polymetallic nodules, <http://www.isa.org.jm/files/documents/EN/Brochures/ENG7.pdf>.

⁶⁶ Hayden, David (2004): Exploration for and Pre-feasibility of mining Polymetallic Sulphides - a commercial case study. David Haydon, Nautilus Minerals Ltd. ISA Workshop presentation 2004.

⁶⁷ Hayden, David (2004): Exploration for and Pre-feasibility of mining Polymetallic Sulphides - a commercial case study. David Haydon, Nautilus Minerals Ltd. ISA Workshop presentation 2004.

⁶⁸ ISA (2006a): Polymetallic nodules, <http://www.isa.org.jm/files/documents/EN/Brochures/ENG7.pdf>.

processing of land-based minerals will depend on sediment characteristics and is further assessed in the technology annex.

Distribution and sales

This is the final stage of the value chain and the least related to deep-sea mining as such. From a technology perspective, this stage is also not very relevant. However, it is an important phase in terms of economic value added. In many cases it will not be different from the distribution and sales of land-based minerals.

4.3 Main components of each value chain step and their TRL levels

Under each stage of the value chain, a number of individual technologies can be defined. An assessment was made of their TRL which is used to assess the maturity of the evolving techniques to be used within deep-sea mining activities. This framework is developed recognizing the several stages a certain technology needs to pass before it is a widely tested and proven technology.

Several industries use the TRL-stages and there are some different definitions of each stage. For example, the US Department of Defence uses slightly different definitions for stages than the National Aeronautics and Space Administration (NASA) or European Space Agency (ESA). Within this study, the following definitions of the TRL-stages are applied.

Table 4.1 Technology readiness levels

TRL	Definition
TRL 1	Basic principles observed
TRL 2	Technology concept formulated
TRL 3	Experimental proof of concept
TRL 4	Technology validated in lab
TRL 5	Technology validated in relevant environment ⁶⁹
TRL 6	Technology demonstrated in relevant environment
TRL 7	System prototype demonstration in operational environment
TRL 8	System complete and qualified
TRL 9	Actual system proven in operational environment

Source: European Commission (2013) Horizon 2020 Work programme.

The technological readiness level is visualised within this report (as well as in annex 3 where further details of each activity and technology are presented) by using the following colour-scheme.



A summarised overview of key technologies for each step and a judgment of their TRL level is provided in the table overleaf.

⁶⁹ Industrially relevant environment in the case of key enabling technologies.

Value Chain Phase	Phase Activities	Ore Deposit Type(s) Involved	Technique	Technological Readiness Level									Comments			
				TRL - 1	TRL - 2	TRL - 3	TRL - 4	TRL - 5	TRL - 6	TRL - 7	TRL - 8	TRL - 9				
Exploration	Locating															
		SMS, Nodules, Crust	Research vessels											X	The echo sounding systems are proven techniques already applied in the deep-sea environment.	
		SMS, Nodules, Crust	Echo sounding bathymetry											X	The technology has been proven as ship-mounted operation (TRL-9), for electromagnetics applied at AUVs, there has so far only been tests (TRL-7).	
		SMS	Electromagnetics								X			X	The technologies and knowledge is so far mainly restricted to active vents, in order to trace inactive vents as well, new technologies and research is required.	
		SMS	Water chemistry testing											X	AUV's are ready for deepsea usage and replace many of the ship-mounted systems. However, there is still potential for further improvement, like gravity gradiometer application	
		SMS, Nodules, Crust	AUV											X	ROVs are well developed systems being currently deployed at depths of around 6000m and ROVs are developed at the moment to reach depths up to 11.000m.	
		SMS, Nodules, Crust	ROV											X		
	Sampling															
		Nodules, crusts	Free fall devices												X	The device is in use already since the 70s and has been used for sampling nodules in a deepsea environment.
		SMS, Nodules, Crust	Grab samplers												X	Grab samplers are developed to reach depths of around maximum 6000m. They are in use for scientific and commercial purposes.
		Nodules	Box corer												X	Box corers are used in the operational environment of exploring for nodules.
		SMS	Gravity corer												X	Gravity corers are used in the operational environment of exploring for SMS.
		SMS	Piston corers												X	Piston corers are used in the operational environment of exploring for SMS. They have been used for many other oceanographic exploratory studies already since the 50s.
		SMS	Vibrocoring												X	Vibrocorers are used in the operational environment of exploring for SMS. They have been used for many other oceanographic exploratory studies and oil&gas industry.
Drilling																
	SMS	Drill rigs												X	Advanced drilling tools for deep sea applications should be developed to penetrate deeper into the SMS deposits and allow for representative sampling	
	SMS	Ship based drills								X					So far, these vessels have not yet been able to achieve the same depths as Drill rigs and ROVs and not yet been used for SMS drills.	
Resource Assessment, Reserve Evaluation and Mine Planning	Resource Modelling															
		SMS, Nodules, Crust	3D spatial modelling				X								3D spatial Modelling need to be adapted to account for multiple data sources (direct and indirect) + Geometallurgy	
		SMS, Nodules, Crust	2D multivariate modelling											X	Techniques are already commercially available. No further development needed	
	Reserve Estimation															
		SMS, Nodules, Crust	Long term planning								X					Deep sea geotechnical site investigation and evaluation methods and procedures for pit design, including slopes and ground conditions as well as for predicting extraction efficiencies are subject of current research, however need to be validated in lab and real environment.
	SMS, Nodules, Crust	Short and medium term planning				X										
Reserve/Resource reporting codes																
	SMS, Nodules, Crust	Reporting Codes								X						
Extraction and Materials Handling	Excavation Design & Excavation Operation															
		SMS	Drum Cutter ROV				X	X							Limited tests performed with land based cutter drum at 1600mbsl, technical issues need to be solved, especially effective cutting and removal of cuttings from rock face	
		SMS	Rotating Cutter Head ROV				X	X							Cutter heads are successfully applied in shallow depth dredging operations today, experiments should focus on applicability of technique to cut SMS deposits in a deep marine environment	
		SMS	Clamshell Grab				X								Already deployed successfully today, but not considered as true mining option. The focus should be on efficiency in combination with a subsea rock crusher or skip hoist system.	
		Nodules	Passive Collectors								X				Inefficiency and lack of control combined with the large environmental impact (massive plume formation) resulted in the abandonment of this method.	
		Nodules	Active Mechanical Collectors							X					Mechanical collector systems proved to work and the technique was tested at 410m depth by NIOT (India), and tests currently scheduled to test at depth of 6000m (operating environment)	
		Nodules	Active Hydraulic Methods							X					Developed since early 1990's by COMRA (China) this technique was successfully tested in a laboratory using simulated conditions. Needs testing in real operating environment	
		Crust	none				X								Equipment requirements have been identified but due to limited thickness of the deposit and hence difficult mining operation crusts are not considered technically, economically and environmentally viable at the moment.	
	Pre-Processing on the sea floor prior to despatch															
		SMS, Nodules, Crust	Identification						X	X						Sensor solutions for Presorting before cutting (Ore identification), and sampling to obtain a 'real time' quality map to decide to mine or not / decide on production order/combination of areas
		SMS, Nodules, Crust	Separation						X							Separation principles are well understood and finds various applications in terrestrial materials processing. The technique can significantly upgrade the value of the ore stream and sediments displacement is minimized. Apart from nodules/sediment separation by simple screening no research has been carried out in a sub-sea environment.
		SMS, Nodules, Crust	Size Reduction						X							Crushing is required to separate valuable material from some of the invaluable material and is applied in combination with concentration
		SMS, Nodules, Crust	Concentration				X									This step should not aim to produce a concentrate ready for shipping but aim to pre - upgrade the average grade of the material that is sent to the dispatch system prior to vertical transportation.
	Dispatching															
		SMS, Nodules, Crust	Stock & Dispatch Systems				X									A stock and dispatch system is required as it will act as a buffer between the excavator(s) and the continuous riser system or batch lifting system. Also allows for ore blending to retain a merely constant headgrade.
	Vertical Material Transport															
		Nodules	Continuous Line Bucket								X					Lack of manoeuvrability, lack of production control, heavy plume formation and low cutting power make that the method is inefficient and abandoned.
		SMS, Nodules, Crust	Airlift System								X					Proven technique and widely applied in limited water depth dredging operations, method validated to transport nodules from a depth of 15.000ft. in a pilot test. Largely replaced by hydraulic pumps in recent studies due to high power requirements of airlift systems and vulnerability to clogging. Maturation is addressed by FP 7 Blue Mining project.
		SMS, Nodules, Crust	Hydraulic Pump System								X					Technique already exists and is applied in oil & gas industrie to transport drill cuttings in deep ocean drilling operations. The system should be tested for deep sea ore transportation (particle sizes, clogging and wear on the system). Maturation is addressed by FP 7 Blue Mining project.
		SMS, Nodules, Crust	Batch Cable-lift System				X									No such system exists to date. Technique should be relatively easy to apply if one can also successfully lower/lift heavy ROV's to and from the seafloor. Simple to increase TRL by experimental modeling and field test.
	Surface Operations															
		SMS, Nodules, Crust	Dewatering											X		The dewatering plant has a simple flow sheet and installing such a plant on board a vessel/platform should not be problematic. Not demonstrated on ship
	SMS, Crust	Concentrating							X						Known land based applications. Limited testing of techniques to concentrate deep sea ores. Issues that need to be resolved are: Handling of wet ore, Power, Tailings disposal	
	SMS, Nodules, Crust	Metallurgical Processing				X									Metallurgical processing on board a vessel/platform is unlikely due to; very high energy costs, requirement of extraction chemicals	
Surface Operations																
	SMS, Nodules, Crust	Support Vessel											X			
	SMS, Nodules, Crust	Platform											X			
Logistics	Sea-transport and Terminal Operations															
		SMS, Nodules, Crust	Storage											X		
		SMS, Nodules, Crust	Land Transport											X		
Processing	Comminution															
		SMS, Nodules, Crust	Crushing/Milling				X								Well developed for land based operations processing dry ore. Experiments should be conducted to evaluate comminution efficiency of equipment when processing wet/moist ore.	
	Classification															
		SMS, Nodules, Crust	Screens/Hydrocyclones										X		Well developed method capable of handling wet material. Classification separates material according to size before further processing (e.g. separation) and can send different size range material streams to different processes (e.g. undersize to flotation, oversize back to grinding mill). Screening is routinely used in offshore diamond mining. Hydrocyclones not demonstrated on board ship (likely to work)	
	Separation															
		SMS, Crust	Spiral Concentrators, Gravity Separation Tables, Jigs, Magnetic Separation, Froth Flotation							X						Some individual separation techniques have been tested in laboratory experiments (e.g. flotation). Attempts should be made to design a pilot processing plant to identify the best concentrating technique.
	Tailings Handling															
			Tailings Disposal				X									Especially when processing takes place at sea, a solution must be found to deal with (very fine grained) process tailings.
Metal Extraction																
	SMS	Concentrating, acid leach, smelting, electrowinning											X		The chemical characteristics of SMS deposits are similar to land based VMS deposits, hence the metal concentrate can be delivered to a smelter. Not yet demonstrated on board ship. Scale of anticipated mine & requirement for stockpile buffer are problematic for shipboard application. Energy requirements & safety concerns may also be problematic in a shipboard application.	
	Nodules	Cuprion Process, Sulphuric Leaching, Smelting				X									Several metals extraction methods have been proposed and tested on a small scale	
	Crust	Concentrating + Smelting, Magnetic Separation + Smelting				X									Concentrating of the mined material to separate ore from substrate and subsequent extraction of the ore using the same processes as used for nodules.	

4.4 Critical components

From the table above, it is clear that for many technologies required for exploiting seabed minerals, TRL levels are still far from the desired proven system. The majority of research efforts till date have focused on the exploratory part and in particular on exploration itself and on resource assessment and evaluation (and to a lesser extent mine planning). Apart from a few tests there has been no fully working system applied in a relevant environment.

Table 4.2 Level of advancement per value chain stage and deposit type

Value change stage		SMS	Nodules	Crusts	Notes
Exploration		moderate	high	moderate	Challenge esp. related to drilling (high costs/high intensity vis-a-vis current findings). In addition, gravity gradiometer is needed for SMS exploration.
Resource estimation		moderate	moderate	low	2D modelling fairly developed, 3D modelling poses requirements
Extraction and Materials Handling	Excavation	low	low to moderate	very low	Hardly any experience for crusts, only exploratory level for the others
	Vertical transport	low	low	very low	No longer term higher capacity testing
	Surface operations	moderate	moderate	moderate	Similar development stage/requirements for each deposit type
Logistics		high	high	high	Technologies mature; ship-to-ship transshipment may pose challenges still on vessel-to-vessel operations.
Processing		moderate	low	low	Depend on metal composition and extraction aims (which metals to take out from the ores)

Source: Ecorys based on TRL estimation of previous table.

Apart from the technologies required to actually mine seabed deposits, for starting up commercial scale operations, it is of key importance to have a reliable resource assessment. From information on projects currently being undertaken and from scientific research into technical applications, some concerns regarding technical needs in the exploration and excavation part of the value chain can be highlighted:

- Detailed evaluations of potential resources to define a commercial business case are not available for any of the deposit styles, with only 2 exceptions: Atlantis II and Solwara 1/12. Possibly exploratory work by the Japanese, South Koreans and Chinese has provided similar evaluations for other sites but such information is not known of;
- Prospecting tools have developed greatly in the past decade, but further development is required for tools such as gravity gradiometer⁷⁰, acoustic corer⁷¹, subsea gliders as well as increased use of Prompt Gamma Neutron Activation Analysis for grade control (research into some of these tools is already taking place funded by private and public bodies);

⁷⁰ Measuring the Earth's density needed to identify the more significant subsurface metal accumulations that would not be seen from surface or water column mapping. Gravity gradiometers already exist for terrestrial exploration and they require miniaturisation to be fit onto an AUV.

⁷¹ Subseafloor imaging (Pan Geo Subsea tool) for hard rock environment

- Tools/methods for detailed resource evaluation to support commercial decision making either do not currently exist or are prohibitively expensive;
- Mining technology/concepts exist (including material handling, dewatering, alternative fuels), but are not yet proven in a real 1:1 operational environment.

From a review by experts and building on inputs gathered in an expert workshop, two areas in particular are identified as critical to the successful evolution of deep-sea mining into a commercial metal supplier:

- The cutter / collector system that operates on the seabed;
- The riser, or vertical transport system, to bring the excavated ores to the surface.

It is noted that the development of these components is not a stand alone activity but is developed in interaction with other parts of the mining system. For both the sea floor remotely operated vehicles (ROVs - cutter for seafloor massive sulphides and crusts, collector for nodules), the water depth in which to operate is an important factor (pressure, temperature), as is the ruggedness of the seabed. Furthermore the greater the depth the more challenges are posed to the vertical transport system.

Cutter/collector system

For seafloor massive sulphides and crusts, a cutter is needed to excavate the hard seabed rock in which the metal ores are found. For seafloor massive sulphides these have been developed but not yet for applications on crusts. It consists of a cutter mounted on an ROV.

Seafloor massive sulphides deposits present several challenges for extraction technology. First, the ore body is comprised of a combination of loose material such as fallen chimneys, and solid fused minerals such as re-crystallized sulphides and deposition layers. Second, the seafloor terrain may be rugged due to tectonic activity⁷². Extraction technology for the mining of Polymetallic Sulphides has been adapted from that used in deep-ocean petroleum operations, such as seabed pipe trenching operations, and from offshore placer diamond mining, the latter of which is being adapted from shelf-depth operations to deep-water operations⁷³. Polymetallic Sulphides rock has been shown to have strength properties similar to coal and as such, terrestrial coal mining techniques form the basis for the design of seafloor mining equipment⁷⁴. An example of an seafloor massive sulphide cutter/collector system consisting of three machines is shown in the picture below.

⁷² Herzig, P. (1999): Economic potential of seafloor massive sulphide deposits: ancient and modern. London: Phil. Trans. R. Soc. London.

⁷³ Hein et al. (2013): Deep-ocean mineral deposits as a source of critical metals for high- and green-technology applications: Comparison with land-based resources (Vol. 51). Santa Cruz: Ore Geology Reviews, Elsevier.

⁷⁴ Jackson, E., & Clarke, D. (2007): Subsea Excavation of Seafloor Massive Sulphides. New Westminster, BC, Canada: Cellula Robotics Ltd.

Figure 4.3 Auxiliary cutter ROV (left), Bulk-cutter ROV (right) and collecting machine (below)



Cutter (AC) - cuts material on uneven surfaces; benching the site

Bulk Cutter (BC) - cuts material at high rates on area benching by Auxiliary Cutter

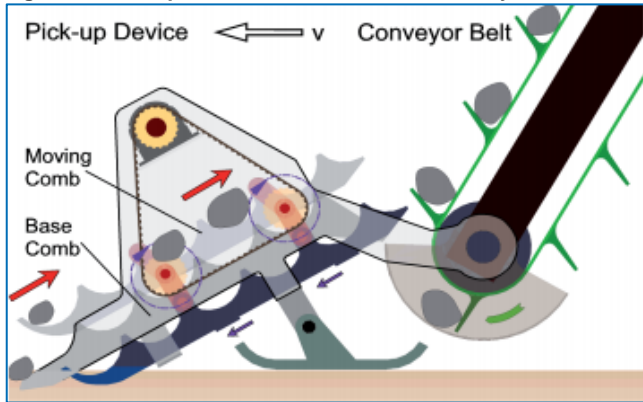
Collecting Machine (CM) - collects cut material with seawater, pumping and transfers the slurry to the RALS

Source: Nautilus Minerals

For polymetallic crusts, also an ROV capable of cutting the rocky deposit layer is required. Till date however, no conceptual designs for this type of deposits have been identified.

For nodules, no cutting of rocky layers is needed, but they can 'simply' be collected from the seabed. One of the challenges though is that the sediment layers on which the nodules are found are usually very soft, and a too heavy vehicle would sink. Active collectors are able to filter sediments from the nodules collected and possibly also to crush the nodules to reduce and homogenise their size before entering the vertical transport system. A picture of the concept is given below.

Figure 4.4 Example active mechanical collector system



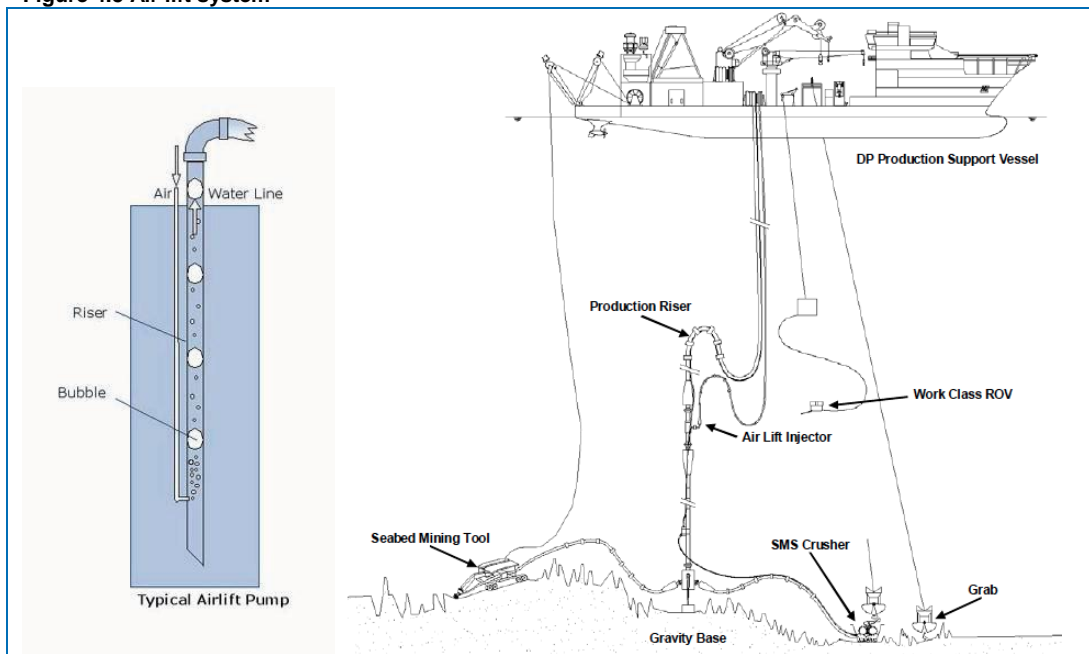
Vertical transport system

Two main concepts are being developed in the context of the various exploration and research projects:

- An air lift system.
- A hydraulic system.

Airlift systems are three-phase flow systems based on the injection of compressed air into the riser pipe at intermediate depth. By injecting compressed air, the density of the slurry water above the injection point reduces and displaces the hydrostatic pressure equilibrium. As a result a vertical flow of water is induced towards the surface that can lift the ore to the surface production vessel^{75 76}. The technique has been used in the past on a pilot-scale to dredge polymetallic nodules from a depth of 15.000 ft (~4.500 m).

Figure 4.5 Air lift system



⁷⁵ Brockett, T. (1999): 'Nodule collector subsystem',. Workshop on Proposed Technologies for Deep Seabed Mining of Polymetallic Nodules (pp. 67-93). International Seabed Authority.

⁷⁶ Feenan, J. (2009): Seafloor Massive Sulphide Mining Concept. Offshore Technology Conference (pp. 1-11). Houston: Offshore Technology Conference.

Hydraulic lift systems are considered simple and reliable and have a high lifting capacity. The required systems already exist as the same hydraulic pumps are currently applied in deep-ocean drilling of oil and gas wells. During these drilling operations, slurry (drill cuttings and drill-fluids) is transported to surface whereas in deep-sea mining applications it is the excavated ore that is being transported. This hydraulic pump system is part of the conceptual mining plan of Nautilus minerals in which several excavators are extracting the ore from the seafloor to provide a continuous ore flow to the hydraulic pump system and up to the production support vessel.

A first prototype of the subsea hydraulic pump system was built and successfully tested during test drilling in the Gulf of Mexico⁷⁷. Instead of placing electrically driven pumps at the seafloor, the system was redesigned to be powered by seawater supplied from surface through a conduit to the pump located on the seafloor. The benefit of using such a system is that all the power-generating components are located at the surface and thus, in case of failure, can be repaired without having to pull the subsea portion of the pumping system. A backup pump can be installed to allow continued production in case of maintenance or breakdowns.

4.5 Ongoing EU research efforts

Several publicly funded research projects are being carried out on the national as well as the EU level related to deep-sea mining and deep-sea exploration technologies. Research is often supported by engineering firms and technology providers themselves who work closely together with research institutes and universities.

In the table below, EU-wide research projects are listed related to deep-sea activities and (partially) funded by the EU.

Table 4.3 Table 4.4. EU-wide research projects related to deep-sea mining and ocean floor ecosystems

Project	Funded by	Research scope
Blue Mining (2014-2018) http://www.bluemining.eu	FP7 (€15mio of which €10mio EC funded)	Blue Mining's aim is to develop all key technologies for exploration (discovery and assessment) and for exploitation of deep sea mineral resources up to TRL6, i.e. system/subsystem model or prototype demonstration in a relevant environment. Blue Mining will also prepare an exploitation plan for the next phases in the technology and business. Focus on Manganese nodules and seafloor massive sulphides
MIDAS (2013-2016) http://www.eu-midas.net	FP7 (€12mio of which €9mio EC funded)	MIDAS has a set of objectives, aimed at building the knowledge base to underpin sound environmental policies in relation to deep-sea exploitation: impact on ecosystems, solutions for socially acceptable commercial activities, cost-effective technologies for monitoring, best practice in international and national regulations. Focus on seafloor massive sulphides, REE, Gas hydrates.
HERMIONE (2009-2012) http://www.eu-hermione.net	FP7 (€9mio EC funded)	To investigate the dimensions, distribution and interconnection of deep-sea ecosystems; To

⁷⁷ SRK study Solwara 1, 2010

		understand changes in deep-sea ecosystems related to key factors including climate change, human impacts and the impact of large-scale episodic events; To understand the biological capacities and specific adaptations of deep-sea organisms, and investigate the importance of biodiversity in the functioning of deep-water ecosystems; To provide stakeholders and policy-makers with scientific knowledge to support deep-sea governance aimed at the sustainable management of resources and the conservation of ecosystems.
HERMES (2004-2009) http://www.eu-hermes.net/intro.html	FP6 (€15mio EC funded)	HERMES study sites extend from the Arctic to the Black Sea and include biodiversity hotspots such as cold seeps, cold-water coral mounds and reefs, canyons and anoxic environments, and communities found on open slopes. These important systems were chosen as a focus for research due to their possible biological fragility, unique genetic resources, global relevance to carbon cycling and susceptibility to global change and human impact.
Deep-Sea and Sub-Seafloor Frontier (DS3F) (2010-2012) http://www.deep-sea-frontier.eu/	FP7	The 'Deep-sea and sub-seafloor frontier' (DS3F) project brings together scientists from Europe's major ocean research centres and universities to identify the primary issues that need to be addressed in sub-seafloor sampling with relevance to deep-sea ecosystems, climate change, geohazards, and marine resources in the next 10-15 years. It is aiming to provide a pathway towards sustainable management of oceanic resources in the broadest sense on a European scale and to develop sub-seafloor sampling strategies for enhanced understanding of deep-sea and sub-seafloor processes by connecting marine research in life and geosciences, climate and environmental change, with socio-economic issues and policy building.
ECORD, the European Consortium for Ocean Research Drilling. As part of the Integrated Ocean Drilling Program - IODP and from 2013 onwards International Ocean Discovery Program (IODP) "Exploring the Earth under the sea". (2003-date) http://www.ecord.org/about/aboutecord.html	Through ECORD-membership, ECORD funds mission specific platform operations	The International Ocean Discovery Program (IODP) is an international marine research collaboration that explores Earth's history and dynamics using ocean-going research platforms to recover data recorded in seafloor sediments and rocks and to monitor subsea floor environments. IODP depends on facilities funded by three platform providers with financial contributions from five additional partner agencies. Together, these entities represent 26 nations whose scientists are selected to staff IODP research expeditions conducted throughout the world's oceans.
EMSO (European Multidisciplinary Seafloor Observatory) as part of ESFRI (the European Strategy Forum on Research Infrastructures)	Through MS (national programmes), EC (FP7), EIB.	The European network of seafloor observatories (cabled & acoustically linked), constituting a distributed infrastructure for long-term (mainly) real-time monitoring of environmental processes related

http://www.emso-eu.org/	to ecosystems, global changes and geo-hazards to study also the interactions between geo-, bio- and hydro-sphere
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Of the above listed projects, Blue Mining and MIDAS are especially aimed at deep-sea resource extraction. Blue Mining explores the needs for developing the technologies required for nodule and seafloor massive sulphides mining, while MIDAS focuses on environmental impacts from deep-sea activities. The remaining research efforts are linked with deep-sea mining, but have a wider scope.

In all of the projects above, national research institutes, universities and commercial companies play all a major role. The current state-of-play of deep-sea mining requires additional research and development efforts before commercial activities can be performed. This means that cooperation between actors and researchers will remain important.

4.6 Position of the EU industry

Generally speaking, the EU manufacturing industry has a strong competitive position when it comes to:

- R&D and innovations;
- Manufacturing of high tech components and applications.

Such conclusions can be drawn for the marine technology industry (see for instance the study on Green Growth opportunities in shipbuilding ⁷⁸ or the patents & publications overview in the Blue Growth study)⁷⁹ as well as for other technology intensive industries (see for instance sectors assessed in light of the EU competitiveness framework).⁸⁰ Also the technology parallels to the oil & gas industry in terms of working in deep water in rough offshore environments and in sensitive areas suggest that technology providers from Europe are well-positioned.

While technology development, research and manufacturing are typically strongly developed in Europe, mining operations are not broadly led by EU enterprises. In the terrestrial mining sector, the top-6 (top-4 nowadays) companies are based in leading resource countries like Canada, Australia and South Africa, although they are global players also operating in Europe. If we consider aggregates mining, in this sector European dredging operators play an important role, but mainly locally. If the oil & gas sector is also taken into account, European players are among the oil majors (Shell, BP, Statoil) due to Europe's resource base. Whether their operating expertise will be applied in the deep-sea mining sector however remains to be seen.

Within pipe or cable laying, an industry also operating in deep waters with high complexity, the European influence is evident. The main world players are based in Europe; Allseas, Heerema, IHC Merwede (NL), Technip, Serimax (FR), Subsea 7 (UK) and Saipem (IT). Exceptions are the Houston based McDermott and Oceaneering. Given the wider and multifunctional character of these companies and their vessels, it can be expected that similar European expertise will also be of use for the deep-sea mining industry.

⁷⁸ Ecorys (2012), Green Growth opportunities in the EU shipbuilding sector. Study on behalf of EC DG ENTR, http://ec.europa.eu/enterprise/sectors/maritime/files/green_growth_shipbuildingfinal_report_en.pdf.

⁷⁹ Ecorys (2012), Blue Growth, Scenarios and Drivers for Sustainable Growth from the Oceans, Seas and Coasts. Study on behalf of EC DG MARE.

⁸⁰ References to various studies can be found at www.sectorcompetitiveness.com.

Deep-sea mining typically fits in the high tech innovation profile. As a developing industry, not yet at commercial application stage needs for technology development to support exploration and to investigate possibilities for exploitation are very diverse. On the basis of identified suppliers, for each value chain stage an overview and qualitative scoring of the EU position is given, in the table below.

An important remark to be made is that, as Deep-sea mining has not arrived at the commercial application stage yet, many technologies associated to the various value chain stages are in their development as well and not available as commercial products yet. Hence the assessment of the position of EU players is based on their involvement in research and testing rather than in their market shares or client base.

Table 4.5 Assessment of the EU competitive position by value chain component

Value chain stage	Key technologies	EU players & competitors	Rating of EU competitive position
Exploration	Locating: <ul style="list-style-type: none"> - Research vessels; - on board equipment; - AUVs; - ROVs; - echo sounders etc. 	Research vessels: high tech yards in EU (NL, GE, NO, FR), competition from advanced shipbuilding nations like Korea; AUVs & ROVs: EU & US companies present.	High
	Sampling	Only a limited number of devices available, mainly for scientific research, no clear market leaders identified.	Average
	Drilling (coring)	Technology known from shallow water applications and from oil & gas; main challenge to reduce costs. Presumably EU companies active along with others but no specific players identified.	Average
Resource assessment, evaluation and mine planning	Modelling techniques & software; application for deep sea deposits requiring type specific modifications.	Specialised companies in FR, UK.	Average
Extraction, lifting and surface operations	Extraction: cutter, grab & drill technologies. Various principles depending on deposit type. Combination with seabed pre-processing (grinding/sizing of particles) for vertical transport.	Cutting technologies from terrestrial applications: leading role for Germany based manufacturers; for underwater applications, IHC (NL), Technip (FR, oil & gas background), SMD (UK).	High
	Lifting / vertical transport systems, using water suspension (hydraulic pump) or air pressure (air lift). Both require high power input and are so far sensitive to unstable flows.	Technology still in its infancy for all three deposit types. Few tests done, none long term. Manufactures Aker Wirth (GE) and IHC (NL) working on the concept.	High
	Surface operations:	Dewatering technology proven, also	Average to high

Value chain stage	Key technologies	EU players & competitors	Rating of EU competitive position
	dewatering & possibly concentration on the ship.	applied in terrestrial mining (e.g. lake mining). No specific position of EU players versus others. For the surface vessels EU offshore shipbuilders are well placed. For platforms, others (Asia, Brazil) are also competitive.	
Offshore and onshore logistics	Mature technologies also applied for handling terrestrial ores.	No unique position for EU players. Ship-to-ship transshipment technologies are being investigated under FP7 project Blue Mining. Ship to shore technology is standard.	Average
Processing stage	Similar principles as for processing terrestrial ores. However need for development of.	No unique position for EU players. Technology less advanced than previous stages and often manufactured elsewhere. Operations usually performed locally.	Average

As a conclusion the position of EU technology suppliers appears strong in the sub-sea exploration, extracting and lifting components of the value chain. The involvement of EU operators in this field is however not extraordinary compared to those from elsewhere (see also the project section hereafter). Downstream activities including logistics and onshore processing involve more mature technologies and processes for which EU industries are not considered better placed (neither worse) than other players.

4.7 Integral environmental impact

Deep-sea mining is a pioneering activity which interacts with flora and fauna on the seafloor and water column. As 'unknown' practice, the environmental effects of deep-sea mining are monitored closely. The question therefore may rise; to what extent are the different techniques available and under development for deep-sea mining activities impacting the environment? Is it true that some techniques disturb less?

First of all, it is important to note that there are differences in impacts depending on the deposit type as well as the geomorphological setting, physical conditions, the scale of operations, and therefore also depending on the technology used for extraction. The technology being developed for deep-sea mining depends on the above mentioned characteristics of the setting, deposit and location. Tailor-made solutions are developed depending on these different mining characteristics. It is therefore impossible to 'pick' or choose a certain technology. Technologies are yet still under development, as the TRL levels have shown in this report.

Pioneering in this field involve major investments to make, not without financial risk. Given the attention the deep-sea mining industry receives from stakeholders, none of the companies would be willing to add risks to their investment by developing environmentally harming techniques. Before licenses are issued, environmental impact assessments need to be approved, including the techniques and mitigating actions concerning the environment.

Therefore, it can be expected that the technologies being developed at the moment are technologies that mitigate environmental impact as much as possible. Acting not environmentally friendly is per se non-economically attractive, as the risk is too high that the projects will be cancelled or licenses will be retracted.

Though, there are certain stages in the deep-sea mining value chain which are expected to impact the environment more than others. This holds especially for the extraction phase, as interference takes place with the seafloor habitat. The extraction processes that are expected to have environmental impacts are the following:

- Disaggregation
- Lifting
- Dewatering.

The companies spoken to during the course of this study have all shown their efforts and concerns regarding the environmental impact of deep-sea mining. The above activities are developed with great concern.

More about deep-sea mining and the environment can be found under Chapter 6, environmental implications.



5 Ongoing and planned activity

5.1 Summary

This chapter of the study looks at the currently ongoing projects in Areas Beyond National Jurisdiction (ABNJ), these are waters under the supervision of ISA, as well as those exploration activities that are currently taking place in the (EEZ) of individual states.

So far only exploration licences have been issued by the ISA. Up until May 2014, 19 applications have been approved out of which:

- 13 concern the exploration of polymetallic nodules, four for polymetallic sulphides and two the exploration of cobalt-rich polymetallic crusts;
- 12 of the exploration projects are located in the CCZ. This area is located in international waters of the Pacific Ocean. The remaining projects are located in the Indian Ocean (3), the Atlantic Ocean (2) and the north-western Pacific Ocean (2);
- These 19 approved projects cover an area of 1 million km². Six of these licenses will expire in 2016.

In 2013, seven additional applications, covering an area of around 234.000 km², were made to the ISA for exploration projects. These were discussed at the ISA's 20th annual session in July 2014, and were approved, but still need to be contracted out.. This means that by the end of 2014/beginning of 2015 there will be 26 approved projects by the ISA with a total covered area of around 1.2 million km². This is an area as big as Portugal, Spain and France together.

Generally applications can be submitted by national governments (e.g. China, India, Korea and Russia) as well as private enterprises.

Creating an overview of the licences granted within the national jurisdiction area of individual states' EEZ is more difficult as there is not a single source or database where this information can be gathered from. Extensive desk-research and interviews have been carried out to collect the relevant information, and we have identified 26 projects in EEZ areas. At the same time it must be stated that due to unavailability of data and information, specific projects in South America, Africa and Russia could not be identified. It is estimated however that the number of projects in the EEZ of these countries is limited since the two private companies that hold the majority of (exploration) licenses within EEZ zones (Nautilus Minerals and Neptune Minerals) do not hold any license in the EEZ zones of these two continents and Russia.

National governments have until now issued two deep sea marine exploitation (or mining) licenses: one by the government of Papua New Guinea (Solwara 1 project in the Bismarck Sea) and one by the governments of both Saudi Arabia and Sudan (Atlantis II project in the Red Sea). In both projects mining has not yet started. All other issued deep sea licenses by national governments concern exploration projects⁸¹.

⁸¹ Other mining licenses have been issued but these cannot be characterized as deep-sea mining licenses since the depth of these locations does not exceed 500 meters. This is for example the case for Sandpiper Marine Phosphate project off the coast of Namibia (depth of 180-300 meters) and the location Chatham Rise within the EEZ zone of New Zealand (depth of 350-450 meters).

The sizes of the areas granted for mining, exploration or areas under application in EEZs are not always known. Based on the information available we estimate the total area licensed or under application in EEZ areas of countries to be around 800 000 – 900 000 km². All EEZ licenses are for polymetallic sulphides deposits only.

5.2 Introduction

Experiences in deep mining or exploration can be gained by running or participating in relevant projects. A project is understood to encompass both the application for a deep-sea mining or exploration license, as well as licenses granted for deep-sea mining or exploration activities. Before starting a deep-sea mining or exploration project a license is needed. Marine exploration or mining licenses can be issued by either the ISA or by national governments, depending on where the project is located. National governments issue the licenses for activities that take place within the EEZ of a country. The EEZ comprises the Area up to 200 nautical miles from the territorial sea baseline. Within its EEZ, a coastal state has exclusive sovereign rights for the purposes of exploring and exploiting, conserving, and managing the natural resources (living or non-living) of the water column, seabed, and subsoil. The national governments also issue the licenses for the Continental Shelf. The Continental Shelf (as defined by UNCLOS) is the sea floor that extends beyond the territorial sea up to 200 nautical miles from the territorial sea baseline or beyond that to the outer edge of the continental margin. Within its continental shelf, a coastal state has sovereign rights for the purposes of exploring and exploiting mineral and other non-living resources of the seabed and subsoil, together with sedentary living organisms⁸².

The seabed and subsoil beyond the limits of national jurisdiction (i.e., all of the seabed that lies beyond each country's continental shelf) is known as the Area. The Area and its mineral resources are declared by UNCLOS to be "the common heritage of mankind." The seabed minerals of the Area are managed on behalf of all by the ISA, an institutional body established under UNCLOS. No country may claim or declare sovereign rights or try to appropriate any part of the Area or its resources. But any UNCLOS member country is eligible to undertake seabed mineral activities in the Area, subject to the rules of UNCLOS and the ISA. This means that exploration or mining activities in the Area may only be carried out under a contract with the International Seabed Authority⁸³.

Besides deep-mining exploration or exploitation projects the European Innovation Partnerships (EIPs) can be mentioned. EIPs were launched under the European Commission's Innovation Union to accelerate the market take-up of innovations which address key challenges for Europe. One of the EIPs is the EIP on Raw Materials⁸⁴. The Partnership aims to reduce the possibility that a shortage of raw materials may undermine EU industry's capacity to produce strategic products for EU society. Projects (so-called commitments) aiming at deep-sea mining are part of the EIP on Raw Materials and are therefore also included in this chapter.

⁸² SPC (2013): Deep Sea Minerals: Deep Sea Minerals and the Green Economy. Baker, E., and Beaudoin, Y. (Eds.) Vol. 2, Secretariat of the Pacific Community.

⁸³ Contracts are approved by ISA's executive council, on the recommendation of the Legal and Technical Commission. SPC (2013): Deep Sea Minerals: Deep Sea Minerals and the Green Economy. Baker, E., and Beaudoin, Y. (Eds.) Vol. 2, Secretariat of the Pacific Community.

⁸⁴ Other EIP's focus on Active & Healthy Aging, Agricultural Sustainability and Productivity, Smart Cities and Communities and Water (see http://ec.europa.eu/research/innovation-union/index_en.cfm?pg=eip).

5.3 Ongoing projects

Ongoing projects for the most part are exploration projects, only two are mining projects (Solwara 1 and Atlantis II). The greatest licensed area for projects can be found in the North Pacific Ocean, they comprise all projects in the Area for which the licenses have been issued by the ISA. In annex 5 we present the underlying data that have been used. The second section of Annex 5 gives more detailed information on each of the identified projects.

5.3.1 Projects in The Area

Projects in The Area need to have a license issued by the ISA. This can be a prospecting license, an exploration license or an exploitation/mining license.

Characteristics of ISA licenses

The ISA can issue prospecting licenses, exploration licenses or exploitation/mining licenses. A prospecting license provides no resource rights. It only allows for a reasonable quantity of minerals to be recovered for testing. Prospectors are required to submit an annual report on the status of prospecting and the results obtained. Exploration licenses, costing \$500 000 each, are granted by ISA for a 15 year term in respect of reserved areas, providing for the collection of minerals for analysis and testing to determine whether a reserved area may be viable for commercial exploitation. Explorators also have to report on their programs of activities annually. Exploitation licenses shall grant the right to the license holder to commercially exploit a specified area and to benefit from such mining activities. The ISA is currently working on the development of exploitation licenses (they were not developed before because there was no demand. The first exploration licenses however will expire in 2016). For the exploitation licenses the ISA is considering a permitting regime involving an initial three year “pilot” license, followed by a long term tenured license. Such long term mining license would be subject to ISA approval, to be granted where the feasibility and bankability of a project can be shown from the results of the three year pilot phase activities.

Licenses by ISA may be awarded to States Parties (signatories of UNCLOS), state enterprises sponsored by States Parties, or to natural or juridical persons having the nationality of States Parties and sponsored by States Parties. This element of sponsorship is fundamental to the international regime, as it is designed to ensure that a State Party to UNCLOS ultimately has international responsibility for the activities of contractors with the International Seabed Authority. As private entities, they are not directly bound by UNCLOS.

So far no exploitation/mining licenses have been issued by the ISA.

Only one prospecting license has been issued to date. This licence has been issued to the Federal Institute for Geosciences and Natural Resources of Germany (BGR) in 2011 for Polymetallic Sulphides in the Area of the southern central Indian ridge and the northern south-east Indian ridge. This subsequently resulted in an application in 2013 for an exploration license in the same area⁸⁵.

All other licenses issued by the ISA for projects are exploration licenses. Between 2001 and May 2014, the ISA approved 19 applications for exploration projects in the Area of which:

- 13 concern the exploration of polymetallic nodules, four for seafloor massive sulphides and two the exploration of cobalt-rich polymetallic crusts;

⁸⁵ Unfortunately India has also applied for an exploration license in the same area resulting in the fact that the application by BGR and India now partly overlap each other. It is unclear how the ISA will solve this problem.

- 12 of the exploration projects are located in the CCZ⁸⁶. This area is located in international waters of the Pacific Ocean. The remaining projects are located in the Indian Ocean (3), the Atlantic Ocean (2) and the north-western Pacific Ocean (2);
- These 19 approved projects cover an area of 1 million km². Six of them will expire in 2016.

In 2013 an additional seven applications covering an area of around 234.000 km², have been made to the ISA for exploration projects which will be discussed at the ISA's 20th annual session in July 2014. This could mean that by the end of 2014/beginning of 2015 there will be 26 approved projects by the ISA with a total covered area of around 1.2 million km². This is an area as big as Portugal, Spain and France together.

In the period 2001-2011 the licenses issued by the ISA were all for nodules exploration projects. Only in recent years applications for exploration projects of seafloor massive sulphides and crusts were received.

Table 5.1 Licenses issued by the ISA and approved applications (A) for projects in The Area by year and deposit type

Country	Nodules	Crusts	SMS
Interoceanmetal b)	2001		
Russia	2001	2014 a)	2012
Korea	2001		2014
China	2001	2014	2011
Japan	2001	2014	
France	2001		2014
India	2002		2014 a)
Germany	2006		2014 a)
Nauru	2011		
Tonga	2012		
Belgium	2013		
UK	2013 + 2014 a)		
Kiribati	2014		
Singapore	2014 a)		
Brazil		2014 a)	
Cook Islands	2014 a)		

a) = application approved and to be signed as of the 20th Annual Assembly of the International Seabed Authority held from 14 - 25 July 2014

b) = Bulgaria, Cuba, Czech Republic, Poland, Russian Federation and Slovakia.

5.3.2 Projects in areas under coastal state jurisdiction

It is much more difficult to get an overview of projects that are being carried out in areas under coastal state jurisdiction since countries/individual companies are not always willing to make such information public. Based on desk research, interviews with governments, experts and companies

⁸⁶ This area is located in the eastern central Pacific, to the south and south-east of the Hawaiian Islands. It lies in international waters, and stretches approximately from 0°N – 23°30'N, and from 115°W – 160°W, an area of approximately 4.5x106 km². Within the CCZ, nine regions were designated as Areas of Particular Environmental Interest as part of an environmental management plan administered by the International Seabed Authority, which prohibits mining for nodules in these regions. Source: University of Southampton (2012) : Feasibility Study on Manganese Nodules Recovery in the Clarion-Clipperton Zone, https://www.southampton.ac.uk/assets/imported/transforms/peripheral-block/UsefulDownloads_Download/8BC7B9645A8E4690A375D527F98DF7EC/LRET%20Collegium%202012%20Volume%202.pdf

like Nautilus Minerals and Neptune Minerals, the list of projects in areas under coastal state jurisdiction has been prepared (see annex 5).

Due to the unavailability of data it is not known what projects are being undertaken in areas under coastal state jurisdictions of countries in South America and Africa. Nor is such data available for Russia. It is estimated, however, that the number of projects in the areas under the jurisdiction of these countries is limited since the two private companies that hold the majority of (exploration) licenses relating to areas under coastal State jurisdiction (Nautilus Minerals and Neptune Minerals) do not hold any licenses there.

National governments have until now issued two deep sea marine exploitation (or mining) licenses: one by the government of Papua New Guinea (the Solwara 1 Project in the Bismarck Sea) and one joint licence by the governments of both Saudi Arabia and Sudan (the Atlantis II Project in the Red Sea). In both cases mining has yet to begin. All other issued deep-sea mining licenses by national governments concern exploration projects⁸⁷.

The sizes of the areas granted for mining, exploration or areas under application are not always known. Based on the information available we estimate the total area licensed or under application in areas under coastal state jurisdiction of countries to be around 800 000 – 900 000 km². All licenses are for seafloor massive sulphides deposits only.

Pacific Islands

In 1997, Papua New Guinea (PNG) became the first country in the world to grant exploration licenses for seafloor massive sulphides deposits⁸⁸. In January 2011 the PNG issued the world's first deep-sea mining license (valid for 20 years) for Solwara 1 encompassing an area of 59 km². The Solwara 1 project is a 85:15 joint venture between Nautilus Minerals and the PNG government (through the government's resource development arm Petromin). A dispute between Nautilus and the PNG government has put the project on hold but recently (April 2014) both parties have come to a new agreement. Since not all the equipment for mining is ready yet, mining is not expected to start before 2015. The main part missing is a special manufactured ship. Nautilus already had a contract with a manufacturer, but it went bankrupt (due to the economic crisis). They are therefore in the process of finding a new contractor. To date, Nautilus has mapped out a total of 12 viable mining sites named Solwara 1 to Solwara 12. The company expects the Solwara 1 project to be active for three years before moving on to the next location⁸⁹.

Other Pacific Islands have issued exploration licenses for projects as well (the Solomon Islands, Kingdom of Tonga, Fiji and Vanuatu). The Cook Islands have not issued any licenses yet but are planning on issuing exploration licences early next year, once all their relevant legislations are in place. The government of the Cook Islands wants to spend the deep-sea mining revenues on upgrading infrastructure (they are in need of a proper hospital, school infrastructure, roads etc.). The Federated States Micronesia has also not issued any deep-sea mining licenses for either exploration or mining. There have been two applications received by the National Government but due to the absence of the prerequisite Legal Framework these applications are still pending and will

⁸⁷ Other mining licenses have been issued but these cannot be characterized as deep-sea mining licenses since the depth of these locations does not exceed 500 meters. This is for example the case for Sandpiper Marine Phosphate project of the coast of Namibia (depth of 180-300 meters) and the location Chatham Rise within the EEZ of New Zealand (depth of 350-450 meters).

⁸⁸ Annual information form for the fiscal year ended December 31, 2013, Nautilus Minerals Inc, Vancouver, March 28, 2014.

⁸⁹ Oxford Business Group (2012): The report: Papua New Guinea 2012, http://books.google.nl/books?id=OMZSJzswem0C&pg=PA93&lpq=PA93&dq=neptune+bluewater+bismarck&source=bl&ots=zS3U2V6bI&sig=N9VoRCG1gZjg01MqElpSAImgZ_k&hl=nl&sa=X&ei=uOOCU_X-NsLvPLvTgOgK&ved=0CHYQ6AEwCQ#v=onepage&q=neptune%20bluewater%20bismarck&f=false.

remain as they are until the Legal Framework that SPC/AGTG/SOPAC/EU supported is put in place⁹⁰.

To conclude, the Pacific Islands are preparing themselves for deep-sea mining. Papua New Guinea can be seen as the front runner despite the fact that they have not all their legislation and policies in place⁹¹. The fact that PNG has a 15% interest in Solwara 1 could lead to a conflict of interest: it can be questioned, if regulatory activities can be conducted in an objective way, if the state has a 15 % interest. Deep-sea mining is seen by most of the Pacific Islands as a way to generate substantial revenues. The Kingdom of Tonga for example previously had an income of \$20 000 per year from the tenements, but in 2013 they added amendments to the fee and managed to get around \$3 million.

Oceania

Within Australian waters there are currently no deep-sea mining projects. For the moment it is unknown whether there are any deep-sea exploration projects going on. The northern territory government in Australia reached a decision in March 2012 with a total ban on seabed mining until 2015 around Groote Eylands in the Gulf of Carpentaria until a review of actual or potential impacts of seabed mining has been undertaken.

The government of New Zealand has received two applications for exploration projects: one by Nautilus in 2007 and one by Neptune in 2011. These projects have not been approved yet due to administrative delays (New Zealand changed their license procedure). Besides this, both applications are located in the Offshore Reserved Area. For this area the Minister of Energy and Resources of New Zealand will not be accepting any new mineral licence applications. This area is subject to a review by the government of New Zealand (until 4/7/2015).

Africa

For the countries in Africa no information has been found regarding deep sea exploration or mining projects for seafloor massive sulphides, crusts or nodules. Since both Neptune and Nautilus did not apply for exploration licenses nor hold exploration licenses in the areas under coastal state jurisdiction of African countries, it is expected that deep-sea mining for seafloor massive sulphides, crusts or nodules only plays a marginal role in Africa. The Namibian Government decided in October 2013 to place an 18-month moratorium on marine phosphate mining⁹² to enable the government to conduct a strategic environmental assessment.

Europe

As regards areas under the coastal state jurisdiction of European countries three applications for exploration projects are currently pending: one in Italy, one in Norway and one in Portugal. In Norway the Norwegian University of Science and Technology is currently mapping the seabed between the islands of Jan Mayen and Svalbard, in collaboration with Statoil and the mining company Nordic Ocean Resources. Almost the entire area in question lies within Norway's EEZ. Nordic Ocean Resources has recently applied for an exploration license(s) in the Norwegian sector

⁹⁰ Ambassador of the Federated States of Micronesia in Suva (Fiji).

⁹¹ Thomas Imal, Lawyer with the Centre for Environmental Law & Community Rights (CELCOR) says in December 2013: 'The PNG Government has put the cart before the horse by issuing Nautilus Minerals Solwara 1 mining license without adequate and independent scientific studies, or comprehensive national policy, laws and regulations for DSM'. Source: <http://ramumine.wordpress.com/2013/12/18/deep-sea-mining-is-not-the-answer-pacific-civil-society/>. See also Chapter 4.

⁹² Swakopmund Matters (2014): Namibia celebrates as govt maintains moratorium on seabed mining, <http://ramumine.wordpress.com/2014/04/12/namibia-celebrates-as-govt-maintains-moratorium-on-seabed-mining/>.

of the Mid-Atlantic Ridge. This application is still pending. The Norwegian Government is currently working to establish a legal and procedural framework for the exploitation of subsea resources⁹³.

In Italy an application for an exploration project has been submitted by Neptune Minerals. In the case of Portugal an application for an exploration project near the Azores was submitted by Nautilus in 2012.

North America

In the USA there are currently no deep sea exploration or exploitation projects within their areas under US jurisdiction. There is also no program within the USA to assess the resource potential of its continental shelf⁹⁴.

For the Commonwealth of the Northern Mariana Islands (CNMI)⁹⁵, an US island territory, the USA has only recently (March 2013) transferred their mineral rights to the CNMI⁹⁶. In 2006 Neptune Minerals applied for exploration licenses to mine along the Marianas Arc and the associated back-arc basin offshore from the CNMI. These licenses have however not been granted by the USA. Now with the transfer of the mineral rights this could change in the near future.

Canada also has not yet issued any deep sea exploration or mining licenses for projects in their areas under coastal state jurisdiction .

Asia

In the respective EEZs of Korea and China there are no licensed deep-sea mining projects⁹⁷. Korea however has been carrying out test mining activities using deep-sea mining equipment at depths of 1 300 metres within the Korean EEZ. In Japan the state company JOGMEC has since 1998 been involved in a project to assess natural resources such as minerals and to collect data necessary for claims to extend Japan's outer continental shelf. This survey program consists of geophysical and geological sampling surveys⁹⁸.

5.3.3 European Innovation Partnerships

The EIP on Raw Materials targets non-energy, non-agricultural raw materials. Many of these are vital inputs for innovative technologies and offer environmentally-friendly, clean-technology applications. They are also essential for the manufacture of the new and innovative products required by our modern society, such as batteries for electric cars, photovoltaic systems and devices for wind turbines. The Partnership aims to reduce the possibility that a shortage of raw materials may undermine EU industry's capacity to produce strategic products for EU society.

⁹³ Source: Norwegian sea may hold vast mineral and metal deposits, Svein Magnason, 18-12-2013
<http://www.noraregiontrends.org/metals-minerals/metalsnews/article/norwegian-sea-may-hold-vast-mineral-and-metal-deposits-1/196/>.

⁹⁴ Source: U.S. Geological Survey.

⁹⁵ CNMI is one of the five inhabited U.S. island territories (the other four are Guam, Puerto Rico, the U.S. Virgin Islands and American Samoa). It is one of two territories with "Commonwealth" status; the other is Puerto Rico). It consists of fifteen islands in the western Pacific Ocean, about three-quarters of the way from Hawaii to the Philippines. The United States Census Bureau reports the total land area of all islands as 475.26 km². As of the 2010 census, the Northern Mariana Islands had a population of 53,883, of whom over 90% live on the island of Saipan. Source:
http://en.wikipedia.org/wiki/Northern_Mariana_Islands.

⁹⁶ Source: CNMI accepts US transfer of mineral rights, Saipan Tribune, March 28, 2014.
<http://mining.einnews.com/article/197713298>.

⁹⁷ Source: Korean Institute of Ocean Science and Technology (KIOST) and Central South University of China.

⁹⁸ Japan Oil, Gas and Metals National Corporation (2014): **Continental Shelf Survey Program**
http://www.jogmec.go.jp/english/metal/technology_021.html.

The EIP on Raw Materials is not a new funding instrument. It aims to bring stakeholders together to exchange ideas, create and partner in projects which produce concrete deliverables⁹⁹.

In order to achieve the EIPs objectives, a joint undertaking by several partners (industry, public services, academia etc.), can be made in so-called commitments. Commitments must aim to deliver innovative products, processes, services, technologies, business models or ideas that can be brought to the market or that would bring wider societal benefits. In March 2014¹⁰⁰ 80 commitments were recognized as 'Raw Material Commitments, out of which, six are related to deep-sea mining (see next table). In annex 5 more information regarding these six commitments can be found.

Table 5.2 Raw Material Commitments that have a relation with deep-sea mining

Commitment	Acronym	Period to implement the commitment	Name and country of coordinator
Environmentally Responsible Deep-sea Mining	ERDEM	1/6/2014 – 31/5/2019	BMT Group Ltd, UK
"Alternative Blue Advanced Technologies for Research On Seafloor Sulfides": securing long term raw material supply to Europe by developing and testing deep-sea technologies for exploration and evaluation	ALBATROSS	1/1/2015 – 31/12/2020	ERAMET SA, France
Securing the supply of Primary resources	SecPRIME	1/1/2014 – 31/12/2020	Luleå University of Technology, Sweden
Innovative Mining of Marine Mineral Resources – A European Pilot Mining Test in the Atlantic on Tools, Facilities, Operations and Concepts	Blue Atlantis	1/4/2015 - 31/3/2020	Working Group Marine Mineral Resources; German Association for Marine Technology, Germany
Breakthrough Solutions for Seafloor Mineral Extraction and Processing in deep water environment	SeaFlores	unknown	Technip, France
3DS European Mineral Asset Definition and Valuation System	EUROASSET	1/1/2015 – 31/12/2018	Dassault Systemes GEOVIA Ltd. UK

Source: <https://ec.europa.eu/eip/raw-materials/en/call-commitments>.

5.4 Characteristics of the ongoing projects and applications for projects

5.4.1 Water depth

The water depth in the projects depends on the deposit type. Projects involving seafloor massive sulphides usually have a depth between 1 000 and 3 000 meters, for crusts the depth varies between 2 000 and 4 000 meters and for nodules the depth is between 4 000 and 6 000 meters.

5.4.2 Size of expected deposits

The size of the expected deposits is not available for all projects due to confidentiality. Additionally, in many cases a great part of the licensed areas have not been explored yet. Neptune for example indicated that it has only explored about 3% of its licensed areas until now. Information, however, is available about the extent and nature of mineralisation at Solwara 1, as depicted in the following table.

⁹⁹ On the website a list of funding sources that may be accessed to fund projects of the EIP on Raw Materials can be found (although the list is not exhaustive, see: <https://ec.europa.eu/eip/raw-materials/en/funding-opportunities>).

¹⁰⁰ New calls for commitments are scheduled for 2015, 2017 and 2019.

Table 5.1 Mineral resource estimate for Solwara 1 at 2.6% Cu equivalent cut off¹⁰¹

Area	Class	Domain	Tonnes (kt)	Cu%	Au (g/t)	Ag (g/t)	Zn (%)
Solwara 1	Indicated	Sulfide dominant	1030	7.2	5.0	23	0.4
	Inferred total		1440	8.2	6.4	34	0.9

The zone of mineralization classified as Indicated Mineral Resource was tested by drill holes spaced from less than 10 m to a maximum of approximately 50 m. In the Area classified as Inferred Mineral Resource the drill hole spacing ranges up to 200 m, but is generally less than 100 m, and the core recovery was more variable.

5.4.3 Companies and governments involved: Main contractors

In most of the projects in international waters the main contractors are governments (Korea, Russian Federation, India) or companies sponsored and funded directly or indirectly by Governments through public funding, for example KIOST (Korea), COMRA (China), JOGMEC¹⁰² and DORD (both Japan) and the Federal Institute for Geosciences and Natural Resources (BGR, Germany). A small part of the project licenses are held by private companies like UK Seabed Resources Ltd, Tonga Offshore Mining Ltd (a subsidiary of Nautilus) and Marawa Research and Exploration Ltd.

The majority of (governmental) companies that have exploration licences in international waters (for polymetallic nodules in most cases) can in fact be seen as the customers as well: China, India, Japan, Korea, Germany and Russia are all seeking to secure major resources directly for their own demand. This can be illustrated by the next table that gives an overview of the world's 10 biggest consumers of nickel and copper by country.

Table 5.3 Overview of the world's 10 biggest consumers of nickel and copper by country

	Major importers of refined nickel (2011) ^{a)}	Major importers of copper ores (2010) ^{b)}
1	China	China
2	Japan	Japan
3	US	India
4	Germany	South Korea
5	South Korea	Spain
6	Italy	Germany
7	Taiwan	Bulgaria
8	India	Finland
9	Spain	Philippines
10	Belgium	Sweden

a) Source: Bloomberg (2012): World's 10 biggest nickel-consuming countries in 2011, <http://www.bloomberg.com/news/2012-05-28/world-s-10-biggest-nickel-consuming-countries-in-2011.html>.

b) Source: International Copper Study Group (2013): The World Copper Factbook 2013.

Most of the projects within areas under coastal state jurisdiction are executed by Nautilus Minerals and Neptune Minerals, two private companies. The only two mining projects within areas under coastal state jurisdiction are to be executed by Nautilus Minerals and Diamond Fields International.

¹⁰¹ Nautilus Minerals Inc. (2013). Annual Information Form for the Fiscal Year ended December 31, 2013, p. 44.

¹⁰² established by the Japanese government in 2004.

Nautilus Minerals, a Canadian company, was founded in 1987. The main shareholders of Nautilus are three large mineral company investors (Mawarid Mining, an oil and gas, mineral mining and processing group based in Muscat, Oman, Metalloinvest Holding (Cyprus) Limited¹⁰³, engaged in producing iron ore, and Anglo American, one of the world's largest mining and natural resource groups). Nautilus Minerals can be seen as the leading company in deep-sea mining with a mining license in Papua New Guinea for the Solwara 1 project and the first private-sector company to be granted exploration territory in international waters through the formal grant of the exploration licence for Nautilus Minerals' Tongan subsidiary, Tonga Offshore Mining Ltd (TOML).

Neptune, a US company, was formed in 1999 specifically to pursue the mining of (only) seafloor massive sulphides deposits, becoming a public company (listed on London's Alternative Investment Market) in 2005. Neptune is exclusively working within areas under coastal state jurisdiction.. The company has only one large (not controlling) shareholder: Odyssey Marine Exploitation Inc. Odyssey Marine Exploration, Inc. is engaged in archaeologically sensitive exploration and recovery of deep-ocean shipwrecks worldwide¹⁰⁴. Subsidiary seafloor mining companies of Neptune are Bluewater Metals (located in Australia) and Bismarck Mining Corporation.

Diamond Fields International is a Canadian mining company with land and marine mining licenses in several areas of the world. In 2005 Diamond Fields started marine diamond mining operations off the coast of Namibia in a licensed area of around 720 km².

Other companies that execute projects in areas under coastal state jurisdiction, besides Neptune and Nautilus, are KIOST, JOGMEC and Nordic Ocean Resources AS (NORA). KIOST and JOGMEC are (as previously mentioned) public/governmental companies. NORA is the current sole company in Norway with focus on seabed minerals. NORA is owned by Nordic Mining ASA¹⁰⁵ (85 percent) and by Ocean Miners AS (15%) (both private companies).

It can be concluded that only Diamond Fields, Nordic Mining and, through Nautilus, a few of the 'conventional' mining companies currently have a stake in marine deposits (Anglo American, Mawarid Mining, Metalloinvest). Most of the conventional mining companies however, such as BHP Billiton (copper), Vale SA (the world's largest producer of iron, but also a producer of cobalt), Glencore Xstrata (one of Australia's top nickel producers but also of cobalt and copper) do not have a stake in international waters. One reason mentioned why traditional big mining companies are reluctant in applying for exploration licenses is that everybody 'sees' their money. If a big mining company applies for an exploration license, the relevant country or agency believes that it must be of high value for them and raises the price for exploration. Therefore it is easier for small exploration companies to get a license to "have a look" and to involve mining companies at a later level when more clarity about the actual existing resources is achieved. Furthermore, the work of exploration is very different from the one of extraction. Exploration requires specialised tools to collect small amounts to be analysed. Actual mining needs equipment to extract high quantities for the lowest possible costs.

Other companies

Besides the companies that are the main contractor in the several deep sea marine projects, more companies are involved in these projects. Nautilus has formed strong technical alliances with

¹⁰³ This company is a subsidiary of the Russian mining company Metalloinvest.

¹⁰⁴ The Company employs technology, including side-scan sonar, magnetometers, remotely operated vehicles (ROVs), and other advanced equipment that enables the Company to locate shipwrecks and natural resource sites at depths.

¹⁰⁵ Nordic Mining is a private company that can be seen as a 'conventional' mining company with interest in gold mines in Ecuador mines producing industrial and aggregate products. Source: <http://www.nordicmining.com/nordic-mining-minerals-for-the-future/category118.html>.

companies who they see are at the forefront of their industry and represent best-in-class technology. These companies comprise¹⁰⁶:

- Soil Machine Dynamics ("SMD") of the UK, one of the world's leading subsea engineering companies specialising in the design and manufacture of remotely operated vehicles ("ROV's") and seabed trenching systems;
- Technip, a French company, who was awarded the contract for engineering, procurement and construction management of Nautilus's Solwara 1 Riser and Lifting System ("RALS");
- Ocean Floor Geophysics Inc, a Canadian company experts in deep-ocean electromagnetic technology; and
- GE Oil & Gas of the USA who was awarded the contract to build the subsea slurry pump for the RALS in Solwara 1.

Nautilus mentions that technology is coming to a large extent from Europe¹⁰⁷. Other European companies that are involved in the different licensed projects are:

- Kongsberg Maritime of Norway, an international technology corporation, provides underwater positioning technology and systems for survey vessel operation;
- Fugro Subsea Services Limited, located in Aberdeen UK, specializes in providing ROV support vessels, ROVs, Trenching systems and remote engineering services to clients in a wide range of offshore projects in the geographical region of the North Sea, Mediterranean and West Africa;
- Balmoral Offshore Engineering, based in Aberdeen UK, designs and manufactures products including thermal insulation, rigid and distributed riser, ROV/AUV and subsurface buoyancy;
- Bore Ltd, a Finnish shipping company, owns a RoRo Fleet consisting of 9 vessels sailing under the Finnish and the Dutch flags, including MV Norsky, the operating vessel of Nautilus Minerals' MV Norsky 2008 exploration program to Tonga and Papua New Guinea.

Governments and public companies like KIOST, JOGMEC and BGR use national organisations/companies to assist them in the exploration projects. BGR for example hires the University of Bielefeld to perform the resource assessment and the Senckenberg Institute to perform the environmental study. The government of India has entrusted the tasks of exploration, environmental impact assessments, mineral processing, metallurgy and development of deep-sea mining technology to different institutes in the country, for example to the National Institute of Ocean Technology (NIOT). Since marine exploration is expensive, and it is eventually the taxpayer who has to pay, it is to be expected that licenses held by national governments/public companies will use national companies to perform the needed activities. In this way jobs and knowledge are created in the 'home' country.

Conclusions

Companies from the EU (Belgium, France, Germany, UK) are the main contractors in some of the projects that take place in The Area. This is not the case for projects in areas under coastal state jurisdiction. The projects where EU companies are the main contractor tend to focus more on nodules and less on seafloor massive sulphides and crusts. EU companies are however, in many cases providers of technology for exploration projects (for all three types of deposit).

In order to improve the position of EU companies with regard to deep-sea mining, it is mentioned (in interviews) that EU policy can play a strong supporting role in the development of technology. Exploration companies only pay for technology of which they are convinced that it will work (as each individual exploration mission is very costly). However, developers want to be paid to develop. This leads to a vicious circle. Public development funding can help to improve the situation.

¹⁰⁶ <http://www.nautilusminerals.com/s/techalliances.asp>.

¹⁰⁷ According to Nautilus more than 100 million euro spent for Solwara 1 went to Europe.

5.4.4 Obstacles

The obstacles regarding the exploration and exploitation/ mining of deposits that have been encountered by the parties directly involved since licenses came into force are listed below. The information on obstacles has been collected through literature research and interviews with relevant stakeholders.

Obstacles for governments

- Almost all countries (including those that are looking to contract deep-sea mining in their EEZ area) lack a strong and clear policy framework for this new sector. In 2011 the Deep Sea Minerals Project started at the Pacific Islands¹⁰⁸, to develop a legislative and regulatory framework for deep-sea mineral mining over a four-year period;
- For impoverished countries in the Pacific the question is how to arrange for the capability and resources to properly monitor (future) mining projects;
- Environmental campaigners have claimed that not enough is known about deep-sea ecosystems. This has led to the fact that some governments have put all applications for deep sea exploration or exploitation/mining on hold. For example the northern territory government in Australia has put a total ban on seabed mining until 2015 around Groote Eylands in the Gulf of Carpentaria until a review of actual or potential impacts of seabed mining has been undertaken;
- Public opposition is rising in several countries.

Obstacles for deep-sea mining companies:

- Access to capital/financing is the biggest challenge. It is very difficult to attract investments. One reason for that is decreasing metal prices. As a consequence budget cuts affect explorations;
- Companies need deep pockets: substantial expenditures are required to discover and establish sufficient resources. In comparison to exploration on land, where it is easy to get a map of the Area and start digging holes, in the sea it is already very expensive to get a clear picture of the Area under exploration. Mapping such an area costs millions of euro. Also the development of the mining and processing facilities and infrastructure at any site chosen for mining is very expensive;
- A big challenge is the absence of legislation relating to deep-sea mining in many areas under coastal state jurisdiction. Issues arising in addition are specific requirements like e.g. in Japan where the applicant needs to provide a Japanese partner and it is not always easy to get one. In New Zealand the costs of licensing are very high etc.;
- Limited availability of modern and state-of-the-art research vessels in the Indian Ocean that can be contracted for exploration purposes.

5.4.5 Expected future developments

Increased mining of seafloor massive sulphides in the near future is seen as realistic as it happens at about 2 000 metres depth (similar as oil & gas). Therefore, skills from other sectors can be transferred. Mining of crusts would be possible as well, but there is not much commercial interest (there are no applications for exploration licenses in areas under coastal state jurisdiction and only two in the Area). At this stage mainly scientists are interested in exploring this mining opportunity. With regard to nodules the future is uncertain. For the moment the exploration for nodules is seen more as a strategic positioning of countries. However, if there is a technological breakthrough, processes may speed up. For now the depth of the nodules is a problem (too deep in the water)

¹⁰⁸ The Project is funded by the European Union under the 10th European Development Fund and is implemented by the Secretariat of the Pacific Community (SPC) through the Applied Geoscience and Technology Division (SOPAC). The goal of the project is to expand the economic resource base of Pacific ACP States by facilitating the development of a viable and sustainable marine minerals industry. The objective is to strengthen the system of governance and capacity of Pacific ACP States in the management of deep-sea minerals through the development and implementation of sound and regionally integrated legal frameworks, improved human and technical capacity and effective monitoring systems.

and there are many questions still unanswered: e.g. what pumping technology and what are the environmental effects at great depth.

5.5 Conclusions

Based on an analysis of the different on-going projects and pending applications for licenses the following conclusions can be drawn:

- In the period 2001-2011 the only project licenses issued by the ISA were exploration licenses for nodules. Only in recent years project applications for the exploration of seafloor massive sulphides and crusts were received. The main projects however remain nodules exploration. All project licenses issued by the ISA are mainly held by governments or state-sponsored companies;
- Project licenses issued by individual countries are almost entirely for the exploration of SMS. So far only two exploitation/mining licenses have been issued, both for SMS. These licenses are all for greatest part given to non EU private companies of which Neptune Minerals and Nautilus Minerals hold the majority;
- This means that private companies are obviously more interested in the exploration and future exploitation of SMS and the governments/state-funded companies are more interested into nodules. This situation can be explained from the fact that most experts think that seafloor massive sulphides are the first to be mined (there is no commercial interest for crusts and nodules are too deep). This also explains why the ISA concludes that *“there is little evidence of any sense of urgency for commercial development”* by contractors in The Area and that *“most programmes continue to be prolonged scientific research campaigns, without any commercial viability”*¹⁰⁹;
- The total area under contract in the projects (for exploration and mining) or under application totals around 2 – 2.1 million km². This area is equal to the size of Greenland. Approximately 55% is located in The Area and 45% in areas under coastal state jurisdiction;
- The Pacific Islands are preparing themselves for deep-sea mining. Papua New Guinea can be seen as the front runner despite the fact that they have not all their legislation and policies in place. Deep-sea mining is seen by most of the Pacific Islands as a way to generate substantial revenues;
- In areas under coastal state jurisdiction in Europe three exploration projects for seafloor massive sulphides are currently under application: one in Italy, one in Norway and one in Portugal;
- in many cases a great part of the licensed project areas have not been explored yet. Neptune for example indicated that it has only explored so far about 3% of its licensed project areas;
- Governments and public companies like KIOST, JOGMEC and BGR use national organisations/companies to assist them in the exploration phase. Since marine exploration is expensive, and it is likely the taxpayer to pay for it, it is to be expected that licenses held by national governments/public companies will use national companies to perform the needed activities. In this way jobs and knowledge are created in the ‘home’ country;
- In order to improve the position of EU companies with regard to deep-sea mining, it is mentioned (in interviews) that EU policy can play a strong supporting role in the development of technology. Exploration companies only pay for technology of which they are convinced that it will work (as each individual exploration mission is very costly);
- Regulatory obstacles remain such as: no specific legislation and incoherent legislation;
- Access to finance is an issue for companies interested in exploration activities;

¹⁰⁹ ISA (2013): Periodic review of the implementation of the plans of work for exploration for polymetallic nodules in The Area, IISBA/19/C/9/Rev.1.

- Research needs to remain in order to reduce costs.



6 Environmental implications

6.1 Summary

A considerable amount of scientific information has been generated on the physical attributes of sea-floor massive sulphides, manganese nodules, and cobalt-rich ferromanganese crusts. However the habitats, biodiversity, ecosystem structure, and resilience associated with these types of mineral deposits are less well-understood. If deep-sea mining is developed, environmental policies will need to be adjusted as new information, technologies and working practices emerge. This will require an on-going, collaborative approach involving industry representatives, policy makers, field scientists and subject matter experts, environmental managers, government authorities, international agencies, civil society and the general public. As deep-sea mining activities will, for the most part, be carried out in remote locations which may make independent observation difficult, transparency will need to be a key consideration in developing such approaches.

The major impacts from mining will be similar for the three types of mineral deposits considered here, namely:

4. loss of substrate,
5. effects of mining on the seabed, the operational plume and re-sedimentation and
6. discharge plume and its effects on pelagic and/or benthic fauna depending on the depth of discharge,

it is important to note that there are differences in impacts depending on the deposit type as well as the geomorphological setting, physical conditions, the scale of operations, and the technology used for extraction. The extraction processes that are expected to have strongest environmental impacts are the following:

- Disaggregation
- Lifting
- Dewatering.

The three mineral deposit types are expected to return different environmental results when it comes to the:

- duration of the impact;,
- size of the area impacted;
- nature of the impacts and the
- potential for recovery.

One of the most important drivers behind the impacts is the actual removal of the minerals which often hosts a number of species. Seafloor massive sulphides based in active hydrothermal vents are expected to recover relatively quickly (months to years) while inactive sites will take considerably longer ranging from tens to hundreds of years. Nodules will likely take the longest time when it comes to recovery after the removal of the elements and may take tens to hundreds of years or even longer in heavily mined areas (nodule faunas may take millions of years to recover). Similarly crusts are expected to recover slowly meaning tens to hundreds of years.

Another impact will be the spread of sediments which depending on the depth, technology, currents and the types of deposits mined can have varying levels of impacts. For all three elements the spread of sediment laden plumes near the seabed can go various kilometres beyond the mining site and can potentially smother seabed animals. Sediment in the water column can cause a

reduction in light penetration and in temperature. These factors are likely to reduce plankton growth with knock-on impacts to the whole food chain. Additionally, ecosystems as a whole can be impacted by the shift on sediment grain size (sediments may change towards sandier or finer composition).

Pollution from ships onto the surface water and noise pollution from the vessels as well as the underwater equipment can potentially have negative impacts; however as to date no extraction has taken place the extent of these impacts cannot be measured. With regard to noise pollution short-term masking effects on marine mammals are likely. As for all mining activities the disposal of tailings¹¹⁰ on land or sea can also have long term impacts.

Finally, it is important to caution that although coastal marine mining in shallow waters (e.g. aggregates, diamond, placer gold) has a relatively long history, no actual commercial scale deep-sea mining operation (i.e. beyond 500m water depth) has ever been conducted. Only scientific mineral extraction and limited technological testing has taken place (as early as the 1970s). A cautious approach is thus a vital consideration when considering the topic of deep-sea mining, in order to avoid repeating destructive practices evident in the deep sea from, for instance, bottom trawling.

This chapter provides a “state of the latest knowledge” overview of the range of environmental impacts policy makers need to consider when contemplating the issue of extracting metals from the deep sea. If plans are developed for such activities, it will be useful to consider that although environmental management plans are expected to be site-specific, set within the context of a wider regional framework, they will also likely accommodate broader themes, such as economic opportunity, legal frameworks, and conservation priorities¹¹¹ - as set out within the context of national legislations or international agreements.

The social aspect

Embedded within the environmental and economic impacts there are important social implications that need to be considered. For the local population, the sea and the minerals it contains are often considered a property and the minerals under the sea can in some cases have cultural value associated with them. Therefore, it is important that stakeholders are sufficiently involved regarding the different aspects of the mining operations including safety and sharing of its benefits. Furthermore, transparency and continuous communication is necessary in order to ensure there is a common understanding on the principles of the operations and on the conduct of the mining company. Communication would preferably involve topics related to the entire value chain (from exploration through processing to decommissioning).

6.2 Approach

The environmental analysis focuses on EU specific issues requiring particular policy considerations. The EU's Marine Strategy Framework Directive is one of several important approaches for regulating the environmental aspects in the deep sea, within EU waters. In Areas Beyond National Jurisdiction (ABNJ) regulatory regimes are developed by the International Seabed Authority (ISA) and aspects of the Marine Strategy Framework Directive (MSFD) may provide useful inputs, such as to the developing policy instruments for the exploitation of minerals from the seabed.

¹¹⁰ waste and refuse remaining after the ore has been processed

¹¹¹ Baker and Beaudoin 2013a

Additionally this report builds on the development of Regulations by the Southwest Pacific Islands Region lead by the Secretariat of the Pacific Commission¹¹². Considering the vast ocean areas under their jurisdiction and limited land space, the Pacific Islands have a particular interest in ensuring the long-term health of the oceans and are thus have been granted an extension to continue the EU supported exercise to develop environmental and economic regulatory frameworks. Many aspects of the knowledge and experience gained with the Pacific are integrated in this summary.

Furthermore, with regard to international waters there are detailed Regulations for the exploration for polymetallic nodules, polymetallic sulphides and cobalt-rich crusts¹¹³; as well as comprehensive guidance to contractors on the physical, chemical, geological and biological factors to be considered in baseline environmental surveys¹¹⁴. The Guidance to Contractors also includes activities, such as test mining, which require the submission of an Environmental Impact Assessment and agreement with the ISA before operations can begin¹¹⁵.

6.2.1 Overview of environmental concerns

This chapter presents an overview of the environmental impacts for the three types of minerals (sulphides, nodules and crusts) assessed in this study. A more detailed look at the deposit types follows the overview (from chapter 2.2.2 onwards) while a comprehensive analysis of impacts can be found under chapter 3.2.

While the major impacts from mining will be similar for the three types of mineral deposit considered here, namely:

7. loss of substrate,
8. effects of mining on the seabed, the operational plume and re-sedimentation and
9. discharge plume and its effects on pelagic and/or benthic fauna depending on the depth of discharge.

It is important to note that there are differences in impacts depending on the deposit type as well as the geomorphological setting, physical conditions, the scale of operations, and the technology used for extraction. The extraction processes that are expected to have environmental impacts are the following:

- Disaggregation
- Lifting
- Dewatering.

The three mineral deposit types are expected to return different results when it comes to the:

- length of the impact (in terms of time),
- size of the area impacted,
- nature of the impacts and the
- potential for recovery.

One of the most important impacts is the actual removal of the minerals which often hosts a number of species. Seafloor massive sulphides based in active hydrothermal vents are expected to recover

¹¹² In December 2013, GRID-Arendal in support of the Secretariat of the Pacific Commission's Applied Geoscience and Technology Division (SPC/SOPAC) and in partnership with UNEP, an extensive group consisting of the top global experts in the field (including the ISA, academics, industry, governments, NGOs), delivered a broad assessment on the state of the knowledge on deep sea minerals and mining for the Pacific.

¹¹³ International Seabed Authority, 2013a, International Seabed Authority, 2010, International Seabed Authority, 2012

¹¹⁴ International Seabed Authority, 2013b

¹¹⁵ Deep Seas Environmental Solutions Ltd, a member of the Ecorys consortium worked with the ISA Secretariat to produce the revised environmental guidelines adopted by the Authority

relatively quickly (month to years) while inactive sites will take considerably longer ranging from tens to hundreds of years. Nodules will likely to take the longest time when it comes to recovery after the removal of the elements and may take tens to hundreds of years or even longer in heavily mined areas (nodule faunas may take millions of years to recover). Similarly crusts are expected to recover slowly meaning tens to hundreds of years.

Another impact will be the spread of sediments which depending on the depth, technology, currents and the types of deposits mined can have varying levels of impacts. For all three elements the spread of sediment laden plumes near the seabed can go kilometres beyond the mining site and can potentially smother seabed animals. Sediment in the water column can cause a reduction in light penetration and in temperature. These factors are likely to reduce plankton growth with knock-on impacts to whole food chain. Additionally, ecosystems as a whole can be impacted by the shift on sediment grain size (sediments may change towards sandier or finer composition).

Pollution from ships onto the surface water and noise pollution from the vessels as well as the underwater equipment can potentially have negative impacts; however as to date no extraction has taken place the extent of these impacts cannot be measured. With regard to noise pollution short-term masking effects on marine mammals are likely. As for all mining activities the disposal of tailings¹¹⁶ on land or sea can also have long term impacts.

6.3 Seafloor massive sulphides

Description

Sea-floor massive sulphides are mineral deposits that form as a result of hydrothermal activity. They may be associated with “black smoker” chimneys, which can form where hydrothermal fluids (in excess of 350° C) are being emitted on the seafloor. Black smokers were first discovered in 1977 at the Galapagos Rift. Since then hydrothermal venting and SMS deposits have been found in all the world’s oceans associated with oceanic plate boundaries – mid ocean ridge spreading centres, volcanic arcs and back arc basins. Copper, lead, zinc, and gold are among the valuable metals found in SMS deposits. SMS deposits are the modern analogue of terrestrial massive sulphide deposits found globally in a variety of geological settings.

Sulphide deposits are precipitated as reduced compounds in a wide area around the hydrothermal vent. During mining activities the deposit will be ground into finer particles and during initial dewatering, carried out on board ship at the sea surface, it will be oxygenated. These activities may lead to phase changes in critical elements, some of which may be toxic in low concentrations. The pH of the water may also be changed, and the discharge plume may have a higher temperature than the surrounding water. The exact processes and environmental consequences of these changes require further investigation.

Habitat and biodiversity

The physical and ecological characteristics of hydrothermal vent systems are unlike that of other ecosystems or biomes that use light as a source of energy. In an environment of elevated temperatures and the complete absence of light, hydrothermal vents support food webs based on chemoautotrophic primary production. The distribution of the hydrothermal vents is sporadic¹¹⁷ (the spacing between vent sites can be up to hundreds of kilometres), and their existence can be ephemeral. The life cycle of a vent system can range from thousands to tens of thousands of years

¹¹⁶ waste and refuse remaining after the ore has been processed

¹¹⁷ Ferrini et al 2008 and Baker 2009

depending on the rate of spreading (for deposits on spreading ridges) and the ease with which fluids can circulate the subsurface (efficiency of plumbing system).

However, at slow spreading ridges, such as the Mid Atlantic Ridge, and ultra-slow spreading ridges, such as the Gakkel Ridge in the Arctic Ocean, where seafloor massive sulphides are more likely to occur, vent systems may persist for extended periods. It is important to appreciate that vent fauna at fast spreading ridges in the Pacific Ocean with high disturbance regimes, may have different life history characteristics to vent fauna on other ridge systems¹¹⁸.

Changes in vent fauna may occur in relation to fluid flow (temperature, volumes, and location) and substrate (chimney collapse, eruptive magma events, etc.). These dynamics influence the point sources of hydrothermal emissions and also the lifespan of the individual “chimneys” and associated ecosystems¹¹⁹.

Based on current deep-sea exploration technologies (which use “plume sniffing” to locate SMS sites), only active seafloor hydrothermal systems (and/or inactive ones found in proximity to active sites) have been the targets of possible deep-sea mining efforts. Therefore the following information is focused on impacts related to these sites.

The mining of SMS will create permanently (in terms of human timescale) disturbed areas at the mine site. As SMS mining targets highly spatially concentrated deposits (as opposed to manganese nodule mining), the geographical extent of the physical disturbance from an individual mine is likely to be less than for comparable land operations. For example the Solwara 1 site in Papua New Guinea has a surface area of only 0.112 km² and when mining is completed is expected to leave a hole that is approximately 30 m deep¹²⁰. Compare this to terrestrial massive sulphide mines, which are generally orders of magnitude larger e.g. the Broken Hill mine in Australia is 2km² and 1600 m deep, the Canadian Kidd Creek mine covers an area of more than 8 km² and by 2017 is expected to reach a depth of more than 3000 m.

Hydrothermal vent ecosystems are important places of biodiversity where the vent-endemic species have adapted to tolerate such challenging conditions. The list of endemic species numbers over 600 and new species are being identified regularly¹²¹.

The communities of vent-endemic animals vary regionally throughout the global oceans. For example, the eastern Pacific vents are dominated by giant tubeworms, but they do not occur in the Atlantic or Indian Oceans, where varieties of shrimp, anemones, and snails dominate¹²². The current research on the variability of vent communities shows that there may be at least five “biogeographic provinces” for vent-endemic animals, although studies have yet to produce specific boundaries for these areas¹²³.

While localised hydrothermal active vent ecosystems¹²⁴ are the focus of some commercial activities, such as Nautilus Minerals Inc. within the Exclusive Economic Zone (EEZ) of Papua New Guinea, the largest seafloor massive sulphides are likely to occur at inactive sites on mid ocean ridges. Some contractors to the International Seabed Authority, for instance, have indicated their

¹¹⁸ Boschen et al. 2013

¹¹⁹ Baker and Beaudoin, 2013; Johnson et al 2000

¹²⁰ Coffey 2008

¹²¹ Desbruyères et al 2006a, Van Dover 2011

¹²² Baker et al. 2010; Boschen et al. 2013

¹²³ Van Dover et al 2002; Bachraty et al 2009; Moalic et al 2011; and Rogers et al 2012; Boschen et al. 2013

¹²⁴ Vent ecosystems are highly localized as they are entirely dependent on venting hot fluids. Even going just a few meters away from a source of hot fluids, biodiversity and biomass levels drop very significantly.

exploration for seafloor massive sulphides is focussed on inactive sites¹²⁵.

The organisms associated with these areas are more typical of mid ocean ridge rocky fauna, the actual nature of which will depend on depth and the geomorphological / physical oceanographic setting¹²⁶. Areas in which massive sulphide deposits will occur may also be a mosaic of rocky surfaces and sedimented areas¹²⁷.

Environmental issues of relevance to seafloor massive sulphides will relate not only to vent fauna, but also to fauna on rocks, such as corals and sponges, and sediment communities. Benthic communities will include micro-organisms, meiofauna, macrofauna, megafauna, necrophages and fish. Areas of sulphide deposits that are not hydrothermally active may provide an inactive surface. The existence of a specialised fauna associated with weathered sulphide deposits is at present unknown¹²⁸. In addition, impacts may occur on pelagic ecosystems, including specialised benthopelagic organisms, such as swimming sea cucumbers¹²⁹.

Mining activities at one depth may impact deeper living communities through downslope transmission of sediment-laden plumes or the initiation of turbidity currents. Deep-sea fauna are highly specific in their depth ranges owing to the effects of temperature and pressure on their cell wall structure and enzyme systems¹³⁰. Direct impacts by mining at one depth may therefore have also have a significant effect on very different assemblages of species at greater depths.

Environmental impacts on SMS

The technology currently proposed for extraction of seafloor massive sulphides involves digging and grinding of the mineralised rock. The mining processes will remove the surface habitat and the mineralised subsurface part of the deposit – at Solwara 1 this is estimated to be down to a depth of 30 m. There is some indication that following the removal of active chimneys at some sites, some regeneration may take place. For example at a Solwara 1 mining test site, active chimneys have been observed to “grow back” on a scale of weeks¹³¹.

Organisms living at active vent sites¹³² may have adapted to withstand relatively frequent loss of habitat related to volcanic and seismic activity¹³³ and the intermittent nature of the vent fluid discharge. Thus, they may be able to recover from mining-induced disturbance. Studies have shown how larvae from other vent sites can be transported from tens or even hundreds of km away¹³⁴. Other studies have shown how sites can have strong indications of recovery within a few years¹³⁵. However, this may be dependent on whether the sulphide resource is associated with fast-spreading, slow-spreading or ultra-slow spreading ridges (see above). In non-vent areas the deep-sea fauna typically have long generation times and may take decades to hundreds of years to recover. It is important to note that the number of such examples is trivial compared to the diversity of fauna found at such sites.

¹²⁵ International Seabed Authority, 2011, 2012

¹²⁶ Boschen et al. 2013

¹²⁷ e.g. Priede et al. 2013

¹²⁸ Van Dover 2007

¹²⁹ Billett et al. 1985

¹³⁰ e.g. Billett, 1991; Howell et al. 2002; Carney, 2005; Menot et al. 2010

¹³¹ S. Smith personal communication

¹³² Active vents are home to complex ecosystems with high biodiversity and relatively high biomass. Inactive vents located amongst active ones will be part of that complex ecosystem. Inactive vents isolated from active ones will have simple ecosystems with limited biodiversity and biomass.

¹³³ Van Dover 2011a

¹³⁴ e.g. Millieux et al. 2010

¹³⁵ Tunnicliffe et al. 1997, Shank et al. 1998

Apart from the physical destruction of habitat the mining process will also generate increased turbidity related to the extraction/operational plume on the seafloor and from the release of wastewater and fine particulate material (< 8 µm) in a discharge plume following initial on-board dewatering of the ore¹³⁶. The plumes released by the mining process will travel across the seabed potentially impacting areas adjacent to, and downslope from, the mine site. Particles settling from this plume may smother organisms and/or be toxic to some organisms (due to the presence of sulphides and heavy metals). The plume released into the water column during the transfer of ore to the sea surface and during any pre-processing on board the vessel could have similar effects and may include changes in pH and temperature. These plumes may have different properties to the naturally occurring hydrothermal plumes and may impact different areas. This is especially the case for any plumes released in mid-water that could potentially affect large areas.

The impact of the discharge plume will depend on the depth at which the plume is released. If the plume is released at the sea surface it could have a major impact on plankton by possibly reducing light penetration, or by stimulating greater growth by the introduction of nitrate, phosphate silicate and other nutrients, and through possible toxic chemical content.

Acknowledging that naturally occurring plumes are common at active sites, human activity-caused discharge plumes released at the sea surface at lower than ambient temperature may affect local weather (Ocean Thermal Energy Conversion – OTEC - environmental effects). If released at midwater plumes may have an impact due to particle load and possibly toxicity. Many gelatinous zooplankton in the mesopelagic and bathypelagic zones filter feed and may be harmed by the increased particle content. Changes in oxygen concentrations may occur if the discharge occurs in and around a mesopelagic oxygen minimum zone. In addition, if waste water is released at depth but has a higher temperature than the ambient water it may rise towards the sea surface where it will have a larger impact.

Ultimately the optimal conservation zone size (to protect species diversity, habitat diversity and genetic diversity) may differ in relation to the type of venting (rift valley, crest etc.), vent flow rates, surrounding currents and connectivity to other populations¹³⁷. Consideration must also be given to near-vent fauna or background fauna. It has long been hypothesised that background fauna among vents benefit from the chemosynthetically produced organic matter, but the scale of this is only beginning to be constrained. A recent study¹³⁸ illustrated that non-vent fauna had considerable portions of their dietary requirements met by chemosynthetic organic carbon sources at locations hundreds of m from active vent sites in the Manus Basin.

6.4 Polymetallic nodules

Description

Manganese nodules are concretions of iron and manganese hydroxides and occur in a variety of sizes (most are in the range of 5-10 cm in diameter). They are most abundant in the abyssal areas of the ocean (4000 – 6500 m water depth). Manganese, or more accurately polymetallic, nodules contain significant concentrations of nickel, copper, cobalt, manganese and trace metals, such as molybdenum, rare-earth elements, and lithium. The trace metals have industrial importance in many high- and green-technology applications. The abundance of nodules and the concentrations of metals within nodules vary with location. Nodules of commercial interest have been found in

¹³⁶ Coffey 2008

¹³⁷ Van Dover 2011

¹³⁸ Erickson et al. (2009)

parts of the Clarion-Clipperton Zone (CCZ) of the equatorial eastern Pacific, around the Cook Islands in the SW Pacific, and in an area of the Central Indian Ocean Basin.

The occurrence of polymetallic nodules has been well known for more than a century, but it was during the 1970s that interest was formed in mining the nodules. This interest did not translate to commercial operations, but in recent times polymetallic nodules have been put back on the agenda as a potential source of minerals. The International Seabed Authority presented a model for deposit locations within the Clarion-Clipperton Zone and the equatorial north Pacific region, which helped to build momentum for exploration in the Area¹³⁹.

Habitat and biodiversity

Manganese nodules are found in highly stable environments where the flux of particles to the seabed is low – they typically occur under low productivity areas within the tropical Pacific and Indian Oceans. In the open ocean, far from land influences, sediment arriving at the seabed generally falls as a particulate rain of biological origin from the sunlit surface waters above. Organisms that exist on the deep-seafloor rely on this gradual downward flux of organic matter from the surface waters above for their survival¹⁴⁰. However, even in the equatorial Pacific Ocean there is spatial, seasonal and inter-annual variation in the dynamics of surface water productivity and the subsequent flux of organic matter to the seafloor¹⁴¹ and this is likely to have a significant effect on the fauna that occur across the vast expanse of the Clarion-Clipperton Zone¹⁴².

Research into biodiversity on abyssal plains has revealed high species diversity, with organisms living in the fine sediment on the seafloor, on the surface of the sediment, attached and within nodules, and in the overlying water column¹⁴³. The sediment community includes many new species including meiofauna (such as nematode worms and protozoan foraminiferans)¹⁴⁴, macrofauna (such as polychaete worms and isopod crustaceans)¹⁴⁵, and larger animals (megafauna) such as seastars, and sea cucumbers¹⁴⁶ and 'giant' protozoan such as komokiaceans and xenophyophores¹⁴⁷.

Most of the research into biology assemblages associated with polymetallic nodules to date has been done in the CCZ (a vast area across the Pacific Ocean floor similar in breadth to the United States of America). Significant faunal change in sediment communities is evident across the CCZ¹⁴⁸. Similar assemblages are found in the Indian Ocean, although there will be some differences in terms of specific species¹⁴⁹. There is a significant problem in achieving a consistent taxonomy of species within an ocean basin, let alone across oceans and this is a significant obstacle to determining the geographic distributions of species that may be impacted by mining.

The fact that diverse life on the deep ocean floor covers such large areas has led some researchers to suggest that deep-sea assemblages play significant roles in the ocean processes. For example, the great abundance of foraminiferans just by their combined biomass may be important in global carbon cycling, and thus the climate system¹⁵⁰. Likewise the huge abundance of bacterial

¹³⁹ International Seabed Authority, 2010

¹⁴⁰ Smith and Demopoulos 2003; Smith et al. 2008a

¹⁴¹ Wedding et al. 2013

¹⁴² International Seabed Authority, 2008a,b; 2009

¹⁴³ Snelgrove and Smith 2002

¹⁴⁴ Nozawa et al 2006; Smith et al 2008b, and Miltjutina et al 2010

¹⁴⁵ Glover et al 2002; Brandt et al 2005; and Ebbe et al 2010

¹⁴⁶ Billett, 1991

¹⁴⁷ Gooday, 1991

¹⁴⁸ International Seabed Authority, 2008

¹⁴⁹ Rodrigues et al. 2001

¹⁵⁰ Lamshead et al 2002; Miltjutina et al 2010

microfauna is likely to exert significant control on ecosystem dynamics of the seafloor, such as the remineralisation of organic matter¹⁵¹.

Environmental impacts

Mining polymetallic nodules is expected to occur over very large areas of the abyssal sea floor because the ores are present in a very thin layer about 30 cm thick on the seabed. This is in contrast to SMS deposits that are three-dimensional ore bodies extending some metres or tens of metres into the seabed. The CCZ covers approximately 4.5 million km² with an estimated 300 billion tonnes of nodules. A single polymetallic nodule mine site may disturb about 300 km² of seabed area each year and there may be multiple operators mining at the same time at different sites. The mining process is likely to rake the nodules from the sediment surface. It is expected that many organisms living on the sea floor within the top 50cm of the sediment will be destroyed. However, portions of the microbial fauna and meiofauna (e.g. nematode worms, foraminiferans) may survive.

The systems used will also compact the sediment surface. Jets of water may be used to wash the nodules creating a plume of very fine sediment which will cover surrounding areas of the abyssal plain. This turbid plume may adversely impact the surrounding fauna, including on surrounding seamounts and abyssal hills deep-sea fauna are likely to be poorly adapted to cope with disturbance, as the deep sea is one of the most stable environments on the planet. It may also have a significant effect on gelatinous zooplankton and micronekton in the benthic boundary layer and perhaps even higher up in the water column depending on the buoyancy character of the water used and produced.

Mining the nodules will also permanently remove them as a habitat for attached species, such as sponges, sea anemones, komokiaceans and xenophyophores, as they will not regenerate (nodules take millions of years to form). It is expected that there may be many other species using nodules as a preferred habitat.

A numerical simulation study using a 3-dimensional time-resolved particle tracing tool estimated that the finer fractions of re-suspended material from mining activity could remain in the water column for 3-14 years depending on factors such as inter-annual variation in environmental conditions¹⁵². Two key aspects of this will be the increase in physical presences of fine particles in the water as well as the gradual redistribution of finer particles from the mining area to surrounding areas. These processes will result in altered sediment fabric and habitat structure that would vary depending on the intensity, method, and duration of mining. The use of particle tracking models is likely to play an important role in estimating the possible trajectories and lifetimes of particle suspension across various size classes including the importance of time of year or climatic condition (e.g. El Niño vs. La Niña).

The discharge from nodule mining is unlikely to have any toxic effects as the mined material is generally inert. If the discharge plume is released at the sea surface, ecosystem effects can be expected by introducing cold, nutrient rich and particle-laden water into tropical surface waters. Strict control of water brought to the surface will have to be maintained and the integrity of riser pipes and discharge pipes will require continuous monitoring. In nodule areas the depth of the ocean will be great (4000 to 6000m) increasing options for where a discharge plume might be released. Oxygen Minimum Zones (OMZ) between c. 100 and 1000m are often associated with polymetallic nodule areas, such as the Clarion-Clipperton Zone. While these areas are generally

¹⁵¹ Smith and Demopoulos 2003

¹⁵² Rolinski et al. 2001

lower in biomass than in more productive parts of the ocean, they may contain many species with very poorly known levels of endemism. Metals in a discharge plume in OMZs may go through phase changes. Deeper discharge in the mesopelagic zone (at depths down to c. 1500m) may affect some species that undertake diurnal vertical migrations into surface waters. Pelagic biomass typically decreases with increasing depth before increasing in the benthic boundary layer. Options for discharge in the bathypelagic and abyssopelagic zones may need to be considered, although these zones also have characteristic fauna. However, the pelagic species are likely to have wider geographic distributions, at least on the regional scale. There may be a requirement for efficient heat exchangers within the discharge pipeline in order to cool the discharge water to the exceptionally low ambient temperatures (1 to 2 °C) found in the deep sea. Deep-sea organisms are sensitive to small changes in temperature.

Abyssal plain communities like those found in the CCZ have been shown to respond to increases in available food supplies within days to weeks in a range of data spanning increases in sediment community oxygen consumption to changes in macro and megafauna densities¹⁵³. Such changes in food supply have also been linked to changes in the size distribution of fauna, or in the energy consumption distribution among animals in various size classes illustrating so called compensatory dynamics¹⁵⁴. However, these changes did not take into account the kind of changes in sediment structure and grain size that would result from mining activity. Indeed some fauna may be adversely affected in relation to such structural habitat changes. Studies of recovery from experimental mining over periods of up to 7 years suggest that larger fauna such as crustaceans may recover more quickly in areas of simulated or test mining than nematodes.¹⁵⁵ However, it should be noted that the larger fauna are exceptionally difficult to study at abyssal depths owing to their low abundance. A much longer-term study covering 26 years revealed that nematode communities still have reduced density and diversity and differing composition inside experimental mining areas when compared to areas nearby¹⁵⁶.

6.5 Polymetallic crusts

Description

Similarly to polymetallic nodules, cobalt-rich ferromanganese crusts are formed by the precipitation of manganese and iron from cold seawater. Both nodules and crusts form very slowly growing only a few millimetres every one million years. However, unlike polymetallic nodules, which occur on sediments at depths > 4000m, crusts coat the rocky slopes and summits of seamounts (undersea mountains) at depths as shallow as 600m.

Valuable crusts occur on the flat tops of guyots in the western Pacific. There are about 1,200 seamounts and guyots which may be of commercial interest in the western Pacific Ocean¹⁵⁷. Crusts of commercial interest are found principally at water depths between 800 – 2500 m¹⁵⁸. The crusts can be up to 25 cm thick. The crusts have commercially important metals such as cobalt, nickel, tellurium, and rare earth elements¹⁵⁹.

Mining crusts might be inherently difficult in some cases, given that they are attached to the underlying hard substrate and occur in areas of irregular geomorphology. Mining operators will face

¹⁵³ e.g Ruhl et al. 2008

¹⁵⁴ Ruhl et al. 2014

¹⁵⁵ Bassau et al. 1995; Radziejewska, 2002

¹⁵⁶ Mijutin et al. 2011

¹⁵⁷ Clark et al. 2012

¹⁵⁸ Hein et al. 2000, 2009

¹⁵⁹ Hein, 2010

a challenge to develop technology, which can remove crusts from steep rocky surfaces with minimal waste rock and its attendant environmental effects¹⁶⁰. There may be problems in removing sediment overburden¹⁶¹, and operations near the summits of seamounts have the potential to impact deeper depths through the creation of downslope sediment plumes.

Habitat and biodiversity

Ferro-manganese crusts form on bare rock surfaces that are swept clean of sediment by strong currents. The seamounts and guyots with thick crusts are widely distributed, and as such have differing physical conditions – e.g. depth of summit, total depth range, steepness of slopes, current speed, substrate, nutrient concentration¹⁶². Very few seamounts are alike and all possess considerable heterogeneity. The physical heterogeneity leads to great biological variety¹⁶³. Surveys carried out at crust sites in the Pacific regions have identified foraminiferans, sponges, corals, squids, echinoderms (sea stars, sea cucumbers, feather stars), crabs, and sea squirts¹⁶⁴. Of these large organisms, foraminiferans have been found to be conspicuously abundant and diverse¹⁶⁵.

The isolated nature of many seamounts, although often occurring in groups or chains, led to various hypotheses that seamounts were hotspots of diversity, abundance, biomass and endemism. In many ways these views were built on what was known about island biogeography¹⁶⁶. Subsequent sampling, however, has challenged these initial thoughts, and today the 'distinctness' of assemblages on seamounts is unproven¹⁶⁷. Other sources claim that while many species are shared with other deep-sea habitats such as continental slopes and banks, seamount assemblages may have a different community structure¹⁶⁸. However, seamounts are very poorly sampled and genetic studies of connectivity show a variety of patterns depending on the taxon studied¹⁶⁹.

The lack of comprehensive data has led to generalisations about seamounts as a whole which probably apply only to a subset, depending also on the bio-geographical province in which they occur¹⁷⁰. A major step forward has been made, however, in compiling a relational database of geomorphological, physical oceanographic and biological characteristics of seamounts, with strict quality control and a measure of confidence in the data¹⁷¹. These data have highlighted that the degree of knowledge decreases very markedly with increasing depth. The level of knowledge of seamount ecosystems at depths at which cobalt crusts may be mined is extremely limited.

Cobalt crusts may also occur on large ridge like features on the seafloor, such as the Rio Grande Rise off Brazil¹⁷². As for seamounts, recent research on non-hydrothermal vent fauna on the Mid Atlantic Ridge (MAR) in the North Atlantic has shown large-scale affinity of fauna at bathyal depths (c. 200 to 3000m) on the MAR to fauna found on the European and North American continental margins at similar depths¹⁷³. It is likely therefore that benthic fauna are widely distributed within any one particular ocean basin, although there may be differences between ocean basins.

¹⁶⁰ International Seabed Authority, 2002

¹⁶¹ sediment covering the ores

¹⁶² Clark et al. 2010

¹⁶³ Pitcher et al. 2007; Consalvey et al. 2010

¹⁶⁴ Rogers, 1994; Fukushima 2007; International Seabed Authority, 2011; Schlacher et al. 2013

¹⁶⁵ Mullineaux 1987

¹⁶⁶ McClain, 2007

¹⁶⁷ McClain, 2007; Rowden et al. 2010

¹⁶⁸ Clark et al. 2012

¹⁶⁹ Shank, 2010; Baco & Cairns, 2012; Bors et al. 2012; O'Hara et al. 2014

¹⁷⁰ McClain, 2007; Clark et al. 2012

¹⁷¹ Kvile et al. 2013

¹⁷² Perez et al. 2012

¹⁷³ Priede et al. 2013

Environmental impacts

Mining crusts involves removing the relatively thin layer of ore from the underlying rocky surface. While the technology to undertake this has not been established, it is generally considered that it will involve grinding or scraping the crust off. This is a difficult process due to the lack of uniformity in the thickness of the crust and physical conditions likely at the mine sites: fast currents, steep inclines and rugged geomorphology. However, initial cobalt crust mines are likely just to mine the tops of guyots or the upper flanks of a seamount where slopes are reduced. Removing the crust will destroy all the sessile organisms. It is thought that the marine life on the rocky surfaces may recolonize, but this may occur over very long timescales¹⁷⁴.

Corals on seamounts at depths where mining may occur may be as old as 2300 years¹⁷⁵. A study of habitat recovery from bottom trawling on seamounts found that there was little recovery over periods of 5 – 10 years with statistically significant recovery found in only a few taxa¹⁷⁶. As with SMS mining, the sediment plume generated during the extraction process, may also impact surrounding and downslope fauna. Waste water extracted from the ore slurry will also be returned to the water column as described above for polymetallic sulphides. Should there be fast currents present, these are likely to quickly disperse this material but it may still impact surrounding fauna.

6.6 Findings

Deep-sea mining will directly impact habitats, resulting in the removal of fauna and seabed rock and sediments. Because this is a known outcome, environmental management plans that guide seabed mineral extraction should aim to strike a balance between economic opportunity associated with resource revenue, conservation objectives, and the environmental impacts described herein. Consideration of the lessons learned from terrestrial mining, particularly those that address conservation and minimum impact objectives, may aid in developing sound policy.

6.6.1 Overview of findings

As outlined by Clark and Smith¹⁷⁷ environmental impacts from deep-sea mining can generally be divided into four categories:

- *impact from dislodging minerals* which includes the physical removal of organisms, rock and sediment;
- *impact from a sediment plume* that generally accompanies mining activities and can potentially have a spatial extent larger than the mining footprint itself (depending on ocean currents, the amount of sediment removed and the technology used);
- *impact from the dewatering process* which delivers contaminated and potentially highly turbid seawater into the water column; and
- *impact from the operation of the mining equipment*. This includes noise and light (although very little is known about their effects on deep sea organisms the negative impacts of noise on marine mammals living closer to the surface are well documented), oil spills and leaks from hydraulic equipment, sewage and other contaminants from the ore carriers and support vessels.

Combined, these impacts can reach organisms at the mine site and beyond. Although there is some understanding about their individual effect, very little is known about the cumulative effect that these impacts have on the marine environment.

¹⁷⁴ Meaning beyond human timescale sourced from Rowden et al. 2010

¹⁷⁵ Carreiro-Silva et al. 2013

¹⁷⁶ Williams et al. 2010

¹⁷⁷ Clark and Smith (2013 a, b)

In addition to potential impacts from normal operations, natural hazards, such as extreme weather events, volcanic activity, etc. will also need to be considered in the management plans. These impacts may include those that are more generally associated with the presence of marine vessels and primarily occur at the surface. They may be the introduction of noise and air pollution generated by ships and equipment, fluid leaks and discharges from vessels and equipment, and vibrations. More specific to mining is the introduction of light into seabed environments that are normally light-deprived. Light is known to be either a source of attraction or a deterrent to some fish species, which may or may not alter their normal behaviours for feeding and reproduction, although due to deep sea setting of currently targeted DSM deposits of interest, is not likely to affect fish stocks linked to fisheries

From a non-ecosystem perspective, there are other impacts to consider. The presence of mining vessels will necessitate site closures before, during, and potentially after mining activities. Such restrictions may extend beyond the mining site to the shipping routes. This may displace or disrupt fisheries and have an effect on revenue. Anthropogenic noise, is an important factor and with the involvement of the mining vessels both on the surface and below it is expected to increase the already significant levels of noise pollution that exist in particular areas. The exact impact on the mining areas would have to be determined taking into consideration the population of marine mammals present in the Area as well as the level of noise pollution present in the mining area as a result of other industries. It is important that when it comes to biodiversity the population of animals living in shallow waters are also given as much attention as those of the deep-seas.

There are also impacts on the water column that merit consideration. Impacts on the water column are generally caused when the mined material is lifted from the sea-bed to the mining vessel at surface level, when there are routine discharges and also spills from the vessel, and during the release that takes place when the ore is dewatered¹⁷⁸. When the mined material is lifted, the amount of material that escapes back into the water column will be dependent on the lifting system itself and whether or not it is a fully- or partially-enclosed mechanism. There is also likely to be a physical impact to any fish or other organisms present in the water column at the time when equipment is in use. This may result in direct, perhaps fatal, strikes with the organisms or displace them. These impacts however are not likely to affect a full population, but rather the local population found at that mining site. A sound management plan for site selection will include criteria for looking at the nursery and spawning grounds of fish in the vicinity and for avoiding mining activities during ecologically important times. Dewatering in the water column (versus as near to the seabed as possible) may have a clouding effect, or an impact that restricts the normal amount of light penetration through the water column. This may result in localized impacts to primary productivity and potentially reduce oxygen levels – again however, these impacts while not insignificant are not thought to impair a full animal population.

An additional consideration for the impact of dewatering and the water column is that the released seawater will be different in composition from when it was collected with the ore. It is now likely to contain trace amounts of toxic metals or chemicals that will be emitted into water where those materials (which may be naturally found in vent plumes) were not previously present, and this may have an impact on biodiversity. Additionally, when dewatering is done at the surface, the released seawater may have different characteristics than the surrounding seawater into which it is discharged, such as different levels of salinity or temperature. Again, this may have impacts to localized biodiversity. In this instance, modelling may be used to estimate the impact of discharge water.

¹⁷⁸ removal of excess water that has been absorbed within the ore

6.6.2 Steps of the Mining Process that Impact the Environment

Extracting the ore involves basic processes that are common to all three mineral types. As described by Clark and Smith¹⁷⁹ they are:

Table 6.1 Basic mining processes

Process	Description
Disaggregation	Crushing and grinding techniques will generally be used for removing both SMS deposits and crusts. Polymetallic nodules will be “vacuumed” up from the sea floor.
Lifting	The ore is pumped up to the collection vessel in a seawater-slurry via a lifting system. At present it is generally considered that this will be done using a closed system – the riser and lifting system (RALS). However the continuous line bucket system (CLB) has also been proposed for nodule collection. The CLB operates like a conveyor belt transporting the nodules in buckets from the seafloor to the surface.
Dewatering	Once on-board the excess water is removed from the slurry and returned to the water column at a predetermined depth.

A cautionary approach will need to be taken when designing controls for the technology, equipment, and techniques for deep-sea mining¹⁸⁰. The technology used in these processes can significantly influence the extent of the environmental impact. Currently technology and tools are not fully adapted to deep sea conditions and require further development, however some of the technologies such as hydraulics, and cutting, crushing, and drilling are being adapted from the offshore petroleum and tunnelling industries. Pumping and riser systems as well as the vessels and watering systems specifically developed for deep sea environment are being patented¹⁸¹.

6.7 Environmental Impacts Unique to Mineral Type

The impacts that are unique to sea-floor massive sulphides, manganese nodules, or ferromanganese crusts are considered here. Risks and impacts to biodiversity and physical habitat will need to be evaluated according to the extent to which they will occur, both in duration and distance from the mine site. The following tables summarize the potential impacts of mining activities relevant to each deposit type.

Not included in the table below are accidents or exploration activities. Accidents could include the deposition of mining equipment onto the seafloor, the breakage of riser pipes and the unexpected release of produced water or toxins. Some accidents might also result from geologic instability and collapses of sloped seafloor during or after mining. While some of these may not be of trivial scale, others might be more localised than accidents that result in long-term uncontrolled release of toxins (e.g. oil leaks/spills or well blowouts). Exploration activities will likely be similar to mining activities, but at a much reduced scale, excepting the possible addition of extra acoustic noise from seismic surveys done for resource assessment. Frameworks for such noise impact assessment could be adopted from the oil and gas industry.

¹⁷⁹ Clark and Smith (2013 a, b)

¹⁸⁰ Hoagland et al., 2010

¹⁸¹ www.google.com/patents/CA2735901C?cl=en.

Table 6.2 Nodule mining impacts: Area licensed to each operator - 75,000 sq. km

Impact	Length of impact	Potential impacted area	Nature of impact	Potential for recovery	Relevance for GES descriptor
Removal of nodules, complete disturbance of seabed and its compaction	Long term. Probably tens to hundreds of years for a non-compacted surface layer to reform; millions of years for nodules to reform	Between 120 (Petersen) and 600 (Sharma) km ² per year per operator. ISA consider 3-10 operators at any one time. Therefore 360-6000 km ² per year	Destruction of habitat and associated organisms	Likely to be extremely slow. For the substrate - may take tens to hundreds of years or even longer in heavily mined areas. For the nodule faunas will take millions of years.	1. Biodiversity is maintained 6. Sea floor integrity ensures the structure and functions of ecosystems are safeguarded
Sediment laden plumes near seabed containing particle load	During mining activity	Spread will depend on mining process and local currents. Could be tens of kilometres beyond licensed area boundaries	Smothering of seabed animals. Will affect suspension feeders on other nodules in the licensed area and on any seamounts in the vicinity of mining operations	Likely to be slow especially in areas heavily impacted by plume fallout. Elsewhere may take tens of years	1. Biodiversity is maintained 4. Elements of food webs ensure long-term abundance and reproductive capacity 5. Eutrophication is minimised 6. Sea floor integrity ensures the structure and functions of ecosystems are safeguarded 7. Permanent alteration of hydrographical conditions does not adversely affect the ecosystem 8. Concentrations of contaminants have no pollution effects 9. Contaminants in seafood do not exceed agreed standards
Sediment laden plumes in water column	During mining activity	Spread will depend on local currents, grain size of material and volume of material released plus length of time of release. The depth at which the plume is released may also determine its spread. Potential areas affected could be very large – thousands of square kilometres	If plumes are released in the photic zone (c200 metres) they will cause a reduction in light penetration and in temperature. These are likely to reduce plankton growth with knock-on impacts to whole food chain. Sediment load likely to affect feeding of gelatinous zooplankton. High nutrient load from deep waters introduced into oligotrophic waters	Recovery will be rapid once activity ceases	1. Biodiversity is maintained 4. Elements of food webs ensure long-term abundance and reproductive capacity 6. Sea floor integrity ensures the structure and functions of ecosystems are safeguarded 7. Permanent alteration of hydrographical conditions does not adversely affect the ecosystem

Impact	Length of impact	Potential impacted area	Nature of impact	Potential for recovery	Relevance for GES descriptor
			may stimulate primary production and of different species than those normally occurring in the area.		8. Concentrations of contaminants have no pollution effects 9. Contaminants in seafood do not exceed agreed standards
Size and ecosystem function fractionated impact on life	Shifts in sediment grain size distribution	Depending on position relative to mining and/or sediment plume impacts, sediments may change in their grain size towards sandier or finer composition.	This changes the habitat in terms of the sizes of life that will either be benefited or be impacted negatively	These effects may be long lasting as background sedimentation rates are low.	1. Biodiversity is maintained 4. Elements of food webs ensure long-term abundance and reproductive capacity
Noise	During mining activity	The sound characteristics of deep sea mining have yet to be established. It is likely to be similar to shallow water dredging in terms of frequencies emitted (generally low frequency, but with some high frequency components). The amplitude is unknown. The area impacted is generally a product of frequency and amplitude, so cannot be determined at present.	Probable masking effects on marine mammals that use the main frequencies emitted.	Impacts on species are not known. While short term masking can occur for individuals within the area affected, the long-term consequences and effects at the population level from masking are unknown.	11. Introduction of energy (including underwater noise) does not adversely affect the ecosystem
Potential loss of ship or pollution from ships	During mining activity		Pollution of surface waters		8. Concentrations of contaminants have no pollution effects 10. Marine litter does not cause harm to the marine and coastal environment
Tailing disposal on land/sea	Long term	Potentially hundreds of km ²			1. Biodiversity is maintained 4 Elements of food webs ensure long-term abundance and reproductive capacity 5. Eutrophication is minimised 6. Sea floor integrity ensures the

Impact	Length of impact	Potential impacted area	Nature of impact	Potential for recovery	Relevance for GES descriptor
					<p>structure and functions of ecosystems are safeguarded</p> <p>7. Permanent alteration of hydrographical conditions does not adversely affect the ecosystem</p> <p>8. Concentrations of contaminants have no pollution effects;</p>

Table 6.3 Impacts of SMS mining - Are of each mine site – 0.1km² for Solwara 1 but could be larger

Impact	Length of impact	Potential impacted area	Nature of impact	Potential for recovery	Relevance for GES descriptor
Mining of seabed, with removal of habitat	On active vent sites may be some years beyond the mining phase. On off-axis vent sites may be hundreds of years to due deposition of toxic chemicals	Area of mining maybe c300 m diameter (based on proposed Solwara 1 mine, Papua New Guinea). However several adjacent locations may be mined sequentially giving rise to a mined area of some km ²	Destruction of habitat and associated organisms by initial mining and pollution of the environment by chemical toxins. This will have a greater impact in off-axis sites	On active vent sites maybe relatively short term (months to years). On off-axis vent sites likely to be of longer term - probably tens to hundreds of years	<p>1. Biodiversity is maintained</p> <p>6. Sea floor integrity ensures the structure and functions of ecosystems are safeguarded</p>
Sediment laden plumes near seabed containing particle load and potentially chemical toxins	During mining activity and for many years beyond due to the chemical toxins	Spread will depend on mining process and local currents. Could be kilometres beyond mined area boundaries. Plumes will flow downslope	Smothering of seabed animals by the particulates especially proximal to the mined area and downslope. Potential poisoning of animals in all areas affected by the plume due to the chemical toxins	Recovery from the particulates will probably take a few years. In the off-axis vents recovery from chemical pollution may take tens to hundreds of years	<p>1. Biodiversity is maintained</p> <p>4. Elements of food webs ensure long-term abundance and reproductive capacity</p> <p>5. Eutrophication is minimised</p> <p>6. Sea floor integrity ensures the structure and functions of ecosystems are safeguarded</p> <p>7. Permanent alteration of hydrographical conditions does not adversely affect the ecosystem</p> <p>8. Concentrations of contaminants have no pollution effects</p>

Impact	Length of impact	Potential impacted area	Nature of impact	Potential for recovery	Relevance for GES descriptor
					9. Contaminants in seafood do not exceed agreed standards
Sediment laden plumes in water column containing particle load and chemical toxins	During mining activity	Spread will depend on local currents, grain size of material and volume of material released plus length of time of release. Potential areas affected could be very large – thousands of square kilometres.	If plumes are released in the photic zone (c200 metres) they will cause a reduction in light penetration and in temperature. These are likely to reduce plankton growth with knock-on impacts to whole food chain. Sediment load likely to affect feeding of gelatinous zooplankton. High nutrient load from deep waters introduced into oligotrophic waters may stimulate primary production and of different species than those normally occurring in the area. Toxins in the plumes could cause loss of organisms at all levels in the food chain and could impact commercial fish stocks	Recovery will be rapid once activity ceases	1. Biodiversity is maintained 4. Elements of food webs ensure long-term abundance and reproductive capacity 6. Sea floor integrity ensures the structure and functions of ecosystems are safeguarded 7. Permanent alteration of hydrographical conditions does not adversely affect the ecosystem 8. Concentrations of contaminants have no effects 9. Contaminants in seafood do not exceed agreed standards
Size and ecosystem function fractionated impact on life	Shifts in sediment grain size distribution. May also include changes in fine scale (biologically relevant) bathymetry	Depending on position relative to mining and/or sediment plume impacts, sediments may change in their grain size towards sandier or finer composition. Shifts at SMS sites likely larger than nodule mining sites	This changes the habitat in terms of the sizes of life that will either be benefited or be impacted negatively	These effects may be long lasting as background sedimentation rates are low.	1. Biodiversity is maintained 4. Elements of food webs ensure long-term abundance and reproductive capacity
Potential loss of ship or pollution from ships	During mining activity		Pollution of surface waters		8. Concentrations of contaminants have no pollution effects 10. Marine litter does not cause harm to the marine and coastal environment

Impact	Length of impact	Potential impacted area	Nature of impact	Potential for recovery	Relevance for GES descriptor
Noise	During mining activity	The sound characteristics of deep sea mining have yet to be established. It is likely to be similar to shallow water dredging in terms of frequencies emitted (generally low frequency, but with some high frequency components). The amplitude is unknown. The area impacted is generally a product of frequency and amplitude, so cannot be determined at present.	Probable masking effects on marine mammals that use the main frequencies emitted.	Impacts on species are not known. While short term masking can occur for individuals within the area affected, the long-term consequences and effects at the population level from masking are unknown.	11. Introduction of energy (including underwater noise) does not adversely affect the ecosystem
Tailing disposal on land/sea	Long term				<ul style="list-style-type: none"> 1. Biodiversity is maintained 4. Elements of food webs ensure long-term abundance and reproductive capacity 5. Eutrophication is minimised; 6. Sea floor integrity ensures the functioning of the ecosystem; 7. Permanent alteration of hydrographical conditions does not adversely affect the ecosystem; 8. Concentrations of contaminants have no effects

Table 6.4 Impacts of cobalt-crust mining

Impact	Length of impact	Potential impacted area	Nature of impact	Potential for recovery	Relevance for GES descriptor
Removal of crusts	Long term. Probably hundreds to thousands of		Destruction of habitat of attached epifauna	Likely to be very slow (tens to hundreds of years).	<ul style="list-style-type: none"> 1. Biodiversity is maintained 6. Sea floor integrity ensures the

Impact	Length of impact	Potential impacted area	Nature of impact	Potential for recovery	Relevance for GES descriptor
	years				functioning of the ecosystem
Sediment laden plumes near seabed containing particle load	During mining activity	Spread will depend on mining process and local currents. Could be tens of kilometres beyond licensed area boundaries. Plumes are likely to flow down the seamount flanks	Smothering of seabed animals	Likely to be very slow (tens to hundreds of years) if epifaunal organisms are impacted on bare rock surfaces	<ul style="list-style-type: none"> 1. Biodiversity is maintained 4. Elements of food webs ensure long-term abundance and reproductive capacity 5. Eutrophication is minimised 6. Sea floor integrity ensures the structure and functions of ecosystems are safeguarded 7. Permanent alteration of hydrographical conditions does not adversely affect the ecosystem 8. Concentrations of contaminants have no pollution effects 9. Contaminants in seafood do not exceed agreed standards
Sediment laden plumes in water column	During mining activity	Spread will depend on local currents, grain size of material and volume of material released plus length of time of release. Potential areas affected could be very large – thousands of square kilometres	If plumes are released in the photic zone (c200 metres) they will cause a reduction in light penetration and in temperature. These are likely to reduce plankton growth with knock-on impacts to whole food chain. Sediment load likely to affect feeding of gelatinous zooplankton. High nutrient load from deep waters introduced into oligotrophic waters may stimulate primary production and of different species than those normally occurring in the area.	Recovery will be rapid once activity ceases	<ul style="list-style-type: none"> 1. Biodiversity is maintained 4. Elements of food webs ensure long-term abundance and reproductive capacity 6. Sea floor integrity ensures the structure and functions of ecosystems are safeguarded 7. Permanent alteration of hydrographical conditions does not adversely affect the ecosystem 8. Concentrations of contaminants have no pollution effects 9. Contaminants in seafood do not exceed agreed standards
Size and ecosystem function fractionated	Shifts in sediment grain size distribution.	Depending on position relative to mining and/or sediment plume	This changes the habitat in terms of the sizes of life that will either be	These effects may be long lasting as background sedimentation rates	<ul style="list-style-type: none"> 1. Biodiversity is maintained 4. Elements of food webs ensure

Impact	Length of impact	Potential impacted area	Nature of impact	Potential for recovery	Relevance for GES descriptor
impact on life	May also include changes in fine scale (biologically relevant) bathymetry	impacts, sediments may change in their grain size towards sandier or finer composition. Shifts at crust sites likely larger than nodule mining sites	benefited or be impacted negatively	are low.	long-term abundance and reproductive capacity
Potential loss of ship or pollution from ships	During mining activity		Pollution of surface waters		8. Concentrations of contaminants have no pollution effects 10. Marine litter does not cause harm to the marine and coastal environment
Noise	During mining activity	The sound characteristics of deep sea mining have yet to be established. It is likely to be similar to shallow water dredging in terms of frequencies emitted (generally low frequency, but with some high frequency components). The amplitude is unknown. The Area impacted is generally a product of frequency and amplitude, so cannot be determined at present.	Probable masking effects on marine mammals that use the main frequencies emitted.	Impacts on species are not known. While short term masking can occur for individuals within the area affected, the long-term consequences and effects at the population level from masking are unknown.	11. Introduction of energy (including underwater noise) does not adversely affect the ecosystem

Impact	Length of impact	Potential impacted area	Nature of impact	Potential for recovery	Relevance for GES descriptor
Tailing disposal on land/sea	Long term				<ul style="list-style-type: none"> 1. Biodiversity is maintained 4. Elements of food webs ensure long-term abundance and reproductive capacity 5. Eutrophication is minimised; 6. Sea floor integrity ensures the structure and functions of ecosystems are safeguarded 7. Permanent alteration of hydrographical conditions does not adversely affect the ecosystem 8. Concentrations of contaminants have no pollution effects



7 Supply and demand

7.1 Summary

This chapter gives an overview of the materials markets which deep-sea mining companies are facing. It goes on to scrutinise the potential of supply from deep-sea mining, covering costs, economic viability, and potential price effects due to deep-sea mining. The final part is a short comparison of seabed and terrestrial mining in terms of costs and competitiveness.

Market conditions vary significantly between minerals and metals, but some common characteristics in metals markets and terrestrial mining can be observed. The common “flaw” of the (land-based) mining industry is its boom-and-bust cycles: mining operations are inflexible in the short and medium term and therefore the market often fluctuates between states of oversupply and supply shortage, as could also be observed recently. Following a demand surge starting in the early 2000s, prices increased substantially. In search of an increasing quantity of ores, companies have turned to lower ore grades, thus increasing costs which in the current situation of a moderate demand outlook may already be too high. Another development that most materials have in common is that we observe an increase in state-owned mining (mainly driven by China) or attempts of the state to secure mining rents. Deep sea mining can be seen as part of the move towards more difficult ores.

Despite these general observations, market conditions and main players differ strongly per material or material group. Precious metals (gold, silver) are characterised by low production concentration and existing market exchanges, which however are only marginally influenced by physical demand and supply (due to the role of these metals as investment and hedging vehicles). Therefore additional supply from deep-sea mining is not expected to have an influence on the price. The markets for base metals (copper, nickel, zinc) are functioning well, but deep-sea operations would not produce the quantities to make a difference on the market. In markets for minor metals (cobalt) deep-sea mining could make a difference because they are traded in relatively low quantities and with a low elasticity of supply; in the case of cobalt, deep-sea mining has a role to play as this material has a high supply risk and expected tonnages from deep-sea mining are comparatively high in comparison to global production.

Looking at the economic viability of deep sea mining in this context, a basic economic model was developed and tentative commercial viability calculations were made for each deposit based on assumptions on capital expenditure, operational costs and revenues. Assumptions regarding these costs have been based on a range of available sources, but should be treated with caution as no actual operations have yet taken place, and technologies have not yet been fully developed and proven. The results show that polymetallic sulphides are expected to show the highest commercial viability, whereas nodules and crust are only marginally or not commercially feasible. Key uncertainty regarding polymetallic sulphides is that it assumes an operation of 15 years to generate returns on investment, whereas most resources and proven reserves seem to point to smaller sizes and a strain of operations on different locations needs to be established.

Apart from the overall uncertainty within the assumptions, a specific uncertainty exists regarding potential revenue streams for manganese, which is abundantly present in these latter two types of deposits, but for which the commercial viability of the additional processing costs are highly uncertain. This directly points to the importance of further efficiency increases not only in mining itself but in particular in processing as this would allow additional revenue streams (also potentially

including REEs). Finally obviously, scarcity and increasing prices will have a direct impact on the commercial viability of deep sea mining operations, although this will obviously also trigger further terrestrial (including recycling) developments. Deep sea mining operations in itself are not expected to directly influence global prices of most metals, except for cobalt. This will limit the number of operations that can be exploited in parallel in crust and nodules to avoid boom and bust developments.

Security of supply policies

In addition to the rising demand for metals, geo-political issues can also limit the availability of metal resources. With China claiming ownership over a large quantity of terrestrial mineral reserves for specific critical raw materials, ensuring access to ores of sufficient quality and maintaining a predictable price level with acceptable ranges of volatility becomes a challenge. Exploration into new resources takes time and the bargaining power is on the side of the – relatively few - suppliers who are confronted with a large demand.

This may be further influenced by the phenomenon where metals are pledged in as collateral to obtain financing from banks. Anecdotal evidence suggests that in China copper and aluminium were used to raise capital (Yuan) on a secured basis¹⁸². If the same stock of metal is used as collateral for different loans, banks could ask to freeze this inventory and even seize the collateral which in return (depending on the quantity) which can have a direct impact on global prices¹⁸³. A further consequence could be increasing control of specific countries over commodity prices¹⁸⁴. These aspects carry the risk of monopolistic behaviour (prices) but also may pose a supply risk (strategic behaviour and impact on critical industries and sectors in Europe's economies). Bringing in a new source for metal supply, particularly if located in international waters, may alleviate the price competition and provide more security for Europe.

7.2 Most relevant metals in deep-sea mining deposits

While numerous metals and minerals can be found in deep-sea deposits¹⁸⁵ not all are relevant for deep-sea mining operations, due to the economic viability to extract them (which in turn often depends on the price, grades and alternative supply sources) and their importance with regard to security of supply of raw materials. The three types of mineral deposits that are being analysed in this report contain a range of different metals that drive deep-sea mining interest. The following metals are commonly considered to be relevant for deep-sea mining:

¹⁸² The Wall Street Journal (2014): BHP Calms China Commodity Fears, <http://online.wsj.com/articles/bhp-calms-china-commodity-fears-1404296229>.

¹⁸³ Financial Times (2014): China probe sparks metals stocks scramble, <http://www.ft.com/cms/s/0/7928cdaa-f07e-11e3-8f3d-00144feabdc0.html#axzz36sQePuul>.

¹⁸⁴ Ke Tang, Haoxiang Zhu (2014): Commodities as collateral, http://www.mit.edu/~zhuh/TangZhu_CommodityCollateral.pdf.

¹⁸⁵ See e.g. Hein et al. (2013): Deep-ocean mineral deposits as a source of critical metals for high- and green-technology applications: Comparison with land-based resources (Vol. 51). Santa Cruz: Ore Geology Reviews, Elsevier.

In table 3 an extensive overview is given of the chemical composition of crusts and nodules in selected areas.

Table 7.1 Most relevant metals for deep-sea mining

Deposit	Most relevant metals	Price/ton 2013 ¹⁸⁶	Commercial interest	Criticality ¹⁸⁷		
				Economic importance for EU industry	Supply risk	Critical raw material
SMS	Copper	4,686	Medium/high	Medium	Low	no
	Zinc	1,138	High	High	Low	no
	Gold	26,776,178	High (depending on grade)	Low	Low	no
	Silver	401,643	Medium	Medium	Low	no
Polymetallic nodules	Manganese	1,540	Medium (abundant alternative supply; market uncertainty)	High	Low	no
	Cobalt	16,735	High	Medium	High	yes
	Copper	4,686	Medium/high	Medium	Low	no
	Nickel	10,041	High	n.a.	n.a.	no
	Trace metals (REE, Molybdenum, Lithium)	8,702 ¹⁸⁸	Medium (traces)	High	High	yes
Cobalt rich crusts	Manganese	1,540	Medium (abundant alternative supply; market uncertainty)	High	Low	no
	Cobalt	16,735	High	Medium	High	yes
	Nickel	10,041	High	n.a.	n.a.	no
	Platinum	30,123,200	Medium	Medium	Medium	yes
	Other trace metals (REE, Tellurium)	8,702 ¹⁸⁹	Medium	High	High	yes

Note: composition of deposits differs from place to place, as shown earlier, so in particular areas other metals can also become relevant if revenue merits processing costs.

7.3 Key commodity trends and market structure

There are a number of economic issues that have an influence on the functioning of deep-sea mining, these include market structure, trends and developments in metal mining and commodity markets are detailed in the subsequent chapters.

¹⁸⁶ 2013 prices/ton. Source: www.infomine.com.

¹⁸⁷ Based on European Commission (2014): Report on critical raw materials for the EU – Report of the Ad Hoc Working Group on defining raw materials)

¹⁸⁸ Market price of Cerium.

¹⁸⁹ Market price of Cerium.

7.3.1 Market structure

The value chain of mining operations includes exploration and resource assessment, mining and extraction as well as processing (smelters) and distribution. A large variety of stakeholders are involved in the value chain such as smelters/refineries, although in the case of global/major mining companies these might be vertically integrated. In fact vertical integration in the mining sector has been a much debated topic in recent years.¹⁹⁰ Nonetheless vertical integration is still often perceived as complex and risky and has mainly happened in an upstream direction (such as zinc smelters acquiring zinc mines). The underlying rationale for this is the issue of security of supply in a market with a prospect of long-term increasing demand and decreasing mine grades. In addition exploration is perceived to be moving slowly the bargaining power is on the side of the - relatively few - suppliers who are confronted with a large demand. Prices for the ores are often determined at a fixed date in the future, shifting the risk of the possible price changes to the mining company.

Within the mining sector “major mining companies” represent about 83% of the total value of all non-fuel minerals production, whilst the remaining 17% is accounted for by about 1000 medium sized and small companies¹⁹¹, that often specialise in exploration. “If juniors find a deposit, it is usually sold to a major mining company, capable of raising the necessary capital, experience and competence to invest in actual production.”¹⁹² Nevertheless, junior exploration companies require capital for their activities as well, meaning that exploration is highly dependent on shareholder / venture capital participation and thus on the general financial markets environment.

Table 7.2 Overview of the formal mining industry

Company category	Approximate asset base	Approximate number of companies	Comment
Global	Exceeds US\$10 billion	50	Global and senior companies which have access to the largest portion of available capital
Seniors	US\$3 – US\$10 billion	100	
Intermediates	US\$1 – US\$3 billion	350	Companies often on a growth path to become seniors
Juniors (producers)	US\$500 million – US\$1 billion	1,500	Companies which often have one mine
Juniors (explorators)	US\$5 – US\$50 million	2,500	Volatile and share market dependent; they are finders, not producers and their focus is on their exploration activities
Junior juniors	Below US\$5 million	1,500	Focus is on accessing venture capital and enhancing their stock price

Source: ICMM (2012).

In deep-sea mining, most activities so far are focused on exploration and are conducted by small and medium sized companies referred to as juniors, or by firms specialized in exploration

¹⁹⁰ See for the upstream integration: PwC (2011): Mine 2011: The game has changed. Review of global trends in the mining industry, http://www.pwc.com/en_GX/gx/mining/pdf/mine-2011-game-has-changed.pdf.

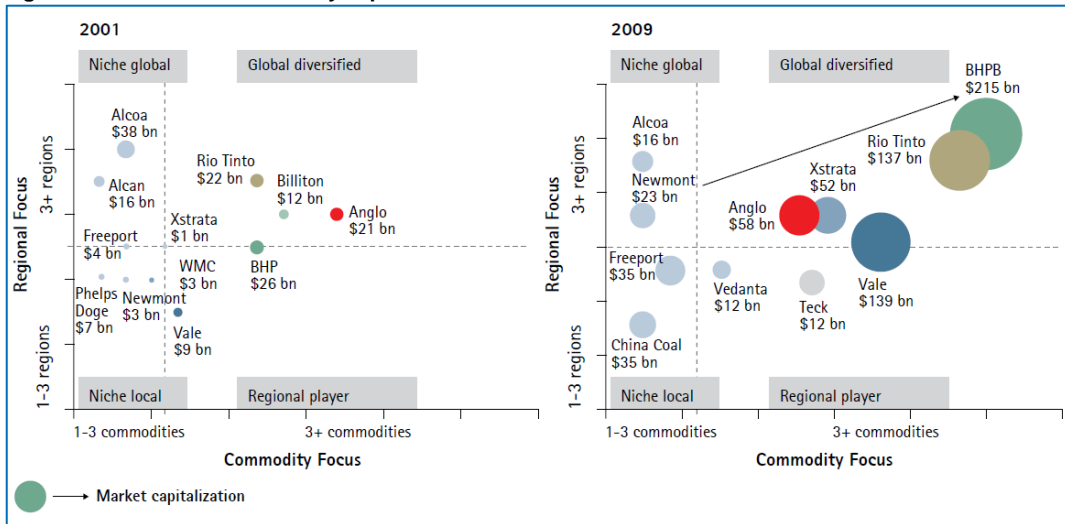
¹⁹¹ European Commission (2008), Commission Staff Working Document accompanying the Communication from the Commission to the European Parliament and the Council: The Raw Materials Initiative – Meeting our Critical Needs for Growth and Jobs in Europe.

¹⁹² European Commission (2008), Commission Staff Working Document accompanying the Communication from the Commission to the European Parliament and the Council: The Raw Materials Initiative – Meeting our Critical Needs for Growth and Jobs in Europe.

technologies only (such as Lockheed Martin).¹⁹³ It can be expected that, similarly to other emerging industries, deep-sea mining will see global players joining the race to the sea bottom as soon as the economic viability has been proven.

The mining industry has witnessed a phase of mergers as well as new entrants. While some national or commodity-specific companies emerged, the dominant business model turned out to be that of a globally active, diversified, large player. **Figure 7.1** shows the impressive overall growth (measured in market capitalisation) in the industry over the first decade of the 2000s, with global giants showing the most pronounced increases.

Figure 7.1 Global and commodity expansion between 2001 and 2009



Source: Accenture (2011): Global Operating Models for Mining Companies. Adding value beyond the individual assets. Mining Executive Series, http://www.accenture.com/SiteCollectionDocuments/PDF/Accenture_Mining_Global_Operating_Models_POV_FINAL.pdf.

Figures from recent years in general confirm this trend as the largest growth in 2012 was observed at BHP Billiton, Rio Tinto, Xstrata, Grupo Mexico, and Inner Mongolia Baotou Steel Rare Earth High Tech: “three diversified, one copper, and one rare earth producer”¹⁹⁴. 2012 also was a year in which profits started to drop significantly and the decreasing productivity, volatile commodity prices, and increased state involvement have affected the performance and outlook of industry negatively. In addition, the sluggish Chinese economic growth has led many to reconsider their demand expectations¹⁹⁵.

Market concentration differs strongly per metal/commodity, as can be measured by the Herfindahl-Hirschman Index of concentration (HHI) for mine production of several materials, and in addition processing for some of them.¹⁹⁶. In terms of individual commodities, it becomes apparent that concentration is relatively low for the materials with high revenues, such as zinc, copper, or gold. Examples for highly concentrated markets are Nb / niobium (Moreira Salles Group, Brazil: 76.1%)

¹⁹³ http://panq.org/fi/wp-content/uploads/2013/03/Note-regarding-DSM-and-Fiji_cm_hl.pdf, <http://www.lockheedmartin.com/us/what-we-do/space/earth-observation-exploration.html>

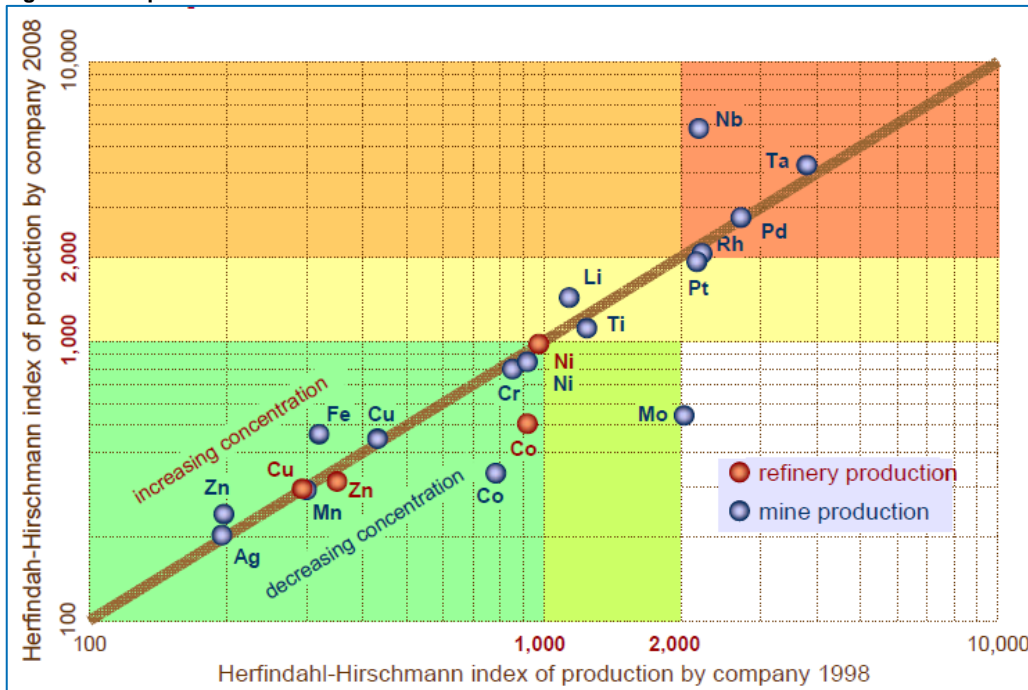
¹⁹⁴ PwC (2013): Mine. A confidence crisis. Review of global trends in the mining industry – 2013, http://www.pwc.com/en_GX/gx/mining/publications/assets/pwc-mine-a-confidence-crisis.pdf.

¹⁹⁵ See for example: Martin, B. (2013): Analysts call end to mining boom. The Telegraph, April 26, 2013, <http://www.telegraph.co.uk/finance/markets/10021885/Analysts-call-end-to-mining-boom.html>.

¹⁹⁶ The HHI is calculated as the sum of squared market shares of all market competitors, with values ranging from 0 to 10,000 (0<HHI≤10,000).

and Pd / palladium (Norilsk Nickel, Russia: 50.5%; Anglo American plc, UK: 18.0%; Impala Platinum Holdings Ltd, South Africa: 11.0%).¹⁹⁷

Figure 7.2 Corporate concentration 1998/2008



Source: European Commission (2010): Critical raw materials for the EU, p. 25; using data from Raw Materials Group and Bundesanstalt für Geowissenschaften und Rohstoffe.

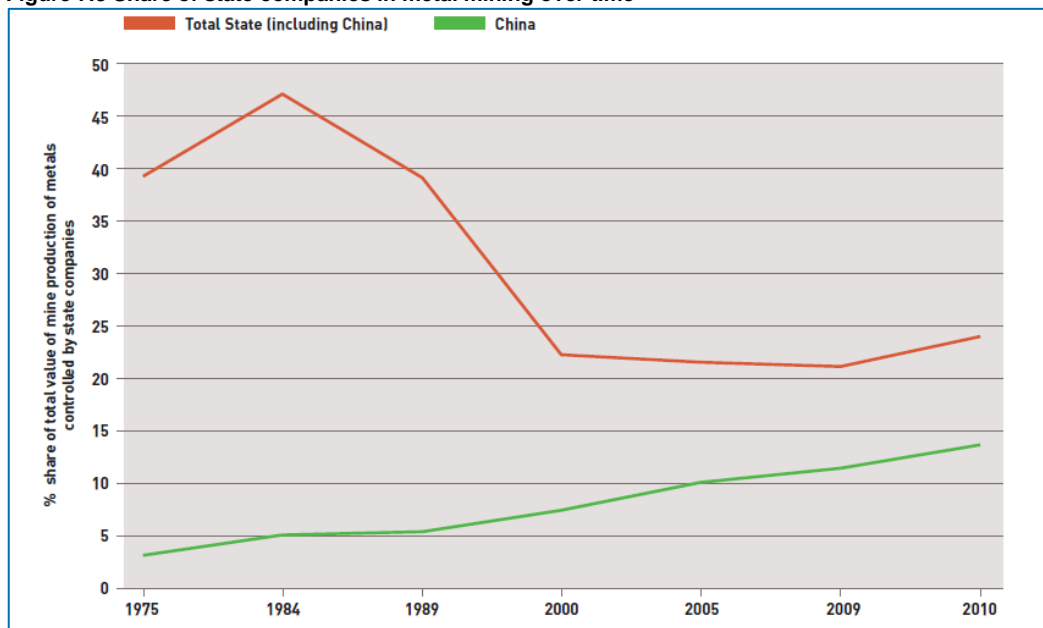
State control and “resource nationalism” in terrestrial mining

The formal (terrestrial) mining sector also includes state-owned companies. Among the top 40 mining companies in 2012 measured by market capitalisation, there are a number of Chinese state-owned ones: apart from some large coal mining companies, these include Inner Mongolia Baotou Steel Rare-Earth Hi-Tech Co., Jianxi Copper Company Limited, or Zijin Mining Group Company Ltd. (China’s largest gold producer).¹⁹⁸ The rise in importance of Chinese mining is then also reflected in the development of the share of state companies in metal mining (see figure below).

¹⁹⁷ Values for 2009. Taken from: Ericsson, M. (2012): Mining industry corporate actors analysis. POLINARES Working Paper no. 16, http://www.polinares.eu/docs/d2-1/polinares_wp2_chapter4.pdf.

¹⁹⁸ See PwC (2013): Mine. A confidence crisis. Review of global trends in the mining industry – 2013, http://www.pwc.com/en_GX/gx/mining/publications/assets/pwc-mine-a-confidence-crisis.pdf.

Figure 7.3 Share of state companies in metal mining over time



Source: ICMM (2012).

A study by the World Bank (2011)¹⁹⁹ highlights that state control in mining has increased mainly due to the growth of Chinese (state-controlled) operations. Additionally in other emerging economies there is a growing interest in state-controlled mining, especially in Latin America (Venezuela, Ecuador, Bolivia) as well as industrialised countries such as Finland while in Poland, the state continues to be the largest shareholder of the biggest copper mining company. In many African countries, state control is described to be characterised by large uncertainty over the state's aims and actions²⁰⁰ State control is higher in refining than in mining, which is attributed to the higher value added in this sector.²⁰¹

Chinese mining industry – state control and international influence

According to a 2011 study by the World Bank²⁰², state control worldwide has increased mainly due to the growth of Chinese (state-controlled) operations, as suggested by the chart above (note that state control can refer to the central government or regional / local authorities). However:

- Chinese mining is increasingly privatised or characterised by small-scale private mining (there are several thousands of mining enterprises for tin, lead, or zinc, for example);
- Chinese mining has a large influence on total mining figures measured by value, which are dominated by iron ore. However, it also has an important role in strategic minerals with lower trade value, but high significance (such as rare earths), which are sometimes “almost exclusively produced in China by state-controlled Chinese companies”²⁰³;
- Chinese foreign investments have been the subject of much discussion. So far, the activities are quite focused on iron ore, with some investment in copper and other minerals. In geographical terms, Australia and Asian neighbouring countries are the main investment targets. Most of the

¹⁹⁹ World Bank (2011): Overview of State Ownership in the Global Minerals Industry – Long Term Trends and Future. Extractive Industries for Development Series no. 20, <http://siteresources.worldbank.org/INTOGMC/Resources/GlobalMiningIndustry-Overview.pdf>.

²⁰⁰ In this case however, where large shares of mining are small-scale activities involving illegal trading, more “control” of the state would rather be beneficial for market functioning (see section on ASM).

²⁰¹ As noted above, this shows that the primary interest of states is to secure rents rather than to control the primary supply, except in cases where a country has a monopoly.

²⁰² World Bank (2011): Overview of State Ownership in the Global Minerals Industry – Long Term Trends and Future. Extractive Industries for Development Series no. 20, <http://siteresources.worldbank.org/INTOGMC/Resources/GlobalMiningIndustry-Overview.pdf>.

²⁰³ World Bank (2011), p. 5.

foreign investments go into minority stakes and concentrate on known deposits, without investing in exploration activities.²⁰⁴

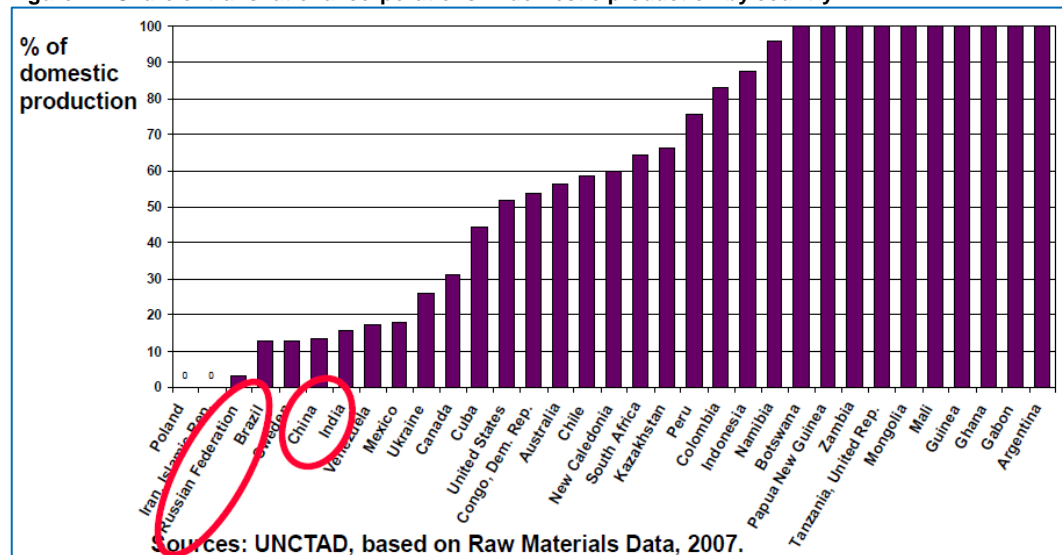
Direct control of operations is only one option for states to gain influence in mining – another is to secure rents of mining activities for or within the state, without exerting direct control. A report by PwC (2013)²⁰⁵ highlights “resource nationalism” as one of the industry’s most important risks in 2012, manifesting itself in:

- Increasing resource taxes (such as in Australia, Canada, India, Brazil, the USA, Ghana, Zambia);
- The attempt to control and profit from activities downstream the value chain by direct laws or by export restrictions of unrefined products (such as in India, Indonesia, Brazil, South Africa, the DRC);
- Implementing local ownership requirements, requiring a certain percentage of the mine being locally owned (such as in Indonesia, Russia, Mongolia, Zimbabwe).

Nevertheless, it should be noted that many of these “resource nationalism” attempts, while being a risk for mining companies, do not necessarily mean a global supply risk of the mineral in question. The increasing interest in refining is more of an indication of the interest that countries have in securing rents, rather than being related to controlling upstream supply of the resource itself.

The share of transnational corporations in domestic production differs by country. Note that the remaining share could be either state-controlled or privately owned – in both cases the rents are likely to stay within the country. Alternatively it could be produced by artisanal or small-scale miners, in which case the national revenues from these activities depend on the functioning of the state. In the case of the DRC for example, a significant share of the small-scale mined (conflict) minerals are smuggled out of the country (see also following chapter).²⁰⁶ In the main EU mining countries, such as Poland and Sweden, national or state-owned mining clearly dominates.

Figure 7.4 Share of transnational corporations in domestic production by country



Source: Ericsson, M. (2012): Mining industry corporate actors analysis. POLINARES Working Paper no. 16., http://www.polinares.eu/docs/d2-1/polinares_wp2_chapter4.pdf.

²⁰⁴ On the international role of China in Mergers & Acquisitions, see also Ericsson, M. (2012): Mining industry corporate actors analysis. POLINARES Working Paper no. 16, http://www.polinares.eu/docs/d2-1/polinares_wp2_chapter4.pdf, p. 8.

²⁰⁵ PwC (2013): Mine. A confidence crisis. Review of global trends in the mining industry – 2013, http://www.pwc.com/en_GX/gx/mining/publications/assets/pwc-mine-a-confidence-crisis.pdf.

²⁰⁶ U.N. Security Council (2014): Final Report of the Group of Experts on the Democratic Republic of the Congo, U.N. doc. S/2014/2, http://www.securitycouncilreport.org/atf/cf/%7B65BFCF9B-6D27-4E9C-8CD3-CF6E4FF96FF9%7D/s_2014_42.pdf.

From the perspective of deep-sea mining, three conclusions on state control and resource nationalism are relevant:

- State control brings a level of **supply risk** for certain minerals, especially those which are currently produced by mainly one country – such as rare earths in China, or cobalt in the DRC (although in the case of the DRC, armed conflict is more of an issue than increasing or unclear state control). For such materials, deep-sea mining can be a game changer by diversifying supply;
- “Resource nationalism” may be an important issue to consider for deep-sea miners entering **contracts with states**: they need to keep in mind that the taxes and royalties to pay may increase, or that engaging in downstream activities may not always be easily possible without granting the state some control over it.

Box 7.1 State involvement in ISA licenses

Although not fully exemplary for eventual mining operations the state involvement in deep-sea mining in exploration licenses can provide a tell-tale for state interest in deep sea mining versus private interests. Of the current 19 exploration licenses granted by ISA 7 are held by the government or directly government controlled entities of India, China, Korea and Russia. Another contract with the Government of India is awaiting signature as of August 2014.

The Pacific Island States also hold exploration licences in the Area. As part of the site-banking system (annex III, article 8, of UNCLOS) they are allocated half of the total area (reserved area) licenced for nodule mining by an individual contractor. The contractors agree with the developing state of their choice prior to submitting an application for nodule exploration to cooperate on the reserved area site and potential share the revenues.

7.3.2 Commodity trends/developments

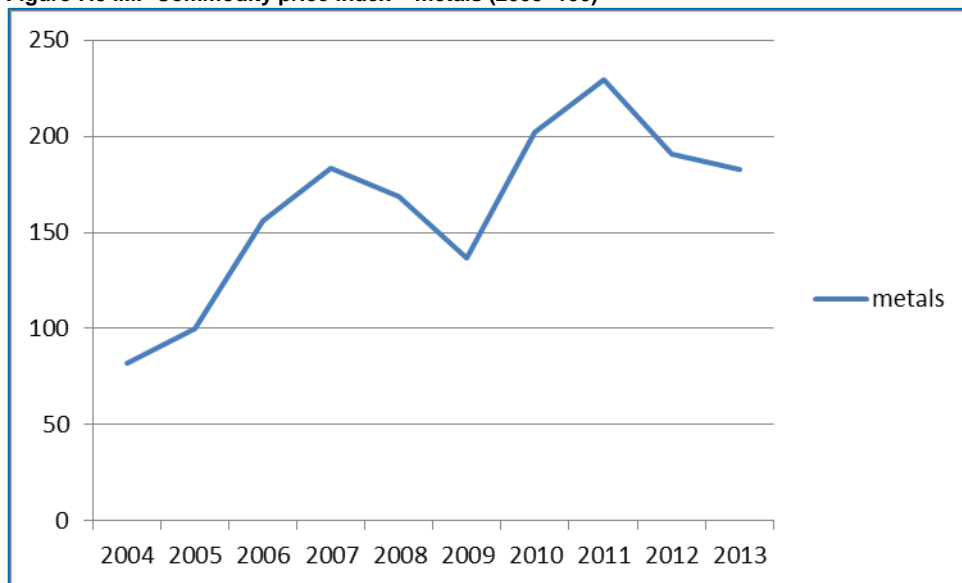
Demand trends

The current status in commodity and mining markets has been shaped by a remarkable demand surge in the early 2000s, which changed the business as a whole. Until around 2000, miners expected a long-term slow decline in demand and prices, and consequently they have concentrated on cost-cutting measures and efficiency at mine level. The years before 2000 were also characterised by a development towards privatisation and vertical disintegration.

The remarkable increase in demand for mining products since around 2004 – mainly due to growth in emerging and developing countries, notably China – has changed the picture profoundly. While profitability increased with the rising prices, it was difficult for the supply side to serve demand in volume terms, and miners increasingly turned to mines with lower ore quality which had become profitable; the main objective of mining companies shifted from performance of individual mines to global performance and expansion.

In the past decade this has led to an increase in prices for most metals, although increase rate and price volatility per metal might differ.

Figure 7.5 IMF Commodity price index – metals (2005=100)



Supply trends

Estimated resources of metal at land and in the deep sea differ per types of metal. Table 7.3 gives an overview of expected resources in polymetallic crusts (Prime Crust Zone²⁰⁷) and polymetallic nodules (CCZ) in comparison to global land reserves and resources.

Table 7.3 Metal resources and reserves at land for crusts and nodules (millions of tonnes)

Elements	Cobalt crusts in the Prime Crust Zone (PCZ)	Global reserves on land (economically minable deposits today)	Global reserves and resources on land (economically minable as well as sub-economic deposits)	Manganese nodules in the Clarion-Cliperton Zone
Manganese (Mn)	1714	630	5200	5992
Copper (Cu)	7.4	690	1000+	226
Titanium (Ti)	88	414	899	67
Rare earth oxides	16	110	150	15
Nickel (Ni)	32	80	150	274
Vanadium (V)	4.8	14	38	9.4
Molybdenum (Mo)	3.5	10	19	12
Lithium (Li)	0.02	13	14	2.8
Cobalt (Co)	50	7.5	13	44
Tungsten (W)	0.67	3.1	6.3	1.3
Niobium (Nb)	0.4	3	3	0.46
Arsenic (As)	2.9	1	1.6	1.4
Thorium (Th)	0.09	1.2	1.2	0.32
Bismuth (Bi)	0.32	0.3	0.7	0.18
Yttrium (Y)	1.7	0.5	0.5	2
Platinum group	0.004	0.07	0.08	0.003
Tellurium (Te)	0.45	0.02	0.05	0.08
Thallium (Tl)	1.2	0.0004	0.0007	4.2

Source: Maribus (2014), World Ocean Review 3- Marine resources – opportunities and risks, chapter 2

Reserves (or actual production) are sometimes also concentrated in a limited number of countries. The table below gives an overview of leading metal producers and their share in world production.

²⁰⁷ This is an area the size of Europe in the Western Pacific about 3000 kilometers southwest of Japan where crusts are particularly abundant

The geographical concentration of reserves feeds directly into the supply risk of certain minerals for Europe's economy.

Table 7.4 Leading metal producers and their percentage in world production

Elements	Largest producer	Second largest producer	Third largest producer	Application
Aluminium (Al)	Australia 31 %	China 18 %	Brazil 14 %	Vehicle bodies, consumer goods
Antimony (Sb)	China 84 %	South Africa 2.6 %	Bolivia 2.2 %	Flame retardants, electronic components, consumer goods
Arsenic (As)	China 47 %	Chile 21 %	Morocco 13 %	Semi-conductors, solar cells, optical components
Cadmium (Cd)	China 23 %	Korea 12 %	Kazakhstan 11 %	Accumulators, pigments, solar cells
Chromium (Cr)	South Africa 42 %	India 17 %	Kazakhstan 16 %	Stainless and heat-resisting steels
Cobalt (Co)	Democratic Republic of the Congo 40 %	Australia 10 %	China 10 %	Wear- and heat-resisting steels
Copper (Cu)	Chile 34 %	Peru 8 %	USA 8 %	Electric cable, electric motors, building industry
Gallium (Ga)	China	Germany	Kazakhstan	LEDs, solar cells
Germanium (Ge)	China 71 %	Russia 4 %	USA 3 %	Smartphones, solar cells
Gold (Au)	China 13 %	Australia 9 %	USA 9 %	Investment, jewellery, electrical industry
Indium (In)	China 50 %	Korea 14 %	Japan 10 %	Displays, alloys, photovoltaics
Iron (Fe)	China 39 %	Brazil 17 %	Australia 16 %	Steel, industrial magnets
Lead (Pb)	China 43 %	Australia 13 %	USA 10 %	Radiation shielding, batteries, metal working
Lithium (Li)	Chile 41 %	Australia 24 %	China 13 %	Accumulators, aviation- and space technology
Manganese (Mn)	China 25 %	Australia 17 %	South Africa 14 %	Stainless steel, LEDs
Molybdenum (Mo)	China 39 %	USA 25 %	Chile 16 %	Steel
Nickel (Ni)	Russia 19 %	Indonesia 13 %	Canada 13 %	Corrosion protection, corrosion-proof steels
Niobium (Nb)	Brazil 92 %	Canada 7 %	–	Stainless steels, jewellery
Palladium (Pd)	Russia 41 %	South Africa 41 %	USA 6 %	Catalysts (chemical industry), jewellery
Platinum (Pt)	South Africa 79 %	Russia 11 %	Zimbabwe 3 %	Catalytic converters, jewellery, metal coatings
Rare earth metals	China 97 %	India 2 %	Brazil 1 %	Permanent magnets, accumulators, LEDs
Selenium (Se)	Japan 50 %	Belgium 13 %	Canada 10 %	Semi-conductor and steel production, fertilizers
Silver (Ag)	Peru 18 %	China 14 %	Mexico 12 %	Investment, jewellery, chemical industry (catalysts)
Tellurium (Te)	Chile	USA	Peru	Stainless steels, semi-conductors, photo diodes
Tin (Sn)	China 37 %	Indonesia 33 %	Peru 12 %	Component of bronze, LEDs, displays
Vanadium (V)	China 37 %	South Africa 35 %	Russia 26 %	Steel alloys, cladding for nuclear fuel rods
Zinc (Zn)	China 25 %	Peru 13 %	Australia 12 %	Corrosion protection, batteries, construction industry

Source: Maribus (2014), World Ocean Review 3- Marine resources – opportunities and risks, chapter 2.

Reactions to supply and (physical) demand changes are relatively slow. In the case of the main source of supply, large-scale mining, this means that by the time a new ore has been explored and a mine has been established, prices might have significantly changed. In a period of low supply and high prices, it is likely that many miners invest in new capacity; while their mines are developing, high prices and supply risk may prevail. Once significant capacity has entered the market, the situation can turn around: oversupply drives down prices, and the capital bound in the mines incentivises the companies to continue to exploit their resources. In short, supply from mines is extremely inflexible to react to demand (in both directions) and the rush for increasing supply tends to drive up costs.

Even in a longer time perspective, the adjustment of supply to demand can be hampered by structures in the mining market: as exploration activities are predominantly performed by junior companies, they depend on access to venture capital. In times of financial market turmoil – such as around 2009 – this meant that despite high resource demand, only limited exploration took place, resulting in restricted possibilities for miners to invest and produce in the medium term.

This inflexibility in the short and medium term leads to **boom and bust cycles** characterised by alternating situations of oversupply and supply shortage. In the current situation, we see supply shortage for some materials, but the times of large profits of mining companies appear to be over, despite relatively steady demand and stable prices. The current situation may not reflect oversupply but rather mis-investment, with the extraction costs too high in the mines that were started in the demand boom phase, and a declining demand outlook.

Matching supply and demand

Based on their market characteristics, the metals relevant in deep-sea mining can be grouped into six categories.

Table 7.5 Market grouping of materials

Type	Examples relevant in DSM	Price mechanism, transparency	Industry concentration
Base metals	Copper, nickel, zinc	Open, transparent markets. Prices linked to varying supply and industrial demand, traded at London Metal Exchange (LME). High price elasticity of supply	Low
Minor metals / by-products	Cobalt, manganese	Often mined as a by-product and thus lower price elasticity of supply; smaller quantities than base metals; most not traded at LME (exception: cobalt, molybdenum)	Medium
Precious metals	Gold, silver	Well established and transparent markets. Prices especially for gold often not clearly linked to demand and supply	Low
Platinum group metals (PGM)	Platinum	Prices set by sales offices of major producers	High
Mineral sands and rare earths	Rare earths (light, heavy)	Occur frequently, but in low concentrations. Not publicly traded, but mostly directly via long-term or yearly to quarterly contracts	High, also high regional concentration
Steel raw materials	Cobalt, manganese, nickel, zinc	<i>Demand heavily influenced by steel industry</i>	

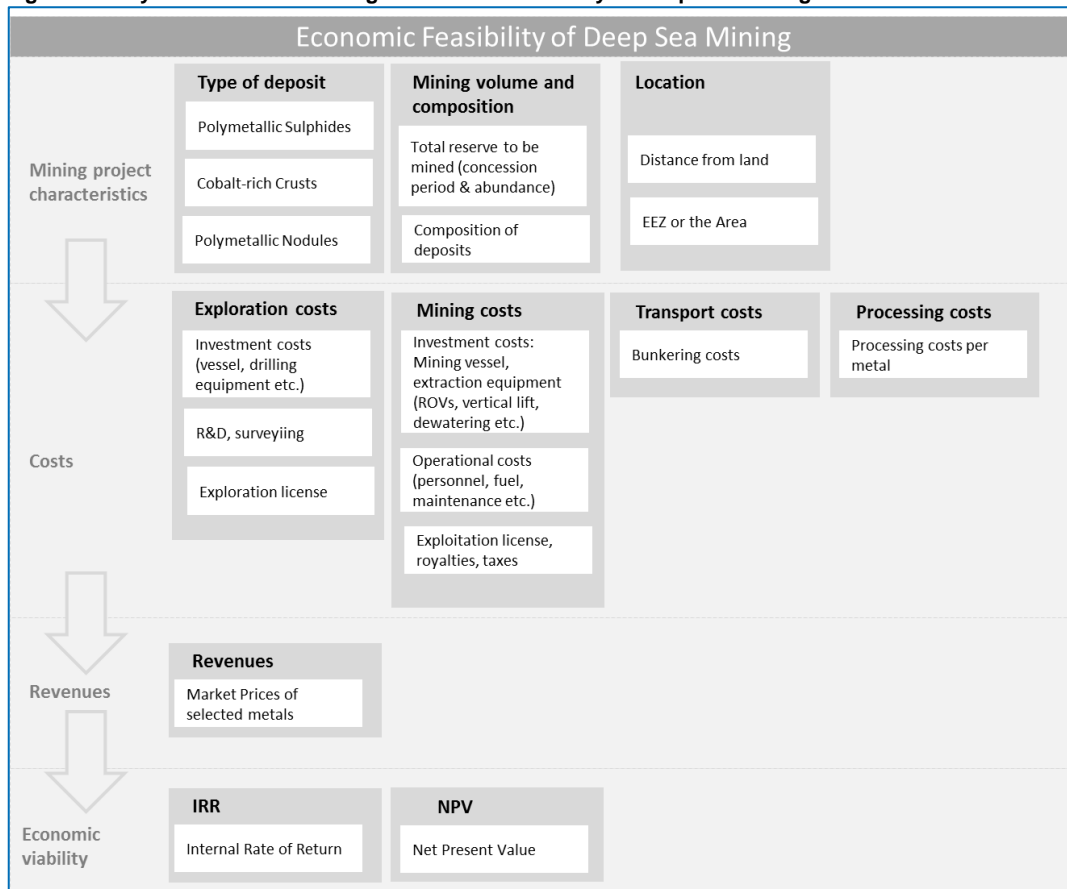
Source: Ecorys based on <http://metals.about.com/od/investing/a/Metal-Markets.htm>, Dunbar (2012), <http://www.infomine.com/investment/industrial-minerals/>.

7.4 Main components of assessing the economic viability of deep-sea mining

A number of different building blocks can be discerned which together determine the feasibility of deep-sea mining operations. These also form the basis of the simple economic model that has been developed as part of this project. The components take account of the specific mining project

characteristics (scenario) but also of costs incurred along the deep-sea mining value chain from exploration and extraction from the seabed to processing and the sale of refined metals.

Figure 7.6 Key elements determining the economic viability of Deep-Sea Mining



7.4.1 Project characteristics

The project characteristics flow from the main characterisation of major deposits:

- Polymetallic sulphides;
- Polymetallic nodules;
- Cobalt-rich crusts.

Composition and size of mining areas, but also location can be related to these three main types of deposits although differences may exist within one specific mineral types as well depending on the specific mining site, the composition and size of the deposit. Key differences between the various deposits are described in the earlier chapters. In terms of distance from land it is important to make a distinction between the distance from the processing location (relevant to transport the extracted material) and the distance to the closest port for personnel, fuel etc.

In terms of mining volumes different sources use different assumptions. These should be confronted with actual mining volume estimates for the licenses under discussion.

The following assumptions are found in different references (sorted by deposit group).

Seafloor massive sulphides

Table 7.6 production volume on seafloor massive sulphides

Document			Production volume (per annum)	
Source	Author	Year	Wet	Dry
Exploration for and pre-feasibility of mining polymetallic sulphides – a commercial case study	Mr. David Heydon, (CEO, Nautilus Minerals)	2004	2 Mt	
ISA workshop on mining of cobalt rich ferromanganese crusts and polymetallic sulphides - technological and economic considerations	ISA	2006		
Potential Deep-Sea Mining of Seafloor Massive Sulphides: a case study in Papua New Guinea	Birney e.a.	2006		
Model mining units of the 20th century and the economies	T. Yamazaki	2008	0.3 Mt	0.07 Mtr
Offshore Production System Definition and Cost Study – Solwara 1	SRK Consulting	2010		1.35 Mt
Conquering the deep sea	M. van Wijngaarden, R. Burger	2013		
Seafloor Massive Sulfide Mining	Masuda e.a.	2014	1.3 Mt	1.1 Mt

It appears that production volumes of 1.1-1.3 Mt/annum are common assumptions in the assessed studies. This is also the value which is used in the studies which have been carried out for Solwara 1.

Polymetallic nodules

Table 7.7: Production volume nodules

Document		Production volume (per annum)		
Source	Author	Year	Wet	Dry
Distribution Patterns of Manganese Nodule Deposits in the Northeast Equatorial Pacific	Andrews e.a.	1983	2.3 Mt	1.5 Mt
Mining Deep Ocean Manganese Nodules: Description and Economic Analysis of a Potential Venture	Hillman and Gosling	1985	4.2 Mt	3 Mt
Views on Future Nodule Technologies based on IFREMER-GEMONOD Studies	Charles e.a.	1990	2.3 Mt	1.5 Mt
Deep Ocean Mining Reconsidered: a Study of Manganese Nodule Deposits in Cook Islands	Soreide e.a.	2001	1.1 Mt	0.7 Mt
Model mining units of the 20th century and the economies	T. Yamazaki	2008	2.2 Mt	1.4 Mt
Report on the ISA workshop on polymetallic nodule mining technology	ISA	2008	1.5 Mt	
Cook Islands	Imperial ²⁰⁸	2010	1.3 Mt	
Deep-sea mining: economic, technical, technological and environmental considerations for sustainable development	Rahul Sharma	2011	1.5 Mt	
Collegium Volume II	LRET ²⁰⁹	2012	0.5 Mt	
Collegium Volume II	LRET	2012	1.03 Mt	0.54 Mt
Technological and economical challenges of manganese nodule mining in the CCZ	Aker Wirth GmbH	2013	2.2 Mt	
Economic evaluation of Cook Islands DSM Deposits	Darryl Thorburn	2014		3 Mt

According to the above sources, in general production volumes of nodules are expected to be higher than for seafloor massive sulphides deposits. Typical production values range 1.3 and maximally 3Mt per annum²¹⁰.

Cobalt crusts

Table 7.8 Production volume on crusts

²⁰⁸ Cited in IHC 2014, Commercial realities in Delivering DSM project

²⁰⁹ Cited in IHC 2014, Commercial realities in Delivering DSM project

²¹⁰ The costs model that was developed for ISA in 2008 assumes a production volume of 1.5 million tons per year)

Document					
No.	Source	Author	Year	Wet	Dry
1	Model mining units of the 20th century and the economies	T. Yamazaki	2008	910,000 t/y	
2	ISA workshop on mining of cobalt rich ferromanganese crusts and polymetallic sulphides - technological and economic considerations	ISA	2006	8,775,000 t (total production in lifetime)	

Information on mining of cobalt crusts is scarce and shows a wide variation. As a result it is hard to come to a reliable point estimate. Yamazaki (2008), which includes a comparative assessment for all three types of mining, adopts a production volume which stands at 40% of manganese nodules,

7.4.2 Costs

Cost categories relate to the phases of the mining process: exploration, extraction, transportation and processing and the related investment costs. The below tables give an overview of existing assessment in different references. It should be noted that in most cases costs for exploration are not included in the cost calculations.

Seafloor massive sulphides

Table 7.9 SMS extraction costs

Document		Capital costs						Operation			
Author	Year	R&D Explor ation	Sea floor mining tool	Lifting system	Mining vessel	Transp ort	Processi ng	Mining	Transport	Processing	
ISA	2006	300 M\$									
Birney e.a.	2006	0.2 M\$/d									
T. Yamazaki	2008		55 M\$			9.6 M\$	19.5 M\$	14 M\$ (50 (wet)-200 (dry) \$/tn	5.3 M\$	4.3 M\$	
SRK Consulting.	2010		383 M\$					70 \$ tonne; 94,5 M\$/yr			
M. van Wijngaarden, R. Burger	2013		84 M\$	101 M\$	198.5 M\$	11 M\$		76 M\$/y	13.8 M\$/y		

According to the above estimates, capital investment would be estimated at some 300-400 M\$ for a typical seafloor massive sulphides operation. However based on actual costs developments for the Nautilus Solwara 1 operation are expected to be significantly underestimated. In practice total CAPEX (capital expenditure) including exploration costs is estimated to be closer to 1 billion \$²¹¹. Operational costs (including transport to shore) are assumed to range between 70-100 \$/tonne based on the above sources. By adding processing costs are expected to rise to 140-200 \$/tonne²¹².

²¹¹ For example, the equity participation of PNG in Nautilus which was agreed in 2014 is valued at 120 m\$ for a share of 15%, but also interviews with technology providers indicate a much higher CAPEX number

²¹² Based on a share of 50% of processing costs in total operating costs. Sensitivity calculation can be made with lower processing costs.

Polymetallic nodules

Table 7.10 Polymetallic nodule extraction costs

Source		Capital costs				Operations			
Author	Year	R&D/ exploration	Mining Equipment and vessel	Transport	Processing	Mining	Transport	Processing	
Andrews e.a.	1983		180 M\$	176 M\$	513 M\$	45 M\$	25 M\$	165 M\$	
Hillman and Gosling	1985	3 M\$	590 M\$	310 M\$	727 M\$	77 M\$	37 M\$	111 M\$	
Charles e.a.	1990		282 M\$	188 M\$	470 M\$	48 M\$	46 M\$	156 M\$	
Soreide e.a.	2001	1.9 M\$	127 M\$	93 M\$	271 M\$	21.8 M\$	13.5 M\$	22.9 M\$	
ISA	2006	650 M\$							
ISA	2008		372-562 m\$	495 M\$ (or 77 m\$/yr if lease)	750 M\$	70-95 M\$	94 M\$	250 M\$	
T. Yamazaki	2008		202.6 M\$	142.7 M\$	417 M\$	71.5 M\$	57.5 M\$	74.2 M\$	
Imperial	2010				1,196 M\$	117 \$/t			
Rahul Sharma	2011		372 - 562 M\$	495 - 600 M\$	750 M\$	69-96 \$M	93 - 132 M\$	250 M\$	
LRET	2012				660 M\$	290 \$/ tpa			
LRET	2012		198 M\$	132 M\$	330 M\$	54 M\$ (108 \$/t dry)	36 M\$ (72 \$/t)	55 M\$ (110 \$/t)	
Aker Wirth GmbH	2013								

Source		Capital costs				Operations			
Author	Year	R&D/ exploration	Mining Equipment and vessel	Transport	Processing	Mining	Transport	Processing	
Darryl Thorburn	2014		> 1 billion \$			100m \$ / year	20\$/t	250\$/t	
Shipandoffshore.net	2014		180 - 260 M\$ (vessel)						

Based on the above overview estimates for capital expenditure range between 500 m\$ to 1800 m\$. In most cases exploration costs are not included in these figures. In interviews it was remarked that nodules mining is expected to be slightly more capital intensive than seafloor massive sulphides mining due to the larger depths. As a result an estimate of 1.2 bn \$ seems to be plausible. Almost half of these capital investments are made up of investments in a processing facility²¹³. Also for operational costs a wide range of estimates exists ranging from 85-300\$/tonne (including processing)²¹⁴. Again (operational) costs related to processing form an important cost component. As many if not most authors exclude manganese as a revenue source for polymetallic mining, as recovery and commercial viability are not expected to outweigh the additional processing costs in relation to land based resources²¹⁵, it is assumed that these operating costs do not include recovery and processing of manganese.

Cobalt crusts

Table 7.11 crusts extraction costs

Document		Capital costs				Exploitation	Transport	Processing	
No	Author	Year	R&D exploration	Mining equipment/ vessel	Transportation	Processing plant			
1	T. Yamazaki	2008		107.3 M\$	45.7 M\$	28.5 M\$	31.2 M\$	16 M\$	40.2 M\$

Only a single source has been assessed. The same author has also estimated the CAPEX and OPEX for nodule mining. Capital costs are expected to be some 50% of manganese nodule mining and operational cost stand at 45%. However assumed production volumes (dry) in these estimate for cobalt crusts stands at some 40% of manganese nodules which makes the CAPEX and OPEX per tonne some 25% resp. 12.5% higher than for manganese nodules.

²¹³ This is also indicated by the study done by Aker Wirth in 2012.

²¹⁴ At this moment we assume a range of 150-200 \$/tonnes as a plausible estimate

²¹⁵ See e.g. Aker Wirth 2013, Yamazaki 2008

7.4.3 Revenues

Revenues in most existing economic assessment of deep-sea mining are related to the composition of the minerals and the recovery rates, multiplied by revenue per ton. In a number of cases net revenues are calculated after deducting royalties (in case of ad valorem royalties) and taxes. Subsequently outcomes are expressed in NPV, IRR or payback periods.

The following table gives an overview of composition and recovery assumptions made, followed by an overview of revenues per tonne mined material per main deposit category.

Table 7.12 Composition of mined deposits (dry weight) and recovery rates (in brackets)

Composition	SMS ²¹⁶	Polymetallic nodules ²¹⁷	Cobalt crusts ²¹⁸
Copper (Cu)	7,2%	1,17% (95%)	0,13% (95%)
Gold (Au)	5.0 g/t		
Silver (Ag)	23 g/t		
Manganese (Mn) ²¹⁹ – excluded from revenue analysis		28,8% (93%)	23% (93%)
Cobalt (Co)		0,16% (85%)	0,64% (85%)
Nickel (Ni)		1,36% (95%)	0,5% (95%)

Based on an average annual production volume (dry) of 1.3 million tonnes for SMS mining, 2.0 million tonnes for polymetallic nodules and 0.8 million tonnes for cobals crusts, production volumes of the different metals can be calculated. Using the average recovery rates as indicated in the above table the amount of metals that can be sold per annum for a typical mining operation can be estimated. These are shown in the following table.

Table 7.13 Estimated total amount of minerals entering the market (tonnes per annum)

Total amount (dry tonnes)	Polymetallic Sulphides	Polymetallic Nodules	Cobalt-rich Crusts
Copper (Cu)	93 600	22 230	990
Gold (Au)	6.5		
Silver (Ag)	29.9		
Cobalt (Co)		2 720	4 350
Nickel (Ni)		25 840	3 800

In order to estimate the potential revenues that may arise, it is essential to have an understanding of the global prices for the minerals. Table 7.13 (below) shows the current (August 2014) state of the market.

In order to put current prices in a historical context we have examined price trends over the past 5 years²²⁰. Copper prices have been fluctuating around the \$7.000 mark since 2012 following a steep increase between 2009-2012 which saw prices rise from \$3.000 per ton to \$10.000. Gold prices have been declining since 2012 when they peaked at \$60 per gram and are currently around \$40 per gram. Trends for silver were remarkably similar to gold and prices are currently at \$0.6 per gram. Nickel prices peaked in 2011 and have been steadily declining until 2013 from which point they have been following an upward curve for the past one. Manganese prices are currently close

²¹⁶ Based on Nautilus (factsheet Q2 2014) see www.nautilusminerals.com. Assumed to be net amounts after recovery from the ore.

²¹⁷ Based on Aker Wirth 2012

²¹⁸ Based on ISA and Yamazaki (2008)

²¹⁹ Uncertain whether additional processing costs outweigh revenue. Hence not included in the revenue calculation

²²⁰ Information on prices from Infomine <http://www.infomine.com>

to a 5 year low at around \$2.300 per ton. It is worth noting that manganese has been strongly fluctuating prior to 2009 with a price increase of 200% between 2005 and 2008. At present it is not expected that manganese can be mined and processed in a commercial viable manner from the sea bed as argued earlier. Cobalt prices are back to a more or less steady level at \$25.000 dollar per ton, they peaked in 2008 registering over \$110.000 per ton.

Table 7.14 Market prices for key metals per tonne

Market prices	Prices in USD/tonne
Copper (Cu)	7,000
Gold (Au)	40,000,000
Silver (Ag)	600,000
Manganese (Mn)	2,300
Cobalt (Co)	25,000
Nickel (Ni)	15,000

It is worth pointing out that metals are quite prone to price fluctuations on the world's market. An example of this comes from China where financial traders pledged metal as collateral to obtain financing from banks²²¹. Anecdotal evidence suggests that primarily copper and aluminium were used to raise capital (Yuan) on a secured basis. The cash generated this way is then reinvested in the international market into unsecured loans with various risk levels. There is a real concern that if the same stock of metal are used as collateral for different loans that can result in banks asking to freeze this inventory and even seize the collateral which in return (depending on the quantity) can have a direct impact on global prices²²². Further consequence could be increasing control of specific countries over commodity prices²²³.

Impact of deep sea mining operations on prices

For precious metals (gold and silver), the prices formation at exchanges is only to a limited extent related to physical supply and demand; therefore seabed mining is not expected to have an influence on the price.

For the other materials, it is necessary to compare the potential mining tonnages from the deep sea with terrestrial production and reserves, and to look at their market environment.

Currently, global annual production of copper is around 20 million tonnes from diversified sources. Looking into the estimated annual volume of 0.1 million tonnes of copper from a typical deep sea mining operation that may come from seafloor massive sulphides it is unlikely to have a substantial impact on global prices. Taking into account that SMS will be primarily mined for gold, silver and copper it is not expected that these operations will have a major impact on commodities prices world wide, unless the number of operations becomes large.

In the case of cobalt the impact on price may be more substantial as global annual production is around 70 thousand tonnes²²⁴. An estimated annual output of 10% could have an impact on market prices and price fluctuation, particularly in view of cobalt's supply risk, which might limit production sites to some 3 maximum without having a downward impact on prices. However, this obviously depends strongly on the size of the actual mine operation.

²²¹ The Wall Street Journal (2014): BHP Calms China Commodity Fears, <http://online.wsj.com/articles/bhp-calms-china-commodity-fears-1404296229>.

²²² Financial Times (2014): China probe sparks metals stocks scramble, <http://www.ft.com/cms/s/0/7928cdaa-f07e-11e3-8f3d-00144feabdc0.html#axzz36sQePuul>.

²²³ Ke Tang, Haoxiang Zhu (2014): Commodities as collateral, http://www.mit.edu/~zhuh/TangZhu_CommodityCollateral.pdf.

²²⁴ with a reserve size of 7.1 million tonnes

Revenue

Based on the total amount of mineral output and the current market prices revenue streams per annum have been calculated (table below). The table confirms previous assumptions that copper would have a high revenue generating potential, but also nickel and cobalt are essential drivers. Seafloor massive sulphides deposits will have the advantage of precious metal content as well as a soon-to-be proven technology which can lower risk and attract investors.

Table 7.15 Estimated revenues per metal in million USD per annum

Revenues	Polymetallic Sulphides	Polymetallic Nodules	Cobalt-rich Crusts
Copper (Cu)	655	155	7
Gold (Au)	260		
Silver (Ag)	18		
Cobalt (Co)		68	108
Nickel (Ni)		387	57
Total	933	611	172
Average revenue/tonne mined (dry)	718	306	216

7.4.4 Economic viability of deep sea mining

Based on the above assumptions tentative calculations have been made on the economic viability of deep sea mining. These calculations should be treated with caution as there is no actual experience with deep-sea mining and costs and revenues are hence highly uncertain. In addition costs might decrease over time as deep-sea mining is still in its infant stages and further efficiency gains might be reached over time.

Table 7.16 Key assumptions

	SMS	Polymetallic nodules	Cobalt crust
Production volume (dry)	1.3 m tonnes/yr	2.0 m tonnes/yr	0.8 m tonnes/yr
Capital expenditure ²²⁵	1.0 bn \$	1.2 bn \$	0.6 bn \$
Operational expenditure ²²⁶	170 \$/tonne	175 \$/tonne	200 \$/tonne
Revenue (excluding manganese)	718 \$/tonne	306 \$/tonne	216 \$/tonne
Years of operation	15	20	20

Using the above assumptions the following results on the commercial viability can be noted..

Table 7.17 Estimated annual revenue generation per mineral type in USD

Year	Polymetallic Sulphides	Polymetallic Nodules	Cobalt-rich Crusts
-	\$ -1.000.000.000	\$ -1.200.000.000	\$ -600.000.000
1	\$ 679.117.011	\$ 72.748.462	\$ -115.993.648
	\$ 679.117.011	\$ 72.748.462	\$ -115.993.648

²²⁵ Including processing, however assumed to exclude processing of manganese

²²⁶ Including processing, however assumed to exclude processing of manganese

Year	Polymetallic Sulphides	Polymetallic Nodules	Cobalt-rich Crusts
2			
3	\$ 679.117.011	\$ 72.748.462	\$ -115.993.648
4	\$ 679.117.011	\$ 72.748.462	\$ -115.993.648
5	\$ 679.117.011	\$ 72.748.462	\$ -115.993.648
6	\$ 679.117.011	\$ 72.748.462	\$ -115.993.648
7	\$ 679.117.011	\$ 72.748.462	\$ -115.993.648
8	\$ 679.117.011	\$ 72.748.462	\$ -115.993.648
9	\$ 679.117.011	\$ 72.748.462	\$ -115.993.648
10	\$ 679.117.011	\$ 72.748.462	\$ -115.993.648
11	\$ 679.117.011	\$ 72.748.462	\$ -115.993.648
12	\$ 679.117.011	\$ 72.748.462	\$ -115.993.648
13	\$ 679.117.011	\$ 72.748.462	\$ -115.993.648
14	\$ 679.117.011	\$ 72.748.462	\$ -115.993.648
15	\$ 679.117.011	\$ 72.748.462	\$ -115.993.648
16		\$ 72.748.462	\$ -115.993.648
17		\$ 72.748.462	\$ -115.993.648
18		\$ 72.748.462	\$ -115.993.648
19		\$ 72.748.462	\$ -115.993.648
20		\$ 72.748.462	\$ -115.993.648
IRR	68%	2%	no positive cash flow over period

In the current set of assumptions SMS mining appears to have the strongest commercial viability. However it should be noted that this assumes the availability of sufficient reserves to continue operations for 15 years. If this is not possible viability will be heavily compromised.

In all deposits the exact composition of the mining deposit will have a large impact on its viability. For cobalt crust and nodules in addition the commercial viability of manganese processing will have a significant impact given the sheer volume of manganese which can be mined. If manganese revenue would be added, without raising the cost of the operation, internal rate of returns for nodules and crust would rise to 109% and 46% respectively.

This also point to the fact that further efficiency increases in mining but also processing will have a major impact on the commerciality of deep sea mining operations as this will determine whether additional revenue streams can be tapped (also including REEs). Finally increasing prices of metals will impact commerciality of operations. Previous trends indicate increasing price levels for most metals in the past period.

8 Comparison with terrestrial mining and recycling

8.1 Summary

Currently land-based mining is the main source of metals used. As demand increases and high-grade deposits are getting depleted, industry is driven towards lower-grade sites as well as towards more “remote and challenging environments”. For terrestrial sites, this implies larger areas need to be excavated to deliver the required demand volumes, potentially in more vulnerable eco-systems with longer rehabilitation times, resulting in large land disturbance, large waste generation and large biodiversity losses.

Many aspects of the proposed deep-sea mining involve the same steps used in conventional mining. Hence a number of impacts is facing the same direction, although of course the detailed nature varies as marine eco-systems differ substantially from terrestrial ones.

In addition to land-based and deep-sea mining, an alternative source of supply for raw materials would be recycling. According to UNEP, recycling rates of metals are in many cases far lower than their potential for reuse. Less than one-third of the 60 most common metals have end-of-life recycling rate above 50%; 34 are under 1%.²²⁷ In Europe, recycling rates of critical metals show strong differences. This is partially due to lack of adequate technology, or sub-optimal pre-processing techniques, but also to insufficient collection or illegal exports of e.g. waste of electrical and electronic equipment (WEEE)²²⁸.

The analysis of recycling has shown that despite high end-of-life recycling rates for the relevant deep-sea mining metals (with the exception of rare earth elements), recycled content remains rather low. This means that a significant amount of metal content is lost during the recycling process. This suggests that even by elevating recycling rates to 100% recycling content this would still not be sufficient to substitute r mining operations and fully cater demand. Nonetheless, it is possible that increased recycling could cover a share of new metals arriving to the market from mining (deep-sea or terrestrial). In order to identify the extent to which recycling could cover demand for new metals a number of variables would have to be analysed, including:

- reserves available from current and soon-to-be-opened land-based mines;
- prices of commodities;
- global demand for metals;
- quantity of cost-efficiently extractable high concentration ores from seabed reserves;
- expected changes in European metal demand for commodities that can also be sourced from the seabed; and
- price implications of metals sourced from seabed minerals.

The cumulative impacts of such a focused exercise could lead Europe closer to a circular economy by closing the loop on the recycling systems and at the same time could facilitate research into innovative technologies for recycling.

²²⁷ Journal of Industrial Ecology, What Do We Know About Metal Recycling Rates, Volume 15, Issue 3, pp 355–366, June 2011.

²²⁸ ECSIP consortium (2013): Treating waste as a resource for the EU industry.

http://ec.europa.eu/enterprise/newsroom/cf/itemdetail.cfm?item_type=254&lang=en&item_id=7100

8.1 Comparison with land-based mining

Generally, it is becoming harder to find new, high-quality land-based mineral deposits²²⁹ yet the demand continues to increase. This has pushed miners towards mining lesser-grade deposits, which return lesser yields and increase production costs due to having to mine more rock for the same metal product. A decreasing supply of high-quality ores also drives mining operators towards more “remote and challenging environments” such as the seabed which is likely to have certain environmental and social impacts (particularly on the rights, uses and values of the sea of indigenous people).

Additionally, for some countries including many in the EU that have limited land-based resources or have difficulties accessing them, deep-sea mining could present a new opportunity to diversify resource streams and ensure provided it is a financially viable alternative. However, in addition to financial feasibility of such projects environmental, social, and economic factors would also need to be considered.

Economic comparison with terrestrial mining

It's hard to make an exact comparison with terrestrial mining costs as the composition of deposits makes it almost impossible to make a direct comparison. In general it can be observed that seabed mining comes with relatively high initial investment costs in comparison to terrestrial mining. Hence other measures of comparison may be useful.

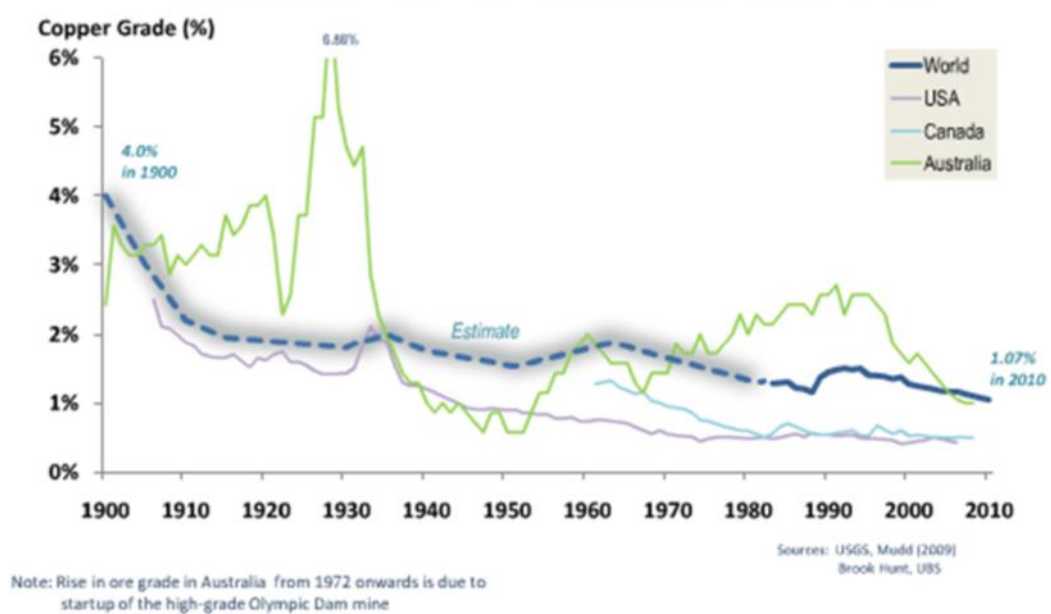
It is also clear that the estimates depend on a number of assumptions. As a rule of thumb, the cost ratio between terrestrial and seabed mining is around 1:10, while the ratio between land deposit and seabed deposit grades is about 10:1. Typical payback times for example for open pit gold mines indicate a payback period of close to 2 years. Given the high capital outlay for deep sea mining payback periods will be much longer.

However, literature sources show that terrestrial ore grades have been declining over the years, a development that pushed the engagement in deep sea mining.

²²⁹ Paterson 2003; SNL Metals and Mining 2013

Ore grades mined have declined over time

Copper ore grade for World and selected countries: 1900-2008



Source: Hein 2011

Comparison of environmental impacts

Deep-sea mining is a new industry with many unknowns, but there are lessons that can be learned from onshore mining and offshore oil and gas extraction. These industries share the need to manage physical habitat destruction, the potential loss of biodiversity and the dispersal of toxic waste. The technology required for deep-sea mining is still being developed and must be able to operate at the great pressures associated with deep water. These difficult conditions will require expert management and maintenance of equipment to ensure that accidents do not occur.

At present, there is **insufficient information** to determine whether the environmental impact of deep-sea mining is greater or less than land-based mining. For seafloor massive sulphides, in particular, it is conceivable that a smaller volume of waste rock and overburden would be displaced than for land-based operations, in order to access the ore. However, some sediment overburden will be removed in seafloor massive sulphides mining and the resulting plume will have effects over a much larger area, and deeper, than the mine site.

As we have described earlier, many aspects of the proposed deep-sea mining involve the same steps used in conventional mining. Countries and regions with already limited biocapacity would simply be adding to their overall "ecological debt" if some trade-offs are not at least considered. Deciding on such trade-offs is by no means straightforward. It is unknown whether a deep sea mine can replace a new land-based mine, or if the resource streams for specific metals may be diverted from ecologically (and socially) costly land-based operations to deep-sea efforts that may potentially be less ecologically costly. In all cases countries would need to evaluate independently - taking into consideration the market and environmental conditions of the individual minerals - whether the economic and environmental footprint of deep-sea mining would be smaller or larger than that of land-based mining.

Embedded within the environmental and economic impacts there are serious social implications that need to be considered. The sea and the minerals it contains are often considered a property of the indigenous people of the land, the minerals under the sea can have strong cultural value

associated with them. Therefore it is essential that a consensus is reached between the stakeholders regarding the safety and benefits of the operations. Furthermore, continuous communication is a necessary local stakeholders in order to ensure there is a common understanding on the principles of the operations and on the conduct of the mining company. This communication would preferably involve areas relatable to the complete value chain (from exploration through processing to decommissioning).

However if policy is designed in a holistic, cross-sectoral manner based on resource frugality (i.e. reduced total consumption), replacement of ecologically high cost activities for lower ones, and the integration of economic progress within a framework of nature-based performance, it may indeed be possible for mineral extraction activities to be a corner stone of an ecologically sustainable and socially inclusive “blue economy”.

Table 6.5 below contrasts the environmental impact of land-based mining with potential impacts from marine mining. Please note that the actual impacts for both land-based and seabed mining will need to be evaluated on a case-by-case basis as they depend on a variety of factors including the type of activity, the ore etc. Additionally until commercial extractions begin impacts of seabed mining activities are hypothetical.

Table 8.1 Comparison of land based and deep sea mine sites²³⁰

Parameters	Land based mines	Marine mines
	Volcanogenic Massive Sulphides	Seafloor Massive Sulphides
Land disturbance	Large area of disturbance (due to buried nature of the deposit type) both at the mine (open cut and underground). Some disturbance associated with infrastructure such as roads, concentrator, smelter. Mine life can be measured in decades. Potentially require relocation of communities.	Limited spatial extent of physical disturbance because individual mines are of small scale, but destruction of site-specific habitats possible, limited and reusable infrastructure. Short mine life. Effects of operational and discharge plumes will affect a much larger area than on land. No relocation of communities.
Waste generation	Large amounts of waste including waste rock, tailings, effluent (potential for acid mine drainage), air pollution, potential oil/chemical spills.	Little or no overburden, limited (if any) tailings (in comparison to land based deposits) due to lack of overburden and also because the ores will be shipped intact. Waste-water plumes may transport toxic substances over large distances, limited air pollution from vessels, potential oil/chemical spills.
Biodiversity	Total biodiversity loss over a large spatial scale at open cut mines. Recovery possible over centuries time scale to a state of functional ecosystem; millennia scale for return to state closer to pre-mining.	Total biodiversity loss at sites of extraction and adjacent areas affected by plumes. Recovery possible within a decade for active sites; can expect similar ecosystem to pre-mining state.
Rehabilitation potential	Major changes to landscape and hydrological regime, but good potential for general rehabilitation over decades to centuries.	Major changes to seafloor topography but on limited spatial scale due to near surface nature of deposit type and lack of overburden. Rehabilitation rates variable, potentially fast for active hydrothermal vents (months to years) but otherwise very slow (decades to centuries)

²³⁰ The actual combined environmental impacts of the operations including processing and transportation would have to be compared and evaluated on a case-by-case basis

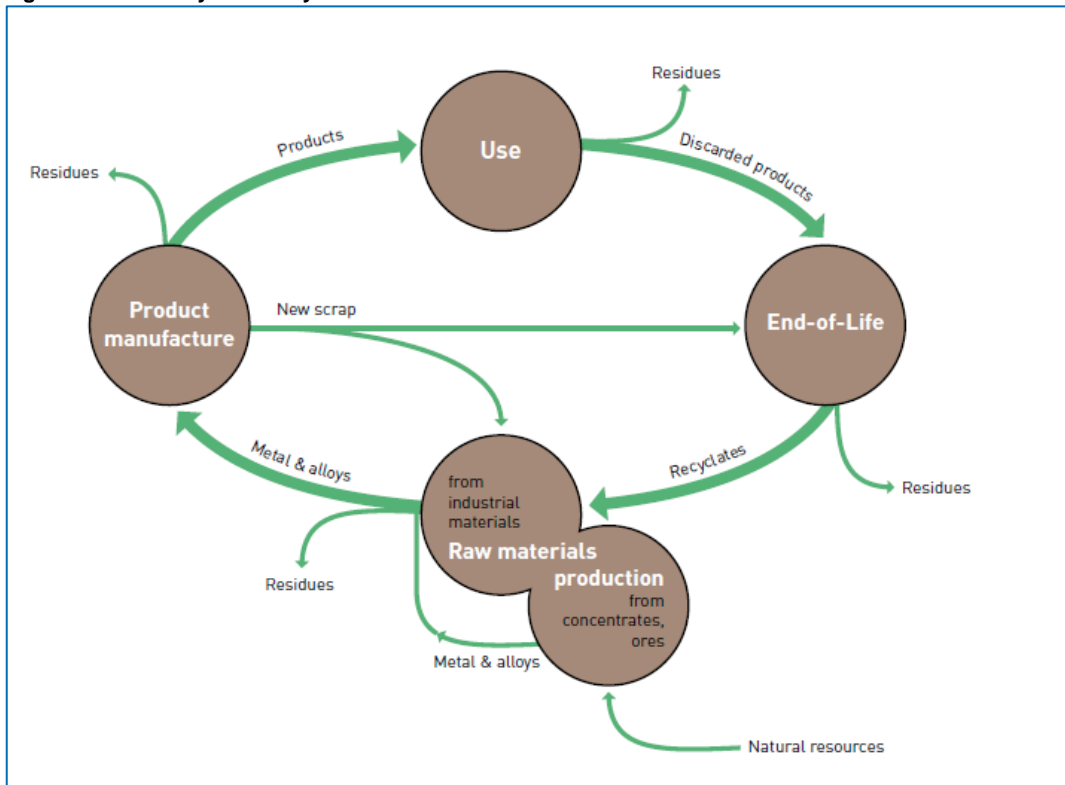
Parameters	Land based mines	Marine mines
Energy use and GHG emissions	GHG emission via transport and cement production, air pollution, high energy use (depending on the extraction technique energy costs can account for 10-12% of all costs)	Off-shore processing of the minerals and transportation by air or water while undoubtedly contributing to GHG emissions could reduce the environmental and social impacts caused by the infrastructural developments linked to road transportations and building of on-shore processing plants.
	Manganese	Manganese nodules
Land disturbance	Large area of disturbance both at the mine (open cut and underground). Some disturbance associated with infrastructure such as roads, concentrator, smelter. Mine life can be measured in decades.	Very large areas of disturbance of benthic layer at mined areas and potentially areas adjacent. Potentially short mine life.
Waste generation	Large amounts of waste including waste rock, tailings, effluent, air pollution, potential oil/chemical spills.	No overburden, limited tailings (in comparison to land based deposits) due to near seabed surface nature of the deposit type and also because the ores will be shipped intact, some waste-water discharged as a plume which may disperse considerable distance, limited air pollution, potential oil/chemical spills.
Biodiversity loss	Total biodiversity loss over a large spatial scale at open cut mines.	Total biodiversity loss at sites of extraction and potentially adjacent areas due to plume spread and smothering. Loss of nodules substrate for attached fauna.
Rehabilitation potential	Major changes to landscape and hydrological regime, but good potential for general rehabilitation over decades to centuries.	Although changes to the seafloor morphology may be limited, current scientific evidence indicates that there is likely to be very poor rehabilitation potential within human time scales.
Energy use and GHG emissions	GHG emission via transport and cement production, air pollution	Off-shore processing of the minerals and transportation by air or water while undoubtedly contributing to GHG emissions could reduce the environmental and social impacts caused by the infrastructural developments linked to road transportations and building of on-shore processing plants.
	Nickel mines	Cobalt rich crusts
Land disturbance	Moderate area of disturbance both at the mine. Some disturbance associated with infrastructure such as roads, concentrator, smelter. Mine life can be measured in decades.	Spatial area of a commercial mine is currently undefined, but could be significant and on a larger spatial scale than for land mining. Top of individual guyot (seamount) may be 200 km ² . Several guyots may be mined within the same area
Waste generation	Large amounts of waste including waste rock, tailings, effluent, air pollution, potential oil/chemical spills.	No overburden, limited tailings (in comparison to land based deposits) due to near seabed surface nature of the deposit type and also because the ores will be shipped intact, some waste-water discharged as a plume which may disperse considerable distance, limited air pollution, potential oil/chemical spills.
Biodiversity loss	Total biodiversity loss over a large spatial scale at open cut mines.	Total biodiversity loss at sites of extraction and potentially areas immediately adjacent.
Rehabilitation potential	Major changes to landscape and hydrological regime, but good potential for general rehabilitation over years to decades.	Major changes to substrate, slow recovery over tens to hundreds of years. May never fully recover in some areas of altered substrate.

Parameters	Land based mines	Marine mines
Energy use and GHG emissions	GHG emission via transport and cement production, air pollution	Off-shore processing of the minerals and transportation by air or water while undoubtedly contributing to GHG emissions could reduce the environmental and social impacts caused by the infrastructural developments linked to road transportations and building of on-shore processing plants.

8.2 The potential of recycling as an alternative to deep-sea mining

An alternative source of raw materials – in addition to land-based and deep-sea mining - would be recycling. The EU flagship initiative “Resource Efficient Europe” highlights the importance of finding new ways to reduce inputs and minimise waste. This could potentially reduce the need for mining more virgin materials, thereby saving energy and water and overall environmental degradation.²³¹ According to UNEP recycling metals is between 2 to 10 times more energy efficient than smelting the metals from virgin ores. The exact conversion rate depends on the metal used.

Figure 8.1 The lifecycle of recycled material



Source: UNEP (2011): Recycling Rates of Metals – A Status Report.

Recycled metals require highly efficient life cycles, as they compete with non-recycled material on price. Recycling markets typically requires materials to travel from open to (nearly) closed life cycles that enable waste or scrap materials to be collected in an optimum fashion. A major challenge for recycling of the metals concerned is that the products they end up in tend to be consumer goods such as cars, electronics, and small appliances, products which typically have so-called “open” life cycles. Waste streams of open life cycles tend to be relatively inefficiently organised and are therefore less suitable for recycling.

²³¹ UNEP (2011): Recycling Rates of Metals – A Status Report.

Table 8.2 Open and closed life cycles and corresponding industries and products

Type	Definition	Industries and products
Open life cycle	End-of-life products are neither collected for recycling nor entering recycling streams that are capable of efficiently recycling the metal.	Typical for many deep-sea mining metals used in consumer goods such as cars, electronics and small appliances.
Closed life cycle	End-of-life products link up with recycling chains, allowing scrap metal (recyclates) to displace primary metals. More efficient system as external costs are internalised.	Typical for industries such as industrial machinery, tools and process catalysts. From a system view this is more efficient and effective as external costs are internalised and there is a limited change of ownership, throughout the life cycle.

Source: Ecorys.

Another challenge for recycling in general is the length of the life-cycle of recycled products. Two major indicators are relevant to express the recycling potential of a material or metal:

- The end-of-life recycling rate (EOL-RR), which measures the share of end-of-life metal which is recycled²³².
- The recycled content (RC), which measures the fraction of scrap in the total metal input of metal production.

According to UNEP, the recycling rates of metals are in many cases far lower than their potential for reuse. Less than one-third of the 60 most common metals have end-of-life recycling rate above 50%; 34 are under 1%²³³. The End-of-Life recycling rates (EOL-RR) for metals are generally rather low as well as they are dependent on the efficiency of the collection and processing of discarded products and relative abundance and low cost of primary material (which keeps down the price of scrap). That said, not all metals are created equal. With the exception of rare earth elements, for the metals that are considered to be relevant in deep-sea mining, EOL-RR are above or close to 50%. On the other hand recycled contents remain rather low, which indicate that even if recycling is accelerated the loss of metal content during processing leaves relatively little recycled content to be used.

Table 8.3 Recycling estimates for selected metals²³⁴

Metal (unit)	EOL-Recycling Rate	Recycled Content (RC)
Cobalt	68%	32%
Copper	45%	9%
Gold	10-15% (electronics); 90-100% (jewelry)	30%
Manganese	53%	37%
Nickel	56%	41%
Platinum	60-70%	16-50% (depending on application)
REE	Below 1%	Below 1%
Silver	30-50%	20-30%

²³² i.e. isolated from products at the end of their lifetime and added to the scrap market.

²³³ Journal of Industrial Ecology, *What Do We Know About Metal Recycling Rates*, Volume 15, Issue 3, pp 355–366, June 2011.

²³⁴ The table only reports estimates for worldwide figures when possible; for magnesium, cobalt, tin, manganese, and niobium only values pertaining to the US were available, indicated by italics. Differing values / value ranges are the result of different reference years, system boundaries, and/or underlying data in the different studies.

Metal (unit)	EOL-Recycling Rate	Recycled Content (RC)
Zinc	35-75%	25%

Source: UNEP (2011)

The above table shows that if recycling estimates for products containing metals or metal alloys that can be sourced from the deep sea show would be 100% the recycled content of the individual metals would still not be close to 100%. The following two tables summarise the overall recycling potential and the key characteristics for metals that can be sourced from the deep-sea.

Table 8.4 Potential of recycling deep-sea mining metals

DSM Metal group	Market description	End Of Life recycling content (RC) per metal type	RR	and	Current recycling activities	Potential
Ferrous metals	- open/transparent markets and low concentration; - high price elasticity of supply.	Manganese	53% EOL-RR	37% RC	- Highest group of recycled metals due to its role in the iron/steel scrap industries; - Range of recycling activities for ferrous metals is wide.	●●●
		Nickel	56% EOL-RR	41% RC		●●●
Non-Ferrous metals	- open/transparent markets and low concentration; - high price elasticity of supply.	Cobalt	68% EOL-RR	32% RC	- Used widely and sufficiently valuable, that their recycling and reuse is reasonably high.	●●
		Copper	45% EOL-RR	9% RC		●●
		Zinc	35-75%	25% RC		●●
Precious metals	- very transparent markets and low concentration; - government disinvestment etc. can be an alternative source of demand and supply; - market prices are often influenced by factors beyond physical demand and supply.	Gold - Jewellery. - Electronics.	EOL-RR 90-100% 10-15%	30% RC	- Precious metals are sufficiently valuable that they are efficiently recycled except in some applications, or when used in very small amounts, or when End-of-Life products fail to enter recycling chains (open life cycle loops); - Generally not recycled in a non-functional fashion because their (intrinsic) value is so high.	●●
		Silver Jewellery Electronics Industrial applications average	EOL-RR 90-100% 10-15% 40-60% 30-50%	RC 20-30%		●●
Platinum-group metals (PGMs):	- high producer concentration; - prices set by sales offices of major producers.	Platinum	60-70%	19-50% RC	- Recycling of PGM metals in industrial applications usually very efficient because product life cycles are closed allowing substantial re-use of EOL flows.	●●●

DSM Metal group	Market description	End Of Life recycling content (RC) per metal type	RR	and	Current recycling activities	Potential
					- No exact data available for recycling from industrial applications.	
Rare earth elements (REE)	<ul style="list-style-type: none"> - high regional concentration; - occur frequently, but only rarely in significant concentrations; - not publicly traded, but mostly directly via long-term or yearly to quarterly contracts. 	Range of light and heavy rare earth metals. Below 1% EOL-RR and RC.			- Not recycled since concentrations are too low in (single) materials.	●
The potential of recycling is assessed qualitatively with three degrees: ● Low potential ●● medium potential ●●● high potential.						

Table 8.5 Supply sources and market structure per material

Metal (unit)	Supply from land-based mining 2012 ²³⁵	Known reserves, land-based ²³⁶	Yearly input from recycling ²³⁷ , % of total supply ²³⁸	EOL-RR ²³⁹ (“Recycling reserves”)	Estimated resources from DSM ²⁴⁰	Demand sources (industries, products), substitution possibilities	Other factors influencing price or accessibility
Copper (1000 t)	World: 16,615 <i>Chile:</i> 5,370 (32%) <i>China:</i> 1,500 (9%) <i>Peru:</i> 1,240 (7%)	World: 680,000 <i>Chile:</i> 190,000 (28%) <i>Australia:</i> 86,000 (13%) <i>Peru:</i> 76,000 (11%)	1,643 (9%)	45%	233,000	Electrical appliances, construction, transport, machinery. Can partly be substituted by cheaper materials such as aluminium, plastics and fiber optics.	Increasing use of export restrictions for unrefined ore.
Nickel (1000 t)	World: 2,100 <i>Philippines:</i> 330 (16%) <i>Indonesia:</i> 320 (15%) <i>Russia:</i> 270 (13%)	World: 75,000 <i>Australia:</i> 20,000 (27%) <i>New Caledonia:</i>	1,459 (41%) ²⁴¹	56% ²⁴²	302,000	Stainless steel, alloys, batteries, catalysts Hardly substitutable in steel alloys (negative environmental impact); some substitution in batteries by lithium and other materials; no substitutes for use	(Stainless) steel production and consumption

²³⁵ Unless stated otherwise, data comes from USGS (2013) and pertains to 2012.

²³⁶ Unless stated otherwise, data comes from USGS (2013) and pertains to 2012.

²³⁷ Calculated from data on recycled content (sourced from UNEP (2011), unless otherwise stated) and total annual supply from mining.

²³⁸ “Recycled content”, defined as the fraction of scrap in total metal input of metal production.

²³⁹ Unless stated otherwise, numbers are sourced from UNEP (2011), which in turn cites consensus statistics or presents the opinion of the expert group of authors. End of Life Recycling Rate (EOL-RR): measures the share of end-of-life metals which is recycled (i.e. is isolated from products at the end of their lifetime and added to the scrap market). It is used as a proxy measure for “recycling reserves”: it gives an indication whether the yearly input from recycling can be significantly increased.

²⁴⁰ Based on Maribus (2014), World Ocean Review 3- Marine resources – opportunities and risks, chapter 2. See also earlier tables. Totals refer to totals for crusts (PCZ) and nodules (CCZ) only.

²⁴¹ Figure on recycled content from European Commission (2010): Annex V to the Report of the Ad-hoc Working Group on defining critical raw materials, http://ec.europa.eu/enterprise/policies/raw-materials/files/docs/annex-v_en.pdf

²⁴² Figure from European Commission (2010): Annex V to the Report of the Ad-hoc Working Group on defining critical raw materials, http://ec.europa.eu/enterprise/policies/raw-materials/files/docs/annex-v_en.pdf

Metal (unit)	Supply from land-based mining 2012 ²³⁵	Known reserves, land-based ²³⁶	Yearly input from recycling ²³⁷ , % of total supply ²³⁸	EOL-RR ²³⁹ ("Recycling reserves")	Estimated resources from DSM ²⁴⁰	Demand sources (industries, substitution possibilities)	Other factors influencing price or accessibility
		12,000 (16%) Russia: 6,100 (8%)				in particular applications such as jet engines	
Zinc (1000 t)	World: 12,881 China: 4,900 (38%) Australia: 1,510 (12%) Peru: 1,280 (10%)	World: 250,500 Australia: 64,000 (26%) China: 43,000 (17%) Peru: 24,000 (10%)	4,294 (25%)	35-75% ²⁴³	n.a.	Galvanized steel for automotive production and construction, diecasting, alloys. Substitution is sometimes possible, but leads to different specifications and/or is costly.	Steel production and consumption
Manganese (1000 t)	World: 16 South Africa: 3.515% Australia: 3.4 (14%) China: 3 (13%)	World: 630 South Africa: 150 (28%) Ukraine: 140 (26%) Australia: 97 (18%)	9.4 (37%)	53%	7,706,000	Steel production, corrosion protection and Non-metallurgy applications: it is used for the production of dry cell batteries, fertilization of plants and animal feed. Manganese has no substitutes.	Steel production and consumption
Cobalt (1000 t)	World: 103 Congo: 51	World: 7,203 Congo:	48 (32%)	68%	94,000	Rechargeable batteries and magnets (for IT, consumer	"Significant" share of artisanal and small-scale mining in Congo ²⁴⁴ ; no

²⁴³ The 75% estimate comes from European Commission (2010): Annex V to the Report of the Ad-hoc Working Group on defining critical raw materials, http://ec.europa.eu/enterprise/policies/raw-materials/files/docs/annex-v_en.pdf.

Metal (unit)	Supply from land-based mining 2012 ²³⁵	Known reserves, land-based ²³⁶	Yearly input from recycling ²³⁷ , % of total supply ²³⁸	EOL-RR ²³⁹ ("Recycling reserves")	Estimated resources from DSM ²⁴⁰	Demand sources (industries, products), substitution possibilities	Other factors influencing price or accessibility
	(49%) China: 7 (7%) Canada: 6.6 (6%)	3,400 (47%) Australia: 1,000 (14%) Cuba: 500 (7%)				electronics, electric mobility) and superalloys. Limited substitution possibilities, mostly in magnets but increasingly in batteries.	conflict mineral status, as mined outside conflict areas. Nevertheless situation in Congo important. Note that EU demand is concentrated on cobalt use for hard metals.
Gold (t)	World: 2,700 China: 370 (14%) Australia: 250 (9%) United States: 230 (9%)	World: 52,000 Australia: 7,400 (14%) South Africa: 1,154 (12%) Russia: 5,000 (10%)	1,157 (30%)	between 10-15% (electronics) and 90-100% (jewellery)	n.a.	Jewellery, IT/ electronics, renewable energy, <i>finance (note: much of this is not involving physical transactions).</i> Several substitution options for industrial use; not widely substituted in its use in finance.	World economic stability/ uncertainty, inflation, interest rates, sovereign debt, conflict minerals legislation (defined as conflict mineral by US authorities), high share of artisanal and small-scale mining (25%).
Silver (1000 t)	World: 24 Mexico: 4.25 (22%) China: 3.8 (16%) Peru: 3.45 (14%)	World: 540 Peru: 120 (22%) Poland: 85 (16%) Chile: 77 (14%)	8 (25%)	around 50% (90% for jewellery)	n.a.	Industrial applications (electronics), jewellery, coins, silverware, analogue photography, dissipative use (RFID, textiles), <i>finance/ investment (coins and non-physical).</i> Substitution in electronic uses possible with loss of performance; no substitution options for dissipative use	World economic stability/ uncertainty, industrial innovation. Low price elasticity of supply because mostly mined as by-product.

²⁴⁴ USGS (2010): Minerals Yearbook. Area Reports: International 2008, volume III, Africa and the Middle East. See also Liakounakou, A (2012): DRC: Katanga's Artisanal Miners Face Uncertain Future, <http://thinkafricapress.com/drc/uncertain-future-katanga-artisanal-miners-copper-cobalt>; according to this report, In 2007, an estimated 150,000 to 200,000 people in the cobalt-rich Katanga province made their living through ASM.

Metal (unit)	Supply from land-based mining 2012 ²³⁵	Known reserves, land-based ²³⁶	Yearly input from recycling ²³⁷ , % of total supply ²³⁸	EOL-RR ²³⁹ ("Recycling reserves")	Estimated resources from DSM ²⁴⁰	Demand sources (industries, products), substitution possibilities	Other factors influencing price or accessibility
Platinum (t)	World: 182.8 <i>South Africa: 133 (73%)</i> <i>Russia: 24.6 (14%)</i> <i>Zimbabwe: 11 (6%)</i>	World: 66,110 <i>South Africa: 63,000 (95%)</i> <i>Russia: 1,100 (2%)</i> <i>United States: 900 (1%)</i>	61% (16-50%; 33% avg)	60-70%	n.a.	Car manufacturing (autocatalysts, highly important for EU industry), jewellery. Limited substitution possibilities, mostly with other (rare) PGMs.	Demand in car manufacturing is procyclical; demand in jewellery responds to gold price changes.
Rare earth elements (1000 t)	World: 110 <i>China: 100 (91%)</i> <i>Australia: 3.2 (3%)</i> <i>India: 2.9 (3%)</i>	World: 140,000 <i>China: 55,000 (39%)</i> <i>Malaysia: 30,000 (21%)</i> <i>Brazil: 22,000 (16%)</i>	Below 1.1 (below 1%)	Estimated at or below 1%	n.a.	Magnets (for IT, energy...), fluid cracking catalysts, electric and hybrid cars.	Export restrictions, world trade regulations, environmental concerns.

Source: various sources, compiled by Ecorys.

8.3 The environmental impacts of recycling

While the recycling process itself can contribute to a reduction of consumption of primary resources as well as in some cases to the conservation of energy²⁴⁵ (compared to primary metals production), there might also be some negative environmental impacts associated with the activities, which can include additional resource use, GHG emissions, release of toxic materials etc. The following table compares the environmental impacts of recycling and land-based mining. Please note that the following table does not aim to present recycling and land-based mining as interchangeable alternatives to one-another (based on the findings of the economic analysis it is evident that recycling cannot replace land-based mining as an adequate source of metals supplying European consumers and industries), rather it seeks to identify the amalgamated environmental consequences of different sourcing techniques.

Table 8.6 Comparison of recycling and land based mining

Parameters	Recycling	Land based mines
Land disturbance	The infrastructural development related to establishing a recycling facility and connecting it via road infrastructure does entail a certain amount of land disturbance. However, recycling facilities require permitting which ensures none or limited ecosystem impact.	Large area of disturbance both at the mine (open cut and underground). Some disturbance associated with infrastructure such as roads, concentrator, smelter. Mine life can be measured in decades. Potentially require relocation of communities.
Waste generation	Toxins in metal can be released into the environment during processing e.g. lead from circuit boards released as dust. Paper recycling can require the use of chemicals to remove ink. Wastewater can contain dioxins and other carcinogens. Waste sent to landfills may contain heavy metals.	Large amounts of waste including waste rock, tailings, effluent (potential for acid mine drainage), air pollution, potential oil/chemical spills.
Rehabilitation potential	Recycling infrastructure does not cause significant changes to the landscape and the site can be re-used shortly after the infrastructure has been	Major changes to landscape and hydrological regime, but good potential for general rehabilitation over decades to centuries.
GHG emission	Transportation of recycled materials through collection as well as to and from the recycling facilities can cause significant emission	GHG emission via transport and cement production
Energy use	Energy use is particularly significant in the sorting and processing of scrap metal (but varied for alloys). Energy requirement for the production of virgin paper is also significant	High energy use (depending on the extraction technique energy costs can account for 10-12% of all costs)

It is worth noting that meanwhile there might be common practices (sorting, shearing, melting), metals recycling is a diverse practice. Some recycles specialise in handling particular types of metals or alloys while others might accept all types of scrap metal. As products in increasing numbers contain metal mixed to form alloys, the recycling practices for retrieving particular metals

²⁴⁵ The extent of energy use in recycling depends largely on the materials and the process in question. Therefore overall energy consumption will have to be evaluated on a case-by-case basis

may also differ. In the case of nickel for example there are thousands of different alloys each with their particular combination of technical properties (corrosion resistance, mechanical properties and service life)²⁴⁶. In order to optimise the retained value of the scrap metal, the industry develops specific technologies which may differ per metal or per alloy type. Further details on the practices and the economic impacts of recycling can be found within the economic analysis chapter of this study.

With regard to environmental impacts metals recycling in general transportation and related GHG emissions are one key concern. Transportation of recycled material through collection and processing as well as the transportation of recycled material to the manufacturing facility are all stages where GHG emissions occur. Appropriate planning during the design stage can help identify the most suitable locations for the recycling facilities hence avoid any disturbance to land-use and allow for short haul connections between the value chain partners.

Energy use is also a factor in sorting and processing scrap metal however this energy use is much less in comparison to primary production or extraction of ores. In the case of copper for example extraction of the ore requires around 95 million Btu/tonne whereas recycling copper uses much less energy, about 10 million Btu/tonne²⁴⁷. It is worth pointing out that in the case of highly mixed metal alloys figures on energy use for recycling can be higher. In light of the fact that up to date no extraction had taken place we have no information on how this data would compare to the energy use of deep-sea mining operations.

The above overview illustrates that even though recycling – as any other industrial activity – does have an environmental footprint, it constitutes to a significant added value when it comes to resource and energy efficiency however, these benefits depend on the efficiency of the recycling technology applied.

8.4 Requirements to assess recycling as an alternative to deep-sea mining

In line with the EU's strong commitment to waste reduction and recycling, it is important to assess whether a significant share of the metal demand driving Europe's interest in deep-sea mining could be met by increased recycling (taking into consideration both pre- and post-consumer recycling) activity. In such an assessment, it would be important to consider the forthcoming review of key waste legislation which aims to significantly increase recycling rates, and shift towards a fully 'circular' economy, whereby valuable materials are extracted from old products, to serve as secondary raw materials for new ones. Such an approach resonates with the (UNEP recent call for stepping up metal recycling practices²⁴⁸.

In order to understand whether increasing European recycling potential could cover the increasing metal demand three key areas need to be assessed; these are:

- global metal demand;
- European metal demand; and
- European recycling potential.

²⁴⁶ Nickel Institute: Recycling of Nickel-Containing Alloys, <http://www.nickelinstitute.org/en/Sustainability/LifeCycleManagement/RecyclingofNickel/HowNickelisRecycled/RecyclingofNickelcontainingalloys.aspx>

²⁴⁷ Bureau of International Recycling <http://www.bir.org/industry/non-ferrous-metals/>

²⁴⁸ UNEP, 2013: Soaring Demand for Metals Calls for Rethink of Recycling Practices, Says International Resource Panel <http://www.unep.org/newscentre/Default.aspx?DocumentID=2713&ArticleID=9484&l=en>

In order to assess global metal demand, it is worth noting that an increasing number of applications – including environmental²⁴⁹ and commercial technologies – are being developed using types of metals that can also be sourced from the seabed. The demand for such applications and products particularly from emerging economies on the medium to long term could prove to be a driver for increasing extraction. However, it is not all clear what share of these metals would or could potentially come from seabed sources taking into consideration:

- reserves available from current and soon-to-be-opened land-based mines;
- prices of commodities;
- global demand for metals; and
- quantity of cost-efficiently extractable high concentration ores from seabed reserves.

Once minerals sourced from the seabed enter the global market it is expected that they would - to a smaller or larger extent depending on the quantity of minerals in question, geo-political environment as well as the abundance of land-based resources – influence the prices of metals. An additional consideration at this point would be the share of these metals that would be imported to Europe. The particular points to analyse here can include European demand and global prices of these commodities. As no commercial scale deep-sea mining has taken place yet at this stage assumptions would have to be made regarding the quantity of metals sourced from the seabed that would be imported to Europe, with particular focus on key industrial areas. This means that the European markets of the key applications – e.g. hybrid cars, wind mills, batteries and electronic devices etc. - that are expected to drive the demand for these metals in the future should be analysed in light of:

- expected changes in European metal demand for commodities that can also be sourced from the seabed; and
- price implications of metals sourced from seabed minerals.

Once an analysis on the European demand for these metals²⁵⁰ has been carried out, taking into consideration different price scenarios, it would be important to assess the extent to which the European recycling industry would be able to cover this demand. For this, a number of variables would need to be analysed, including:

- changes in the quantity of metals entering the recycling chain;
- current recycling potential for metals in Europe;
- foreseeable increase in recycling capacity in Europe;
- distortions in practices and recycling potential between Member States;
- trends in other disposal and recovery activities for metals;
- innovations in recycling technologies for metals;
- current quantity of waste shipments (old and new scrap²⁵¹) to non-OECD countries.

Underpinning this assessment should be an analysis of the regulatory and policy environment, including the forthcoming "Circular economy" package of proposed revisions, as well as the wider EU waste acquis, including, *inter alia*:

- The Waste Framework Directive;
- The Landfill Directive;
- Mining Waste Directive;
- Waste Shipments Regulation;
- The Waste Electrical and Electronic Equipment (WEEE) Directive;
- The Batteries Directive;

²⁴⁹ Including metal components in cell phones, wind mill turbines, hydrogen fuel cells, hybrid and electric car batteries etc.

²⁵⁰ Including copper, nickel, gold, silver, manganese, zinc and cobalt

²⁵¹ New scrap is generated during the manufacturing processes and has a known composition and origin. Old scrap is end-of-life scrap

- End of Life Vehicles Directive; and
- Ship Recycling Regulation.

The above described assessment of seabed mining sourced minerals and recycling potential within Europe could help to identify the particular challenges the European recycling sector could face in the future in light of a projected increased demand. A recent study²⁵² from the European Association of Metals (Eurometaux) has identified some of the current challenges for metals recycling in the European Union, which include the following:

- recyclability of finished products;
- suboptimal end-of-life collection schemes;
- landfilling of post-consumer goods;
- shortage of secondary raw material due to exports to non-European countries partly due to illegal or dubious shipments of waste;
- lack of level playing field worldwide and quality recycling;
- technological and economic hurdles to recycle increasingly complex products; and
- transparency across the value chain and better enforcement of legislation.

The cumulative impacts of such a focused exercise could lead Europe closer to a circular economy by closing the loop on the recycling systems and at the same time could facilitate research into innovative technologies for recycling.

²⁵² Eurometaux (2013): Boosting Recycling to support access to raw material and resource efficiency, http://www.eurometaux.org/DesktopModules/Bring2mind/DMX/Download.aspx?Command=Core_Download&EntryId=6603&PortalId=0&TabId=57



9 Standards and transparency

9.1 Summary

Currently there are no internationally approved and applied standards for deep-sea mining performance, technology and environmental impact assessments (see also the legal section). Furthermore, there are no internationally recognised practices for managing communication with stakeholder groups and ensuring transparency of operations. These factors are seen as barriers for the future development of the industry as they lead to misinformation and ultimately can harm relations with stakeholder groups, particularly NGOs and the local population.

There are a number of ongoing initiatives when it comes to performance and environmental standards for the industry, however these are not harmonised and coordination has not been rolled-out to involve a wide stakeholder base. As the starting date for commercial practices is getting closer, even if it applies so far only to the EEZ areas of the Pacific Island States, an international agreement to clarify technical, environmental, reporting and transparency criteria is ever more pressing.

9.2 Standards in deep-sea mining

With regards to standards one of the most important issues for deep-sea mining are environmental protection standards. At present, as already noted at several points in this report, detailed exploitation standards have yet to be developed by ISA for deep-sea mining in the Area or by individual States with respect to areas under their jurisdiction.

The lack of standards has a potentially negative impact on the development of the deep-sea mining sector in that the type of standards set, thus the level of environmental protection that they provide for, will in turn impact on the types of technology to be used. At the same time, though, pending the development and testing of new technology on the deep seabed it will be difficult to determine the precise levels at which environmental standards should be set. A zero-pollution extraction standard, for example, even if technically possible (which is doubtful), would likely be so expensive that it would render deep-sea mining un-economical.

To date the only published set of environmental standards are those contained in the Code for Environmental Management developed by the International Marine Minerals Society.²⁵³ These may provide a useful starting point for the development of standards for deep-sea mining by ISA as well as by national governments.

In terms of the Area it is clear that standards for deep-sea mining will be developed in due course and there is no reason to doubt that these will provide for a high level of environmental protection.

What is potentially of more concern is the question of standards applicable to deep-sea mining in areas under coastal State jurisdiction particularly in the case of developing countries. As already

²⁵³ International Marine Minerals Society Code for Environmental Management of Marine Mining International Marine Minerals Society, London, 2011, at http://www.immsoc.org/IMMS_code.htm

noted in this report, it is not entirely clear as a matter of law whether or not the exploitation standards that will be developed by ISA should also apply in areas under coastal State jurisdiction. In other words it is quite possible that different, stricter or less strict, standards may apply in areas under coastal State jurisdiction. Moreover, the fact remains that whatever the precise legal position, the existence of any standards at all for deep-sea mining in areas under coastal State jurisdiction will depend first of all on the adoption of appropriate legislation by the State concerned. Again most states do not have legislation in place that is specifically designed for deep-sea mining and the application of land based rules to the sea may, as the case of PNG suggests, prove challenging. Moreover, if such standards are to have any real effect this suggests a certain degree of enforcement capacity, which may also be lacking in some developing countries.

Of course the issue of a lack of an appropriate legal framework in developing countries, or the non-implementation of legislation on the statute books is not a problem that is confined to the deep-sea mining sector. Investors from the EU and other industrialised countries in mining, manufacturing and infrastructure projects in developing countries are frequently faced with such problems. More responsible investors may seek to supplement basic standards set out in national legislation with a mixture of best practice from their own countries or investment guidelines promoted by international finance institutions.²⁵⁴ The less scrupulous simply take advantage of loose regulatory frameworks. And of course the notion of sovereignty, which is fundamental to international law, means that EU and other industrialised countries cannot simply seek to apply their own national social and environmental standards to investments made by their citizens and/or companies in third countries.²⁵⁵ On the other hand softer policy options such as guidelines may have a role to play.

Otherwise as regards the issue of standards for deep-sea mining in waters under the jurisdiction of developing States, it is again appropriate to return to the ACP-EU Parliamentary Resolution and its emphasis on technical and other support to such countries.

The International Marine Minerals Society (IMMS) has compiled a code of conduct for marine mining in 2001 and amended this in 2011. The Code is meant to serve all stakeholders active and engaged in seabed mining operations. It requires companies, amongst others, to respect the regulations of sovereign states as well as the applicable policies of relevant international bodies as well as to facilitate community partnerships on environmental matters throughout the project's life cycle. The Code also sets a number of operating guidelines which include a commitment from stakeholders on sustainability and environmentally responsible behaviour. This code of conduct however is not meant to set minimum standards and is functioning more as a point of reference when it comes to conducting exploration or exploitation activities.

Establishing harmonised standards for exploration and exploitation activities (performance) that can be applied across countries can improve sustainability of practices as well as support technological innovations, whereas the absence of such practices can lead to damages to the marine environment. It is important that such standards are developed prior to the commencement of large scale commercial practices. It is essential that the above described mechanism already in place are effectively utilised and coordinated to the degree possible. This would allow making use of the information and experiences gained through the implementation of these initiatives.

²⁵⁴ Such as the IFC Performance Standards.

²⁵⁵ More specifically states can make use of nationality jurisdiction to require their nationals, including companies formed under their law, to act in given ways anywhere in the world but they can only enforce such laws within their own borders.

9.3 Other issues

Under this heading can be included the issue of licence and royalty payments. In the case of deep-sea mining in the Area this is one of the matters that ISA is currently working on in connection with the preparation of the exploitation regulations necessary to complete the Mining Code. This is by no means an easy issue to address, complicated as it is by potential differences in the tax treatment of licence and royalty payments to ISA by Sponsoring States in their own legislation. And this is of course a complex area in its own right. Typically, mining fiscal regimes contain some or all of the following elements:

- a. surface rentals/administrative fees/dead rents;
- b. royalties;
- c. corporate income tax;
- d. environmental levies and fees;
- e. additional taxes/surtaxes (such as a 'windfall tax');
- f. resources rent tax;
- g. state participation;
- h. dividend & interest withholding taxes;
- i. indirect taxes and duties.

It is the inter-relationship between these different elements that obviously determines the precise final cost to mining companies of mining operations. Moreover depending on the particular contractual arrangements in force the elements themselves may not be fixed. While royalty levels may, for example, be set at the outset other tax arrangements, such as windfall taxes, may vary depending on inter alia global commodity prices.

In the case of deep-sea mining in the Area a relatively stable financial regime can probably be envisaged given the specifically international nature of ISA. At the same time though, the tax treatment of deep-sea mining investments by sponsoring States may well vary meaning that contractors from certain jurisdictions may enjoy tax benefits over other competitors from other countries.

As regards deep-sea mining in areas under coastal State jurisdiction, the position is much less clear and while existing land based mining regimes may offer some guidance as to future arrangements for deep-sea mining this is by no means guaranteed. At the same time the different licensing and royalty schemes that individual countries adopt will be established by references to their own specific tax, investment, environment and development policies and as such there may well be significant variations from country to country.

All of these considerations are essentially for the future. Licensing and royalty schemes will be established in due course. But what this does mean for deep-sea mining is that at the present time it is difficult to ascertain the economic investment case, in so far as licensing and royalty payments are concerned, with much degree of certainty.

9.4 Transparency

Although, as seen in this report, deep-sea mining, in the sense of the commercial extraction of minerals from the seabed, has yet to begin, concerns over its potential negative impacts have already been raised not only by a range of non-government organisations but also at the political

level: in its 'Resolution on mining for oil and minerals on the seabed in the context of sustainable development'²⁵⁶ (the 'ACP-EU Parliamentary Resolution'), the ACP-EU Joint Parliamentary Assembly recognized the 'persisting concerns' over potential negative social and environmental impacts from deep-sea mining.

Of course, concern over the negative impacts of mining projects, particularly in developing countries, is nothing new. Land-based mines, especially open cast mines, can if not properly planned and managed have significant negative impacts on the environment (including deforestation and harmful impacts on water resources) and on local communities in terms of their human rights and livelihoods. Other concerns include the employment, health and safety conditions of workers employed in mines as well as the negative environmental impacts of initial processing works undertaken or near the mine site. Controversy can also arise about mechanisms whereby the local communities most directly affected by mining projects can receive an appropriate share of the economic benefits in a fair and transparent manner.

In the case of deep-sea mining it is clear that the impacts will be different. The highly technological nature of future deep-sea mining extraction techniques means that there may be little scope for local employment of unskilled workers in deep-sea mining operations in the waters of developing countries. Where deep-sea mining takes place closer to the shore, and it is to be recalled that the Solwara I project is planned to take place within the territorial sea of PNG, impacts on local ecosystems could negatively impact on fisheries and other local livelihoods. But the fact is that most deep-sea mining will likely take place far offshore. This does not mean that impacts on coastal eco-systems are to be entirely discounted. However in practice the more significant impacts on coastal communities are likely to arise from land-based operations in support of deep-sea mining offshore in terms, for example of port enlargement or the initial treatment of extracted minerals.

But this raises further a question. In particular, just what will the environmental impacts of deep-sea mining actually be? And of course until commercial extraction activities actually begin the answers to this question can only remain at the level of informed speculation. Uncertainties as to the potential impacts of deep-sea mining on the marine environment are further exacerbated by the still-huge knowledge gaps about the deep-sea bed and its ecology. Moreover due to its enormous size and the relative lack of human activity there, the deep-sea bed is widely understood to comprise the largest area on earth that remains in a relatively pristine condition. And, of course, as deep-sea mining will take place on the seabed and often far offshore, thus effectively hidden from view, its actual impacts cannot be readily appreciated without expensive scientific monitoring and research. In these circumstances, where only governments, large corporations and international organisations have the resources to undertake such monitoring and research, a key challenge for the deep-sea mining sector as a whole will be to ensure that data and information about the ecology of the deep-sea bed and the potential environmental impacts of deep-sea mining is made readily available to NGOs and civil society so that they can play an informed and effective role in the on-going discussion of deep-sea mining. Put another way, if such information flows are not put in place there is a serious risk that the future of deep-sea mining, in Europe or at the broader level, may be derailed not by technological challenges or movements in commodity prices, but rather by political opposition.

Apart from concerns about the potential environmental impacts of deep-sea mining, a further concern relates to the financial arrangements. This issue has certainly been at the forefront of concerns about proposed deep-sea mining in PNG. The same kinds of questions will likely arise in all developing countries where deep-sea mining takes place. Is the country getting a good deal?

²⁵⁶ Adopted by the ACP-EU Joint Parliamentary Assembly on 19 March 2014 in Strasbourg, France. ACP-EU/101.546/14/fin..

And what will happen to the proceeds from deep-sea mining, including as regards affected communities? The ACP-EU Parliamentary Resolution, referred to above, specifically calls on ACP-EU governments in the context of marine mineral resources, to put an end to the ‘resource curse’ and to ensure that the exploitation of such resources is undertaken for ‘the benefit of the whole population, instead of ... only enriching investors and small elites without benefitting ordinary citizens’. Again such outcomes can only be achieved if there are mechanisms in place to promote transparency.

In examining the issue of transparency in more detail it is appropriate, once again, to distinguish between deep-sea mining in the Area and deep-sea mining in areas under coastal State jurisdiction.

9.4.1 Transparency and deep-sea mining in the Area

In the case of deep-sea mining in the Area the topic of transparency falls to be addressed within the legal framework created by Part XI of UNCLOS and the Part XI Implementation Agreement.

The issue of data is addressed in article 14 of Annex III of UNCLOS. Article 14(1) requires each operator to transfer to ISA, in accordance with the rules, regulations and procedures of the latter and the terms and conditions of the relevant work plan, ‘all data which are both necessary for and relevant to the effective exercise of the powers and functions of the principal organs of ISA in respect of the Area covered by the plan of work’.

However paragraph (2) goes on provide that data ‘that is deemed to be proprietary’ may only be used by ISA in order to enable ISA to fulfil its regulatory role. It goes on to provide that data that is necessary for the formulation by ISA ‘of rules, regulations and procedures concerning protection of the marine environment and safety, other than equipment design data, shall not be deemed proprietary’. The next paragraph provides that data that is deemed proprietary may not be disclosed to anyone outside ISA.

The first question is just what is meant by ‘proprietary’ data? This expression is not defined in UNCLOS but it’s scope would appear to be broad enough to include data that are subject to intellectual property rights such as patents and, of most relevance to marine environmental data, database rights and copyright.

In outline marine environmental data that are contained in a dataset or a report, are subject to, and protected by, copyright.²⁵⁷ Copyright protection does not extend to the data contained in the database (which may however be subject to copyright in its own right) but rather to the manner in which the data are organized and presented. The author of the database is the natural person(s) who created the database or (where national legislation permits it) the legal person designated as the right holder by that legislation (such as the employer of the database creator).

However the effect of article 14(2) appears to be that data necessary for ISA to formulate rules, regulations and procedures on the protection of the marine environment and safety is not to be deemed proprietary. Consequently such data are prima facie not subject to the rules preventing its disclosure to people outside ISA.

²⁵⁷ For a full discussion of the legal aspects of marine environmental data, the reader is referred to the study ‘Legal aspects of marine environmental data which is available on the DG MARE website at: http://ec.europa.eu/maritimeaffairs/documentation/studies/study_lamed_en.htm

The question of what is to happen to data held by ISA is further addressed in article 181 of UNCLOS. Article 181(1) provides that the archives of ISA must be 'inviolable' while paragraph (2) states that: '(P)roprietary data, industrial secrets or similar information and personnel records shall not be placed in archives which are open to public inspection'.

The issue of data is addressed in more detailed in the three sets of regulations adopted to date that together make up the Mining Code. The regulations use a slightly different terminology distinguishing as they do between data that are 'confidential' and data that are not. For example Regulation 36(1) of the Nodules Regulations²⁵⁸ states:

Data and information submitted or transferred to the Authority or to any person participating in any activity or programme of the Authority pursuant to these Regulations or a contract issued under these Regulations, and designated by the contractor, in consultation with the Secretary-General, as being of a confidential nature, shall be considered confidential unless it is data and information which:

- (a) Is generally known or publicly available from other sources;
- (b) Has been previously made available by the owner to others without an obligation concerning its confidentiality; or
- (c) Is already in the possession of the Authority with no obligation concerning its confidentiality.

Paragraph (2) of the Regulation goes on to provide that data and information that is necessary for the formulation by ISA of 'of rules, regulations and procedures concerning protection and preservation of the marine environment and safety, other than proprietary equipment design data, shall not be deemed confidential'. Paragraph (3) goes on to restrict the use of confidential data to ISA officials and the members of ISA's Legal and Technical Committee in certain circumstances. Provision is also made for the periodic review of data by the Secretary General and the contractor to determine whether they should remain confidential. Regulation 37 goes on to set out additional procedures to ensure confidentiality.

In other words the Mining Code regulations take a slightly different approach to the issue of data and the confidentiality that they attract. Data provided by contractors is presumed to be confidential if so designated unless it falls within one of the exceptions provide for in Regulation 36(2) relating to the protection and preservation of the marine environment and safety'. In fact the precise wording of the regulation relates to data necessary for the formulation of rules, regulations and procedures for *inter alia* the protection of the marine environment but in practice such normative instruments can only be reasonably prepared on the basis of reliable datasets meaning that all data relating to the protection and preservation of the marine environment is deemed not to be confidential.

In practice, it is understood much of marine environmental data arrives at ISA in reports and datasets that are stamped 'confidential' meaning that it is up to ISA to determine which data really falls under this category.

In terms of the overall scheme for data management foreseen under UNCLOS and the Part XI Implementation Agreement, the recognition that commercially sensitive data should be treated as confidential is not unreasonable per se, not least given the enormous size of investments necessary for deep-sea mining. To this end data that is directly relevant to assessing the size of ore deposits is quite likely correctly to be classified as confidential data. But where exactly is the boundary line between marine environmental data that may potentially be accessed and that data which may not? Neither UNCLOS nor the Mining Code is entirely clear on this point. A further

²⁵⁸ Similar provisions are contained in the crusts and SMS regulations.

complication that arises here is that only very few organisations, mostly research institutions, are capable of obtaining the marine environmental data necessary for deep-sea mining and a number of these in turn seek to assert their copyright in the data they provide on a contract basis against both the contractors and ISA, thus creating another impediment for access to environmental information.

ISA is committed to publish a summary document of the submission for licences on its website, however these summary documents do not contain the baseline environmental data. Moreover, the environmental impact assessments from the exploration activity are published only when and if the 15 year period for the exploration contract has expired. This allows companies to apply for new exploration licences without having published environmental impact reports of their on-going processes. These factors are currently hindering the adequate evaluation of on-going practices and are seen as a barrier to transparency.

ISA itself does not appear to have a formal data policy. Moreover the ability of ISA to make the marine environmental data that it holds available to international civil society depends on that data being in a suitable format, such as a database or series of databases that can be accessed and interrogated, to enable this. However work on such a database has only recently commenced.

As regards the issue of transparency in respect of the commercial aspects of deep-sea mining, given that exploitation contracts have yet to be concluded for the Area there is no experience yet of this. In any event without sounding complacent it can be assumed that provisions in the future exploitation regulations that will complete the Mining Code will set out a clear and transparent mechanism for the levying by ISA of royalties in connection with deep-sea mining in the Area and that this will be effectively implemented by ISA given its particular characteristics as an international organisation that seeks to balance the interests of all of its members. Equally it can be anticipated that the issue of benefit sharing will be addressed in an equally transparent manner in due course. The international community will demand no less.

9.4.2 Transparency and deep-sea mining in areas under coastal State jurisdiction

As regards deep-sea mining in areas under coastal State jurisdiction the issue of transparency falls to be considered under the relevant laws of the country concerned. The extent to which such legislation can promote transparency, particularly in the case of developing countries is likely to be variable.

For a start many developing countries are unlikely to hold basic data on their marine respective environments. Such data is difficult and expensive to obtain and most developing countries simply cannot afford it. Consequently the main source of baseline environmental data on proposed deep-sea mining activities in developing countries will most likely turn out to be consultants employed by foreign companies seeking contracts to this end. Clear and effective mechanisms whereby civil society can gain access to such data and to participate in assessments of the environmental impacts of proposed deep-sea mining operations are clearly pre-requisites for transparency. It is fair to say that many countries lack such mechanisms in their national legislation. Even as regards the EU, while the scope of the Access to Environmental Information Directive appears to be sufficiently broad to cover marine environmental data relevant to deep-sea mining, deep-sea mining is not subject to the provisions of the EIA Directive.

Moreover, transparency also demands the existence of legal frameworks that clearly set out how deep-sea mining is to be authorized and ensure that appropriate standards are set and enforced.

The ACP-EU Parliamentary Assembly, in its resolution described above, stressed both: (a) ‘...the need both for transparent and efficiently enforceable legislative and regulatory frameworks governing the seabed mineral resources industry...’; and (b) ‘...that countries should ensure that seabed mining licences are issued via a transparent, competitive, and non-discriminatory procedure and that licences should include legally binding provisions on environmental and social standards’. Again as already seen in this report it is fair to say that most countries do not really have appropriate legislation designed for the specific features of deep-sea mining.

A further issue relating to transparency, or the lack of it, concerns the commercial aspects of deep-sea mining projects and just as importantly the final destination of royalty and other payments. Again the most rational approach to ensuring transparency is the adoption and implementation of effective legislation to this end. But this of course pre-supposes that legal systems work correctly and a certain level of governance that may be lacking in some countries. As already noted in this report, EU companies engaged in deep-sea mining in third countries are required in accordance with the provisions of the Accounting Directive to prepare and make public an annual report on payments made to governments thus including the level of royalty and other licensing payments made.



10 Conclusions and recommendations

10.1 Summary

It is very likely that explorations onto the compositions and quantity of minerals on the seabed will continue both on international waters (ABNJ) and in the EEZ of various countries. On the short-term these activities will concentrate primarily around the waters of Pacific Island States, where most of the exploration activities within EEZ areas are taking place.

It is also expected that at the short term the extraction licensed project, Solwara I from Nautilus will go-ahead and mining will commence sometime around 2015-2016. Another operation with strong potential is Atlantis II Deep in the Red-Sea which has also been granted an exploitation license. Several other on-going exploration projects may also be successful on the medium to long-term however currently there is not enough information and data on their findings and readiness levels to evaluate or forecast future potential. It is clear that while for some countries extraction of deep-sea minerals in their EEZ area can bring financial and economic benefits, the operations can also serve wider purposes, such as:

- understanding the deep-sea environment;
- facilitating further research and innovation for exploration and exploitation technologies including increasing seafloor drilling performance, gravity gradiometer²⁵⁹, acoustic corer²⁶⁰, subsea gliders as well as increased use of Prompt Gamma Neutron Activation Analysis for grade control etc.;
- ensuring security of supply for raw materials.

Since the Exclusive Economic Zones of EU Member States – apart from the Azores islands – will unlikely to be subjected to deep-sea mining due to the lack of mineral reserves, the role of European stakeholders in the sector can be two-fold:

- On the one hand the European Commission and the individual Member States are expected to remain an important player in financing research and innovation in exploration, extraction and monitoring devices that may be used for seabed mining;
- On the other hand European private enterprises are likely to continue their involvement as technology and service providers.

Based on the research and interviews carried out in the study the following recommendations are made:

6. Increasing the intensity of bilateral and multilateral communication with Pacific Island States with specific focus on deep-sea mining and possible criteria or standards for environmental assessment and minimum standards for technological requirements (as a way to ensure conformity of requirements across countries);
7. Setting up focused research projects – via available mechanisms such as Horizon 2020 - for issues identified as of primary gaps in the industry (increased performance of seafloor drilling, subsea AUV mounted gravimeter/gradiometer²⁶¹, sub-sea laser imaging, material handling, dewatering, alternative fuels etc.);

²⁵⁹ Measuring the Earth's density needed to identify the more significant subsurface metal accumulations that would not be seen from surface or water column mapping. Gravity gradiometers already exist for terrestrial exploration and they require miniaturisation to be fit onto an AUV.

²⁶⁰ Subseafloor imaging (Pan Geo Subsea tool) for hard rock environment

²⁶¹ Gravity gradiometer is required to identify the more significant subsurface metal accumulations of economic significance. While gravity gradiometers currently exist they need to be miniaturised to fit on an AUV.

8. Training and advisory services for the Pacific Island States through the SOPAC office or other initiatives;
9. Expanding communication with the International Seabed Authority involving EU directorates with direct and relatable experience with stakeholders in the field (DG MARE, DG ENTR);
10. Communication between relevant DGs and the International Marine Minerals Society on expanding and integrating their seabed mining code of conduct into EU guidelines.

In relation to the environmental impacts, based on the analysis carried out, it is our understanding that future research should narrow its focus towards the most relevant and pressing technology needs related to ocean observation (remote sensing as well as in-situ monitoring) and potentially draw on the approach set out by the Marine Strategy Framework Directive (MSFD) to monitor/evaluate environmental status. Technology and methodological advancements could be accommodated into an evolving precautionary approach. Indeed some observational technology could be built directly into industry infrastructures, something already under consideration with oil and gas infrastructures. Ultimately, impact-related research should lead to a better understanding of deep-seabed ecosystems around the world.

10.2 Conclusions on the potential and environmental impacts of deep-sea mining

It is likely that explorations onto the compositions and quantity of minerals on the seabed will continue both on international waters (ABNJ) and in the areas under coastal state jurisdiction of various countries. On the short-term these activities are expected to concentrate primarily around the waters of Pacific Island States, where most of the exploration activities within coastal state jurisdiction areas are taking place.

It is also expected that the so-far only extraction licensed project, Solwara 1 from Nautilus will go-ahead and mining will commence sometime around 2015-2016. Another operation with strong potential is Atlantis II Deep in the Red-Sea. Several other on-going exploration projects may also be successful on the medium to long-term however currently there is not enough information and data on their findings and readiness levels to evaluate or forecast future potential. It is clear that while for some countries extraction of deep-sea minerals in their areas under coastal state jurisdiction can bring financial and economic benefits, the operations can also serve wider purposes, such as:

- understanding the deep-sea environment;
- facilitating further research and innovation for exploration and exploitation technologies including increasing seafloor drilling performance, gravity gradiometer²⁶², acoustic corer²⁶³, subsea gliders as well as increased use of Prompt Gamma Neutron Activation Analysis for grade control etc.;
- ensuring security of supply for raw materials.

It is well-understood that all of the above listed benefits come with the *price* of disrupting the deep-sea ecosystems as a result of the appearance of the vessels and machines carrying out the exploitation and extraction. The level and extent of the impact can only be understood if EIA and monitoring activities accompany and follow each individual exploration and exploitation activity. All commercial activities carried out on the seas will need to respect marine biology and seek to minimise all impacts arising from the operations. It is essential that the EIAs and monitoring

²⁶² Measuring the Earth's density needed to identify the more significant subsurface metal accumulations that would not be seen from surface or water column mapping. Gravity gradiometers already exist for terrestrial exploration and they require miniaturisation to be fit onto an AUV.

²⁶³ Subseafloor imaging (Pan Geo Subsea tool) for hard rock environment

activities are carried out – either by mining companies or third parties - according to a set of standards or criteria which make their results verifiable and comparable. Consequently, reporting on the impacts of the activities against the standards or criteria would need to be made obligatory for all seabed mining operators requiring the involvement of international authorities/regulatory bodies.

Moreover, the geo-political issue of raw material supply cannot be ignored. While land-based resources of those metallic elements that can be resourced from the seabed are available they are, for the most part, located in territories external to the European Union. Therefore, securing areas for exploration - whether it is in the high-seas (ABNJ) or in EEZ - can have strategic importance for the EU. This is a crucial point for the European industries as they seek to ensure reliable resources.

10.3 Conclusions on the technological aspects

The following the assessment of the individual reports within the study the following conclusions were drawn regarding the three different types of minerals:

- Technology for the exploitation of seafloor massive sulphides deposits is the most advanced and it is believed that mining projects will commence on the short term. Currently, there is no conclusive evidence that would suggest that economically efficient extraction of SMS would be possible at a large number of sites Currently short to medium term validity is foreseen. ;
- Potential for large-scale extractions for nodules might be greater, however cost-efficient: extraction will depend on perfecting a riser technology to lift REE's;
- Crusts also offer commercial scale extraction potential and at the same time suffer from the same limitation as nodules. In addition to the fact that resource value is challenging to define as it depends on many aspects – thickness, continuity of grade etc. which require sub-seabed sampling. Thickness is critical for extraction – any extraction method either has to successfully separate the crust from the bedrock or has to be sufficiently economically viable/robust to allow incorporation of underlying bedrock and hence dilution into extraction stream).

10.4 Conclusions on legal elements

The following conclusions can be drawn in terms of the different levels of law that are relevant to deep-sea mining:

International law

- the basic legal framework for deep-sea mining, including as regards regulatory jurisdiction, is set out in UNCLOS as modified by the Part XI Implementation Agreement;
- the regulatory regime for deep-sea mining in the Area is not yet complete. While regulations on explorations have been adopted, ISA is currently in the process of developing regulations on exploitation during the course of which a number of complex issues, such as the basis on which royalties will be set and appropriate environmental standards, will need to be addressed;
- the Advisory Opinion of the Seabed Disputes Chamber has shed important light on the notion of State 'sponsorship' of contractors and the need for such States to adopt laws, regulations and administrative measures to ensure compliance by contractors;
- as regards deep-sea mining in areas under national jurisdiction coastal States clearly have regulatory jurisdiction in terms of international law and can design and adopt their own legislation accordingly. There are no international standards for deep-sea mining in areas

under national jurisdiction although UNCLOS requires that such activities should be subject to EIA. What is less clear is the extent to which environmental standards adopted by ISA in the future as regards exploitation of mineral resources in the Area will influence coastal States meaning that there is a risk that different, stricter standards may apply in the Area than in areas under coastal State jurisdiction;

- although coastal States are subject to a number of obligations in terms of international agreements of global or regional application, these tend to be of a rather general nature and the extent to which they may affect deep-sea mining is not entirely clear. In due course there may be a need for the establishment of specific standards for vessels or platforms engaged in deep-sea mining;

EU law

- the EU and all of the Member States are party to UNCLOS and EU law applies to maritime areas over which the Member States have jurisdiction;
- unlike marine hydrocarbon extraction the topic of deep-sea mining is not yet directly addressed in EU law;
- although plans or programmes that relate to deep-sea mining would be subject to the SEA Directive, deep-sea mining projects are not subject to the EIA Directive. Environmental data relating to deep-sea mining is subject to the Environmental Information Directive;
- while existing general EU waste legislation would apply to deep-sea mining the specific directive on mining waste does not. This may become problematic in the future given the specific nature of mining waste generated by deep-sea mining;
- while EU environmental liability legislation is potentially applicable to deep-sea mining, its effectiveness might be reduced due to the need to prove fault on the part of an operator before liability can be established;
- other environmental legislation may impact on how deep-sea mining is undertaken in European waters but will not prevent it taking place;
- European companies engaged in deep-sea mining both in European waters and elsewhere in the world are subject to the specific reporting requirements of extractive industries under the Accounting Directive.

National legislation

- turning first to national legislation that governs deep-sea mining in the Area, notwithstanding the Advisory Opinion of the ITLOS Seabed Chamber, many States have yet to adopt the necessary laws, including States that are active in ISA in particular or deep-sea mining in general;
- out of the eight Member States considered in this Study, only two, Germany and the UK, have legislation on deep-sea mining in the Area in place, although France has informed ISA that the preparation of such legislation is under way. Other EU Member States that have specific legislation on deep-sea mining in the Area are Belgium and the Czech Republic;
- none of the OCTs have legislation in place on deep-sea mining in the Area;
- many of the other countries considered in this study that have adopted legislation on deep-sea mining in the Area were party to the interim agreements that preceded UNCLOS. Most, but not

all of these States, have updated their laws following the entry into force of UNCLOS. One exception in this respect is the USA which is not party to UNCLOS but which has retained its original legislation on deep-sea mining in the Area;

- as regards national legislation to regulate deep-sea mining in areas under national jurisdiction, in most of the countries considered in the preparation of this Study, the situation is less often that of specific deep-sea mining legislation and more often the case that terrestrial mining legislation applies to the continental shelf or EEZ. In a number of cases, terrestrial mining legislation has been modified so as to include specific reference to deep-sea mining. Only the USA has specific legislation in place on deep-sea mining in areas under its national jurisdiction;
- although deep-sea mining and terrestrial mining are both concerned with the extraction of mineral ores from the ground, the extent to which terrestrial mining legislation is really suitable for application to the sea is surely questionable. The practical questions raised by the case of PNG are instructive in this respect as well as pertinent given that it is anticipated that PNG will be the first State to actually experience deep-sea mining within its waters. Also noteworthy, given that the nearby seabed appears to offer some of the most promising possibilities for deep-sea mining in European waters, is the fact that the Administration of the Azores took the decision to develop specific legislation for deep-sea mining, even though this was subsequently ruled unconstitutional.

10.5 Conclusions for EU industries

Marine mining and deep-sea mining are part of the EU's Blue Growth strategy under the thematic area of marine mineral resources²⁶⁴. According to the Communication, up to 10% of global production of minerals such as cobalt, copper and zinc could come from the ocean floors by 2030, providing global annual turnover of up to €10 billion. In the Blue Growth study, the current size of the sector was estimated at less than 250 jobs and less than € 0.5 bn turnover, however with a strong growth outlook. The activities of EU research centres and industries in research projects and in exploration project participations suggest that these figures have risen, although no quantitative overall figures exist.

Based on this current study it seems **unlikely that the projected 10% seabed mineral extraction would be feasible to achieve by 2030**. As an educated guess the study team estimates that a maximum of 2-4% of global production of minerals could be sourced from the deep sea by 2050. Despite this slower progress it is likely that the sector, which is heavily research and innovation driven, would be able to increase its turnover via the sales of research vessels and specialised equipment. It is also likely that an increasing – but still limited – number of private enterprises would be involved in one or more stages of deep-sea mining. This however, will unlikely to materialise in a significant increase in employment due to the sectors rather specialised skill requirements.

In terms of competitive positioning, as shown already in the marine minerals sub-function analysis that was part of the Blue Growth study, the EU-27 ranked second in terms of inventions related to this field, after the USA and before China, Japan and Korea, based on 2010 data. In terms of scientific citations the EU leads the rankings. However, in terms of patents assigned the picture is more mixed, with several large EU companies present along with enterprises from China, Korea

²⁶⁴ European Commission (2012): Blue Growth Communication, http://ec.europa.eu/maritimeaffairs/policy/blue_growth/documents/com_2012_494_en.pdf.

and other parts of the world. This suggests that the economic value in terms of industry involvement needs to be addressed in further detail so as to identify potential strengths and weaknesses, as well as competitive advantages and disadvantages.

Growth in employment would very much depend on the number of projects taking place at the same time. In the case of deposits such as nodules this is expected to be limited to less than a handful due to the fact that in the foreseeable future terrestrial mines can supply global demand. – Consequently, one may expect jobs to be in the order of 100s rather than 1000s. In addition to the mining operations, service and maintenance may require additional employment. In the latter category European service suppliers in related marine sectors (marine contractors, oil & gas service suppliers) are also in relatively strong competitive positions.

The potential role for the EU industry related to the main components of the value chain is presented in the table below.

Table 10.1 Potential Blue Growth contribution of European industry in the various DSM stages

Stage	Role for European industry	Importance for Blue Growth
Manufacturing equipment	Manufacturing of key technologies in which EU industry base has a leading position (offshore technology in general, and drilling, dredging, pumping etc. technologies in particular – see ch.4 and annex 3).	High
Exploration services	Provision of services for exploration (e.g. identifying sources, measuring quality, surveying impacts). Several leading institutes and enterprises present, but not alone.	Moderate
Exploitation services	(servicing mining equipment, maintenance, operations assistance). Links with manufacturing base above. Some EU operators in the dredging & oil industry might evolve into major contributors here, but this will also depend on the business model development.	Moderate
Logistics	Mature sector & largely mature technologies, no particular advantages for EU players	Average
Processing and downstream	No major mining companies headquartered in Europe.	Low

In the supply of technologies and services to setting up the mining systems, as indicated above EU industries are well-placed. With capital investment in the order of € 1 billion for each mining operation, the associated labour input can be substantial. If an added value of € 100,000 per employee per year is assumed²⁶⁵, one operation would then incur 10,000 person-years of work. The total number of jobs will depend on the number of installations to become operational per year.

²⁶⁵ According to the “Netherlands Maritime Monitor 2013” conducted by Ecorys for Maritime by Holland, the value added per employee of the shipbuilding industry in the Netherlands in 2012 amounted to (745 mln / 9250 jobs = appr. € 80,000 per person-year. For indirect jobs this figure amounts to appr. € 98,000 per person-year. We assume that both figures will be higher for high tech vessels than for the shipbuilding sector as a whole.

Table 10.2: Mineral content of seafloor massive sulphides

Document		Sulphides					Recovery					
No.	Author	Year	Cu	Au	Zn	Pb	Au	Cu	Au	Zn	Pb	Au
1	Martijn van Wijngaarden and Richard Burger, students BSC of the minor Deep Sea	2013	5-15%	2 - 20 g/t	5-50%	3-23%						
3	Masuda e.a.	2014	1-30%	2,6-6,4 g/t	30-55%	0,1-0,3%	23-216 g/t					
4	T. Yamazaki	2008	1,66 %	1,4 g/t	10,50 %	2,45 %	113 g/t					
5	Hegedus e.a.	2010	26%	15 g/t	15%		200 g/t					
9	Solwara Report Q1	2011	7,30 %	3.6 g/t	3,60 %		56 g/t					

Document		Revenues						
No.	Author	Year	Payback period	\$/pta	Royalties	Taxes	NPV	IRR
4	T. Yamazaki	2008	3.1 years				209 M\$	61%
8	LRET, Volume IV	2012					> 1 billion \$	26%

Table 10.3 mineral content of nodules

Document		Nodules					Recovery				
Author	Year	Mn	Co	Cu	Ni	Ti	Mn	Co	Cu	Ni	Ti
Darryl Thorburn	2014	18,00%	0,40%	0,20%	0,30%	1,10%		83%	97%	98%	
Hillman and Gosling	1985							65%	92%	92%	
Andrews e.a.	1983						93%	85%	95%	95%	
Charles e.a.	1990						93%	85%	95%	95%	

Document		Nodules					Recovery				
Author	Year	Mn	Co	Cu	Ni	Ti	Mn	Co	Cu	Ni	Ti
LRET	2012		0,20%	1,10%	1,40%						
Imperial	2010	20,00%	0,50%	0,20%	0,70%						
Aker Wirth GmbH	2013	28,80%	0,16%	1,17%	1,36%			89% - 95%			
Rahul Sharma	2011	24,00%	0,10%	1,04%	1,10%			71-85,5%			
Collegium Volume II	2012	24,00%	0,20%	1,12%	1,44%			90%	94%	97%	
Solwara Report Q1	2011	26,80%	0,24%	1,10%	1,20%						

Document		Revenues				Outcome		
No.	Author	Year	Payback period	\$/pta	Royalties	Taxes	NPV	IRR
1	Darryl Thorburn	2014	9 years					
2	T. Yamazaki	2008	5.7 years			30%	902 M\$	23%
3	Soreide e.a.	2001				10%	-81 M\$	-9,60%
5	Andrews e.a.	1983				46%		6,40%
6	Charles e.a.	1990						12%
7	LRET	2012		550 \$/pta		9,50%	361 M\$ (8%)	14,80%
8	Imperial	2010		548 \$/pta		27%	293 M\$ (10%)	13,90%
14	Golder Associates	2013			\$ 1.25 p/t (< 3 Mt) and \$ 0.75 (> 3 Mt)			
16	Collegium Volume II	2012					361 M\$ (8%)	14,75%

Table 10.4 mineral content of crusts

Document		Crusts			Recovery		
Author	Year	Co	Ni	Cu	Co	Ni	Cu
T. Yamazaki	2008	0,64%	0,5	0,13%			

Document		Revenues				Outcomes		
No.	Author	Year	Payback period	\$/pta	Royalties	Taxes	NPV	IRR
1	T. Yamazaki	2008	NA				NA	NA

10.6 Possible recommendations for the EU

Since the EEZ of EU Member States – apart from the Azores islands - will unlikely to be subjected to deep-sea mining due to the lack of mineral reserves, the role of European stakeholders in the sector can be two-fold:

- On the one hand the European Commission and the individual Member States are expected to remain an important player in financing research and innovation in exploration, extraction and monitoring devices that may be used for seabed mining;
- On the other hand European private enterprises are likely to continue their involvement as technology and service providers.

Based on the research and interviews carried out in the study the following recommendations are made:

1. Increasing the intensity of bilateral and multilateral communication with Pacific Island States with specific focus on deep-sea mining and possible criteria or standards for environmental assessment and minimum standards for technological requirements (as a way to ensure conformity of requirements across countries);
2. Setting up focused research projects – via available mechanisms such as Horizon 2020 - for issues identified as of primary gaps in the industry (increased performance of seafloor drilling, subsea AUV mounted gravimeter/gradiometer²⁶⁶, sub-sea laser imaging, material handling, dewatering, alternative fuels etc.);
3. Training and advisory services for the Pacific Island States through the SOPAC²⁶⁷ office or other initiatives;
4. Expanding communication with the International Seabed Authority involving EU directorates with direct and relatable experience with stakeholders in the field (DG MARE, DG ENTR);
5. Communication between relevant DGs and the International Marine Minerals Society on expanding and integrating their seabed mining code of conduct into EU guidelines.

Finally, with regard to the environmental impacts based on the analysis carried out within this study, it is our understanding that future research should narrow its focus towards the most relevant and pressing technology needs related to ocean observation (remote sensing as well as in-situ monitoring) and potentially draw on the approach set out by the Marine Strategy Framework Directive (MSFD) to monitor/evaluate environmental status. Technology and methodological advancements could be accommodated into an evolving precautionary approach. Indeed some observational technology could be built directly into industry infrastructures, something already under consideration with oil and gas infrastructures. Ultimately, impact-related research should lead to a better understanding of deep-seabed ecosystems around the world.

²⁶⁶ Gravity gradiometer is required to identify the more significant subsurface metal accumulations of economic significance. While gravity gradiometers currently exist they need to be miniaturised to fit on an AUV.

²⁶⁷ Applied Geoscience and Technology Division of the Secretariat of the Pacific Community, www.sopac.org

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Annexes

In a separate file, the following annexes are included:

1. Geological analysis;
2. Legal analysis;
3. Supply and demand analysis;
4. Technological analysis;
5. Analysis of ongoing and planned activity; and the
6. Environmental analysis.

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