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Deep-seabed exploitation

Tackling economic, environmental and societal challenges

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Technology options for deep-seabed exploitation

Tackling economic, environmental and societal challenges

Study

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This report would not have been possible without the kind support and help of many individuals and organizations. We would like to extend our sincere thanks to all the stakeholders who provided input via the interviews.

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Abstract

Exploration and exploitation of the deep-seas in search of marine minerals and genetic resources have over the past 15 years received increased attention. Developments in sub-marine technologies, rising raw material prices and scarcity, and advancements in biotechnology are changing the business-case for furthering activities in the marine environment. This report provides a state-of-play overview on exploring and exploiting deep-sea resources. A Cost-Benefit Analysis identifies the main potentials and challenges in a scenario where exploitation increases. Policy options are suggested to balance trade-offs between economic, social and environmental aspects associated with future developments.

For deep-sea minerals, the future remains uncertain regarding to what extent the seafloor will be tapped of its resources on a commercial scale. Industry players active in the field are generally confident that it is a matter of time before mining will begin. However, there are no commercial activities to date and prospects have been delayed repeatedly. Moreover, there are uncertainties regarding the legal framework and the environmental and social impacts of large scale deep-sea mining.

For biological resources the biotech and pharmaceutical sector sees large potentials for finding more applications from marine genetic and biological resources and European research is on the forefront of the developments. However, competition is fierce with, in particular, companies from the US, Japan and China filing for patents. In comparison with marine mineral resources, the environmental and social impacts of exploration and exploitation are expected to be less significant.

European research and companies are in the forefront on exploration and exploitation of deep-sea resources. The success of the sector to date has relied much on collaborations between public and private actors which underscores the importance for public support and legal framework for operation.

CONTENTS

LIST OF ABBREVIATIONS

ABNJ	Areas Beyond National Jurisdiction
Ag	Silver
Au	Gold
AUV	Autonomous underwater vehicles
BBNJ	Ad Hoc Open-ended Informal Working Group on marine biological diversity beyond areas of national jurisdiction
bn	Billion
CAPEX	Capital Expenditure
CBD	Convention on Biological Diversity
CCZ	Clarion-Clipperton Zone
CCFZ	Clarion-Clipperton Fracture Zone
Co	Cobalt
Cu	Copper
DSM	Deep-sea Mining
EC	European Commission
EEZ	Exclusive Economic Zone
EIA	Environmental Impact Assessment
EIS	Environmental Impact Statement
EMP	Environmental Management Plan
EP	European Parliament
EU	European Union
FAO	Food and Agriculture Organization
FP7	7th Framework Program
GES	Good Environmental Status
IFREMER	Institut français de recherche pour l'exploitation de la mer (French Research Institute for Exploitation of the Sea)
IMMS	International Marine Minerals Society
IOC	Intergovernmental Oceanographic Commission
ISA	International Seabed Authority
ITLOS	International Tribunal for the Law of the Sea
IUCN	International Union for Conservation of Nature
Li	Lithium
LOSC	Law of the Sea Convention
LTC	Legal and Technical Commission
MEPs	Members of the European Parliament
MGR	Marine Genetic Resource
Mn	Manganese
mn	million
MSFD	Marine Strategy Framework Directive
Mt	Million ton
NGO	Non-governmental Organisation
Ni	Nickel

OPEX	Operating Expenditure
PCZ	Prime Crust Zone
PNG	Papua New Guinea
ppm	Parts per million
Pt	Platinum
REE	Rare Earth Element
ROVs	Remotely Operated Vehicles
SMS	Seafloor Massive Sulfides
SPC	Secretariat of the Pacific Community
SOPAC	Applied Geoscience and Technology Division of SPC
TRIPS	Trade-Related Aspects of Intellectual Property Rights
TRL	Technology Readiness Level
UMI	Underwater Mining Institute
UNCLOS	United Nations Convention on the Law of the Sea
UNGA	United Nations General Assembly
Zn	Zinc

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EXECUTIVE SUMMARY

The attraction of harvesting the potential riches of the deep-seas is gaining interest. New technologies for exploring and exploiting raw materials and genetic resources from the seas at great depths, coupled with uncertain resource markets, have spurred enthusiasm from a range of stakeholders including public actors such as states and regions as well as companies and industry organizations to explore the possibilities. Over the past ten years, we have witnessed high and volatile raw material prices, the use of rare minerals as tactical geopolitical tools, and several life-saving drugs being developed, based on marine genetic resources. However, the potential start of harvesting the seas in often pristine, and potentially unique ecosystems and habitats, also has its critics, in particular from environmental and civil society groups but also concerned states. There is very little knowledge on how potentially dramatic perturbations will affect the deep-seabed. And how does one distribute the risk and gains in a fair and transparent manner? Ultimately, the challenge is to decide on trade-offs between the economic, environmental and social aspects of deep-sea mining for raw materials and utilization of genetic and biological material. This report is an attempt to inform decision-making in these often difficult and highly uncertain questions.

When defining the deep sea, the deep-sea starts where the continental shelf ends, i.e. at depths greater than 200 meters. Deep-sea resources are thus generally found in the high-seas and beyond the Economic Exclusive Zone's (EEZs) of nation states. The deep-sea resources are divided into raw material resources and biological resources. Raw material resources include minerals of the most interest to deep-seabed miners including poly-metallic nodules, poly-metallic sulphides and cobalt-rich ferromanganese crusts, which contain valuable minerals such as silver and gold but in particular copper, manganese, cobalt, zinc and rare earths. Genetic and biological resources are those used by, mainly, pharmaceutical, biotechnology and cosmetic industry for different applications to develop new medicine, chemicals or cosmetics.

Based on a large literature review and interviews with 23 experts from academia, NGOs, companies and public authorities, the following observations were made.

What are the main knowledge gaps and risks?

Industry and researchers, in terms of the location of mineral deposits, have a fairly good overview of proven and inferred sites that could be interesting for further exploration. The main knowledge gaps are currently regarding the concentration and size of the resources. This is a major impediment because uncertainty in terms of concentrations and magnitude hinders a robust cost and benefit assessment to be carried out at the individual project level. For instance, the deposits identified by Nautilus in the Solwara 1 resource, the worlds at this point most advanced project for deep-sea mining, are only enough for a couple of years mining. Consequently, it is uncertain whether the enormous investments required for starting up operations, for example building a ship (up to EUR 1 billion), are economically viable. Biological resources do not share the uncertainties of mining in terms of deposits. The scientific evidence shows that the potential for finding new genes is large, particularly in the microbial realm, with more than 1.2 million previously undescribed genes on one cubic meter of water. However, even if the exploration and inventory of marine species have sped up rapidly over the last few years, at current rate, it would take another 250 to 1,000 years before all species are analysed.

In terms of technological gaps to start mining, industry representatives seem confident that once the business-case is there, the current level of technology will not stand in the way. Much has been learnt from deep-sea drilling in the oil and gas industry which have developed techniques to make drilling at up to 2,000 meters common-place. The technologies for mining differ, however, per resource. For both seafloor massive sulfides (SMS) and manganese nodules, technologies are there (at least the blueprints) to start mining. For crusts, the case is slightly different due to the hard character of the seafloor in which the deposits are situated. Therefore, crusts are, technologically, the most challenging type of resources at this point.

Again, for biological resources, the main technological challenges are not in the marine environment but rather on the analytical capacity in laboratories on land.

Across the board, the main gaps and risks appears to be situated in what one interviewee termed "the social and environmental license [for companies] to operate". For deep-sea mining beyond areas of national jurisdiction, the regulatory framework with regards to exploitation is under slow development. As a result, entrepreneurs lack the rules for playing the game and this scares off investors. Environmental groups and many scientists on their hand, argue that the risk for environmental damage to ecosystems we know very little of, is unacceptable and call for rigorous regulation based on the precautionary principle and Environmental Impact Assessments (EIA).

What is the legal framework at the international and European level?

Most of the deep-sea resources examined in this report are situated beyond areas of national jurisdiction and under international waters which complicates the legal framework under which companies and states are expected to operate. Due to the nascent and relatively new issues that have arisen from both mining and the use of genetic resources, there are still large regulatory uncertainties and gaps that need to be filled. The key international regime governing the oceans is the United Nations Convention on the Law of the Sea (UNCLOS), which was adopted in 1982 and entered into force in 1994, signed and ratified by the majority of the world's countries (currently 166 parties) with some notable exceptions, such as the United States of America (USA), is at this point in time the main forum for negotiation.

To govern and coordinate deep-seabed issues, in particular deep-sea minerals, an autonomous international organization called the International Seabed Authority (ISA) has been created under UNCLOS in 1994. All States Parties to the Convention are automatically members of the International Seabed Authority. Currently ISA has adopted regulations on exploration for Nodules (2000), Sulphides (2010) and Crusts (2012), while regulations on exploitation are being developed. Besides multilateral treaty-making, the IMMS Code for Environmental Management of Marine Mining, a transnational non-state initiative in areas beyond international legal regimes for regulating deep-sea mineral resources, has been developed by the International Marine Minerals Society (IMMS). The code was initiated in the year 2000 by IMMS mining industry members at UMI (Underwater Mining Institute), revised in 2011 and is today used by several important players, for example the ISA, EU, the Secretariat of the Pacific Community (SPC), and New Zeeland.

The governance of biological and genetic resources in areas beyond national jurisdiction is less well regulated. Article 133(a) under the UNCLOS, which defines "resources of the Area" is limited to "mineral resources", i.e. the competencies of the ISA are therefore restricted to raw materials and minerals. This is largely because marine bioprospecting, at the time of drafting, was yet to be developed. Instead, a central legal challenge is the sharing of the benefits reaped by companies and developed countries which currently are safe-guarded by a rigorous international patent-system under the TRIPS agreement. Nevertheless, while there is a large gap in international legislation aiming to regulate biological resources, there are several intervening pieces of legislation, in particular environmental legislation. For example, the 1992 Convention on Biological Diversity (CBD) defines biodiversity and promotes the sustainable use of its components, the conservation and the fair sharing of benefits of the genetic resources in areas under national jurisdiction. The Nagoya Protocol on Access to Genetic Resources and the Fair and Equitable Sharing of Benefits Arising from their Utilization (the Nagoya Protocol) to the CBD, which was adopted in 2010, tried to clarify the jurisdictional scope of the CBD in this matter.

The UNCLOS needs further development to accommodate new demands. In August 2015, several Member States envisage an implementation of UNCLOS, with the most likely scenario being the creation of a "package" which takes into consideration a "future global regime for the conservation and sustainable use of marine biodiversity in areas beyond national jurisdiction". At the EU level, the next years will be crucial to develop EU position, by looking at ISA regulations and the progress done at international level, while taking into consideration existing EU legislation (for example the Marine Strategy Framework Directive and other environmental legislation).

What are the main technologies for exploration and exploitation activities?

For both mining and biological resources there are a few key technologies of particular importance. In both the exploration and the exploitation phase, the availability of modern and adequately equipped ships is central. For the exploration, there is already several such ships in operation, often linked to national research institutes and geological surveys. Research cruises are expensive matters and a vessel costs around 50,000 – 100,000 EUR/day in operation. Another key technology is Remotely Operated Vehicles (ROV) which can be used for all different resources in mining. Seafloor Massive Sulfides (SMS) can be collected by ROVs, before they are piped up to the surface. Manganese nodules, which litter the ocean floor beneath a blanket of silt, can be sucked up from the seabed by ROV-vacuums. These ROVs can then deliver them to the surface. Manganese crusts can be harvested by ROVs that drive along the ocean floor and grind up the crust. These ROVs then deliver the mixture to a lift system, which pipes it up to a surface vessel. Furthermore, a deep-sea mining system generally has four components: and extraction tool, a lifting system, a surface platform, and a disposal system. Our report includes an overview of the "technology readiness level" (TRL) of each component. Overall, the TRL is fairly low with several of the technologies in the value chain needing further development.

What are the main economic aspects and costs? What are the main benefits?

The business case for deep-sea mining and biological resources follows different logics. In the case of mining, exogenous forces, including resources prices and cost of capital, are important factors in the equation. For the mining itself, the initial invested capital (CAPEX) for building ships and developing the technology needed are substantive. Not all projects are commercially viable but decisions to go offshore are in many cases strategic. The mining industry has always been a high cost industry, and it is always important to compare the costs of deep-sea mining with terrestrial mining. In the latter case, the overall costs, including the costs of complying with environmental and safety regulation, the fixed infrastructure costs and the cost of labour can make mining deposits in deep-sea attractive for investors.

In this report, an overview of the deep-see mining value chain, the technologies and the estimated costs is given. One day of exploration will cost more than $100,000 a day; most exploration trips need a budget of $50 to 200 million. For exploitation, the costs run in hundreds of millions of euro, depending on the deposit and location. The largest costs are the costs of the vessel, drilling and the cost of crew. In terms of economic benefits, much is decided by the previously mentioned exogenous factors, mainly depending on what market price for the specific resource at the time of sale and the cost savings deep-sea mining can generate vis-à-vis terrestrial mining.

For biological resources the costs structure of venturing into the deep-sea is much different since the sampling and collection under water is limited. For exploration, the costs for vessel time and ROVs are expected to be similar to that of mining. However, the largest costs are in the analysis, research and development of applications for the biotech industry which overall has a high risk/high return structure. Unfortunately, there are few specific figures available for the later step.

What are the main environmental and societal impacts?

The deep-sea is the largest ecosystem on earth, but it remains among the least explored. The deep-sea is recognized as a carbon sink for the planet[1] and human activities such as bottom trawling are already showing the negative impact. Scientists have estimated that as many as 10 million species may inhabit the deep-sea[2]. Deep-sea research surveys continue to discover new geological features, species and ecosystems, including new hydrothermal vents and their unique biodiversity[3].

The European Commission has funded a number of projects focussed on enhancing knowledge of the deep-sea (Hermes; Hermione; DeepFishman; CoralFish; MIDAS). The most relevant project related to deep-sea mining, is the MIDAS Project whose objective is to assess and enhance the state of knowledge of the potential impacts of mining on hydrothermal vent; abyssal plain and seamount ecosystems in the deep-sea. One of the issues highlighted thus far within the project is that despite the many gaps in the scientific knowledge of deep-sea areas of potential interest to the mining industry, the International Seabed Authority does not publicize the scientific information collected by contractors which have obtained licenses to for exploratory mining activity. It is thus difficult to independently assess the impact of mineral exploration and, more importantly, whether sufficient baseline information is being collected to be able to conduct an effective environmental impact assessment prior to text mining or full scale commercial mining. Environmental NGOs as well as other stakeholders have called on the ISA to become more transparent, to allow for greater participation of stakeholders and to ensure that effective conservation oriented regulations are adopted before commercial mining starts.

It is difficult to fully estimate the real environmental impact of deep-sea mining exploration and exploitation activities due to the fragility of these ecosystems, the unknown resilience of this system and as well as the effectiveness of the anticipated efforts to assist natural recovery. Nevertheless, it is predicted that these activities will have significant effects if not properly regulated. When it comes to environmental impacts, bioprospecting of marine genetic resources cannot really be compared with deep-sea mining due to the different techniques to extract the resource and the dimension of area considered. However, due to the small scale of harvesting resources, the environmental impacts are expected to be relatively small.

In terms of deep-sea mining, the most relevant social impacts will likely be associated with several key changes during the mining life cycle, which is potentially a long one (20 - 30 years) and may apply to different stakeholder groups at household, local, regional, national, and international level. Exploration is already occurring in different regions in the absence of regulatory regimes or conservation areas to protect the unique and little known ecosystems of the deep-sea. It is also often lacking sufficient participation by the communities in the decision-making. When it comes to exploitation activities concerns become even more serious as ownership in the marine environment is to some extent unclear or varies depending on exact seabed location (EEZ or area beyond national jurisdiction). It may also be subject to traditional, national, and international norms, laws, and agreements and may be viewed as national property in which every citizen has an interest. This further complicates processes of consultation, usage, and ownership. On the other hand, substantial societal benefits of mining may include, but are not limited to, employment, local procurement, investment in infrastructure, and local business opportunities. Moreover, the society will benefit from new technologies, research and innovation (and development of new medicines/drugs in case of bioprospecting).

[1] Koslow, T. Human impacts on the deep sea: dumping & pollution, mining and fisheries impacts. Available at: http://iod.ucsd.edu/courses/sio277/Hexploit.pdf

[2] Deep sea conservation coalition (2015). Available at www.savethehighseas.org

[3] Qui, J. (2011). Available at http://www.nature.com/news/indian-ocean-vents-challenge-ridge-theory-1.9689

What are the next steps and what could the EU do?

The EU holds a good position in terms of both exploration and exploitation of deep-sea resources. In terms of mining, EU-members like France, Germany, the UK and Belgium have licences with the ISA to conduct exploration. Portugal also has a forefront position due to its possible deposits in the waters of the Azores. For technological development, research institutes and companies in Germany, the Netherlands, France and the UK, have the capacity and knowhow to develop the tools needed to start exploitation. For bioprospecting, European companies such as Bayer and BASF have leading positions in terms of number of patents related to marine organisms.

The EU has actively supported a number of research initiatives on deep-sea resources, mainly through the FP6, FP7 and Horizon 2020 programmes. For example, projects such as BlueMining, MIDAS, PharmaSea and ESONET, contribute in specific ways to build a vibrant and vital research community positioning the EU in the forefront of deep-sea exploration and exploitation.

There are several policy options that the EU could take, addressing technological, legal, environmental, economic and social knowledge gaps and challenges. These range from supporting a pilot mining project, contributing to the development of the legal framework, encouraging communication and knowledge sharing, or alternatively resorting to increased recycling rather than deep-sea mining.

1. INTRODUCTION

Interest in the potential riches of the deep-sea has been waxed and waned since the 1960s and explorers have dreamed about grazing the seabed for valuable mineral and biological resources. Yet to date, few large-scale commercial ventures are operational. Fear of high risk and costly investments coupled with a lack in technical capacity have impeded more extensive operations. Recently, however, technological advances and increased resource scarcity have spurred new enthusiasm – and scepticism – from a variety of stakeholders including public actors such as states and regions as well as companies and industry organizations on exploiting the seabed of our oceans.

The key driver for the renewed interest is the global surge in use of raw materials fuelled by booming upcoming economies with large manufacturing industries. It has created a large demand for a range of minerals and materials of which many can be found on the European list of critical raw materials which identifies resources essential to the European economy.[4] Moreover, high-tech industries increasingly rely on input material from relatively rare materials such as cobalt which often are found in only few parts of the world. For example, China controls over 90 per cent of the global trade in rare earth elements. Hence, resource scarcity and concentration have created a double-incentive for diversifying sources of materials. Furthermore, European industry, for example in the Netherlands, Germany and France, is leading the development of several technologies for deep-sea resources exploration such as drilling and dredging which could prove a lucrative growth market for high-tech companies with experience in deep-sea conditions.

Mapping, exploring and extracting deep-sea resources have a number of technical, legal, environmental, societal and economic challenges. For example, the conditions of the deep-sea, including intense water pressure, rough surface seas and salt water, require extremely robust technology. Legally, deep-sea resource exploration and extraction takes place in the deep-seas under and beyond national jurisdiction under sometimes unclear and overlapping legal frameworks. Moreover, the deep-seas are home to a number of known and unknown unique and often vulnerable ecosystems where species have developed extraordinary biological and physiological properties which allow them to survive in these extreme environments, such as slow growth, late sexual maturity and the ability to withstand cold, dark and highly pressurized environments. These rare properties attract the interest of scientific and commercial sectors, yet the same properties make them highly susceptible to disturbance and change. Hence, any deep-sea activity should consider the short and long-term environmental impact.

1.1. Objectives of this study

The overall objective of the study is to assess the state of knowledge on the technologies available for deep-sea resource exploration and exploitation, and analyse the associated economic, environmental, social and legal aspects. The study covers mineral resources (deep-sea mining) as well as marine genetic resources (bioprospecting). More specifically, the study addresses the following key questions:

- What are the main knowledge gaps and risks?
- What is the legal framework at the international and European level?
- What are the main technologies for exploration and exploitation activities?
- What are the main economic aspects and costs? What are the main benefits?
- What are the main environmental and societal impacts?
- What are the next steps and what could the EU do?

[4] See e.g.: http://ec.europa.eu/enterprise/policies/raw-materials/critical/index_en.htm

1.2. Defining deep-sea resources

We apply a broad and common definition assuming that the deep-sea starts where the continental shelf ends at depths greater than 200 meters.[5] Deep-sea resources are thus generally found in the high-seas and beyond the Economic Exclusive Zone's (EEZs) of nation states which complicates the legal framework regulating the exploration and exploitation of the deep-sea resources.

The biophysical features of the deep-sea are unique and often challenging to any economic activity. The deep-sea covers a vast area representing the largest biome on earth and is characterized by low levels of oxygen and darkness due to limited penetration of sunlight hindering photosynthesis, limited availability of biomass and food, and extremely high pressure and cold temperatures. Low levels of turbidity also create a landscape which changes very slowly compared to more shallow waters which has had an impact on the evolution of the species inhabiting the seabed and the resilience of the habitat to resist abrupt changes.

We divide deep-sea resources into raw material resources and biological resources. Raw material resources include minerals of the most interest to deep-seabed miners including poly-metallic nodules, poly-metallic sulphides and cobalt-rich ferromanganese crusts, which contain valuable minerals such as silver and gold but in particular copper, manganese, cobalt, zinc and rare earths. Genetic and biological resources are those used by, mainly, pharmaceutical, biotechnology and cosmetic industry for different applications to develop new medicine, chemicals or cosmetics. The distinctive characteristics of the two resource types, i.e. their biophysical features, technological requirements for harvesting, supply chains and marketization, and further market potentials, justify treating them separately throughout the report. However, some aspects overlap, for example legal framework and technology used for exploration, and will hence be treated in common sections.

1.3. Value-chains

The value-chains for deep-sea exploitation for minerals and biological resources are fairly different. Mineral resources demand more capital investments in the beginning of a project to develop and build new technologies such as ships and operational expenditures can be fairly limited in contrast. For biological resources, on the other hand, the lion's share of budget is likely to be spent on identifying and testing the raw materials for usable applications which is mainly carried out in labs.

1.3.1. Value-chain for raw materials[6]

The exploration phase includes two main stages:

1. Exploration – this includes locating, sampling and drilling, using technologies such as echo-sounders, sonars, cameras, samplers and corers; and
2. Resource assessment, evaluation and planning – this includes the analysis of exploration data as regards the feasibility of a possible mining project.

The exploitation phase includes five stages:

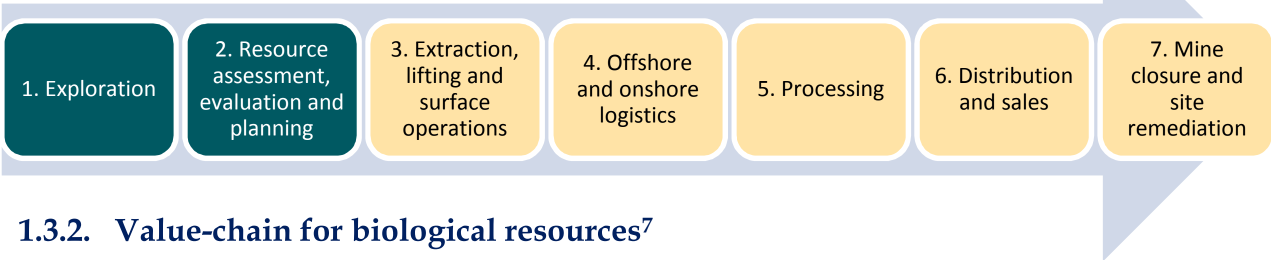
3. Extraction, lifting and surface operations – this is the core of the operation phase, and includes the excavation of the seabed minerals, their transportation to the surface and eventual processing and handling operations taking place offshore;

[5] A number of definitions are available. 200 meters is likely to be a minimum depth to be considered deep-sea and is around the area where the photosynthesis is no longer active. See e.g.: http://www.divediscover.whoi.edu/hottopics/deepsea.html

[6] Ecorys (2014). Study in support of Impact Assessment work on Blue Biotechnology. Revised Final Report FWC.

4. Offshore and onshore logistics - involves technologies similar to those found in 'traditional' land-originating minerals;
5. Processing - also similar to the onshore mining, although mineral composition differences call for development of advanced separation techniques;
6. Distribution and sales;
7. Mine closure and site remediation.

Figure 1-1 Overview of the value chain for raw materials



1.3.2. Value-chain for biological resources[7]

The exploration phase includes two stages:

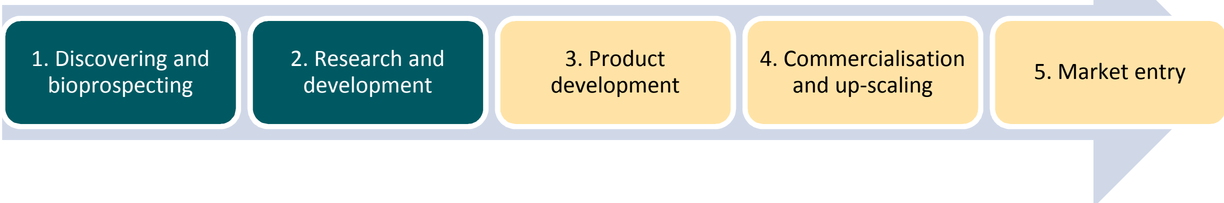
1. Discovering and bioprospecting - including finding of new molecules, collection, preparation, cataloguing and storing of samples;
2. Research and development - including analysis and screening to identify possible candidates for commercialisation, and protecting them by patents.

The exploitation phase includes three stages:

3. Product development – includes testing the product, pre-market preparation;
4. Commercialization and possible up-scaling;
5. Market entry - marketing, product positioning, and selling.

Note that the value-chain for biological resources is restricted to the marine environment only in the exploration phase, and in particular to the first stage, discovering and bioprospecting. The cultivation of the samples, analysis and development is carried out in biotechnological labs on land.

Figure 1-2 Overview of the value chain for biological resources



1.4. Methodological framework

The study is using second hand data complemented by interviews conducted with 23 experts from the industry, NGOs and academia. The list of interviewed stakeholders can be found in Annex C. A large number of reports have been written over the past few years on, in particular, raw material resources, despite very few commercial operations being launched. There is thus a great source of information regarding the *potentials* of deep-sea resource extraction yet there is little empirical evidence of its real value and impacts. In terms of biological resources there is more solid evidence for the commercial use

[7] Ecorys (2014). Study in support of Impact Assessment work on Blue Biotechnology. Revised Final Report FWC MARE/2012/06 – SC C1/2013/03, page 5. and Norway (2009) Marine bioprospecting – a source of new and sustainable wealth growth. Joint project between the Norwegian Ministries of Fisheries and Costal Affairs, Education and Research, Trade and Industry and Foreign Affairs. National Strategy 2009.

of deep-sea resources, not least with regard to the large number of patents pertaining to drugs and cosmetics stemming from deep-sea biological resources. The literature used for the study has been referenced in footnotes throughout the report and a comprehensive list of literature is provided at the end of this report.

The interviewees have been chosen in cooperation with the STOA secretariat and contacted via email and telephone. Interviews have been performed mainly via telephone and Skype. Semi-structured questionnaires have been developed by the research team and tailored to fit the expertise and position of person interviewed. For instance, if a large dredging company has been interviewed, questions are more geared towards the economic and technical aspects of deep-sea resource extraction than on the legal and environmental aspects. However, all respondents have been given the possibility to react on any part of the subject.

Information from the European Commission's Blue Growth study, and in particular their *Study to investigate the state of knowledge of deep-sea mining* (2014) has been useful as a starting point of reference.[8] Moreover, the recently finished public consultation on deep-sea mining launched by the European Commission's DG Maritime Affairs have been used to collect input from various stakeholders even though the final results have not yet been published by the Commission themselves.[9] Having this said, our study team has made use of a large amount of data to provide a comprehensive and independent analysis of the questions spelled out under the objectives of the study.

[8] Full report and annexes can be downloaded here: https://webgate.ec.europa.eu/maritimeforum/sites/maritimeforum/files/FGP96656_DSM_Final_report.pdf

[9] Detailed answers can be found here: http://ec.europa.eu/dgs/maritimeaffairs_fisheries/consultations/seabed-mining/index_en.htm

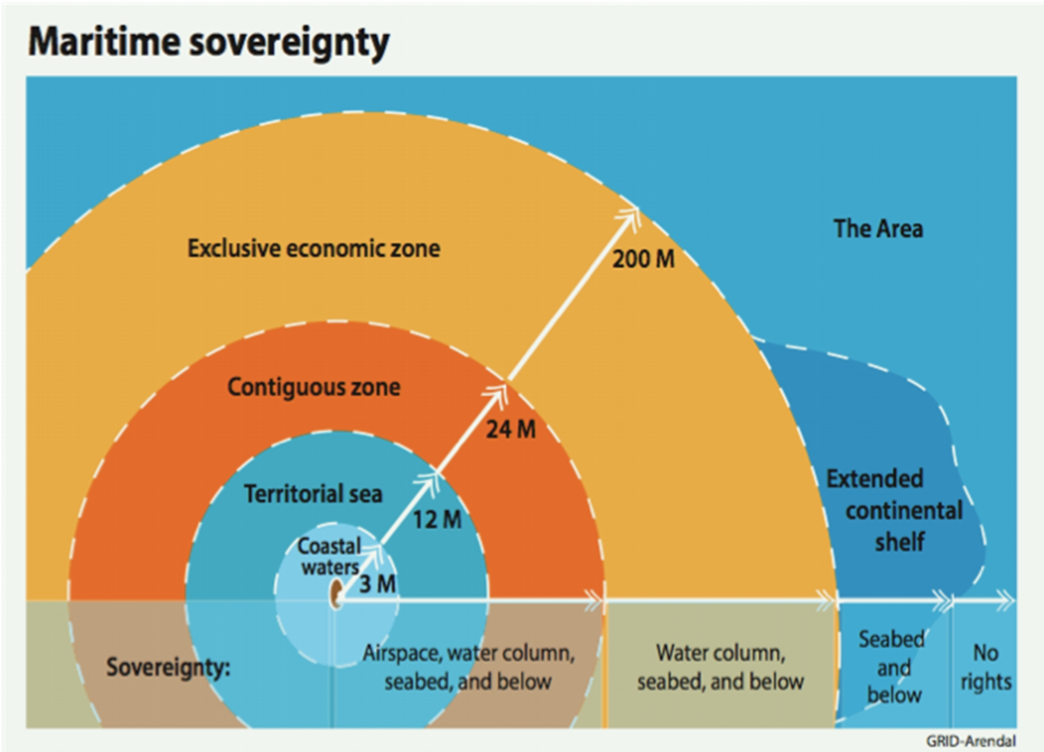
2. Legal framework for exploration and exploitation

In this section, the existing legal frameworks for deep-sea resource governance are described and discussed. First, a brief introduction to the most central legislation is presented, second, the international aspects, i.e. rules for the high-seas, and third, the European level, are explained.

2.1. International level

The United Nations Convention on the Law of the Sea (UNCLOS), which was adopted in 1982 and entered into force in 1994, is the most important piece of international law for governing deep-sea resources. It has been signed and ratified by the majority of the world's countries (currently 166 parties) with some notable exceptions, such as the United States of America (USA). However, many of the UNCLOS provisions are considered customary international law. All EU members are parties to UNCLOS. UNCLOS establishes a legal regime which is based on maritime zones presented in the figure below.

Figure 2-1Maritime zones under UNCLOS



Source: 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). M = nautical mile

A number of provisions under UNCLOS do regulate the use of marine resources within these areas of national jurisdiction. However, for deep-sea resources, which are situated on and under the deep-seabed, far less stringent regulation has been put in place. This is an important distinction to keep in mind when discussing the exploration and exploitation of deep-sea resources. The coming two sections further explain the legislative framework covering deep-sea resources.

Most of the jurisdictional provisions of UNCLOS are declaratory of pre-existing international law, while the Exclusive Economic Zone (EEZ) codifies the latest developments in the law of the sea. The EEZ zone is automatically awarded to a country, but must be claimed by the coastal state and it extends 200 nautical miles from the edge of the Territorial Sea. Coastal states have exclusive rights over the conservation and management of natural resources and jurisdiction for the protection and preservation of the marine environment.

The areas beyond national jurisdiction are subject to the traditional freedoms of the high seas (i.e., fishing, navigation, overflight, laying submarine cables and pipelines, building artificial islands and other facilities and conducting scientific research). The primary responsibility to protect and preserve the marine environment lies on flag states which must ensure that vessels flying their flag comply with existing international rules and standards. UNCLOS declared the seabed area beyond national jurisdiction (the Area) and its mineral resources as the "common heritage of mankind". The Area includes the seabed, the ocean floor and the subsoil thereof, beyond the limits of national jurisdiction. A special legal regime for the Area is elaborated in Part XI of the Convention.

To govern and coordinate deep-seabed issues, in particular deep-sea minerals, an autonomous international organization called the International Seabed Authority (ISA) has been created under UNCLOS in 1994. All States Parties to the Convention are automatically members of the International Seabed Authority. As of mid-2013, it had 166 members (165 states and the European Union). The Organs part of the Authority are: the Council, which is the central operating body of the ISA composed by rotating member elected on a four year term; the Assembly, the "supreme organ" with the power to establish general policies, and consists of all ISA members; the Finance Committee with the role to oversee the financial management of the Authority, and finally the Legal and Technical Commission (LTC) which is the central operating body of the ISA[10]. The LTC consists of 25 members who are elected by the Council for a period of 5 years on the basis of personal qualifications relevant to the exploration, exploitation and processing of mineral resources, oceanography, economic and/or legal matters relating to ocean mining and related fields. The "Mining Code" refers to the whole of the comprehensive set of rules, regulations and procedures issued by the International Seabed Authority to regulate prospecting, exploration and exploitation of marine minerals in the international seabed Area (defined as the seabed and subsoil beyond the limits of national jurisdiction). An important feature of the mining regime is that exploration and exploitation may be approved only on the basis of a contract with the ISA.

Currently, ISA has adopted regulations on exploration for Nodules (2000), Sulphides (2010) and Crusts (2012), while regulations on exploitation are being developed. The procedure requested by ISA needs the exploration developer to submit an Environmental Impact Statement (EIS) providing full documentation of all environmental and social issues associated with exploration, and committing to the application of relevant mitigation measures in relation to the development activity. Each contractor is required to propose a programme for the training of nationals of developing states. Consequently, in order to offer suitable candidates from developing States, ISA provides training by ISA Contractors on the interested sites (where companies are doing exploration activities). The conclusion of contracts allows these contractors to explore specified parts of the deep oceans outside national jurisdiction. A list of contracts for exploration for minerals granted by ISA is available.[11] Each contractor is also required to submit an annual report on the implementation of its programme of activities; these reports are not publically available though.

It should be noted that the Environmental Impact Assessments (EIA) process and the EIS are key inputs, together with comments received from stakeholders to the LTC, which will be used by the authority to assess whether or not a proposal is recommended for approval. The LTC is the only body

[10] International Seabed Autorhity (2015). About the International Seabed Authority. Available at http://www.isa.org.jm/authority

[11] International Seabed Autority (2015). Available at http://www.isa.org.jm/en/scientific/exploration/contractors

within the ISA to review the EIA. LTC reviews contractors' annual reports but as these reviews are not made public, NGOs are requesting a greater transparency of this process.

In territorial waters, commercial activity has progressed more rapidly and the extraction of gold, copper and silver from deep water deposits offshore Papua New Guinea is close to becoming a reality. For example, Pacific Ocean Floor is currently under exploration leasehold for deep-seabed mining to private and national government companies within both territorial and international waters.[12] As part of the progression of mining operations from exploration to exploitation, there is a strong need for detailed environmental assessment, and the development of a formal Environmental Impact Assessment process by the Authority[13].

The IMMS Code for Environmental Management of Marine Mining, a transnational non-state initiative in areas beyond international legal regimes for regulating deep-sea mineral resources, has been developed by the International Marine Minerals Society (IMMS)[14]. More specifically, the code was initiated in the year 2000 by IMMS mining industry members at UMI (Underwater Mining Institute), revised in 2011 and is today used by several important players, for example the ISA, EU, the Secretariat of the Pacific Community (SPC), and New Zeeland. The voluntary nature of the code is heavily emphasised in communication from the IMMS and it aims to complement and improve existing and supplement incomplete or absent international/national environmental regulations, from exploration to post-closure of deep-sea mining activities, setting transparent environmental reporting standards.

Regarding the governance of biological and genetic resources in areas beyond national jurisdiction, a central problem is that the definition of "resources of the Area" (Article 133(a) of the Convention) is limited to "mineral resources", i.e. the competencies of the ISA are therefore restricted to raw materials and minerals. Indeed when the negotiations of the regime for the Area began, it was assumed that deep-sea subsoil under the high seas was rich only in mineral resources due to the absence of light and photosynthesis. However, discoveries that took place from the late 1970s have shown that there are microbes and animals that live in the sea bottom, whose life is based on chemosynthesis. Moreover, technological advancement in genetic sequencing, isolation of compounds and testing, have enabled a rapid increase in the interest and commercialization of genetic and biological resources. It should be noted, however, that exploration and exploitation of biological and genetic resources is far less of an environmental problem than minerals. It requires limited harvesting and once a compound has been found and isolated, it can often be synthesised in the lab. This lowers the urgency for developing management options for environmentally sustainable exploitation. Instead, a central legal challenge is the sharing of the benefits reaped by companies and developed countries which currently are safe-guarded by a rigorous international patent-system under the TRIPS agreement[15].

Nevertheless, while there is a large gap in international legislation aiming to regulate biological resources, there are several intervening pieces of legislation, in particular environmental legislation. For example, the 1992 Convention on Biological Diversity (CBD)[16] defines biodiversity and promotes the sustainable use of its components, the conservation and the fair sharing of benefits of the genetic resources in areas under national jurisdiction. The legal status and, consequently, the legal regime for

[12] Deep-sea mining campaign (2015). Available at http://www.deepseaminingoutofourdepth.org/

[13] ISA Technical study (2011). Environmental management needs for exploration and exploitation of deep sea minerals. Available at http://www.isa.org.jm/files/documents/EN/Pubs/TS10/TS10-Final.pdf

[14] International NGO dedicated to marine minerals and focused on marine minerals as resources for study and responsible use

[15] Agreement on Trade-Related Aspects of Intellectual Property Rights (1994) Available at http://www.wto.org/english/tratop_e/trips_e/t_agm0_e.htm

[16] Convention on biological diversity (2015). Available at http://www.cbd.int/

biological organisms of the Area are not clearly defined and some countries argue that the CBD does not apply to the high seas. In particular the interpretation of article 4 of the CBD, which defines the jurisdictional scope of the convention, is debated. The Nagoya Protocol on Access to Genetic Resources and the Fair and Equitable Sharing of Benefits Arising from their Utilization (the Nagoya Protocol[17]) to the CBD, which was adopted in 2010, tried to clarify the jurisdictional scope of the CBD in this matter. The adapted wording "under the jurisdiction or control of nation states" is somewhat clearer since all activities on the high seas are under the control of nation states, namely flag states, which constitutes another set of problems beyond the scope of this study. The Nagoya Protocol also refrains from rule-making on access and benefit-sharing beyond areas of national jurisdiction. Finally, in 2004 the UN General Assembly established an ad hoc open-ended informal working group (resolution 59/24) to study issues relating to the conservation and sustainable use of marine biodiversity in areas beyond national jurisdiction (BBNJ), calling upon states and international organizations to urgently take action to address destructive practices with adverse impacts on marine biodiversity and ecosystems in accordance with international law.

It is important to note that while provisions relating to living and mineral resources in areas beyond national jurisdiction are included under UNCLOS, a specific regime for the exploitation of marine genetic resources is not included. Therefore, UNCLOS may consider implementing a new agreement for the conservation and sustainable use of marine biodiversity beyond national jurisdiction.[18] However, it would require a substantial overhaul of the institutional architecture and possibly a lengthy renegotiation of the competencies and composition of ISA. Negotiations are currently going on at the UN General Assembly level where some States affirm that the mandate of the Authority UNCLOS and the principle of "common heritage of mankind" should be extended to cover also genetic resources. In August 2015, several Member States envisage an implementation of UNCLOS, with the most likely scenario being the creation of a "package" which takes into consideration a "future global regime for the conservation and sustainable use of marine biodiversity in areas beyond national jurisdiction".[19] In January 2015, the ninth meeting of the Ad Hoc Open-ended Informal Working Group to study issues relating to the conservation and sustainable use of marine biological diversity beyond areas of national jurisdiction took place. The working group decided to develop an international legally binding instrument on BBNJ under UNCLOS and to that to create a Preparatory Committee by 2016 to make substantive recommendations to the General Assembly in 2017. The EU expressed hope that the recommendations will lead to a better regime for oceans and seas.

2.2. European Level

The EU is still assessing gaps in legislative framework on deep-sea resources and due to lack of current knowledge, maintaining a careful approach. Indeed in the last years, the European Commission released its Blue Growth strategy, identifying seabed mining as one of the five "priority areas" that could deliver sustainable growth and jobs in the blue economy (2012). The communication states that "*by 2020, per cent of the world's minerals, including cobalt, copper and zinc could come from the ocean floors, this could rise to per cent by 2030*". The EU engagement should help to ensure that high environmental, legal and security standards are upheld. This includes protecting the marine environment in line with the provisions of UNCLOS, to which the EU and all its Member States are contracting parties. Moreover, in 2014 the EC held a public consultation focusing mostly on the economic and technological side of the matter, with the aim to gather opinions concerning the mining

[17] Convention on biological diversity (2015). About. Available at http://www.cbd.int/abs/about/

[18] UNEP (2012). Green Economy in a Blue World. Available at http://www.unep.org/pdf/Green_Economy_Blue_Full.pdf

[19] Scovazzi T. (2013). The exploitation of resources of the deep-seabed and the protection of the environment. Unpublished manuscript.

activities and its developments in order to help the EU develop its position. The EC is keen to release a first approach to deep-sea mining activities and most likely also including bioprospecting by the end of 2015. Furthermore the next EU legislation on deep-sea mining will also draw on advice and regulations promulgated by ISA and take into account more general legislation such as EU Directives applicable to oil and gas exploration and exploitation and aggregate dredging.

Beyond possible upcoming legislation, the Marine Strategy Framework Directive (MSFD) is a legislative framework in place at the EU level. Its objective is to achieve Good Environmental Status (GES) in the European seas by 2020 and to protect the marine-related resources on which economic and social activities depend. There are 11 Good Environmental Status (GES) descriptors. In particular, Descriptor 6[20], Sea-floor Integrity, is closely linked with pressures that can affect the sea-floor such as fishing, shipping, mining and hydrocarbon production. The Directive has six years for its implementation and includes several reviewing cycles to guarantee full implementation and to achieve good environmental status (GES) by 2020. DSM as a potential activity occurring in the seabed should be regulated in a way which will not delay the objective of achieving the eleven GES by 2020 as required by the MSFD. There are other relevant EU directives that could influence some aspects of DSM activities and its eventual future regulation within the EU: Environmental Impact Assessment, Strategic Environmental Assessment, Mining Waste, and Habitat Directive[21].

[20] European Commission (2015). Our oceans, seas and coasts. Available at http://ec.europa.eu/environment/marine/good-environmental-status/descriptor-6/index_en.htm

[21] Natura 2000 (2011). Non-energy mineral extraction and Natura 2000. Available at http://ec.europa.eu/environment/nature/natura2000/management/docs/neei_n2000_guidance.pdf

3. Deep-sea exploration

This section describes and analyses deep-sea exploration: the state of knowledge and activities regarding both types of resources, the technical aspects and the economics of exploration, and the related environmental issues.

3.1. State of knowledge on resources

3.1.1. Mineral resources

The greatest unexploited mineral resources on earth are on the deep-sea floor. There are many different types of deposits found in the deeper parts of the ocean, but few have potential for future development. This study addresses the most relevant deep-sea minerals, being manganese nodules, manganese crusts and seafloor massive sulphides (hydrothermal deposits). These seabed mineral deposits are composed predominantly of metals. Rare-earth elements (REEs) are also considered possible target metals contained within some deep-seabed mining (DSM) deposits due to the growing global demand for these elements.

The table below shows the metal content of different materials to be found in the three types of deposits.

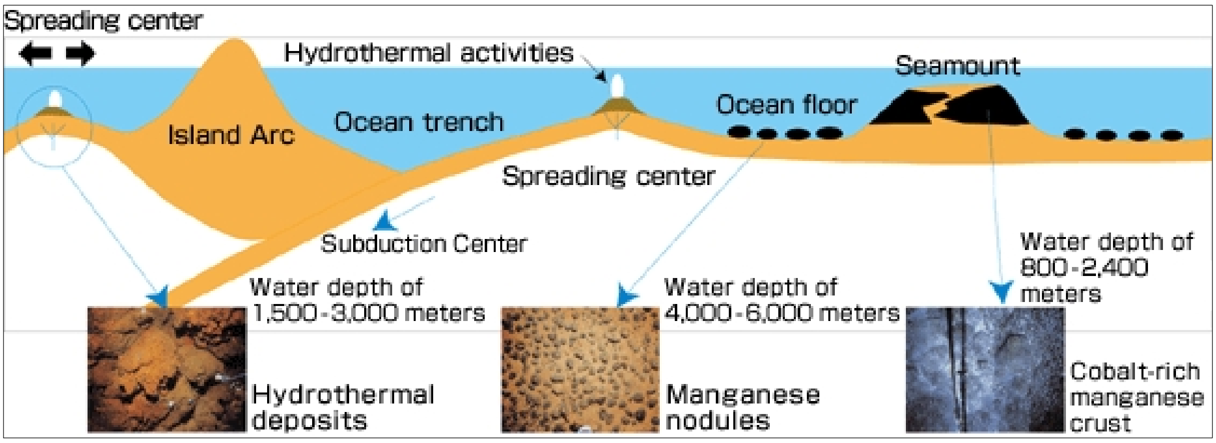
Table 3-1 Metal content of the deposits

<table>
<tr><th>Metals & REEs</th><th>Sulphides (global average)</th><th>Nodules (in CCZ)</th><th>Crusts (in PCZ)</th></tr>
<tr><td>Resource estimate</td><td>600 million tonnes in mid-ocean ridges</td><td>21,100 million tonnes in the CCZ</td><td>7,533 million tonnes in the PCZ</td></tr>
<tr><td colspan="4">Metal content</td></tr>
<tr><td>Cobalt</td><td>-</td><td>0.2 weight per cent</td><td>0.7 weight per cent</td></tr>
<tr><td>Nickel</td><td>-</td><td rowspan="2">2.4 weight per cent</td><td rowspan="2">0.5 weight per cent</td></tr>
<tr><td>Copper</td><td>5 weight per cent</td></tr>
<tr><td>Gold</td><td>5 parts per million</td><td>-</td><td>-</td></tr>
<tr><td>Manganese</td><td>-</td><td>28 weight per cent</td><td>23 weight per cent</td></tr>
<tr><td>Rare Earth Elements</td><td>-</td><td>-</td><td>0.2 weight per cent</td></tr>
<tr><td>Silver</td><td>200 parts per million</td><td>-</td><td>-</td></tr>
<tr><td>Zinc</td><td>10 weight per cent</td><td>-</td><td>-</td></tr>
</table>

Source: table based on Ecorys et al. (2014) Study to investigate the state of knowledge of deep-sea mining, p. 36
Note: CCZ = Clarion-Clipperton Zone, PCZ = Prime Crust Zone

The figure below shows where each of the deposits is typically found.

Figure 3-1 Location of deep-sea deposits



Source: http://www.jogmec.go.jp/english/metal/technology_018.html

In contrast to manganese nodules, which are relatively well known and studied, manganese crusts and seafloor massive sulphides occur in more concentrated areas, are more unevenly distributed and vary more in metal content from place to place[22]. A description of the current knowledge on the resource potential for the three types of metals is below.

Manganese nodules

Manganese nodules are also referred to as polymetallic nodules. They are spherical or elliptic, 2 cm to 15 cm in diameter and consist of ferromanganese oxides. Most important minerals for economic purposes in nodules are nickel, copper, manganese, molybdenum, lithium, rare-earth elements and possibly cobalt.[23] However, the nodules comprise primarily of manganese and iron and the concentration of targeted minerals such as example lithium has been proven to be lower compared to resources found on land.[24] Manganese nodules are predominantly found, often with a wide distribution, half-buried in comparatively flat deep-sea sediment at a depth of 4,000 to 6,000 meters. Being situated on the seabed, they can be identified and collected relatively easily. The largest concentrations of these types of nodules are located between the west coast of Mexico and Hawaii, on the Peruvian coast and in the abyss of the Atlantic and Indian Ocean. These nodules grow very slowly, at only millimetres per million years, and are therefore only found on old ocean floors.

The most explored area for nodules is probably the Clarion-Clipperton Fracture zone, which is located in the Pacific Ocean. Resource content of the area is estimated on 34 billion ton of manganese nodules spread over 9 million km^2.[25] More than 10 different consortia hold concessions and are currently exploring the area[26]. With a mining cycle of 20 – 30 years and estimated around 1.5 million tonnes of resource extracted per year, this area offers great potential for exploitation.

[22] ISA (2009). Polymetallic Sulphides - International Seabed Authority Brochure; ISA, 2008, Cobalt-Rich Crusts - International Seabed Authority Brochure. Available at http://www.isa.org.jm/documents/authority-brochure
[23] Secretariat of the Pacific Community (SPC) (2012). Pacific-ACP States Regional Legislative and Regulatory Framework for Deep-sea Minerals Exploration and Exploitation, ISBN: 978-982-00-0557-0
[24] Ecorys (2014). Study to investigate state of knowledge of deep-sea mining, Client: European Commission - DG Maritime Affairs and Fisheries
[25] Morgan, C.L. (2000). Resource estimates of the Clarion-Clipperton manganese nodule deposits, in: Cronan, D.S. (Ed.) (2000). Handbook of marine mineral deposits. pp. 145-170
[26] Schulte, S.A., (2013). Vertical transport methods for. Deep-sea Mining. S.A. Schulte. Delft University of Technology. Section of Dredging Engineering, MSc Thesis, version 2.0 June 19, 2013

Manganese crusts

Manganese crusts are also referred to as polymetallic- or ferromanganese crusts. Like manganese nodules, a manganese crust is composed of ferromanganese oxides. The target economic minerals for these crusts are cobalt, nickel, manganese, tellurium, rare earth elements, niobium and possibly platinum.[27] The average cobalt content of the crust is three times as great as in manganese nodules. The crusts cover the bedrock on the slope or top of submerged volcanic islands, submarine ridges and seamounts like asphalt with a thickness of several millimetres to tens of centimetres at a depth of 800 to 2,400 meters. Manganese crusts are found at seamounts worldwide with the largest deposits being in the Pacific Ocean, in proximity of Australia and New Zealand.[28] The Pacific Ocean accounts for 57 per cent of the global total of seamounts. However, only few of these seamounts have been mapped and sampled in detail. Its potential has been mapped globally, with some bias pointing towards the samples taken in the Pacific. This area has been proven to have the largest amounts of cobalt, which is the metal of main economic importance for crust extraction.

The table below outline the key difference between manganese nodules and manganese crusts.

Table 3-2 Main differences between manganese nodules and manganese crusts

Manganese nodules	Manganese crusts
Recovery of nodules is easier because they sit on soft sediment	Attached to substrate rock, and have to be recovered without collecting too much substrate
Found in deep waters	Found in shallower waters, but in more concentrated areas and more unevenly distributed
Scattered across deep abyssal plains of the oceans, hundreds of miles from shore and typically three miles or more below the surface	Close to a coastline and in shallower water
Situated just on the seabed and can be collected more easily	Can be considered as rock and the high hydrostatic pressure will make it difficult to excavate
Lower cobalt and REEs content	Higher cobalt and REEs content

Source: Norwegian University of Science and Technology (NTNU), 2013

Seafloor massive sulphides

Seafloor massive sulphides (SMS), also referred to as polymetallic sulphides or hydrothermal deposits, consist of heavy metal sulphides derived from hot water that vented from the seafloor at a depth of 1,500 - 3,000 meters. Hydrothermal vents, also known as 'black smokers' are like geysers on the ocean floor. Mineral-rich waters are heated by magma, then exit the oceanic crust and mix with the cool seawater above. As the vent minerals cool, they solidify into mineral deposits. These SMS deposits consist of sulphide minerals that contain various metals, such as copper, lead, zinc, gold and silver. SMS deposits are distributed along mid-oceanic ridges where tectonic plates diverge, in areas such as the East Pacific Rise, the Central Atlantic Ridge, and the North Fiji Basin in the South Pacific. They are also found in back-arc basins, near volcanic ridges that mark the location where tectonic plates converge, for instance near Japan and Indonesia. Unfortunately, the total number of vents is unknown and it is therefore necessary to rely on more hypothetical estimates. Based on the Earths heat flow, experts believe that there is approximately one black smoker per kilometre of the ridge

[27] Secretariat of the Pacific Community (SPC), (2012) Pacific-ACP States Regional Legislative and Regulatory Framework for Deep-sea Minerals Exploration and Exploitation, ISBN: 978-982-00-0557-0

[28] Greenpeace, (2013). Review of the Current State of Development and the Potential for Environmental Impacts of Seabed Mining Operations, Greenpeace Research Laboratories Technical Report (Review) 03-2013: 50pp

axis.[29] However, the exact location, distribution and concentration of promising SMS deposits is largely uncertain as there is no clear technique for mapping them.

The size of these deposits varies between a few tonnes up to 15 million tonnes (mt) of ore material. However, drilling is necessary in order to get a more precise estimate. This has only been done in a few locations. The exception is the Red Sea Deposit, which has been proven to have 90 mt of reserves. This is a deposit with strong potential, although extraction has yet to commence.

State of play on exploration activities

Up to now, deep-seabed mining activities have been confined to exploratory ventures. Mineral exploration activities have already taken place under licences from ISA. The areas of concern include the abyssal plain, seamounts and hydrothermal vents in the Pacific and in the Atlantic Ocean, in particular mostly around the Clarion-Clipperton Zone (CCZ) in the Pacific Ocean, parts of the Indian Ocean and along the Mid-Atlantic Ridge. A recent and comprehensive study (Ecorys 2014) states that by May 19, 2014, 19 exploration licences – submitted by both governments and companies – have been issued and contracted out by the ISA. Another seven licences were approved and will be contracted out by the beginning of 2015, summing up to 26 ISA approved exploration projects beyond the EEZs. The latest one was agreed upon between International Seabed Authority and Marawa research exploration ltd, for polymetallic nodules on 19 of January 2015. By end of 2015 it is expected that the exploration will cover an area of around 1.2 million km^2. The vast majority of them involve nodules, a few SMS and only two crusts. Six of these licences were approved in 2001 for a term of 15 years and will expire in 2016. A 5-year extension of such a licence is possible.[30] There are more and more applications waiting for approval.

Examining the list of 26 projects beyond the EEZs that are reported by the Ecorys study and that have been granted licences, there is a wide spread in geographical representation in terms of sponsoring countries. Russia and China have sponsored marginally more licences than European countries, Korea or Japan but in absolute numbers, EU countries are in the lead. In total seven individual licences involve EU members (France, Germany and the UK each have two, while Belgium has one). China and Russia hold three licenses each, Japan and Korea have two each, and the remainders are for individual countries. Additionally, four EU Member States and Russia participate in Interoceanmetal[31], which holds a license for nodule exploration.

To collect data on licences for EEZ is more difficult as no centralised database exists. Ecorys study (2014) identifies at least 24 EEZ exploration licences.[32]

Clearly, the exploration and possible exploitation of deep-sea minerals is an activity reserved for rich developed countries and major emerging economies with access to technologies and capital to launch large operations that involve substantial financial and environmental risk. The only exception is the presence of several small island developing states situated in the Pacific including Kiribati, Cook Islands, Tonga and Nauru, which due to proximity to the potential resources, could have a strategic position for launching operations.

[29] Ecorys (2014). Study to investigate state of knowledge of deep-sea mining, Client: European Commission - DG Maritime Affairs and Fisheries

[30] Ecorys (2014). Study to investigate state of knowledge of deep-sea mining - Final report Annex 5 Ongoing and planned activity (FWC MARE/2012/06 – SC E1/2013/04), p. 7

[31] Bulgaria, Cuba, Czech Republic, Poland, Russian Federation and Slovakia

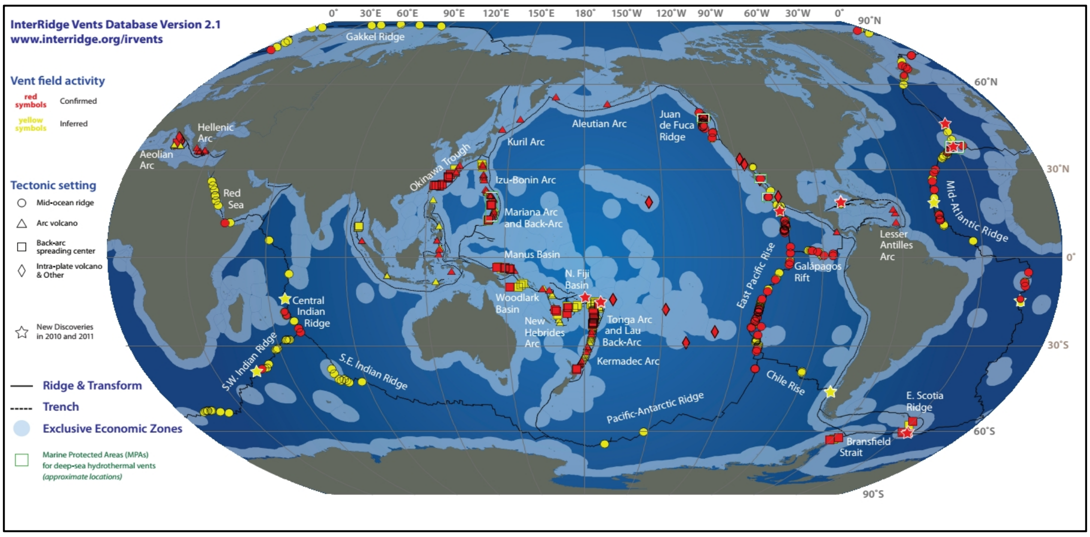
[32] Ecorys (2014). Study to investigate state of knowledge of deep-sea mining - Final report Annex 5 Ongoing and planned activity (FWC MARE/2012/06 – SC E1/2013/04)

3.1.2. Biological resources

Despite the absence of a global legal framework (see section 2), marine biological resources have been explored and exploited for mainly biotech industry, medical and cosmetic purposes over the past decades. For instance, many pharmaceuticals to combat HIV and several types of cancer have their origins from therapeutic agents isolated in marine genetic and biological resources. An often-cited example is the isolation of two chemicals - spongothymidine and spongouridine – from a shallow-water sponge (*Tectitethya crypta*) which eventually led to breakthrough in AIDS treatment during the 1980s.[33] Another examples include a Caribbean coral (*Plexaura homomalla*) rich in prostaglandins (hormones that control blood clotting and inflammatory responses) used as a model for researching human prostaglandin metabolism, a drug based on modified marine cone snail's venom used for treating severe chronic pain, and a group of organisms (including jelly-fish) containing specific substances which could be used as models for developing a new generation of antibiotics[34].

While the bottom of the deep-sea generally is considered a challenging place for survival, pockets of life producing levels of biomass equal to more biodiversity rich places have been discovered, in particular in combination with hydrothermal vents, also called 'black smokers'. The term comes from the dense and intense fluid (coming from the vents) and is the result of magmatic activity and high temperatures.[35] High temperature (400ºC) in combination with extreme pressures and the matter spewed out by the hydrothermal vents creates a unique environment for microbes and highly adapted organisms. In particular the ability of these species to convert the vent fluids to useful energy by chemical processes is of interest to researchers. The largest potential for finding new resources on a deep-sea level is likely to be around the hydrothermal vents situated along the continental mid-ocean ridges. The figure below indicates the location of currently known and inferred ridges.

Figure 3-2 Location of currently known and inferred ridges



Source: Woods Hole Oceonographic Institution, 2011

[33] See e.g. From Sea Sponge to HIV Medicine. Available at http://ocean.si.edu/ocean-photos/sea-sponge-hiv-medicine

[34] World Ocean Review (2010). Chapter 9. Available at http://www.eurocean.org/np4/file/129/WOR_english.pdf

[35] Arico, S., and C. Salpin (2005). Bioprospecting of Genetic Resources in the Deep-seabed: Scientific, Legal and Policy Aspects. UNU-IAS Report

There appears to be over 550 confirmed and inferred vents[36]. For Europe, the mid-Atlantic ridge and the North Atlantic Ocean are of most interest. An overview of the location of marine genetic resources outside the EEZ confirms this observation.

Hence the potential is large to find new useful biological resources in the deep-sea and a recent paper published in the prestigious academic journal PNAS reported that the "*prospect for unique findings is huge, particularly in the microbial realm, as illustrated by recent studies reporting 1.2 million previously undescribed gene sequences using cultivation-independent sequencing techniques on a single cubic meter of water from the Sargasso Sea.*"[37] There is thus still a huge potential for discovery in deep-sea bioprospecting, approximately 0.0001 per cent of all species inhabiting the deep-sea is known[38]. Current expectations are that deep-sea habitats contain a large number of species with greater genetic diversity and larger arrays of structurally and functionally unique molecules than marine species from shallower waters. However, even if the exploration and inventory of marine species have sped up rapidly over the last few years, at current rate it would take another 250 to 1,000 years before all species are analysed.[39]

3.2. Technological aspects

Exploration for deep-sea mining and bioprospecting are similar in many ways to oceanographic research. Basic methods and backgrounds stem directly from the well-developed disciplines of geological, physical and biological oceanography, though with a focus on potential exploitation.[40] The techniques are therefore more mature than techniques for exploitation.

3.2.1. Deep-sea mining

Due to the extreme conditions in the deep-sea such as extremely high pressure and the potential of volcanic activity, exploring deep-sea mineral resources requires state-of-the art technology. The type of equipment needed depends on the type of resources to be explored. Mapping manganese nodules and crusts is more straightforward than the exploration of seafloor massive sulphides. The exploration of deep-sea minerals typically consists of three phases: locating, sampling and drilling.

The table below lists the most commonly used techniques per exploration phase. It indicates that there are already vessels and tools available at all stages for the exploration of deep-sea resources. As we will discuss in section 4.2 of this report, the issue mainly lies with the excavation of minerals.

[36] Inter Ridge (2015). Interridge vents database 2.2. Available at http://interridge.org/irvents/

[37] J.M.Arrieta, S. Arnaud-Haond & C. M. Duarte (2010). What lies underneath: conserving the oceans' genetic resources, PNAS vol. 107(43), 18318–18324

[38] Serrão Santos, R., (2012). Deep-sea Biology, Presentation of Ricardo Serrao Santos (Universidade dos Açores) at the Atlantic Forum workshop in the Azores 20 and 21 September 2012

[39] Ibid.

[40] International Seabed Authority (2009). Protection of the Seabed Environment, Brochure International Seabed Authority. Available at http://www.isa.org.jm/files/documents/EN/Brochures/ENG4.pdf

Table 3-3 Deep-sea exploration techniques

Ore Deposits	Technique	Comments	Tech. readiness level [41]
Locating			
SMS, Nodules, Crust	Research vessels		9
SMS, Nodules, Crust	Echo sounding bathymetry	Proven techniques already applied in the deep-sea environment.	9
SMS	Electromagnetics	The technology has been proven as ship-mounted operation. For electromagnetics applied at AUVs there have been only tests so far.	9
SMS	Water chemistry testing	So far mainly restricted to active vents; in order to trace inactive vents as well, new technologies and research is required.	9
SMS, Nodules, Crust	Autonomous underwater vehicles (AUVs)	AUVs are ready for deep-sea usage and replace many of the ship-mounted systems. However, there is still potential for further improvement, like gravity gradiometer application.	8
SMS, Nodules, Crust	Remotely operated vehicles (ROVs)	Well-developed systems are currently deployed at depths of around 6,000m and have potential to reach depths up to 11,000m with further development.	9
Sampling			
Nodules, crusts	Free fall devices	In use since the 1970s for sampling nodules in a deep-sea environment.	9
SMS, Nodules, Crust	Grab samplers	Developed to reach depths of around maximum 6,000m. They are in use for scientific and commercial purposes.	9
Nodules	Box corer	Used in the operational environment for nodules exploration.	9
SMS	Gravity corer	Used in the operational environment for exploring SMS.	9
SMS	Piston corers	Used in the operational environment for exploring SMS. They have been used for many other oceanographic exploratory studies already since the 1950s.	9
SMS	Vibrocoring	Used in the operational environment for exploring SMS. They have been used for many other oceanographic exploratory studies and in the oil and gas industry.	9
Drilling			
SMS	Drill rigs	Advanced drilling tools for deep-sea applications should be developed to penetrate deeper into the SMS deposits	9

41 Each technique along the DSM value chain is assessed in terms of its "technology readiness level" (TRL) and given a value in the range 1-9 (where 1 is "Basic principles observed" and 9 is "Actual system proven in operational environment").

Ore Deposits	Technique	Comments	Tech. readiness level [41]
		and allow for representative sampling.	
SMS	Ship based drills	So far, these vessels have not yet been able to achieve the same depths as Drill rigs and ROVs and have not yet been used for SMS drills.	6

Source: Ecorys (2014)

Position of the EU

Stakeholders identify European companies as market leaders in technology for exploration activities, even though the market in Europe is small. Ecorys (2014) went into a greater detail on their position. It values the competitive position of EU companies in locating resources as 'high' and in sampling and drilling as 'average'. Further it states that all exploration licenses for the high seas were issued for manganese nodules exploration by governments or state-sponsored companies, and only a few exploration licenses for seafloor massive sulphides and manganese crusts have also been issued since 2011[42].

Project licenses within the EEZ are typically issued to private companies and concern the exploration of seafloor massive sulphides. Three exploration projects for seafloor massive sulphides are currently under application for European waters: one in Italy, one in Norway and one in Portugal[43]. The projects mainly involve non-EU companies, notably Canadian Nautilus Minerals and US based Neptune Minerals.

A list of on-going EU projects can be found in Annex B.

3.2.2. Bioprospecting[44]

Bioprospecting is fundamentally different from deep-sea mining in the sense that it does not require a prolonged, large-scale, and costly operation under water. Instead, the main challenges and costs for bioprospecting start once on land and in the laboratory. Hence, in terms of sub-marine technologies, devices are generally needed for sampling and mapping the seafloor. The latter, however, is generally not carried out with genetic resources in mind but with broader interests in the structure and content of the seabed.

The exploration phase for bioprospecting starts with determining the most promising place for sampling and is carried out based on preliminary data on sampling sites. "Hot-spots", such as coral and temperate reefs in shallow waters and hydrothermal vents and abyssal slopes and planes in the deeper waters, are of particular interest.[45]

To study deep-sea biological communities that could be suitable for further exploration, mapping of the geophysical characteristics of the seafloor are needed. In general, such mappings of the seafloor can be done by modern research ship often geared up with a hull-mounted multi-beam swath

[42] Ecorys (2014). Study to investigate state of knowledge of deep-sea mining, Client: European Commission - DG Maritime Affairs and Fisheries

[43] Ecorys (2014). Study to investigate state of knowledge of deep-sea mining, Client: European Commission - DG Maritime Affairs and Fisheries

[44] Note: For the purpose of this report, only technologies for exploration of marine biological resources are relevant which is why it has been excluded under exploitation, which takes place in laboratories.

[45] FAO (2003). Workshop on Marine Bioprospecting Synopsis. Available at http://www.fao.org/docrep/009/a0337e/A0337E15.htm

bathymetry.[46] However, to understand the physical conditions in which the sampling could take place data on conductivity, temperature and depth are collected continuously during the mapping.

The technology for sampling could be likened with that used in biological studies of deep-sea fauna. The most widely used equipment has traditionally included[47]:

- deep trawls for collecting megafauna (organisms large enough to be determined on photographs, typically larger than 1 cm in size);
- multi-corers and mega-corers to obtain quantitative samples of sediment cores with intact sediment;
- water interfaces used for organic chemistry, nutrient analyses and small benthic invertebrates;
- box-corers for quantitative samples of macro-fauna (benthic or soil organisms, in deep-sea these are animals retained on a 3mm sieve);
- sediment traps for studies of phytodetritus (organic particulate matter resulting from phytoplankton) input to the seafloor; and,
- current meters for the analysis of physical parameters.[48]

Besides a large number of trawling, drilling and other (invasive) technologies, developments in other technology such as deep-sea photographic and video capabilities being towed at large depths are reducing the environmental impact of such activities. Moreover, it is highly likely that developments in other technologies for mapping and exploring the seabed are beneficial to marine bioprospecting. For example, new developments in manned submersibles remote operated vehicles (ROVs) and autonomous underwater vehicles (AUVs), opens up for new possibilities and capabilities for directed and detailed sampling as well as *in situ* experimentation[49].

To reduce the environmental impacts of drilling and some sampling methods as well as reaching even further down the water column, new technologies are being developed. For instance, a device called "Deep Bath" (Deep-Sea Baro/Thermophiles Collecting and Cultivating System), developed by Japan Agency for Marine-Earth Science and Technology (JAMSTEC), allows maintaining samples at *in situ* conditions of pressure and temperature[50], which is necessary for the survival of some very delicate deep-sea organisms (piezophiles). To date, JAMSTEC has been able to isolate 180 microbial species from the Mariana Trench, the deepest point on Earth at 10,898 meters. In Europe, technology organizations specializing in the deep-sea are leading this development, such as French Research Institute for Exploitation of the Sea (IFREMER).

Position of the EU

The biotechnology industry related to marine species and organisms – sometimes referred to as 'Blue Biotechnology' – is according to figures from Ecorys (2012), rather small both in terms of value added (EUR 0.6 billion) and employment opportunities (about 500 people).[51] Overall, the marine

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[46] Ramirez Llodra, E.; Billett, D.S.M., (2006). Deep-sea ecosystems: pristine biodiversity reservoir and technological challenges, in: Duarte, C.M. (Ed.) (2006). The exploration of marine biodiversity: scientific and technological challenges. pp. 63-92

[47] Ramirez Llodra, E.; Billett, D.S.M. (2006). Deep-sea ecosystems: pristine biodiversity reservoir and technological challenges, in: Duarte, C.M. (Ed.) (2006). The exploration of marine biodiversity: scientific and technological challenges. pp. 63-92

[48] Ibid.

[49] Ibid.

[50] VTT (2012). Microbial activity in bentonite buffers. Literature study. Marjaana Rättö & Merja Itävaara. Espoo 2012. VTT Technology 20. 30 p

[51] Ecorys (2012). Blue Growth – scenarios and drivers for Sustainable Growth from the Oceans, Seas and Coasts – third interim report. Report for DG MARE

biotechnology sector in the EU has been characterised as occupied by a few pioneering organisations with strong links to national (Atlantic) research institutes, and mixed funding from public and private sources. [52] While still limited in value added to date, this could change in the near future.[53] Due to the hybridity of the sector in terms of public/private interests and investments, research is central for driving development. European research institutes are world-leading in terms of scientific publications in the fields however lagging behind in terms of number of patents and inventions, in particular from Japan and China.[54] Nevertheless, according to some counts[55], European companies including Bayer, BASF, and Novo Nordisk, have a sizeable share of global patent applications making a reference to marine species.[56] Other key commercial players are cosmetic companies (L'Oreal, Estée Lauder), pharmaceutical companies (Merck, GSK, Pfizer) and large chemical players (Novozymes, BASF)[57].

A list of EU projects in bioprospecting can be found in Annex B.

3.3. Economic aspects

The economic aspects include examining the key challenges preventing commercialisation, drivers for demand and supply and providing cost estimates for the different activities. Companies, both in deep-sea mining and bioprospecting face economic challenges. These include the following:

- Very high initial costs for exploration activities - unlike in land mining, where the investment can be made gradually, to do deep-sea exploration activities, there is a very high investment threshold needed to start the exploration activities.
- Availability of finance/ financial uncertainty.
- Price volatility of raw materials – this creates uncertainty.
- Obligation to share knowledge proceeds and increased environmental concerns decreases the incentives to invest in these activities.

3.3.1. Deep-sea mining

Drivers for demand and supply

The drivers for demand and supply of DSM can be categorised into three main perspectives: global, industry and regional. The table below provides an overview of the main reasons for exploration activities despite their technological, legal and economic challenges.

Table 3-4 Overview of the main drivers for exploration activities

Global	Industry	Regional
Global economic growth – increased demand for metals	Economic benefits (i.e. profits) – revenues made from the value of the ores (land mining more and more costly and difficult –	Pacific: alternative economic development option to increase employment and growth and

[52] COWI & EY (2013). Research & Innovation and Atlantic Ports - Workshop Atlantic Forum (Cork, 4-5 March 2013)
[53] Ibid.
[54] Ibid.
[55] It is difficult to find robust and reliable figures on patents from marine species.
[56] Oldham, et. al. (2014). Valuing the Deep: Marine Genetic Resources in Areas Beyond National Jurisdiction. Contract Reference: MB0128 – A review of current knowledge regarding marine genetic resources and their current and projected economic value to the UK economy.
[57] Ecorys (2012). Blue Growth - Scenarios and drivers for Sustainable Growth from the Oceans, Seas and Coasts, Third Interim Report, Rotterdam/Brussels, 13 March 2012

Global	Industry	Regional
	increasing input and fuel costs).	scope of local economic industries
Increased industrialisation and urbanisation (emerging economies)	Cost savings vis-à-vis land mining (mobile infrastructure that can reallocate from deposit to deposit, clustering of the resource, less waste separation for some deposits, etc.)	EU: securing supply of raw materials is critical for EU manufacturing industries and their competitiveness.
States try to safeguard security of supply of essential raw materials	Apparent higher grade deposits than on land –attractive for companies as the grade of deposits on land is decreasing[58]	EU: potential for a new export market for technology
Green economy – e.g. clean energy technology needs a lot of metal	Develop innovative frontiers – mining industry is used to high-risk investment (main driver)	EU: research and innovation to explore a new area
	No concerns about resource availability from a geological point of view – a lot of research and sampling done to give confidence in explored areas of deep-sea. Less confidence in knowing the resource assessment for SMS (more difficult to find) but for nodules and crusts the industry knows where to find them.[59]	EU: potential to develop new materials (for e.g. clean technologies)

Source: interviews, secondary sources (e.g. Roche and Feenan 2013, Ecorys 2014)

The demand for minerals has increased dramatically over the last decades due to a rapidly growing middle class population.[60] This has led to an increasing market price for metals. As a result, the potential revenue of deep-sea mining increases, and therefore also the incentive for exploration[61].

With respect to supply, market conditions and main players differ strongly per material or material group.[62] For example, precious metals are characterised by low production concentration and exchange markets where prices are not significantly influenced by supply or demand. As regards base metals, although the market is well functioning, deep-sea mining would not produce sufficient quantities to influence the market or the price. On the other hand, deep-sea mining could have a large influence on the price of minor metals, especially cobalt, as currently these metals are traded in low quantities and the supply of them is restricted.

[58] Roche and Feenan (2013). Drivers for the Development of Deep-sea Minerals in the Pacific. Available at http://www.mpi.org.au/wp-content/uploads/2014/05/Roche-and-Feenan-2013-Drivers-for-the-Development-of-Deep-Sea-Minerals-in-the-Pacific.pdf

[59] Interviews. For figures on SMS deposits explored by Nautilus, see their Cost study (2010), for nodules estimates see Sharma (2011) report.

[60] S.E Kesler (2007). Mineral Supply and Demand into the 21st Century. Available at http://www.ivey.uwo.ca/cmsmedia/155037/2._mineral_supply_and_demand_into_the_21st_century__kesler__2007_.pdf

[61] International Council on Mining & Metals (2012). Trends in the mining and metals industry. Available at http://www.icmm.com/document/4441

[62] Ecorys (2014). Study to investigate state of knowledge of deep-sea mining, Client: European Commission - DG Maritime Affairs and Fisheries

Costs for exploration activities

Companies always try to maximise their margins, however, marine operations are very challenging cost-wise, which means they require economies of scale and having the right equipment. Industry is very hesitant to provide figures for costs, however, all companies do their economic calculations.[63]

Table 3-5 Overview of the main costs for exploration activities

Deep-sea mining value chain	Technology	Cost estimate
Exploration		
Exploration in general	Ship time	1 ship (not specified which type) around €1 bn; most expensive part of exploration: around $50,000 -100,000 per day, if 60 days needed → $3-5 mn in total
	ROV	$50,000 – 100,000 a day
	SMS exploration	Nautilus spent $150-200 mn, high cost per tonne of deposit as low amount of deposits found
	Nodules exploration	Cca. 20 months of cruise needed to identify the nodules. The right equipment costs € 10 -15 million per month.
Locating	Mapping (SMS deposits)	Neptune spent more than $100 mn on mapping
	Mapping (nodules)	$5-7 mn cost for mapping time (30-60 days); $30-35 mn rough estimate for the total mapping costs
Sampling	Deep-sea vehicle going down and back to the surface	Up to US$ 1 million per day, excluding maintenance costs[64]
	Analysis of the samples	Less costly than ship time

Source: interviews, unless otherwise stated.
Legend: mn = million, bn = billion

3.3.2. Bioprospecting

Drivers for demand and supply

Unlike for deep-sea mining, it seems from the interviews that the economics of bioprospecting activities are less promising than of DSM. This is due to the large knowledge gaps with respect to the marine ecosystems in the deep-sea, how they work and how they can be manipulated and used. Due to the high cost of marine scientific research and the slim odds of success (only 1-2 per cent of pre-clinical candidates become commercially produced)[65], the potential for making profits is rather small according to one interviewee, which limits the involvement of industry.

However, the commercial importance of marine genetic resources is demonstrated by the fact that all major pharmaceutical firms have marine biology departments. Marine genetic resources are also

[63] Information obtained from interviews. The reports, e.g. Golder Associates (2012) Mineral resource estimate report Solwara project, provide only limited details for costs

[64] UNESCO (2012). Deep-sea technology; the prerogative of the lucky few?, UNESCO Media Services, Natural Sciences Sector: Deep-sea: the last frontier

[65] Status and Trends of, and Threats to, Deep-seabed Genetic Resources beyond National Jurisdiction, and Identification of Technical Options for their Conservation and Sustainable Use, doc. UNEP/CBD/SBSTTA/11/11 of 22 July 2005.

important for biotechnological and cosmetic applications among others. The global market for biotechnology is a promising growth market. In 2004 it was estimated to amount to 2.4 billion US dollars and an average growth of 5.9 per cent per year between 1999 and 2007, generating about 200,000 jobs.[66]

Costs for exploration activities

The costs for exploration activities for bioprospecting are similar to deep-sea mining, particularly with respect to the use of vessels (i.e. $50,000-100,000/day) and other exploration activities done in the deep-sea.[67] Another source mentions that there are few ships available which has created competition for ship-time and the costs can amount to 80,000 US dollars a day.[68] Once the samples are collected, isolated and deposited, the analysis and cultivation is done in labs on land. There is little data on costs available for these activities.

3.4. Environmental impacts

3.4.1. Deep-sea mining exploration impacts

Under UNCLOS, protecting and preserving the marine environment is a general obligation for States. For mineral explorations, UNCLOS requires that application for approval of a plan of work for exploration is accompanied by an assessment of the potential environmental impacts of the proposed exploration activities and a description of a programme for oceanographic and baseline environmental studies. As from January 2012, following informal consultations between the UN Secretary-General and in particular exploration contractors for polymetallic nodules reporting exploration activities by the contractors emerged to be dramatically needed. Further to this, it was decided to organise a series of taxonomic exchange workshops on the megafauna, macrofauna, and meiofauna in contract areas.

According to some interviewees, even though it has been acknowledged that good research was being conducted by universities and institutions, there is still an inadequate knowledge to determine the potential impacts of deep-sea mining on the marine ecosystems, in particular the vulnerable ones. Scientists have now begun describing what the impacts might be to help regulators and the public better understand the potential impacts of this new industrial activity on the ocean and some scientists suggest that before we begin to mine a major research effort of over 10 – 15 years is needed[69].

Moreover, the interviews showed that exploration activities are presumed to have fewer ecosystem impacts than exploitation. Environmental effects of exploitation are discussed in section 4.4. Moreover, it is also clear that the impact of exploration activities varies substantially per type of deposit. For example, SMS deposits are formed over thousands of years of activities of hydrothermal vents, the vents are associated with ecosystems composed of an extraordinary array of animal life and hold intrinsic scientific value.

Nevertheless, there are direct environmental impacts related to the exploration of deep-sea resources (not only raw minerals) and indirect environmental impacts related to ocean acidification and

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[66] Policy Options Paper # 4: Bioprospecting and marine genetic resources in the high seas. A series of papers on policy options, prepared for the third meeting of the Global Ocean Commission, November 2013

[67] Interview.

[68] Policy Options Paper # 4: Bioprospecting and marine genetic resources in the high seas. A series of papers on policy options, prepared for the third meeting of the Global Ocean Commission, November 2013

[69] Greenpeace (2013). Greenpeace report
http://www.greenpeace.org/canada/Global/canada/report/2013/07/DeepSeabedMiningReport.PDF

atmospheric ozone depletion due to changes in the seabed as a consequence of exploration activities .[70] These are for example: introduction of light, waste disposal, dumping and underwater noise. The noise effects caused by exploration systems on cetaceans, fish and marine other organisms are still not known as there are still gaps in the re-colonisation rates on seamounts as consequences of noises.

During the exploration phase for raw materials, physical disturbance will primarily come from drilling for ore samples and ROV sampling which cause underwater noise and destruction of physical structures that represent habitat of the organisms populating the deep-sea. Clearly, exploration does not always lead to mining. On land for example, around one in 100 exploration projects results in a mine,[71] and the deep ocean industry is too young to provide any similar statistics. It is therefore important in the future to get real knowledge about the environmental impacts on the sites caused by exploration. This should be based on a solid EIA and EIS either in the Area or in areas under national jurisdiction.

3.4.2. Bioprospecting exploration impacts

According to the definition in the Convention on Biological Diversity (CBD) bioprospecting is ‘’the exploration of biodiversity for commercially valuable genetic and biochemical resources”[72]. To our knowledge, there are no known studies which make comparisons of effects of exploration activities for raw material and genetic resources. Nevertheless, bioprospecting activities are logically presumed to have fewer ecosystem impacts than exploration for commercial scale mining. However, they still have the potential to cause negative impacts on delicate ecosystems of the deep-seabed and Antarctica introducing light and noise or change water temperature. According to UNEP, bioprospecting activities can also produce pollution such as debris or discharge from vessels and equipment[73]. In general, impact of these activities should be small if conducted on a small scale, and collecting the baseline data will help inform the assessment of impacts in the later stages of a project.

[70] Hermione (2015). Man's impact on the oceans. Available at http://www.eu-hermione.net/learning/mans-impact-on-the-oceans

[71] Sci Dev Net (2012). Deep sea mining: exploration is inevitable. Available at http://www.scidev.net/global/earth-science/opinion/deep-sea-mining-exploration-is-inevitable.html

[72] UNEP (2000). Convention on biological diversity. Available at http://www.cbd.int/doc/meetings/cop/cop-05/information/cop-05-inf-07-en.pdf

[73] UNEP (2015). Bioprospecting in the global commons: legal issues brief. Available at http://www.unep.org/delc/Portals/119/Biosprecting-Issuepaper.pdf

4. Deep-sea exploitation

This section describes and analyses deep-sea exploitation: the state of knowledge on on-going activities, the technical aspects and the economics of exploitation, and the related environmental issues.

4.1. State of knowledge on on-going activities

In the coming sections the state of knowledge on on-going activities is described with a view to understand how much is still in a prospect stage. The overall conclusion is that, while mineral resources have gained much political and economic interest from European and other countries, it has yet to prove any commercial viability. Similarly, biological and genetic resources, even though could be a goldmine for biotech industry, have failed to commercialise with the exception of a handful cases.

4.1.1. Mineral resources

The prospect of deep-sea mining has in recent years gained in interest, owing much to advancements in technology and favourable market conditions of raw materials, but commercial operations have yet to start. In April 2014, Papua New Guinea and Canada's Nautilus Minerals Inc. reached the first-ever commercial agreement for deep-sea mining. Notwithstanding their many missed deadlines, the company is according to self-reporting on track to begin mining of Seafloor Massive Sulphides (SMS) by 2017.[74] The Nautilus' Solwara I project, has repeatedly run into problems and been forced to push their starting date for commercial exploitation forward. To date, exploitation of deep-sea minerals remains a potential rather than reality. Another advanced project is the mining of SMS deposits within the Atlantis II Basin in the Red Sea (by Diamond Fields International)[75].

It is important to mention that prospects at depths between 2,000 and 6,000 meters, where few technologies are available to carry out large-scale operations, are still limited. Since the 1990s, the R&D spending in this area remains small[76] and commercial mining of manganese nodules or manganese crusts appears technologically immature.[77]

There are also several projects which are on the edge of exploitation that concern shallow waters. These projects are Chatham Rock Phosphate that holds a mining permit off the cost of New Zealand, and Don Diego project of Odyssey Marine Exploration, off the cost of Mexico.

4.1.2. Biological resources

In contrast to the lack of operations involving minerals, the exploitation of biological and genetic marine resources in terms of patents is booming and has generated almost 18,000 natural products and 4,900 patents.[78] The exploitation and commercialization (bioprospecting) is embedded in the broader biotechnology sector which continues to grow fast. Since 1999 the number of species with

[74] Nautilus Minerals Inc. (2014). Deep-sea miner Nautilus to charter ship as floating base. Available at http://www.mining.com/deep-sea-miner-nautilus-to-charter-ship-as-floating-base-67529/

[75] Greenpeace (2013). Review of the Current State of Development and the Potential for Environmental Impacts of Seabed Mining Operations, Greenpeace Research Laboratories Technical Report (Review) 03-2013: 50pp.

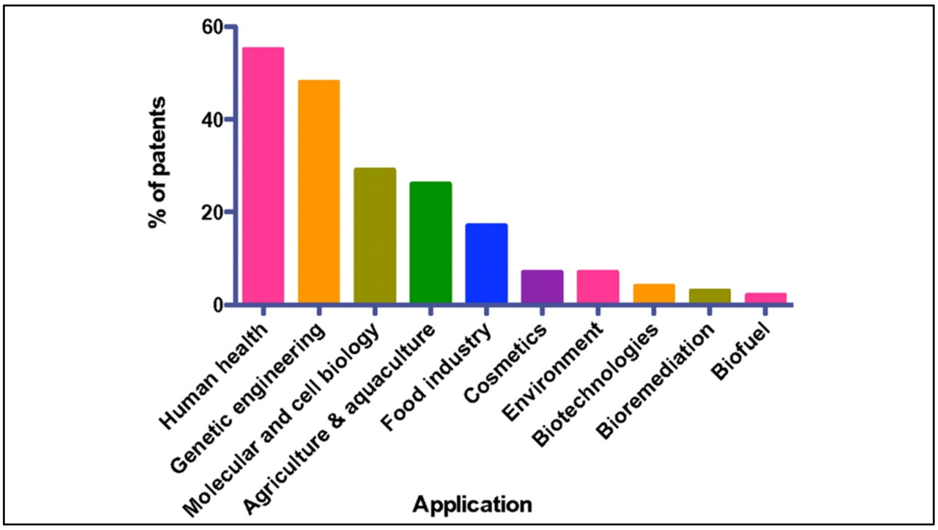
[76] Chung, J.S. (2009). Deep-Ocean Mining Technology III: Developments, Proceedings of The Eighth (2009) ISOPE Ocean Mining Symposium, Chennai, India, September 20-24, 2009, ISBN 978-1-880653-75-3

[77] Greenpeace (2013). Review of the Current State of Development and the Potential for Environmental Impacts of Seabed Mining Operations, Greenpeace Research Laboratories Technical Report (Review) 03-2013: 50pp.

[78] J.M.Arrieta, S. Arnaud-Haond & C. M. Duarte (2010). What lies underneath: conserving the oceans' genetic resources, PNAS vol. 107(43), 18318–18324

genes associated with patents has been growing at a rate of almost 12 per cent per year.[79] The raw genetic materials are used for a range of applications including medicine, fragrances, enzymes and flavours.[80] The graph below shows an overview of the distribution of use of marine genetic and biological resources across areas of application.

Figure 4-1 The uses proposed for patents associated with marine organisms



Source: Arrieta, J. M et al. (2010) PNAS , 107:18318-18324, claims or description of 460 patents deposited at the International Patent Office and associated with genes isolated in marine organism

While the graph clearly shows that the development of new drugs and medicine is dominating the application for patents, it also presents the broad range of products being developed with the use of marine resources (not specified whether deep sea). Nevertheless, only a handful of companies have been successful in putting a product originating from deep sea marine genetic resources on the market. One of these success stories has been PharmaMar (Spanish company).

As described in section 3.2.1, researchers expect the potential of more exploitation to be large and it is worth repeating that recent estimates argue that roughly a mere 0.0001per cent of all species inhabiting the deep-sea is known[81].

4.2. Technological aspects

4.2.1. Deep-sea mining

Trial runs for the mining of manganese nodules have already been done in the late 1970s, however plans were later abandoned due to declining metal prices. About 500 tons of nodules were collected by the combination Ocean Mining Associates (OMA) in 1977 and 1978, using a combination of towed collectors and airlifting. Another consortium, Ocean Management, Inc (OMI), mined about 800 tons at

[79] Ibid.

[80] Ibid.

[81] Serrão Santos, R. (2012). Deep-sea Biology. Presentation of Ricardo Serrao Santos (Universidade dos Açores) at the Atlantic Forum workshop in the Azores 20 and 21 September 2012. Available at https://webgate.ec.europa.eu/maritimeforum/sites/maritimeforum/files/Forum%20Atlantico%20Horta%20v3.pdf

5,500 m water depth using an ROV on a flexible pipe which was connected to a pumping system on a rigid pipe[82].

The current exploitation plans remain marginal, given the unrealized, widespread hype over deep-sea mining in the 1960s, 70s, and 80s. There has been little breakthrough in technology since 1980.[83]

Mining of deep-sea resources is very challenging due to the extreme conditions in the deep ocean, such as:

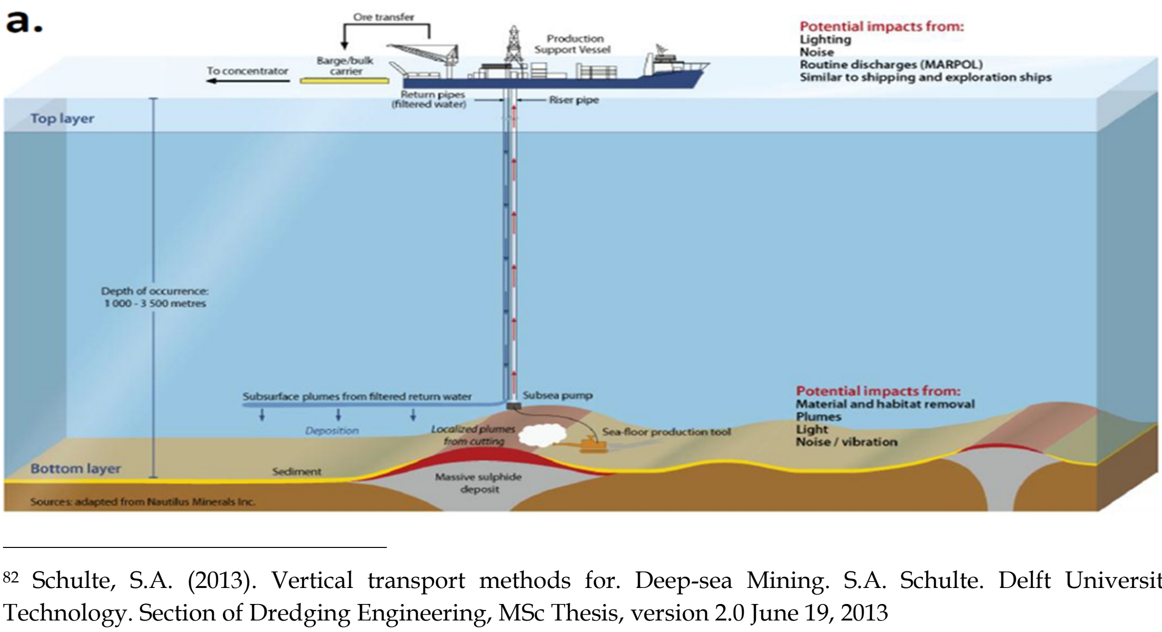
- Hydrostatic pressure ~500 times atmospheric
- Total darkness
- Extreme temperatures, ranging from 2ºC at the ocean floor to 400ºC, at hydrothermal vents
- Limited knowledge of the ecosystems and the consequences of mining, e.g. potential toxicity of metals that will be released into the ocean.
- Varying currents (with time and water depth)
- Variable seafloor characteristics

A deep-sea mining system typically has four major components: (1) Extraction tool, (2) Lifting system, (3) Surface platform, and (4) Disposal system.

Due to the different nature of the deep-sea deposits (manganese nodules, manganese crusts or seafloor massive sulphides), these components are likely to differ per resource. Variations between the different deposit types and DSM operations are likely to vary also with regard to size and duration of the operations, the nature of the specific effects on the marine environment and the potential revenue.

There are three main ways to extract the main deep-sea deposits from their environment, all involving ROVs: (1) Seafloor Massive Sulfides (SMS) can be collected by ROVs, before they are piped up to the surface (see Fig 4-2). (2) Manganese nodules, which litter the ocean floor beneath a blanket of silt, can be sucked up from the seabed by ROV-vacuums. These ROVs can then deliver them to the surface (see Fig 4-3). (3) Manganese crusts can be harvested by ROVs that drive along the ocean floor and grind up the crust. These ROVs then deliver the mixture to a lift system, which pipes it up to a surface vessel (see Fig 4-4).

Figure 4-2 Schematic of deep-sea mining of Seafloor massive sulphides



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[82] Schulte, S.A. (2013). Vertical transport methods for. Deep-sea Mining. S.A. Schulte. Delft University of Technology. Section of Dredging Engineering, MSc Thesis, version 2.0 June 19, 2013

[83] Chung, J.S. (2009). Deep-Ocean Mining Technology III: Developments. The International Society of Offshore and Polar Engineers (ISOPE). ISBN 978-1-880653-75-3

Figure 4-3 Schematic of deep-sea mining of Manganese nodules

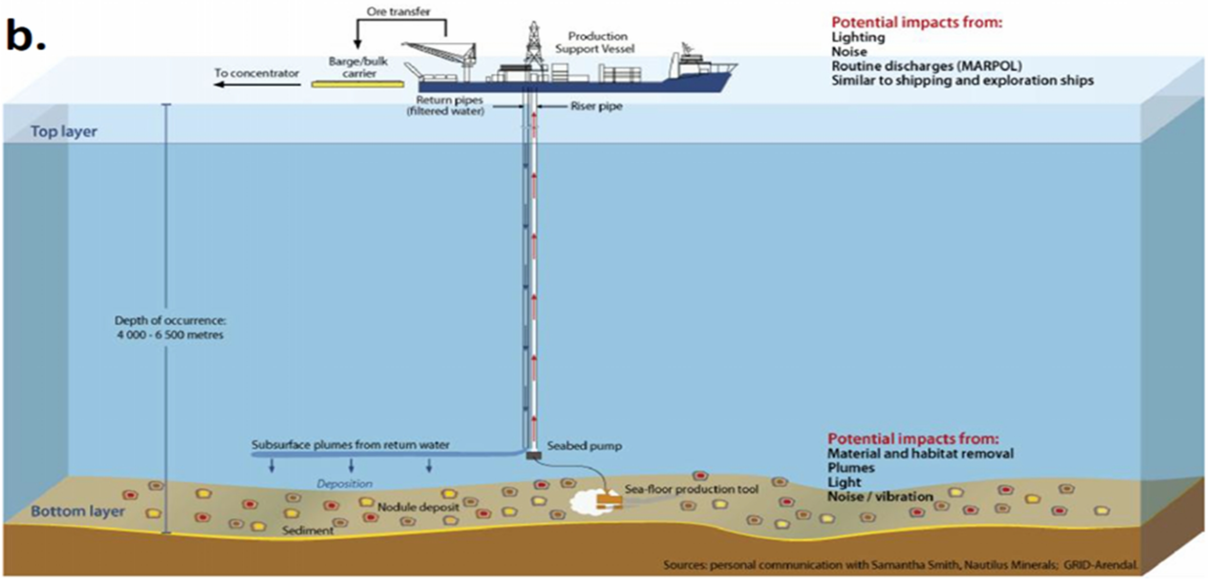
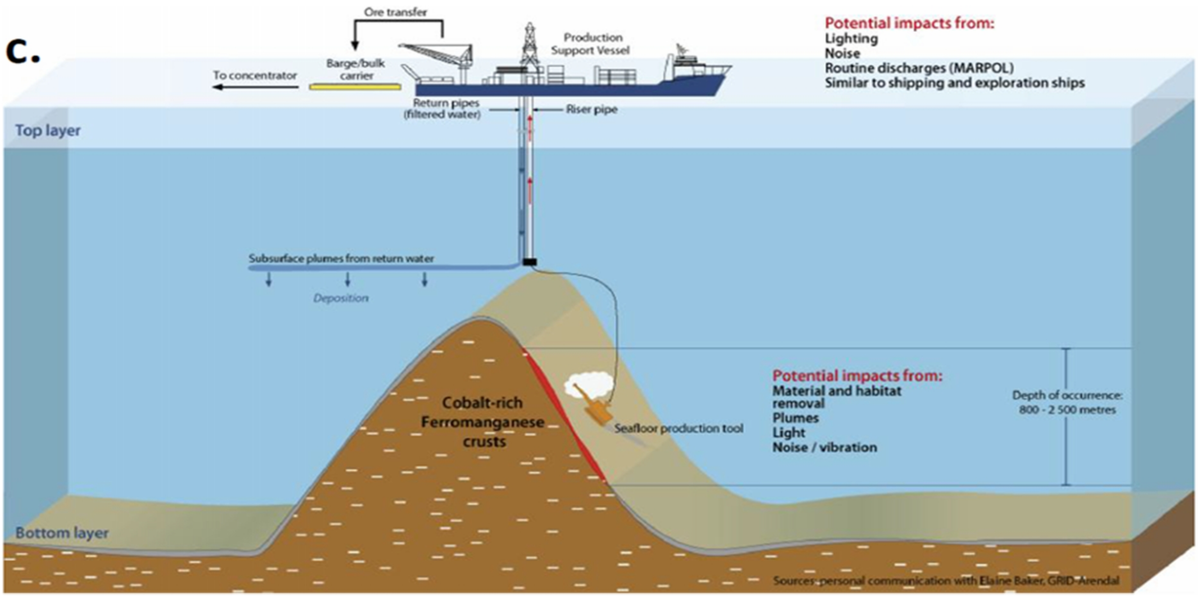


Figure 4-4 **Schematic of deep-sea mining of Manganese crusts**



Source for the three figures: Clark & Smith, 2013[84]

The difficulties for extraction differ between the three types of resources. **SMS** consist of hard rock and therefor require significant force to extract. These exist in areas with significant topographical difference, which might hinder the operability of a ROV which cannot handle steep slopes. In addition, it might be difficult to exclude unwanted materials, i.e. waste rock. For **polymetallic nodules** the problem is not regarding the high density of the rock as they are situated loosely on the seabed and can be excavated through a gathering mechanism such as a suction system or rake. Rather, it is difficult as the resources are located at depths exceeding 3,000m, requiring high tech equipment

[84] Clark, M., Smith, S. (2013). Chapter 3.0: Environmental Management Considerations, in: Baker, E., Beaudoin, Y., (Eds.), Deep-sea Minerals: Sea-floor Massive Sulphides, a physical, biological, environmental, and technical review. Volume 1A, Secretariat of the Pacific Community

which can operate under these extreme conditions. The **manganese crust** has similar issues as the SMS, as the material is very solid. The difficulties lie mainly within removing the thin layer of crust while leaving the waste rock behind.

Technological readiness level

Table 4-1 below shows the technological developments for tools and systems related to deep-sea mining. Using the same system as the EC (Horizon 2020), they are ranked from a scale of 1-9, where 1 is the lowest possible value. As indicated by the table below, the tools for DSM are all in the lower range of the scale, far from being commercially operable. Although many of these technologies are applicable in terrestrial mining, the extreme conditions of the deep-sea make operation difficult. In particular, finding solutions which are both economically viable and environmentally safe has been challenging. For example, passive collectors such as "rakes" have reached a higher technological readiness level, but were eventually abandoned by companies due to their inefficiency and the fact they create huge sediment plumes. In addition, the table also shows the difficulties related to different types of mineral deposits, in particular in relation to ferromanganese crust which due to its geological formation appears extremely difficult to extract. Its low economic potential becomes evident through the underdeveloped technologies related to this resource type.

Low values on the TRL scale are evident throughout many parts of the value chain, indicating significant technological improvements must take place in order for DSM to become a realistic alternative to terrestrial mining.

Table 4-1 Extraction methods for Deep-sea mining.

Ore Deposits	Technique	Comments	Tech. readiness level
Extraction			
SMS	Conceptual drum cutter (ROV)	Based on methods used for terrestrial coal mining, the vehicle minimises the production of ultra-fine particles. Experiments have been conducted at the depths of 1,600m, but no material was collected.	3
SMS	Auxiliary cutter (ROV)	Used to flatten the service, enabling the drum-cutter to excavate resources on the seabed.	2
SMS	Rotating Cutter Head (ROV)	Originally based on deep-sea diamond mining. With a rotating cutter head, it is more flexible to operate than a drum-cutter. However, further testing is needed to find out if it is applicable in a deep-sea environment.	2
SMS	Clamshell grab (ROV)	Not used for excavation, but rather to remove top layers of SMS deposits. Its applicability for gathering rock is uncertain, along with its economic viability.	2
Polymetallic Nodules	Passive Collectors	Advantageous due to its simplistic design and low operating costs. However, it has become an abandoned method, due to lack of control of the quality and quantity of nodules collected, along with great environmental hazards in form of large sediment plumes.	5
Polymetallic Nodules	Hydraulic collector system	The system applies a type of seawater spray in order to separate the nodules from the seabed which results in a limited environmental impact. Hydraulic machines have been tested at shallow depths.	4
Ferromanganese crust	-	Due to the difficulties of mining this resource, an economically attractive option has not been proven yet. The basic principles have been observed but	1

Ore Deposits	Technique	Comments	Tech. readiness level
		the methods have yet to develop further.	
Lifting systems			
Seabed ores	Continuous Line Bucket system	A series of buckets on a line which is towed across the seabed. The method was first tested in 1972, but was however abandoned due to a lack of control of the system along with large environmental impact.	5
Seabed ores	Air-lift system	The system is based on injecting compressed air into a pipe and the ore is pumped up to the surface. It has been tested in very deep waters, but is it very vulnerable to clogging and requires large amounts of energy.	5
Seabed ores	Hydraulic Pump system	A simple and reliable system with high lifting capacity, often applied during the drilling for oil and gas. The concept appears to be a promising concept for DSM, but further research beyond the prototype stage is needed	3
Seabed ores	Batch cable – lifting	Similar to what is applied in terrestrial mining, this is essentially a hoisting system and therefore much more simple than the hydraulic or air-life equivalents. The question lies mainly with if it will be efficient enough to be commercially viable.	2
Surface platforms			
Seabed ores	Dewatering	One of the simplest techniques to upgrade the value of ore. This is crucial in order to increase the economic viability of DSM. The system is well known, and should with ease be applicable to vessels or off-shore platforms.	7
Disposal			
Tailings	-	Due to the fact that large scale commercial operations have yet to take place, this is a highly unexplored area. A clear plan for the handling of tailings is needed.	1

Source: Ecorys (2014)

Technologies for mine closure and site remediation are not discussed in literature to date. However, it is expected that mine closure will be necessary before, during and after mining and that it will, therefore, have social and environmental impacts. For example, closure activities may lead to the displacement of fisheries and loss of revenue. Together with mining itself the closure of the site is expected to increase the noise[85] and air pollution and vibration as well as increase the risk of fluid leaks and discharges.[86] Further concerns with mining and site closure are the risk of vibrations, restricting the movement of species both at deep and at shallow sea and the inadvertent introduction of invasive species.[87]

[85] Ecorys (2014). Study to investigate state of knowledge of deep-sea mining - Final report
[86] Mahapatra, R. (2014). Mining at deep-see. Available at http://www.downtoearth.org.in/content/mining-deep-sea
[87] Ibid.

Position of the EU

The technologies for seabed mining and lifting are less mature than the surface and onshore technologies, as the latter are to a large extent also used in already existing industries. The role of EU industries in deep-sea mining has mainly focused on developing technologies for the sub-sea part. The EU has a strong competitive position in both the mining and the lifting phase. The most advanced mining project to date, the Solwara 1 project off the Papua New Guinea coast, uses European technology (from Soil Machine Dynamics in the UK) for the excavation of the deposits. Present offshore petroleum technology benefited a great deal from the previous large-scale international R&D work in the deep-sea. Today's ocean-mining technology R&D could benefit from a technology transfer from the other offshore practices[88].

The EU is currently (2014-2018) funding a major research project called "Blue Mining", which is a joint effort between 19 international industry and research organisations. The aim is to improve the entire supply chain of deep-sea mining and make it technologically ready to extract deep water resources in a cost efficient manner[89]. Issues to overcome for the future developments of marine minerals exploitation include the location of deposits, the determination of their type and abundance, and the assessment of commercial viability, in particular in view of resource uncertainties and current technological barriers[90].

4.2.2. Bioprospecting

Bioprospecting is situated in the booming global biotechnology industry and increasingly, new discoveries are sought after in the marine environment. A report[91] by COWI and Ernst & Young from 2013, argues that marine biotechnology has developed according to three lines. First, while the exploration of new organisms with potential application in biotechnology has been concentrated to shallow and coastal waters, technological advancements are enabling searches in deeper waters, in particular close to hydrothermal vents. Second, large technological developments in molecular analysis have enabled an upscale and acceleration in the land-based sections of the value-chain. Third and finally, the final stages of the value-chain including exploitation and commercialization of the applications are being hampered in some cases by the limitations to culture new organisms and chemical synthesis. In sum, the key limitations to further developments are not situated physically in the marine environment or with technologies related to sampling or exploration. Hence, discovering new applications and useful organisms require advancements in laboratory technology and capacity rather than marine technology.[92]

4.3. Economic aspects

The key economic challenges related to exploitation are extremely high one-time investment costs ranging in hundreds of millions of dollars. Unlike for land mining, where investment can be made gradually, deep-sea mining requires a very high initial investment to start the operations.

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[88] Chung, J.S. (2009). Deep-Ocean Mining Technology III: Developments, Proceedings of The Eighth (2009) ISOPE Ocean Mining Symposium, Chennai, India, September 20-24, 2009, ISBN 978-1-880653-75-3

[89] Blue mining homepage. (2014) Available at http://www.bluemining.eu/facts-and-figures/

[90] COWI & EY (2013). Research & Innovation and Atlantic Ports - Workshop Atlantic Forum (Cork, 4-5 March 2013)

[91] COWI & EY (2013). Research & Innovation and Atlantic Ports - Workshop Atlantic Forum (Cork, 4-5 March 2013)

[92] Lozada, M and H. M. Dionisi (2015). Microbial bioprospecting in Marine Environments. Pp.307 – 319 in: Kim, S., 2015, Springer Handbook of Marine Biotechnology. Springer.

Similar case is for bioprospecting, where further challenge is the fact that the potential for making money from bioprospecting is rather small as the benefits are unknown. Most activity is done by research institutes, which have problems obtaining sufficient funds for these activities.[93]

4.3.1. Deep-sea mining

Economic viability

Based on the current estimation of the size, location and composition of the deposits, the estimated Capex and Opex[94] (to be treated with caution as no actual operations have taken place yet) and market price for metals, the Ecorys (2014) study concludes that polymetallic sulphides are likely to have the highest commercial viability, while nodules and crust are only marginally commercially feasible. This is due to the fact that copper can be extracted in large amounts from these resources at a moderate market price. Furthermore, it is possible to extract gold from these reserves. This finding is not consistent with the answers given by some interviewees, who mentioned nodules as the most attractive deposits commercially. This is due to the fact that mining companies assume an operation of 15 years to generate returns on investment while key uncertainties exists in case of polymetallic sulphides about the resources and reserves which seem to point to smaller sizes (Ecorys 2014). This has been confirmed by the industry stakeholders, mentioning that it is challenging to find and extract massive sulphides as they are more difficult to spot and are relatively smaller deposits, while the operations are usually calculated with a proven resource for 20 years.[95] For example, Nautilus spent about 600 million dollars and identified only 1 – 3 million resources.

Moreover, decision to extract some deposits, e.g. nodules is strategic rather than a business case, hence many projects are not commercially viable.[96] The calculations of a potential rate of return rely on the assumptions of the abundance of the deposit, grade, mining rate, duration and price.

Costs for exploitation activities

The following table summarises the collected evidence on costs for exploitation activities. There are only two publicly available reports analysing DSM costs – Nautilus Cost study (2010)[97] and Sharma's scientific article (2011).[98] The rest of the figures were obtained from interviews and some additional literature. However, private companies are not willing to share their calculations and figures.[99]

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[93] Interview

[94] Capex are capital expenditures (usually a one time investment cost), Opex are operational expenditures which are recurring costs (usually in $ per day/tonne)

[95] Interview

[96] Interview

[97] Nautilus (2010). Offshore production system definition and cost study. Available at http://www.nautilusminerals.com/i/pdf/NAT005_Solwara_1_Offshore_Production_System_Definition_and_Cost_Study_Rev_3_21_June2010.pdf

[98] Sharma, R. (2011). Deep-sea mining: economic, technical, technological and environmental considerations for sustainable development. Marine Technology Society Journal. Vol. 45 (5), pp. 28-41

[99] Confirmed by industry during the interviews

Table 4-2 Overview of costs for DSM exploitation

Deep-sea mining value chain	Technology	Cost estimate
Extraction, lifting and surface operations		
Excavation	Nodules collectors	€7-13 mn to build a collector, bring it down and collect nodules but not bring them up[100]
Mining system nodules[101]	For nodules totals – incl. different types of collectors, power generation, risers assuming mining of 1.5 mn tonnes per year	**Total: cca. $2.55 bn** Capex ($372-562 mn) Opex ($69-96 mn)/year x 20 years = cca. $2 bn
SMS mining[102]	For SMS deposits – offshore production system **totals**	Capex = $383 mn (incl. a 17.5% contingency)
	For SMS deposits – average Opex for extraction of material and delivery to the port	$70/ tonne (incl. a 10% contingency) or $261,000 per day based on a production rate of 1.35 million tonnes per year
	Subsea Mining Equipment	$84.1 mn (capex) + $20,000/ day (opex)
	Riser and Lift System	$101.1 mn (capex) + $23,000/day (opex)
	Dewatering Plant	$24 mn (capex) + $2.8 mn/ year (opex)
	Production Support Vessel Mobilisation	$6.5 mn (capex) + $145,000/ day (opex)
	Integration and Testing	$59.7 mn (capex)
	Barges	$10.8 mn (capex)
	Barging	$12,700/ day (opex)
	Workclass ROV	$20,000/ day (opex)
	Project & support services	$32.5 mn (capex) + $15,000/ day (opex)
	Owners costs	$7.4 mn (capex)
	Production support vessel	$75,000 / day (daily costs = $145,000)
Logistics & processing		
Logistics & processing	Recovery, transport and treatment of manganese nodules	€ 45 mn / tonne[103]
Ore transfer[104]	Purchasing 3 vessels for nodules transfer	**Total: cca. $3.6 bn** Capex ($495-600 mn) Opex ($93-132 mn)/year x 20 years = cca. $3 bn[105]
Processing plant[106]	For nodules	**Total: cca. $5.75 bn** Capex ($750 mn) Opex $250 mn/year x 20 years = cca. $5 bn
Other		
Exploitation total[107]	Opex cost per tonne of SMS	$80-120 per tonne (Nautilus)
	Harvesting of nodules per tonne	$200-300 per tonne
	Processing of nodules per tonne	$200 per tonne

Legend: mn = million, bn = billion

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100 Interview

101 Ibid.

102 Nautilus (2010). Offshore production system definition and cost study. Available at http://www.nautilusminerals.com/i/pdf/NAT005_Solwara_1_Offshore_Production_System_Definition_and_Cost_Study_Rev_3_21_June2010.pdf

103 Interview

104 Sharma, R. (2011). Deep-sea mining: economic, technical, technological and environmental considerations for sustainable development. Marine Technology Society Journal. Vol. 45 (5), pp. 28-41

105 Sharma 2011 based on ISA 2008

106 Sharma, R. (2011). Deep-sea mining: economic, technical, technological and environmental considerations for sustainable development. Marine Technology Society Journal. Vol. 45 (5), pp. 28-41

107 Interview

The total amounts to $200 million approximate extraction and transfer costs per year, equalling to costs around $80 per tonne of nodules. This shows that the cost per tonne ratio between the land-based deposits and seabed deposits is about 1:10 while the value of the ore ratio is about 10:1.[108]

These cost estimates were discussed during the interviews and the feedback given was that Nautilus estimates for SMS exploitation are outdated and underestimated – by 20-30 per cent, but otherwise in line.[109] Nautilus has also chosen well their deposit and location (the Bismarck Sea – surrounded by islands), and that is why the cost can be lower than usual. For nodules, the cost estimates are more in the range of 2-3 times of those of Nautilus. Sharma (2011) estimates are seen as quite conservative and lacking the operational experience.[110] Moreover, the value of nodules themselves needs to be taken into account as the prices of minerals are foreseen to go up, otherwise the mining industry would not start the deep-sea operations.

4.3.2. Bioprospecting

Economic viability

Exploitation activities for bioprospecting are small scale compared to the deep-sea mining. They provide a "soft touch", e.g. collecting a max of 1 kg of material, use simpler techniques and marine environment is involved only in the first stage of exploration activities, while the rest is done on land.

The increase in exploitation and patenting is driven by technological advances both in water and on land. On land, the rapid development of DNA sequencing technology and related technologies have simplified and sped up the analysis and commercialization of the marine genetic resources. However, currently it is mostly research institutes rather than industry who are involved due to high risk and high costs. The main question is how to choose the most viable production mechanism to succeed in commercialisation. This is a very important aspect of the development of the product and most of the time a production mechanism done in the sea is not sustainable, financially and environmentally.[111]

Costs for exploitation activities

The product development cost is the highest cost element (hundreds of millions to billion and high risks), not the discovery stage.[112] The high cost of marine scientific research is offset by the potential profits. Estimates put worldwide sales of all marine biotechnology-related products at US $ 100 billion for the year 2000.[113] Despite this, only a handful of companies succeeded in putting a product originating from marine genetic resources on the market. One of these success stories is Pharma Mar, which managed to produce three marine organisms for less than $1 billion.[114] A more recent estimate of the costs related to bringing a new drug to the market indicate that the average pre-tax industry cost per new prescription drug before approval is $2,558 million, reaching up to $2,870 million if approved. [115]

[108] Benndorf, Jorg (2014) Deep Sea Mining: State of the Art and Future Perspectives, Lisbon, presentation available at http://www.ordemengenheiros.pt/fotos/editor2/deepseamining.pdf
[109] Interview
[110] Interview
[111] Interview
[112] Interview
[113] Status and Trends of, and Threats to, Deep-seabed Genetic Resources beyond National Jurisdiction, and Identification of Technical Options for their Conservation and Sustainable Use, doc. UNEP/CBD/SBSTTA/11/11 of 22 July 2005.
[114] Interview
[115] Tufts Center for the Study of Drug Development (2014). Briefing: Cost of Developing a New Drug. Available at http://csdd.tufts.edu/files/uploads/Tufts_CSDD_briefing_on_RD_cost_study_-_Nov_18,_2014..pdf

4.4. Environmental impacts

4.4.1. Exploitation of marine raw materials

Mining activity could cause substantial physical harm to deep-sea ecosystems and is likely to bring large quantities of flows (constituted of particle-laden, CO^2 and nutrient-rich, cold water) to the sea surface. Organisms surviving these perturbations would be subject to a radical change in habitat conditions with soft particles settling from the mining plume replacing hard substrata and potentially alter hydrological patterns that supply vent communities with essential nutrients and hot water[116]. Some habitats, such as hydrothermal vents, may be particularly vulnerable to mining impacts. For example, species found in active hydrothermal vents are often site-specific and could be particularly vulnerable and affected by even small-scale mining. For several seamounts, (where cobalt-rich ferromanganese crusts occur) bottom-trawling activities have already showed that seamount biota are particularly sensitive to human disturbances.[117]

Many questions remains related to water acidification, nutrients and disturbances to water column processes. The scale and nature of these impacts requires further investigated but largely depends on the target resource and its associated ecosystems as well as the technology used for extraction.

On-going studies from the European project MIDAS[118] demonstrate that deep-sea mining will potentially affect extensive areas of seabed and will likely produce near-bottom, mid-water or near-surface sediment plumes in the water column. The extent of the plumes is related with the technology, size of the particles, strength of the currents at the mining site, and the topography of the area[119]. Impacts may include the smothering of individual organisms, clogging filter feeders, and as well as increases in toxicity, pollutants and acidic waters across wide areas of the ocean, and alterations food webs[120]. To validate the impacts of mining activities to the ecosystems, MIDAS aims to investigate areas such as those used for test mining of nodules over 25 years ago at the DISCOL (Disturbance-Recolonization) site in the Peru Basin, where past seabed disturbance occurred already, as well as areas of natural disturbance such as in the Canary Islands where submarine volcanic eruption sites took place. Moreover, the SPEED model (Sediment Plume and Environmental Effect from Deep-sea Mining) conducted at the University of Clarkson (New York) can simulate sediment plumes released upwards and downwards at a higher up release station. The effects of different particle sizes, sediment concentration and flocculation on settling velocities are taken into account. A multiple grid scheme is applied when the mining domain is very large or mining time is very long. This model could potentially represent a useful tool to simulate the impact of plumes to microorganisms and deep-seabed and apply it to the area of concern. The most effective way to mitigate these impacts is to evaluate impacts during the development of the extraction technology and designing cutter drums that work in a way that minimizes the plume created thus reducing the loss of material and the impact

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[116] Halfar J. and Fujita R. (2007). Danger of deep sea mining. Science, New Series, Vol. 316, No. 5827

[117] Koslow et al. (2001). Seamount benthic macrofauna off southern Tasmania: community structure and impacts of trawling. Mar Ecol Prog Ser. Vol. 213: 111–125, 2001. ; Clark, M. and D. Tittensor (2010) An index to assess the risk to stony corals from bottom trawling on seamounts. Marine Ecology. Vol. 31, Issue Supplement s1, pages 200–211, September 2010

[118] Midas (2015). The deep sea as a target for exploitation. Available at http://eu-midas.net/science

[119] Donald Bren School Masters Thesis Project Potential Deep-sea Mining of Seafloor Massive Sulfides: A Papua New Guinea Case Study (2006)

[120] Ahnert and Borowski (2000). Environmental risk assessment of anthropogenic activity in the deep sea. Journal of acquatic ecosystem stress and recovery. Vol. 7, No. 4; Jankowski and Zielke (1996). Numerical Modelling of Suspended Sediment due to Deep Sea Mining. Journal of Geophysical Research ; Thiel and Forschungsverbund T. (2001) Evaluation of environmental impact studies in the Southeast Pacific. Deep-Sea Research II: 48, 3427-3882

of plumes. Furthermore, monitoring and modelling of deep-sea currents will support the understanding of the potential extent of the plumes[121].

There are as well several common impacts across the extraction of the three types of deposits[122] that may result with the acoustic impacts from these operations depending on the decibel level and the duration of the operation. If the machinery is operating for extended periods of time it will have a greater chance of impacting marine mammals and other aquatic life. Those impacts are first associated with the presence of marine vessels at the surface or more in the specific with the introduction of light and sounds into sea floor and as well into the water column in environments that are normally light-deprived and silent, occurring when the mined material is lifted from the sea floor to the mining vessel at surface level.

The physical impacts of mining are not just confined to mining activities; pre-processing of ore via mobile platforms at sea will generate waste material that may be discharged back into the water column or at the seabed. The waste water disposal may potentially cover the entire water column and different impacts would be expected at different levels, depending on the size and duration of the plumes. Surface plumes could be narrow but can also extend to 10 to 20 kilometres and mix up to depths of 100 meters[123].

Recovery operations may take decades to centuries as revealed by site tests in the offshore areas of New Zealand and Australia.[124] There are species that have habitat on the sea floor such as cold deep-water corals and sponges that rely on a clean current to supply their nutrients. During mining, those sediments are distressed and the food supply is altered by these activities. The recent literature also suggests that anthropogenic uses of deep-sea communities should include plans for restoration of the disturbed areas[125]. While some possibilities of restorative activities could be effectuated in an environment such as hydrothermal vents, which is relatively limited, the deep-sea is for the most part likely to be impractical for a variety of reasons.

If projects are to be carried out, they should be followed by an Environmental Impact Assessment (EIA). The following should be considered when evaluating the environmental impact caused by deep-sea mining operations[126]:

- The physical destruction of the seabed by mining, creation of mine tailings and the potential for catastrophic slope failures from methane hydrate exploitation;
- The potential effects of particle-laden plumes in the water column;
- The possible toxic chemicals that might be released by the mining process and their effect on deep-sea ecosystems.
- Key biological unknowns, such as the connectivity between populations, impacts of the loss of biological diversity on ecosystem functioning, and how quickly the ecosystems will recover;
- Discharge of waste from vessels and machines;

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121 Donald Bren School Masters Thesis Project Potential Deep-sea Mining of Seafloor Massive Sulfides: A Papua New Guinea Case Study (2006).

122 Clark, M. and Smith, S. (2013) . Chapter 3.0: Environmental Management Considerations, in: Baker, E., Beaudoin, Y., (Eds.), Deep Sea Minerals: Manganese Nodules, a physical, biological, environmental, and technical review. Volume 1B, Secretariat of the Pacific Community.

123 Jankowski and Zielke (1996). Numerical modeling of suspended sediment due to deep-sea mining. Journal of geophysical research. Vol. 101, Issue C2. DOI: 10.1029/95JC03564

124 Clark et al, (2010). The Ecology of Seamounts: Structure, Function, and Human Impacts. Annual Review of Marine Science Vol. 2: 253-278

125 Van Dover, C.L. et al (2014). Ecological restoration in the deep sea: Desiderata, Marine Policy 44, 98-106; Barbier, E. B., et al. (2014): Ecology: Protect the deep sea. - Nature, 505, 7484, p. 475-477. http://www.nature.com/news/ecology-protect-the-deep-sea-1.14547

126 MIDAS

- Possible accidents.

Those steps are fundamental to evaluate and assess the impact that mining will have on ecosystems and should be taken into consideration when carrying out a complete EIA.

Finally, intensive, cumulative and exhaustive mining of a region over a very short period of years could have large impacts to affected ecosystems. Therefore, greater knowledge is needed on the diversity, resilience, species ranges, life cycles and ecosystem functioning of deep-sea fauna before starting vast and spread mining operations.

4.4.2. Exploitation of marine biological resources

The environmental impacts of harvesting biological resources could range from nearly minimal to potentially large. The collection of initial genes for product discovery can be limited to gram and in many cases endlessly synthesised and replicated in laboratories and thus making "wild harvesting" not needed. Since this study has been unable to identify cases of wild harvesting in the deep-sea, it is sufficient to conclude that as long as collection and harvesting of biological resources remains small with the aim to synthesise the active ingredients in laboratories, the environmental impacts of exploiting marine biological resources are very small.

5. Societal impacts/Civil Society Concerns

Exploration and exploitation of deep-sea resources could also have serious societal impacts, such as for example consequences for the livelihoods and well-being of coastal communities. Regarding genetic resources, most activities take place on land in research labs and are difficult to differentiate from other non-marine biotech product developments. These do not directly impact coastal communities. For DSM, the situation is different. So far no exploitation activities have taken place which poses uncertainty with respect to the real impacts of DSM; hence reference to land mining acting as a proxy is crucial. Moreover, predicting the impacts of mining on society is a complicated task that will differ from site to site and will depend upon a range of factors.[127]

5.1. Objective and subjective concerns

In the case of **land mining**, economic benefits usually flow to governments in the form of taxes and royalties paid at a local and national level. The funds created have effects especially in developing nations, on local and national infrastructure, and services.[128] The changes commonly associated with onshore mining projects that can lead to social impacts and risks were summarized in a study in 2011[129] and are also easier to identify since land mining has already taken place.

When it comes to **deep-sea mining**, the most relevant social impacts will likely be associated with several key changes during mining life cycle, which is potentially a long one (20 - 30 years) and may apply to different stakeholder groups at household, local, regional, national, and international level. Exploration is already occurring in different regions in the absence of regulatory regimes or conservation areas to protect the unique and little known ecosystems of the deep-sea. It is also often lacking sufficient participation by the communities in the decision-making.

When it comes to exploitation activities, concerns become even more serious as ownership in the marine environment is to some extent unclear or varies depending on exact seabed location (EEZ or area beyond national jurisdiction). It may also be subject to traditional, national, and international norms, laws, and agreements and may be viewed as national property in which every citizen has an interest. This further complicates processes of consultation, usage, and ownership.

On the other hand, substantial societal benefits of mining may include, but are not limited to, employment, local procurement, investment in infrastructure, and local business opportunities.[130] Moreover, the society will benefit from new technologies, research and innovation (and development of new medicine/ drugs in case of bioprospecting).

Lessons learned from terrestrial mining are provided below together with past relationships between mining companies and Pacific Island communities that have been characterised by complexities, tensions and contradictions:

- Use ecological (systematic) approach
- Be aware that legal limits and scientific data may not be aligned with community expectations
- Societal changes can be indirect, often economic/political in nature

[127] Vanclay, F. and Esteves, A.M. (2011). New Directions in Social Impact Assessment: Conceptual and Methodological

[128] Bainton, N.A. (2010). The lihir destiny: Cultural responses to mining in Melanesia. ANU E-Press

[129] Franks, D.M. (2011). Management of the social impacts of mining.

[130] Esteves, A.M. and Vanclay, F. (2009). Social development needs analysis as a tool for SIA to guide corporate-community investment: Applications in the minerals industry. Environmental Impact Assessment Review. Vol. 29 (2), pp. 137-145

- Socio-environmental concerns are very important (use of coastlines, deep-water pollution and disturbance)
- Land use, ownership and access are also important (e.g. issues of fishing or cultural practices)
- Government institutions are crucial to balance environmental preservation against economic gain
- Corporate governance, corporate social responsibility and transparent procedures need to be established before mining takes place
- Social scientific research needed to understand communities' positions

The **Solwara 1** case represents a real case in which impacts to people in Papua New Guinea are already creating fears for the potentially irreversible loss of cultural heritage and environmental amenity. The details of this case can be found in Annex A. Some of the concerns and desires in relation to deep-sea mining from Early Pacific Islands states community are summarized below[131]:

- Research into impacts of DSM on biodiversity
- Establishment of protected areas prior to mining
- Strategic environmental assessment
- Baseline and impact studies on environmental, societal and cultural aspects
- Application of ecosystem-based precautionary approach to deep-sea mining
- Better research, consultation, legislation and regulation, assessment and monitoring of the proposal and execution (transparency, corruption)
- Free, prior and informed consent of the communities ("social licence to operate")
- Community representation body.

5.2. Overview of possible societal impacts on coastal communities

To conclude our preliminary analysis, the table below presents the potential societal impacts due to deep-sea mining based on examples for terrestrial mining as a proxy. It is important to stress that some impacts of terrestrial mining are less applicable to DSM, while other impacts absent on land are more likely to happen in the sea[132]. It is also important to read this table along with the ecological impacts that these activities could create to the environment since the two impacts are closely related. Therefore the table below lists the societal impacts applicable to DSM only which are at the moment considered to have a significant impact.

Table 5-1 Overview of potential societal impacts on coastal communities

TYPE OF CHANGE	EXAMPLES OF IMPACT		
Political, social and cultural	Labour practices: health and safety, working conditions, remuneration, right to assemble, representations in unions, women labour force	Political: opportunity costs for other development options	Human rights and security: states overriding community self-determination, suppression of opposition and demonstrations, targeting of activists, rights awareness programs

[131] Roche and Bice (2013). Anticipating Social and Community Impacts of Deep-sea Mining. Available at http://www.mpi.org.au/wp-content/uploads/2014/05/Roche-and-Bice-2013-Anticipating-Social-and-Community-Impacts-of-Deep-Sea-Mining.pdf. ; John L Luick (2012) Physical Oceanographic Assessment of the Nautilus EIS for the Solwara 1 Project, Deep Sea Mining Campaign. Available at http://www.deepseaminingoutofourdepth.org/wp-content/uploads/EIS-Review-FINAL-low-res.pdf

[132] The Table 5-1 has been adapted based on Roche and Bice, (2013). Anticipating Social and Community Impacts of Deep-sea Mining.

TYPE OF CHANGE	EXAMPLES OF IMPACT		
Economic	Distribution of benefits: employment, flow of money, training, local business spending, community development and social programs, compensation, managing expectation, equitable distribution, cash economy	Industry: change in composition, dominance of foreign entities	
Socio-environmental	Resources access/competition: marine resources, subsistence fishing, cultural practices, scarce infrastructure, damage to sites	Gender and vulnerable groups: disproportionate experience of impact, marginalisation of vulnerable groups, equity in participation and employment	Social impacts related to environmental concerns, such as noise, dust, chemical use, and water pollution

Source: adapted text based on Roche and Bice, (2013). Anticipating Social and Community Impacts of Deep-sea Mining.

5.3. Societal impact relevant for the EU

Due to the increasing importance of the topic in the immediate future and, the necessity for the EU to start to define a clear policy on the topic, the European Commission launched a Stakeholder Consultation[133] on seabed mining. The responses received were from civil society organization (18), (10) EU Member States and non EU-countries (Australia, Switzerland and the US), as well as from environmental NGOs, but also 28 companies and consultancies (e.g. Nautilus, G-Tec). It is interesting to note that the main outcomes from the consultation showed that according to civil society, NGOs, Member States and some consultancies, commercial mining should not take place unless regulations are in place. Furthermore the consultation showed that the drafting and adoption of regulations must be transparent and participatory and any benefits widely shared. Also the Consultation from July 2014 showed that some European Organizations[134], NGOs and stakeholders want a robust regulation (based on precautionary approach, EIAs). In addition, they require more emphasis on reuse and recycling of materials rather than on deep-sea mining.

Interviews carried out with environmental NGOs showed that in order to ensure that marine habitats, biodiversity and ecosystem functions are adequately protected, exploitation activities must not take place until an institutional framework is in place. An environmental NGO said that much more time is needed to allow for a transparent public debate. In the meantime the NGOs interviewed stated that the European Commission should put in place a moratorium on the deep sea mining activities until further research on the impacts of mining on the marine environment is carried out and a more sustainable alternative is fully investigated[135].

On the other hand, the interviews with industry stakeholders point out the fact that before making any conclusions, the opponents of DSM, scientists and governments should look at the overall risk and impact of DSM vis-à-vis terrestrial mining, and allow things to go forward, as stated before, the land and sea mining impacts can be compared but they also slightly diverge for clear reasons. They point to the fact that real risk is already taking place on land and the increasing need for mineral

[133] Ecorys (2014). Study to investigate the state of knowledge of deep-sea mining. Available at https://webgate.ec.europa.eu/maritimeforum/sites/maritimeforum/files/FGP96656_DSM_Final_report.pdf

[134] International forum for sustainable underwater activities. Available at http://ec.europa.eu/maritimeaffairs/seabed-mining-consultation/respondents.htm

[135] Seas at risk (2014). Deep sea mining at odds with EU's circular economy aspirations. Available at http://www.seas-at-risk.org/news_n2.php?page=682

resources will not be satisfied through recycling and reuse only. Hence, it is important to take the risk to see the benefits, as it has been the case of offshore oil and gas.

To conclude, it is now fundamental to understand and address the social impacts and the further implications related to mining. In particular to distinguish the different range of impacts related from the economic, employment and work practices (such as direct employment, contracting, wages) to the socio-environmental concerns (such as noise, dust, chemical use, fisheries, and water pollution). In particular, one stakeholder interviewed revealed that the societal benefits of DSM when it comes to the local communities, for example in the Pacific area, are limited. Local communities could supply food to the vessels involved in exploitation activities but would not experience a large positive employment or economic impact. They generate only a few high tech jobs and no real economic benefits. This is an important argument to further investigate actual jobs creation potential of DSM activities. The EU should try to properly identify the risks and examine the potential impacts of DSM activities taking into account the ethical impacts those activities could have in the areas of concern like in the Pacific.

It is also important to stress that when it comes to bioprospecting activities, the main gap is to address the conservation and sustainable use of marine biological diversity for all in line with the concept of common heritage of human kind in the areas beyond national jurisdiction. The following years will be fundamental to try to guarantee a more equitable access and use of marine genetic resources for all.

6. Cost-benefit analysis

Cost-benefit analysis (CBA) in this report aims to determine and compare the main costs and benefits arising from deep-sea exploitation along the value chain for as many technologies as possible, categorised into economic, environmental and societal indicators. Further aim is also to compare the current situation ("business as usual") with a situation when technology is fully implemented ("hypothetical scenario").

6.1. Knowledge gaps and barriers

There have been many knowledge gaps and limitations identified by stakeholders and literature research. The main data and knowledge gaps are listed below, classified into six categories. These concern EU companies involved in deep sea exploration and exploitation activities. This sector in the EU is small but nevertheless important from a global perspective.

6.1.1. Technology-related gaps

Mineral resources

Exploration:

- Technological gaps are low, there were also lessons learned from e.g. oil and gas sector. A lot of the technology used for SMS (seafloor massive sulphides) mining is based on existing equipment used in the oil and gas sector. EU companies are involved exclusively in nodules exploration as contractors, however exploration technology developed by EU companies are used for other deposits as well. EU companies are market leaders in exploration technologies.

Exploitation:

- The views on the maturity of the technology diverge as the technology is not proven. Some stakeholders say the technologies are there but some of them need to be adapted better to the deep-sea environment (e.g. crawlers that need to be extrapolated to under water equipment). Others argue new technology might be needed for some deposits (e.g. SMS) as it is very difficult to drill rock on the seafloor. EU companies are a bit lagging behind global leaders in exploitation technologies. However, EU research projects are taking place to develop these (e.g. Blue Mining).
- Another example of technological limitations is the power needed to get down to the seafloor and cut rock. In deep-sea, more power is needed to recover the same amount of material than on the surface. It is not known how much energy is needed due to the influence of the very high pressure, the irregularity of the seabed and its effect on piloting ROVs on the seafloor. However, this is not seen as a barrier but rather as a manageable challenge.
- Specifically challenging are manganese crusts as the technology is not yet there to exploit them. To our knowledge, no EU companies are involved in exploring manganese crusts.
- The exploitation technology needs to be tested in marine environment. Moreover, technologies for remediation are underdeveloped.

Biological resources

Exploration:

- Technology-wise bioprospecting is simpler than DSM as the scope and the amount of the material to be collected is smaller. The main gap is getting the samples as sometimes the samples are located in more than 6,000 metres.

- In general, there is a lack of understanding of the marine ecosystems in the deep-sea, and a lack of tools to understand how to use these genes and how to manipulate, grow and isolate them.

Exploitation:

- There is little research on exploitation of deep sea MGR in the EU at the moment as there are limited resources and will to do so. Investing heavily in deep sea marine genetic resources is not convincing enough yet for the industry in the EU as the potential for success is very limited.
- Only a handful of companies in the world have been successful, including some of the EU companies.

6.1.2. Legal gaps

Mineral resource:

- *Exploration:* the legal gap is low for the EEZ as coastal states have their mining regulations. Legal and governance framework in the Area is governed by ISA.
- *Exploitation*: the legal gap is low for the EEZ but the exploitation legal framework in the Area is currently under development. If there is clarity on what is allowed, the companies can design a mining system according to those benchmarks. This is important for some EU Member States (e.g. France, Germany, Belgium, the United Kingdom) as their industries are involved in several exploration projects whose licences will expire in the near future.

Biological resources

- *Exploration and exploitation*: main gaps and limitations for bioprospecting are legal as there is no legal framework in place in the Area. MGR matters are still under negotiation in the UN. Currently, there is freedom for companies in the High Seas. In the EEZ, it is still challenging to set up a transparent legal system which would be accountable to the country where the samples were taken from. Once again, this is very relevant for bioprospecting industry in some EU Member States. Moreover, EU can play a significant role in the international negotiations.

6.1.3. Economics-related gaps

Mineral and biological resources, exploration and exploitation:

- Financing these projects is an issue due to the very high initial costs, high risks and uncertainty. In some cases, the business case is not there yet and activities are based on strategic decisions to be involved in the offshore mining sector. Some projects in the EU are supported by public financing at national or EU level.
- There is also uncertainty about the benefits of exploration due to no mining activity taking place yet and a few success stories of bioprospecting. Data on benefits are in particular missing from publicly available documentation. The interviewers were also unable to provide any concrete figures.
- Companies are not willing to share their calculations of potential return from exploitation activities (neither from exploration) and little publicly available data on costs and revenues exists.

6.1.4. Environmental & societal impacts related gaps

Mineral resources

- *Exploration*: there are environmental regulations for exploration in the Area done by ISA.[136] These regulations are specific for the different types of deposits and with the scope of setting guidelines for prospecting and exploration of raw minerals. Also, in the case of serious harm to the marine environment caused by the activities of the contractors, ISA may take immediate measures to prevent, contain and minimize the impact.
- *Exploitation*: this is one of the main knowledge gaps. There is uncertainty about environmental and societal impacts due to lack of exploitation activities and huge fragility of deep-sea ecosystems, in particular understanding of the interaction between mining (exploitation) and ecosystems found in the deep-sea, but as well with the recovery of the area where mining could occur. There is some research on this in the EU, whether at the EU level (e.g. MIDAS project) or national levels (e.g. in Germany). There is still a lot more to be done in this area.

6.1.5. Resource related gaps

Mineral resources

- Even though from a geological point of view, it is clear that metals and minerals are there in the deep-sea, there is still lack of knowledge of the true resource potential and deep sea reserves. This holds particularly for SMS as described in section 3.1.1 (e.g. Nautilus found 3 million tonnes that could last for 3-5 years of mining; this amount is not sufficient to turn the area into a minable zone for a period of 20-30 years). In case of manganese nodules which are easier to find, the industry is sure there is enough resources. Manganese crusts are the least mapped and sampled deposit. More research is needed in this area.
- A comprehensive overview of deep-sea resources in Europe is currently lacking. A recently started European Innovation Partnership (EIP), called Environmentally Responsible Deep-Sea Mining (ERDEM), aims to compile overview maps of deep-sea minerals distribution in Europe with quantitative resource potential estimates.[137]

Biological resources

- There is still a lot to be discovered as described in section 3.2.1. Only a very small percentage of marine genetic resources is well known.

6.1.6. Other gaps and challenges

- There are a lot of challenges in the *public perception* as many people are not aware of deep-sea mining or bioprospecting. There is limited public engagement other than on a local scale. Once there is more awareness, this might create challenges in national jurisdictions as public opinion might differ from national policies.
- *Geopolitical* challenges in international waters.

Due to the existing serious data gaps, particularly on the benefits side (as there are no exploitation activities at the moment), it is almost impossible to do a proper cost-benefit analysis based on robust quantitative figures. The following section describes the approach taken to mitigate this problem.

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[136] International Seabed Authority (2015). Protection of seabed environment. Available at http://www.isa.org.jm/files/documents/EN/Brochures/ENG4.pdf

[137] European Commission (2015). Environmentally responsible deep-sea mining. Available at https://ec.europa.eu/eip/raw-materials/en/content/environmentally-responsible-deep-sea-mining

6.2. Cost-Benefit Analysis approach taken

Due to the data and knowledge gaps indicated above, the following steps have been taken in order to perform a "light" CBA.

1) The coming sections largely sum up the expected costs and benefits in terms of economic, environmental and social impacts. For each category of impacts, key cost and benefit indicators have been determined and analysed, along the value chain based on secondary and primary research. Monetary estimates have been provided where possible.
2) We defined a "business as usual" (BAU) scenario and a hypothetical scenario in order to provide insights into the comparison of the current situation and a situation where technologies are fully implemented. This comparison is mainly based on expert judgement rather than facts due to limited data availability.
3) The CBA tries to differentiate per type of deposit (as these use different technologies) but in case of bioprospecting the technology is highly similar.

6.2.1. Deep-sea mining - analysis of economic, environmental and social impacts

The analysis of key CBA indicators showed that, even though data is largely unavailable for the majority of key issues, a number of observations can be made.

The economic impacts will depend on the type of mineral deposit. There are only two publicly available studies to our knowledge (at the time of writing this report) with cost estimates of exploration and exploitation technologies, i.e. the 2010 Cost study of Nautilus[138] with outdated figures, and a scientific article done by Sharma in 2011, which was criticized by the industry that it does not take the practical operations into account.[139] The mining operations go into hundreds of millions to several billions (see Table 6-2 below for some figures). The main revenue streams (economic benefits) for a company involved in DSM come from some cost savings compared to land mining and the value of metal and minerals. These cost savings can be due to:

- processing costs that are much lower in the deep-sea,
- no waste digging costs,
- energy costs are lower as no extra processing for getting rid of the bad material,
- no ground moving costs, or
- first operation infrastructure, second operation much lower costs.[140]

Since only a few EU Member States are involved in deep sea activities, the overall impacts of this sector on the EU are expected to be small.

The environmental impacts of exploitation are expected to be significantly higher than for exploration, particularly at the mining site. The magnitude of the impacts depends on the type of deposit and technology used. Besides possible co-benefits for scientific discovery, e.g. seabed mapping and sampling, there are no additional direct environmental benefits foreseen. There might be some indirect environmental benefits such as less waste generated compared to terrestrial mining. For example, in case of copper, environmental impact is larger and larger on land base vs. in the ocean. Environmental effects of offshore mining could be further mitigated but this is a great knowledge gap that needs to be filled.[141] There have been no figures available quantifying the environmental impacts.

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[138] Nautilus (2010). Offshore production system definition and cost study. Available at http://www.nautilusminerals.com/i/pdf/NAT005_Solwara_1_Offshore_Production_System_Definition_and_Cost_Study_Rev_3_21_June2010.pdf

[139] Interview

[140] Interview

[141] Interview

Since deep sea mining is not taking place in EU waters yet, the environmental impact on the EU is currently non-existent.

The societal impacts are likely to be varied. Benefits could include job-creation in the supply chain; however, estimates are not pointing towards a significant increase, in particular for the EU. The Nautilus Cost study (2010) gives some estimates regarding the long-term employment possibilities arising from DSM (see Table 6-1 below). This shows that each deep sea project in the EU offers only a few hundreds of job opportunities, namely in the high tech industry requiring high skilled workers. This is a relatively very low number of jobs created in the EU compared to land mining or recycling, hence the EU deep sea industry can be seen as marginal in terms of job creation. With respect to the impacts on local communities, job creation effect there is also minimal as the local population often lacks appropriate education. Depending on the level of regulation and environmental damage, the costs could be substantial for local coastal communities if, for example, fish stocks are affected or if land-based processing practices of mining related activities are not controlled. Moreover, if endemic and unique species are negatively affected by mining, it removes the potential of finding applications from bioprospecting with human benefits, such as medicines.

Table 6-1 Personnel Summary

Area	Number Personnel
Vessel Marine Operations	30
Mining Operations	54
Mining Maintenance	31
Medical & HSE	2
Vendor Representatives	4
Total	**121**

Source: Nautilus Cost study (2010)

The table below compiles the expected costs and benefits of deep-sea mining along the value chain and per type of deposit to the extent possible.

Table 6-2 CBA Indicators of deep-sea mining

	Indicators / Value chain	Economic		Environmental		Societal	
	Value chain	**Cost**	**Benefit**	**Cost**	**Benefit**	**Cost**	**Benefit**
1	**Exploration**	Ship time ($50-100,000/ day)x 60 days = 1.8 mn	Access to raw materials	Loss of substrate	Possible scientific co-benefits such as seabed mapping and sampling	Little research conducted on the social costs of exploration. These are expected to be minimal. However, there is the opportunity cost for other options	Some employment opportunities in high tech jobs.
		R&D SMS exploration ($0.2mn/day), surveying[142]	Cost savings in labour compared to land	Emissions from ship			
2	**Resource assessment & evaluation**	Other investment costs (vessel, drilling equipment)	Cost savings in environmental and health & safety regulation compared to land	Seabed disturbed by drilling and sampling	Lower environmental impacts for some deposits than on land		General knowledge & innovation technologies
		Exploration licence (can cost around $500,000)					Less pollution/ impacts on population as if on land
3	**Extraction, lifting and surface operations**	**SMS:** Mining system $287 mn/ 1.35mn tonnes Capex + $261,000/ day Opex Lifting system $101 mn, mining vessel $200mn[143]	Value of the metals and minerals (Ecorys study provides some estimates)[144]	**SMS:** Sediment plumes, large disruption on vents, recover depends on the level of activity of the vent.	Unlikely to have direct environmental benefits	Social costs to indigenous populations are not well documented due to lack of mining. They are expected to be similar to terrestrial mining and oil & gas sector.	Increased security of supply of mineral resources
		Nodules: Mining system $2.55 bn/ 20 years	Cost savings in mobile infrastructure compared to land	**Nodules:** Relatively large area affected and top layer (50 cm of sediments) expected to be significantly disturbed. Recovery capacity and time of habitat overall unknown			Some employment opportunities but little as mostly high tech jobs
		Exploitation licence, royalties and taxes	Cost savings in waste digging costs, lower energy costs	**Crusts:** Unclear what technology will be used but expected that all sessile organism will be destroyed. Recovery times are highly uncertain.[145]		Lack of direct involvement and representation, lack of knowledge base for understanding	Little information on benefits for local communities – impacts could be self-determination, rights

142 Ecorys (2014). Study to investigate state of knowledge of deep-sea mining. Final report Annex 6 Environmental Analysis, FWC MARE/2012/06 – SC E1/2013/04
143 Ibid.
144 Ibid.
145 Ibid.

	Indicators / Value chain	Economic		Environmental		Societal	
	Value chain	**Cost**	**Benefit**	**Cost**	**Benefit**	**Cost**	**Benefit**
4	**Logistics**	**SMS:** Ore transport $10.8 mn/ 1.35 mn tonnes		Discharge plumes, air pollutions from transport		the implications	awareness programmes, community development and social programmes
		Nodules: Ore onshore and offshore transport $3.6 bn/ 20 years					
5	**Processing**	**Nodules:** Processing plant $5.75 bn/ 20 years	Cost savings in separation for some deposits	Disposal of tailings	Less waste is generated for some materials compared to land mining	Social impacts related to noise, dust, chemical use	
6	**Distribution and sales**	Possible fisheries disruption would cause loss of revenues (applicable to other steps in value chain as well)	Value of higher grade ores				
			Royalty payments, Alternative revenues for coastal (poor) states				
7	**Mine closure and restoration**	Estimate of Solwara 1 restoration project direct cost $5.4 mn, around $740 mn per hectar which is incredibly high[146]	In some cases the benefits of mining do not outweigh the costs if restoration is taken into account[147]	Air, water and noise pollution; vibrations; movement restrictions for the aquatic fauna; introduction of invasive species – restoration needs poorly understood	Environmental benefits from restoration of deep sea ecosystems. Return to their historical trajectory.	Possible fisheries disruption would cause loss of jobs	Delivery of natural goods and services if ecosystems restored.[148]
		Deep sea restoration is 2-3 times more expensive than shallow water restoration.[149]	Costs of restoration can be reduced if economies of scale and specialised tools.	Degradation of deep sea ecosystems			
8	**Other**	Legal compliance costs		Land activity in preparation of deep-sea mining, Spill over effects		Dominance of foreign entities	

146 Van Dover, C.L. et al (2014). Ecological restoration in the deep sea: Desiderata, Marine Policy 44, 98-106
147 Newell, R.C. and Woodcock, T.A. (Eds.). 2013. Aggregate Dredging and the Marine Environment: an overview of recent research and current industry practice. The Crown Estate
148 Van Dover, C.L. et al (2014), Ecological restoration in the deep sea: Desiderata, Marine Policy 44, 98-106
149 Ibid.

Indicators / Value chain	Economic		Environmental		Societal	
Value chain	**Cost**	**Benefit**	**Cost**	**Benefit**	**Cost**	**Benefit**
			including negative influence on fisheries, tourism, and potential to find genetic resources			
Estimated totals impacts						
SMS	$ 383 mn (Capex) + $94.5 mn/ year (= $70/ tonne x 1.35 mn tonnes)	Expected $933 mn/year[150]	Significant environmental damage expected on the mining sites, degradation of the ecosystems if no restoration is taking place.	Besides possible co-benefits of improved knowledge on the deep-sea ecosystems, no environmental benefits expected	Lack of education to respond appropriately, potential loss of habitat and biodiversity in affected areas, similar costs to terrestrial mining	Benefits for local communities are expected to be low as low number of jobs created, low revenue generation expected. Potential benefits from royalties to the coastal governments. Larger benefits for the society as a whole – new technologies, robotics, science knowledge, security of supply of raw materials.
Nodules[151]	$1.95 bn (Capex) + $10 bn (Opex, 20 years) = $11.9 bn Opex = ca $500 mn/ year	$21-42 bn/ 20 years given assumptions; $611 mn/ year[152]				
Manganese crusts	Capex expected 50% of nodule mining, opex 45%.[153]	$172 mn/ year[154]				

Source: own analysis based on available literature and interviews. Note: mn = million, bn = billion, n.a. = not available

150 Ecorys (2014) Study to investigate state of knowledge of deep-sea mining. Final report Annex 6 Environmental Analysis, FWC MARE/2012/06 – SC E1/2013/04
151 Sharma (2011)
152 Ecorys (2014) Study to investigate state of knowledge of deep-sea mining. Final report Annex 6 Environmental Analysis, FWC MARE/2012/06 – SC E1/2013/04
153 Ibid.
154 Ibid.

6.2.2. Bioprospecting - analysis of economic, environmental and social impacts

There is even less evidence available for bioprospecting than for DSM. The key findings are summarised below.

Economic impacts – exploitation (or product development and placing it on the market) phase is significantly more costly than exploration phase (which is usually done by industry and research together to minimise costs). There is a very high potential for benefits, however, so far only a few companies succeeded. The pharmaceutical and biotechnological market is tremendous. Recent estimates of the costs related to bringing a new drug to the market indicate that the average pre-tax industry cost per new prescription drug before approval is $2,558 million. Taking into account the additional costs post-approval brings the total costs per new drug to $2,870 million.[155] These estimates can be seen as indicative for costs of bioprospecting exploitation as they refer to the introduction of new drugs on the market regardless of the origin of their compounds.

Environmental impacts – exploration activities have little environmental impact and it is lower than for DSM as it is more about harvesting than mining. Knowledge in this field is lacking. Benefits arising from bioprospecting might include biodiversity conservation and increasing the knowledge about marine ecosystems.[156]

Social impacts – besides some limited job creation, the social benefits of new products based on MGR could be substantial. The social benefit for the mankind as a whole arising from research and development of new technologies (exploration and exploitation) is also significant.

6.2.3. CBA comparison of two scenarios

The **Business-as-Usual (BAU) scenario** is defined as a situation where no policy change happens.

For deep-sea mining at the current speed of development, this scenario is a 'slow and limited exploitation' scenario where further development takes place but only marginally without a significant impact.

For bioprospecting, the BAU is similar to DSM but further development progresses even at a slower pace due to the combination of high economic costs and high risk of failure.

The **'Technology fully implemented' (TFI) scenario** is defined as a situation where policy action happens which promotes implementation of (exploitation) technologies. For DSM this would mean that exploitation of SMS and nodules is happening. Since crusts are the least advanced of the deposits in terms of mining, these are excluded from this analysis.

The case of bioprospecting is very different from mining. Our research indicates that the largest technological hurdle for bioprospecting to advance at an even faster speed than today is not in the marine environment but rather in the capacity to develop applications from genetic resources in laboratories. It is also not confined to marine genetic resources but also true for land-based genetic resources. In the context of this study, the CBA is limited to what happens in the marine environment which also makes the section on biological resources substantially shorter than that of minerals.

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155 Tufts Center for the Study of Drug Development (2014). Briefing: Cost of Developing a New Drug. Available at http://csdd.tufts.edu/files/uploads/Tufts_CSDD_briefing_on_RD_cost_study_-_Nov_18,_2014..pdf

156 Laird, S., Monagle, C. and Johnson, S. (2008). An access & benefit sharing case study. Queensland Biodiversity Collaboration. Available at http://archive.ias.unu.edu/resource_centre/Queensland%20Biodiscovery%20Collaboration_The%20Griffith%20University%20AstraZeneca%20Partnership%20for%20Natural%20Product%20Discovery.pdf

Table 6-3 Comparison of TFI scenario against the BAU

Impacts	Business-as-usual (BAU)	Technology fully implemented (TFI)
Economic		
Industry	DSM: Industry will slowly proceed with exploitation. Low economic impact as overall low activity, in general, industry is expected to make profits. Land mining is expected to move slowly offshore. MGR: similarly as DSM, low activity as high cost high risk industry.	DSM: More rapid development of offshore mining for SMS and nodules. Higher overall economic impact stemming from higher offshore activity. Revenues will dependent on market price of materials (expected to be increasing) & technological developments (costs are expected to be decreasing). Overall positive impact compared to BAU. MGR: in the exploration phase more marine research will be done for scientific and commercial purposes.
Government	DSM: Governments will support the industry in a limited way as still low confidence in DSM. MGR: similar to DSM	DSM: If pilot mining is successful, involvement of more governments expected. EU governments involved for strategic regions, coastal states governments involved for strategic and economic reasons. More public spending expected compared to BAU. MGR: government might give more public funding to deep-sea marine research.
Civil society	DSM + MGR: Economic impact on coastal states limited.	DSM: More activity will mean that coastal states are more likely to generate more income from these activities. However, this is only in form of royalties, rather than income generated for its population. MGR: a lot of exploration and exploitation activities do not involve local communities.
Environmental		
Degradation of deep-sea ecosystem, water quality, etc.	DSM + MGR: Limited exploitation also means limited environmental impact.	The environmental impact and time for recovery will differ based on these conditions: - Choice of extraction technology - Geomorphological setting - Physical conditions - Scale of operations[157] - Duration of impacts; - Size of area impacted; - Nature of the impacts; - Potentials for recovery.[158] More research and more practical experience and related data will potentially help manage environmental impacts better. MGR: little environmental impact in the marine environment.
Social		
Jobs, gender, health	DSM + MGR: There is some benefit from the development of new technologies and products; however, the impact is limited as low activity.	DSM: More exploitation can mean more impact on the population in the coastal states, including job creation but also some negative impacts depending on the proximity of mining activity to coastal areas and scope and stringency of regulation. Job creation is however also limited as most jobs are high tech and local communities do not have such education. MGR: potential positive impact from the development of new drugs and biotech products for the whole mankind.

Source: own analysis

[157] Ecorys (2014). Study to investigate state of knowledge of deep-sea mining. Client: European Commission - DG Maritime Affairs and Fisheries.

[158] Ecorys (2014). Study to investigate state of knowledge of deep-sea mining. Final report Annex 6 Environmental Analysis, FWC MARE/2012/06 – SC E1/2013/04

6.3. Approach on how to extend the scope of the CBA in a follow-up study

This study has identified large limitations with respect to available data on economic, environmental and societal impacts, which allowed us to perform only a "light" CBA. The added value of the "light" CBA presented in this report has been that it created the basis for a more comprehensive CBA by identifying the key economic, environmental and societal indicators and outlining the main steps that can be taken while acknowledging data gaps. In order to fill some of the data gaps and hence broaden the scope of the CBA started in this report, the following approach can be taken. The different methodological tools that could be used are listed for each step of the CBA.

Step 1: Collect further data on economic, environmental and societal indicators

This is the major gap identified which hindered a more detailed CBA within the scope of this study. As already demonstrated in the section on knowledge gaps and limitations, research on particularly environmental and societal impacts is very limited, even non-existent to our knowledge on providing quantitative estimates for costs and benefits. Economic estimates are the most documented. To overcome these challenges, the following is suggested:

Methodology	Data sources
Further literature review	Studies/ reports done by industry (e.g. Ecorys (2014) lists the main companies/ projects for DSM in the annex, for MGR, this report lists the main companies, further research needed) Academic studies (e.g. Sharma 2011 and other sources listed in this report and in Ecorys (2014), including the DISCOL (disturbance-recolonization experiment), etc.) International organisations studies (e.g. ISA studies, European Commission DG Mare studies (e.g. Blue biotechnology study, DSM study, Blue Growth study, etc.) Further literature from outside EU, e.g. national research institutes (Australia, Japan, China, Russia, USA) Documentation from the ongoing EU FP7 and H2020 projects (refer to the non-exhaustive list in the annex of our study) Any recent documentation from national institutions (e.g. German BGR, French IFREMER, Norway, etc.) Literature related to shallow water mining, terrestrial mining and offshore oil and gas Empirical literature related to shallow water genetic resources Empirical literature related to biotech, pharmaceutical and cosmetics product development
Further stakeholder interviews	International Seabed Authority International Tribunal for the Law of the Sea European Science Foundation Marine Board UN division for Oceans Affairs and the Law of the Sea National authorities and public bodies in Europe involved heavily in this topic (e.g. Germany, the UK, Portugal, Norwegian Marine Biobank, etc.) Industry – contractors with exploration licences and technology developers, shallow water mining contractors, biotech, pharmaceutical, cosmetics – continue asking for estimates of their costs and benefits Projects - Nautilus, Neptune Minerals, Chatham Rock Phosphate, Pharma Mar, BASF, etc. Public officials from local communities (can be from 3rd countries that are affected by DSM or shallow water or terrestrial mining within their EEZ (e.g. PNG, New Zealand)) Academics (marine biological research, geologists, etc.)
Workshops	To discuss data gaps and how to overcome them Bring together interested parties who can point to further data sources

Step 2: Build concrete set of assumptions and verify them to calculate aggregate estimates for costs and benefits

As most of the data will most likely be project/micro level, it will be important to create a set of plausible assumptions in order to calculate aggregate estimates for costs and benefits for the different impacts.

There are different ways of how to do this methodologically:

1. **Bottom-up:** Use project/micro level data and upscale it to macro level (national/ EU/ global) – this has been done for example by Ecorys (2014) to estimate the costs and benefits and economic viability for the three mineral deposit types, or by Sharma (2011) to provide rate of return calculations for nodules. They use assumptions for example on the ore grade, price of metals, mining period, and annual mining rate. Hence, there is some limited basis in the existing literature to calculate aggregate economic costs and benefits, what remains problematic are the environmental and societal costs and benefits. This will require looking at project level data on e.g. the size of deep sea area affected, availability of marine species in this area, restoration time needed for these species, average jobs created per project, skills needed for these projects, etc. Assumptions on average values for these indicators will have to be made to calculate the aggregate impact of all projects. These average values may differ per location or deposit type. Once these average values are calculated bottom-up, they can be discussed and validated by stakeholder at e.g. an organised thematic workshop.

2. **Top-down:** Use broader level aggregate data and downscale to deep sea resources industries – another complementary approach is to go top-down, by considering the industry at a broader level and by use of assumptions narrow down the scope to deep sea mining and bioprospecting sector. This lies on the assumption that data on costs and benefits for economic, environmental and societal indicators of the more aggregate industry level are available. For example, research has to be done to identify relevant data for the offshore mining sector and marine genetic resources research. Then assumptions need to be made on the proportion of these costs and benefits to be attributed to deep sea mining and bioprospecting. For example, there are aggregate data on R&D costs in the pharmaceutical industry or the overall turnover figures for the biotech industry. Assumptions will then have to be made based on desk research or stakeholder consultation to estimate the proportion of these costs and benefits related to deep sea sector.

3. **Indirect**: Use proxies from related sectors – another alternative is to use estimates of costs and benefits from other related sectors as proxies for deep sea sector. These sectors include as mentioned shallow water mining, terrestrial mining, bioprospecting from shallow water or in general. These estimates can then be evaluated whether they can be used one-on-one as proxies or whether assumptions are needed, and what these assumptions should be to adapt the values to reflect the deep sea aspect. For example, there is much more going on in the shallow waters which might mean that there are more studies estimating costs and benefits of these activities. However, it should be noted that deep sea environment is in many cases exponentially different from deep sea, which affects the size of the costs and benefits. This has been evident from the literature comparing the restoration costs of marine species in shallow waters and deep sea, where the restoration costs of the deep sea marine species were multiple times more costly (see CBA table for reference to the study).

Step 3: Build a business as usual scenario

Once these aggregate estimates are calculated, a business as usual scenario can be developed using assumptions on how the situation will develop without any further policy intervention. Assumptions should be developed in collaboration with relevant stakeholders. It is important to identify:

- The timeframe for the analysis (e.g. year 2030)
- How the situation is likely to develop within this timeframe with respect to e.g. number of projects, location of activities, proponent and opponent countries, position of different EU Member States, technologies (including remediation technologies), funding programmes available, expected outcomes of these projects (tonnes of minerals and metals extracted, number of deep sea marine genetic resources identified, manipulated and grown, etc.), public perception, and other related matters such as geopolitics and global price developments. How the situation can translate into overall positive and negative impacts (or costs and benefits) for the different relevant stakeholders (e.g. industry, government, NGOs, etc.) to identify the trade offs.

Step 4: Build a hypothetical scenario(s)

One or more hypothetical scenarios will need to be built to compare the situation with the business as usual scenario. These scenarios should be related to specific (public) interventions that would alter the status quo (business as usual). For example, MGR will remain unregulated (assuming in the business as usual scenario, MGR regulation will slowly be adopted) or on the contrary, legal framework will be adopted faster than in business as usual scenario. Another scenario could be that commercial mining will take place without having environmental procedures and framework in place (assuming business as usual scenario will have such a framework), or that EU will not support deep sea mining at all (assuming some support will be given in the business as usual). This only shows the complexity of the issues and the variety of options to perform a CBA on this topic.

Once a hypothetical scenario(s) is developed, the assumptions need to be translated into impacts (or costs and benefits) for the different stakeholders (including different groups of countries) along similar variables as for the business as usual scenario.

Step 5: Compare these scenarios and derive conclusions

Last part of the CBA would be to compare the scenarios and derive conclusions. Depending on the extent of quantification of the different scenarios, the comparison can be done quantitatively or qualitatively.

7. Policy options

The interest, willingness as well as activity to explore (and exploit) the deep-sea has been around for at least 30-40 years among academic and research institutions, governments as well as mining and biotech industry. Developments in sub-marine technologies, rising raw material prices and scarcity, and advancements in biotechnology, are changing the business-case for further investments in the marine environment. However, those interested are still facing a number of significant challenges, including technological, financial, environmental and legal obstacles. Some of these challenges are slowly being addressed, but there is still much to do. On one hand, the international fora might have reached the momentum when the industry is ready to make the next steps towards larger scale resource extraction to try to overcome further exploitation challenges. On the other hand, large uncertainties remain regarding the environmental and social impacts of harvesting deep-sea resources and the scientific community lacks fundamental data and knowledge to estimate the impacts of the mining activities on the marine environment.

In addition, a key problem is the lack of a legal framework governing the exploitation phase. The ISA is in the process to draft its regulations to regulate mining activities and regarding bioprospecting, debates are still ongoing with respect to the responsibilities and the role of heritage of humankind of the MGRs.

It is important to note that in the following years, EU legislators will have to take into consideration other relevant EU legislations related to DSM activities and bioprospecting until a clear agreement will be in place among the different stakeholders.

To support and encourage these activities to be done in an objective way that takes into account sometimes conflicting interests (e.g. industry vs. NGOs), six main areas for policy options and follow up actions for the EU are identified. These can be adopted individually or in combination.

7.1. Policy Option A - Improve communication and raise awareness on the topic

Rationale

Based on the analysis of existing knowledge in deep sea resources, three main reasons could be identified why this option is important. First, there is a general lack of understanding about the topic within the civil society. More knowledge and awareness among a variety of stakeholders, including civil society, could create a better evidence base for decision-making on further development of such projects. In addition, cooperation between industry and academia (or between companies/ academic institutes themselves) is very important and hence should be further encouraged. Lastly, sharing knowledge across sectors is also very important as there are important lessons to be learned from each other. This is for example the case of oil and gas sector which has also made the transition from land to offshore extraction of resources.

Possible actions

This strategy is relevant to both deep sea mineral and biological resources. Specific actions that the EU, in particular the European Parliament could take are the following:

- The Members of the European Parliament (MEPs) could liaise with industry and scientific research to remain updated on the topic. They should also promote cooperation between them since it is a key element not only to share knowledge but also to share costs of deep sea research, e.g. sharing costly equipment or developing and testing technologies. Existing EU research projects are already doing this cooperation between industry and academia to some extent. Some of the current FP7 projects will be finalised in the coming couple of years, for which a follow up would be needed.

- The MEPs or the EU could organise a thematic workshop including discussions on environmental, social and legal aspects.
- Most importantly, they could keep citizens and associations informed about the latest developments and include all stakeholders in the process.
- MEPs or the EU could promote learning and exchange of experience from the oil and gas sector through the organization of roundtables with other sectors. These experiences could provide more confidence to the mining sector of what is available and what can be done to explore resources. Mutual learning between these sectors could be promoted, on the technology side, but also in respect of learning about the environmental impacts of offshore oil and gas.

7.2. Policy Option B – Improve the knowledge base and address the environmental impacts

Rationale

The reasoning behind this option is the fact that there is a big uncertainty on the extent of environmental impacts on marine ecosystems coming from deep-sea mining as well as bioprospecting. In general, the environmental impacts from bioprospecting are expected to be minimal as marine environment is involved only in the first stage of exploration. The rest of the analysis and product development is conducted in labs on land. In the case of deep sea mining, the fact that no mining has taken place yet provides a great uncertainty related to the environmental impacts on marine ecosystems.

Furthermore, there is no regulatory and procedural environmental framework in place yet, with no environmental performance benchmarks. Having such a framework would be beneficial also for the industry according to which they can start adapting their technologies to minimize the environmental impacts on marine life. This can include development of remediation solutions and technologies which do not currently seem sufficient.

Possible actions

To improve the knowledge base and ensure that exploration and exploitation activities (mainly deep sea mining) are done in a sustainable and transparent way, the following actions could be implemented by the EU:

- The EU could participate and negotiate its position in any working group established by the ISA. The EU is member of ISA and EU MS are also attending. If a proper task force is in place, recommendations in this sense could come from MS and from the EC as well. The EC intends to influence the work of the ISA as far as its capacity will allow it. For example, higher transparency of the International Seabed Authority and their processes and documents is needed, at the moment reports from exploration activities stay within the LTC of ISA. The EU should encourage more transparency with its representatives.
- The Members of the Parliament should be aware of the latest developments at the international level. This could be done by a regular contact with the European Commission and/or by organization of symposia on the topic.
- The European Parliament could also establish an ad hoc temporary committee to bring together environment, trade and research at the European Parliament's level. This shows the importance of inter-institutional and inter-committee communication.

- The EU could develop management plans to protect the full range of biodiversity and ecosystem functions and identify areas off limits from mining. These plans should be in line with existing European legislations to protect the marine environment, i.e. MSFD.
- The EU/ MEPs could follow up the message coming from 2014 EU public consultation on deep sea mining, which stressed the importance of addressing environmental concerns before commercial mining takes place and take it into consideration to define an EU approach to deep sea mining.

7.3. Policy Option C – Support the adoption of a complete legal framework

Rationale

The lack of a complete legal framework in the Area for both marine mineral resources (lack of exploitation regulation) and marine biological resources (lack of any legal framework), has been identified as one of the bottlenecks by a variety of stakeholders. With respect to deep sea mining, this is important as several exploration licences obtained in 2001 will be expiring in 2016 and the companies will need to prepare their exploitation plans. This includes European companies from MS involved in deep sea mining (e.g. France, Germany, Belgium, the UK). Having a legal framework in place is expected to decrease uncertainty and could set environmental standards and targets that companies could adhere to.

Regarding marine biological resources, the reasons to get involved are even stronger. The legal framework is patchy, fragmented and incomplete with relevant rules being found in UNCLOS, the Convention on Biological Diversity (CBD), and TRIPS. In particular, issues on access and benefit sharing remain uncertain and are still under negotiation as they have serious economic implications on the main players. This is a great potential for the EU to make an impact and clarify its position.

Possible actions

Specific options for the EU/ European Parliament include the following:

- The MEPs should follow the developments at the UN level and coordinate with Member States in order to facilitate the adoption of a single common EU approach for both MGR and raw materials. This can be done by for example issuing guidelines for the MS specifying the issues and actions.
- Develop a common position of the EU in negotiations on how to deal with exploitation of mineral resources and exploration of marine genetic resources in the ABNJ. In the last negotiations, EU expressed its willingness to adopt a position on exploration of MGR. The EU should strongly negotiate at the international level as already done during last BBNJ meeting in January 2015. Moreover, it should check that ISA activities are transparent and that environmental aspects are taken into account when drafting relevant regulations.
- The EU could further support the Deep Sea Conservation Coalition in its recommendations to the International Seabed Authority to develop a regulatory framework in line with the internationally agreed approach to the management of the impacts of bottom fisheries on seabed ecosystems and deep-sea species in the High Seas.
- The Members of the European Parliament could further investigate how to approach the topic at EU level considering the relevant EU existing legislation and consider establishing an ad hoc working group, with industries, research, environmental associations, specifically tasked with developing, reviewing and monitoring the effectiveness and implementation of the exploitation regulations.

7.4. Policy Option D – Consider supporting a pilot mining project for mineral resources

Rationale

Several industry stakeholders emphasised their interest in a pilot mining project supported by the EU to bridge the gap between exploration and full scale mining. It is a natural intermediary step between exploration and exploitation in order to test the technology, get the technological parameters and environmental impacts right to prepare for a full scale mining project.

Possible actions

The following are some possible actions for the EU:

- The EU could be involved to build confidence among stakeholders. A number of EU companies are among the market leaders in technology development. Without the EU involvement, there is some probability that industry will not have the necessary support and guidelines to proceed.
- The EU (mainly through the European Commission) could potentially provide co-financing for such a project through for example Horizon 2020 funding programme as has been done for the predecessor Blue Mining or MIDAS projects. If this is the case, the EU should also guarantee that public money does not disappear into private sector without any transparency and with uncertain commercial viability. The project should take into account the local communities affected by such a pilot project and include a thorough environmental impact assessment.

7.5. Policy Option E – Further investigate recycling as an alternative to deep-sea mining

Rationale

Even though the study did not investigate recycling as an alternative to deep sea mining, it is important to address this issue as one of the policy option areas because circular economy, and hence recycling are a key EU policy and the 2014 EU public consultation on deep sea mining has emphasised the reuse and recycling as a preferred option to DSM.

On the other hand, the opponents of such a strategy advocate that recycling is not a realistic option, in a sense that it would satisfy the demand for these materials in Europe (and worldwide). Most of these raw materials are traded on global markets which determine their price, which tends to fluctuate and Europe does not offer competitive advantage for international companies to invest in technology to improve recycling in the EU. Lastly, some products do necessitate raw materials rather than recycled.

Possible actions

From the EU/ European Parliament perspective the following actions could be done:

- The Members of the European Parliament could encourage further studies to investigate the recycling rates of minerals and metals relevant to deep sea mining, the potential alternative of deep sea mining and in particular the real job creation and the revenue generation in the near future. The evidence shows that increasing recycling rates of minerals and metals relevant to deep sea mining could be a potential alternative to deep sea mining. Recycling rates of some relevant materials (copper, nickel, gold, silver, etc.) can be increased by improving the technology. In general, the proponents of the recycling strategy as an alternative to deep sea mining claim that from an EU level perspective, deep sea mining does not create substantial amount of jobs (it involves only a few hundreds of – mostly high tech - jobs), revenue generation in the near future is uncertain, and that some of the materials found in deep sea are not scarce on land (e.g. in case of nodules).

- The EU could adopt a stronger position on this matter given the expectation that some of the more engaged non-EU countries will support deep sea mining and will push for exploitation legislation in the Area. The question that remains for the EU is to decide whether it wants to be on board of these developments in the global mining industry despite all its challenges and concerns or whether it wants to be left behind.

7.6. Policy Option F – Address the societal impacts on local communities

Rationale

The rationale behind this policy option is the identified large gap in understanding the societal impacts of deep-sea mining and bioprospecting on local communities.

It is expected that DSM will have similar societal impacts as terrestrial mining, but there are no clear results yet, since mining has not occurred yet. Environmental protection and social responsibility are fundamental EU values that should be applied to 3rd countries as well, in particular if the impacts are caused by EU activities. Societal and ethical concerns should be part of the negotiations to regulate DSM activities.

Possible actions

Specific actions in this area for the EU and the European Parliament include the following:

- Since the majority of current exploration activities are taking place in the Exclusive Economic Zone of less developed countries (e.g. in the Pacific), it is in particular important that the EU addresses these issues as local communities in these areas do not have adequate education to respond properly. Therefore, further studies should be encouraged and supported to identify the risks and potential impacts in an objective way (including economic, social and environmental aspects) taking into account third countries' population. This would include proposing any mitigation solutions to avoid identified risks.
- The EU could also explore the role of DG DEVCO for cooperation with and support to these countries.
- Moreover, EU could support 3rd countries at the negotiation table in order to create a level playing field when facing opposing interests from some more developed and economically strong countries.

8. Conclusions

This report has analysed the state of play on exploration and exploitation activities of deep sea mineral and biological resources with particular importance for the EU using existing literature and interviews with a number of relevant stakeholders. Furthermore, it has investigated the technological, economic, environmental and societal aspects, it has identified the main challenges, costs and benefits and based on the analysis it proposed a set of six areas for policy options for the EU.

The key conclusions for both, mineral and biological resources provide an outlook and justify why this topic is particularly important for the EU.

8.1. Mineral resources

There has been a recent interest from the EU industry and research in deep sea mining as the sector, even though small, has been identified as one of the priority areas of the EU Blue Growth Strategy. As such, there have been several studies conducted on the topic by the European Commission, including an EU public consultation. EU companies from several Member States are involved as contractors in several exploration projects outside the EU, while further companies support the field by providing top quality exploration technologies.

Even though deep sea exploitation regulation in the Area is still under development, it is evident that deep sea mining will take place in the near future and a significant change will happen once exploitation licences will be given. Since the costs are known to be very high while the benefits are still uncertain for some deposits (e.g. seafloor massive sulphides), the business case is not always there. The decision to go forward is in many cases strategic – the technology, the means and the willingness is there. One of the main concerns that tend to slow down the process are the uncertain environmental impacts that deep sea mining can bring. In particular, the EU stakeholders stress that mining should not take place until proper regulations are in place taking into account the environmental and societal impacts. Further they emphasise reuse and recycling as alternatives to deep sea mining. Despite having such alternatives, including land mining, deep sea mining is seen as a natural development of the mining industry and is going to happen. The main question for the EU remains how to go about it – be part of the development or be left behind.

8.2. Marine genetic resources

The EU Blue Growth Strategy is also relevant for marine genetic resources. These are in particular important for the EU biotech, pharmaceutical and cosmetics industries. The marine biotech industry is a highly knowledge-intensive sector in which Europe competes with non-European developed countries such as the US and Japan. Europe must continue to invest in top-level education and research to support the industry in developing new goods.

The main issue to be solved on this front is the regulatory framework as currently it is very fragmented and patchy. The negotiations on this topic are still going on in particular on the issues on Access and Benefit Sharing (ABS) which poses serious challenges. To ensure that gains made from MGRs emerging from deep-seas are distributed in a fair and transparent manner, this needs to be addressed in multiple agreements, including the UNCLOS, CBD, and TRIPS. EU can play an important role at the negotiation table, however, it needs to agree and clarify its common position first.

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Annex A: Solwara 1 case study

Due to the limited scope of this study and in order to provide the most valuable information, the study summarizes an actual project case currently analysed by scientists and experts on the topic. Furthermore, this case is used to illustrate the different impacts related to mining activities for this particular site.

Canadian mining company Nautilus Minerals Inc. (Nautilus) is set to embark on the unprecedented extraction of seafloor massive sulphides from the sea floor known as the Solwara 1 Project, submitted to the Papua New Guinea (PNG) Department of Environment and Conservation (DEC) in 2008. In 2009 the PNG Government issued the environmental permit for the development of the Solwara 1[159]. Nautilus has secured or is in the process of applying for the exploration rights to 534,000 km^2 of the sea floor in PNG, Tonga, the Solomon Islands, Fiji and New Zealand. Solwara 1 is focused on the sites surrounding hydrothermal vents that combine highly mineralized vent fluids with microbes. In recent years, such ecosystems have been found to host over 500 species previously unknown to science.

The proposed Nautilus experimental deep-sea mining activity should start in 2016, although the physical oceanographic elements of the Environmental Impact Statement (EIS) were criticized in 2012 by researchers due to the critical importance of the level of risk that marine ecosystems will be exposed to. The mine will be excavated by a fleet of robotic machines steered from a ship at the surface. A Bulk Cutter weighing 310 tonnes has just been completed by an underwater specialist manufacturer, Soil Machine Dynamics, based in the UK. Very little is understood about the possible impacts of Solwara 1, but it is certain that impacts will be associated with each step of the deep-sea mining process. For example, the topography of the PNG mining sites may be a critical factor in the dispersal of plumes[160].

A study conducted in 2012[161] showed many errors and omissions in the modelling, presentation and analysis of data. According to the study, some data was collected, some standard plots were drawn, and some modelling was done, but there was no sign of expert guidance[162]. The analysis that was attempted was not always correct – for example, plots which were said to show downwelling, actually showed upwelling.

In conclusion, the study shows the PNG government granted a 20-year operating permit to Nautilus on the basis of an EIS which provided:

- no presentation of currents in the upper 250 metres despite a major surface operation involving transfer of material from the processing ship to barges;
- no firm basis for assessing the risk of massive pollution of the local benthic environment or the risk to islanders on nearby New Ireland;
- no presentation of the surface wave climate;
- very inadequate analysis of the oceanographic data, including serious misinterpretations;
- model results unsupported by accompanying validation or sensitivity studies.

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[159] http://www.cares.nautilusminerals.com/downloads.aspx

[160] Donald Bren School Masters Thesis Project Potential Deep-sea Mining of Seafloor Massive Sulfides: A Papua New Guinea Case Study(2006).

[161] Professor Richard Steiner's - Independent Review of the Environmental Impact Statement for the proposed Nautilus. Minerals Solwara 1 Seabed Mining Project, Papua New Guinea

[162] Prof John Luick, Physical Oceanographer, South Australian Research and Development Institute

Nautilus was asked by environmentalists, scientists and local communities to present a full oceanographic data set for the EIS, i.e. all the data gathered and all the analysis conducted by the EIS consultants but not presented in the EIS.

Solwara 1 case: Societal impacts

To PNG, the mining sector's contribution is 29 per cent of GDP and 77 per cent of total exports in 2000.[163] More mining could turn out to increase GDP growth and thus result in positive economic development. For the local communities, the main positive impact is expected to be job opportunities related to the mining activities. On the other hand, PNG has suffered greatly from terrestrial mining pollution and there is a high possibility that deep-sea mining could exacerbate such negative environmental impacts. On the ocean, PNG fishermen are also nervous about the possible impact of mining on fish-stocks. One way to mitigate the negative effects is to increase the participation of local communities in decision-making. A recent analysis conducted in 2013[164], suggests that Pacific Island leaders and commercial operators could use the emergence of marine mining to a mining industry, experienced from terrestrial mining, to promote corporate responsibility and sustainable development, and that includes involving communities in the decision-making processes. The study also concludes that "*it is difficult to predict the timing, extent, or type of social impacts that will flow from development of deep-sea mining in the Pacific. What is certain, however, is that where mining occurs, whether onshore or offshore, communities will be affected*".

[163] PNG forum (2005)

[164] Roche and Bice (2013). Anticipating Social and Community Impacts of Deep-sea Mining.

Annex B: EU projects

The following European research projects have been identified as relevant.

Relevant EU projects in deep sea miing
MIDAS: Managing Impacts of Deep-seA reSource exploitation
The MIDAS project addresses fundamental environmental issues relating to the exploitation of deep-sea mineral and energy resources; specifically polymetallic sulphides, manganese nodules, cobalt-rich ferromanganese crusts, methane hydrates and the potential mining of rare earth elements. http://www.eu-midas.net/
DS3F: The 'Deep-sea and sub-seafloor frontier' project
DS3F provides a pathway towards sustainable management of oceanic resources on a European scale. It will 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. http://www.deep-sea-frontier.eu/
DEEPCO: Connectivity of deep-sea ecosystems under increasing human stressors
An integrative approach addressing vulnerability and ecological risk assessment. An interdisciplinary project that will involve biologists, oceanographers, modellers and end-users (government, industry), to determine population connectivity in New Zealand and Mediterranean deep-sea habitats, and use this information, together with available early-life history, biodiversity and trophic data, in ecological risk assessment models to assess the vulnerability of exploited, or soon to be exploited, deep-sea systems. http://cordis.europa.eu/project/rcn/108780_en.html
BLUE MINING: Breakthrough Solutions for the Sustainable Exploration and Extraction of Deep-sea Mineral Resources
There is a need to initiate pilot studies to develop breakthrough methodologies for the exploration, assessment and extraction of deep-sea minerals, as well as investigate the implications for economic and environmental sustainability. The "Blue Mining" project will address all aspects of the entire value chain in Deep-sea Mining, from resource discovery (WP1) to resource assessment (WP2), from exploitation technologies (WP3) to the legal and regulatory framework (WP5). http://www.bluemining.eu/
ERDEM – Environmentally Responsible Deep-sea Mining
A European Innovation Partnership (EIP) on raw materials with the objective of developing a Framework for Sustainable Deep-sea Mining. In particular, the goal is to develop a novel set of solutions for exploration, extraction and processing of deep-sea ores, more efficient real time monitoring of the environmental impact and provide advanced understanding of deep-sea mining associated geological processes. http://ec.europa.eu/eip/raw-materials/en/content/environmentally-responsible-deep-sea-mining
ALBATROSS - Alternative Blue Advanced Technologies for Research On Seafloor Sulfides

Relevant EU projects in deep sea miing
An EIP on raw materials whose aim is to develop and test cost-effective technologies to explore and evaluate SMS deposits and enable sustainable access to resources in EEZ. https://ec.europa.eu/eip/raw-materials/en/commitment-detail/431
SeaFlores - Breakthrough Solutions for Seafloor Mineral Extraction and Processing in deep water environment
An EIP on raw materials with the aim of developing and testing innovative DSM system. The key innovation in this project is the generic design and in-situ demonstration activities of a cost-efficient and environmentally-acceptable deep-sea mining pilot system. This project is complementary to ALBATROSS. http://ec.europa.eu/eip/raw-materials/en/content/breakthrough-solutions-seafloor-mineral-extraction-and-processing-deep-water-environment

The following European research projects have been identified as relevant.

Relevant EU projects in Bioprospecting
EUROFLEETS - towards an alliance of European research fleets & EUROFLEETS 2 - New operational steps towards an alliance of European research fleets
FP7 Research Infrastructure projects to foster the coordination and cooperation within research fleets across Europe. http://ec.europa.eu/research/infrastructures/pdf/eurofleets.pdf (ran till August 2013) http://www.eurofleets.eu/np4/home.html (currently running)
PharmaSea
An FP7 project uniting participants from industry, academia and NGOs with the goal to research biodiversity and the potential for the development of new substances (for novel drugs, antibiotics or nutrition use) from marine organisms. http://www.pharma-sea.eu/
Bluegenics
A multidisciplinary project, driven by high-tech genomics-based SMEs with focus on bringing marine-biotechnology-derived products to the market, will also involve the discovery and sustainable production of bioactive molecules from unexploited extreme environments including deep-sea sources. http://www.bluegenics.eu/cms/
SeaBioTech
An FP7 project driven by SMEs with the goal of creating innovative marine biodiscovery pipelines in order to convert the potential of marine biotechnology into novel industrial products for the pharmaceutical (human and aquaculture), cosmetic, functional food and industrial chemistry sectors. http://spider.science.strath.ac.uk/seabiotech/index.php

Relevant EU projects in Bioprospecting
MaCuMBA - Marine Microorganisms: Cultivation Methods for Improving their Biotechnological Applications
An FP7 project whose main goal is to research the diversity of marine microbes using cultivation-dependent strategies. http://www.macumbaproject.eu/
Micro B3 - Marine Microbial Biodiversity, Bioinformatics, Biotechnology
An FP7 project dedicated to developing innovative bioinformatic approaches and a legal framework in order to make large-scale data on marine viral, bacterial, archaeal and protists genomes and metagenomes accessible for marine ecosystems biology and to define new targets for biotechnological applications. http://www.microb3.eu/
EMSO-European Multidisciplinary Seafloor & Water Column Observatory
A large-scale European Research Infrastructure project of deep-seafloor observatories with the goal of long-term monitoring of the interaction between the geosphere, biosphere, and hydrosphere, including natural hazards. http://www.emso-eu.org/
ESONET-European Seas Observatory NETwork
ESONET is a Network of Excellence (NoE) funded within FP6, whose goal is to promote the implementation and the management of a network of institutions, persons, tools and know-how on long-term multidisciplinary ocean observatories in deep waters around Europe. http://www.esonet-noe.org/
MARUM – Centre for Marine Environmental Sciences in Bremen
A research centre whose objectives include developing a better understanding of key processes in the marine environment in order to provide information for sustainable use of the ocean and developing technology and infrastructure for marine research in cooperation with industry. http://www.marum.de/en/index.html
SERPENT – Scientific and Environmental ROV Partnership Using Existing Industrial Technology
SERPENT is a global project hosted by the DEEPSEAS group at UK's National Oceanography Centre, Southampton (NOCS) with a growing network of UK and global partners in the oil and gas industry. The project's objective is to make cutting-edge industrial ROV technology and data more accessible to the world's science community, share knowledge and progress deep-sea research. http://www.serpentproject.com/default.php

Annex C: List of stakeholders interviewed

Interviewee	Organisation	Country
Anonymous	Royal Netherlands Institute for Sea Research	Netherlands
Johan Gille	Ecorys, NL	Netherlands
Matthew Gianni	DSCC	Netherlands
Ann Dom	Seas at Risks	Belgium
Iain Sheperd	DG MARE, European Commission	Belgium
Yannick Beaudoin	Grid-Arendal	Canada
Seline Trevisanaut	Utrecht Centre for Water, Oceans and Sustainability	Netherlands
John Feenan	IHC Mining/ OceanflORE	Australia
Dr. Ulrich Schwarz-Schampera	Bundesanstalt für Geowissenschaften und Rohstoffe (BGR)	Germany
Anonymous	TU Delft	Netherlands
Tullio Scovazzi	University of Milan	Italy
Prof. Marcel Jaspars	PharmaSea	United Kingdom
Robert van de Ketterij	MTI Holland/ IHC Merwede	Netherlands
Paul Vercruijsse/ Kris Van Nijen	DEME/ OceanflORE	Belgium
Luis Martins	Assimagra	Portugal
Fernando Barriga	University of Lisbon	Portugal
Luis Menezes Pinheiro	University of Aveiro	Portugal
Pedro Miguel Madureira	EMEPC	Portugal
Charlie Bavington	GlycoMar	United Kingdom
Greg Stemm	Odyssey Marine Exploration	United States
Rodney Norman	IHC Mining	Netherlands
Charles Roche	Mineral Policy Institute	Australia

Exploration and exploitation of the deep-seas in search of marine minerals and genetic resources have over the past fifteen years received increased attention. Developments in sub-marine technologies, rising raw material prices and scarcity, and advancements in biotechnology, are changing the business-case for further investments in the marine environment.

This report provides a state-of-play overview on exploring and exploiting deep-sea resources. A Cost-Benefit Analysis identifies the main potentials and challenges in a scenario where exploitation increases. Policy options are suggested to balance trade-offs between economic, social and environmental aspects associated with future developments.

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