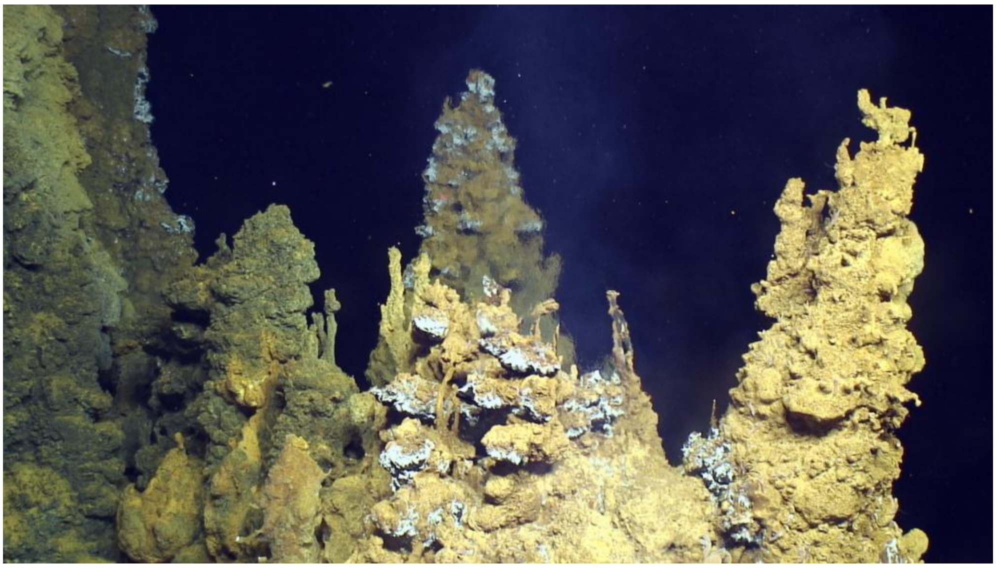
Deep-seabed exploitation

Tackling economic, environmental and societal challenges



IN-DEPTH ANALYSIS

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Technology options for deep-seabed exploitation

Tackling economic, environmental and societal challenges

In-depth Analysis

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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.

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1. Introduction

The deep sea is home to a number of marine organisms and mineral resources, whose riches are gaining interest among scientific community as well as industry in and outside of EU. The business-case for exploring and exploiting raw materials and marine genetic resources (MGR) has become more attractive following the development of new technologies for exploring and exploiting the deep sea. For minerals, high resource prices, volatile markets, geopolitics and scarcity have contributed to renewed enthusiasm from a range of European stakeholders including public actors such as states and regions as well as companies and industry organizations. For MGR, life-saving drugs, biotech products and cosmetics are being developed based on organisms found in marine environment. However, the potential 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. Unfortunately, there is very little knowledge on how potentially dramatic perturbations will affect the deep seabed, which makes a proper environmental impact assessment difficult. Several unresolved issues also remain with regard to the distribution of risks and gains in a fair and transparent manner. Ultimately, to enable a sustainable use of our oceans, we need a clear and robust regulative framework which properly regulates the extraction procedures.

This is a layman's summary of a larger report commissioned by the European Parliament's Scientific Foresight Unit with the objective to assess the state of knowledge on the technologies available for deep sea resource exploration and exploitation, and analyse the associated economic, environmental, societal and legal aspects. It covers mineral resources (deep sea mining) as well as marine genetic resources (bioprospecting) and addresses the following key questions:

- What are deep sea resources?
- 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?

2. What are deep sea resources?

There are many ways to define the "deep sea". A common and comprehensive definition situates the deep sea where the continental shelf ends at depths greater than 200 meters. Deep sea resources are thus either found in the Exclusive Economic Zone but also in Areas Beyond National Jurisdiction (ABNJ) of nation states, which has consequences for the legislative framework under which they are regulated (see section 4). Furthermore, deep sea resources can be divided into raw material resources and marine genetic resources (MGR).

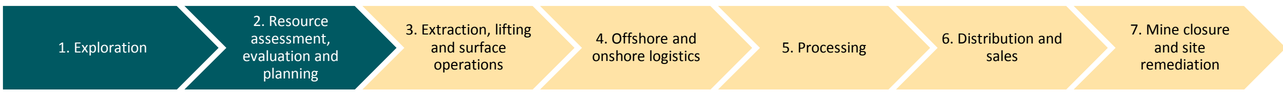
Raw material resources can further be divided into three different types, polymetallic (or manganese) nodules, poly-metallic sulphides (or seafloor massive sulphides) and cobalt-rich ferromanganese crusts.

- ✓ **Manganese nodules** are extremely slow-growing formations of 2 cm to 15 cm in diameter, consisting of ferromanganese oxides. These contain valuable minerals such as nickel, copper, manganese, molybdenum, lithium, rare-earth elements and possibly cobalt. However, the nodules comprise primarily of manganese and iron. The nodules are predominantly found 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.
- ✓ **Seafloor massive sulphides (SMS)** consist of heavy metal sulphides derived from hot water that vented from the seafloor at a depth of 1,500 - 3,000 meters. 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.
- ✓ **Manganese crusts** are also composed of ferromanganese oxides and contain cobalt, nickel, manganese, tellurium, rare earth elements, niobium and possibly platinum. 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. The Pacific Ocean accounts for 57 per cent of the global total of seamounts.

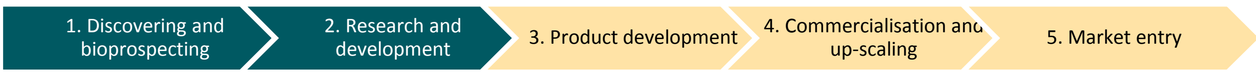
Marine genetic resources (MGR) consist of genetic resources from marine macro- and microorganisms and represent the most valuable part of marine biological resources, thus are interesting to be used for human purposes. The process of sampling and commercializing MGR's is generally called bioprospecting. The main applications are found in pharmaceutical, biotechnology and cosmetic industry to develop new medicine, chemicals or cosmetics.

The differences in characteristics of raw materials and MGR put them on very different value chains and equally different cost-benefit analyses. For instance, while harvesting raw materials would incur long-term sustained environmental damage to the locations in questions, the sampling of MGR often is limited to a kilo of matter.

Overview of the value chain for raw materials



Overview of the value chain for biological resources



3. What are the main knowledge gaps and risks?

For raw materials, industry and researchers have a fairly good overview of proven and inferred sites that could be interesting for further exploration. For example, in terms of manganese nodules, the most explored area is 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. More than 10 different consortia hold concessions and are currently exploring the area. 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. However, **overall global estimations of concentration and size of raw material resources are not available**. 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 example, the deposits identified by Nautilus in the Solwara 1 resource, the world's at this point most advanced project for deep sea mining, suffice only for a couple of years mining. Consequently, it is uncertain whether the enormous investments required for starting up operations (in the range of a couple of hundreds of millions of euros) are commercially viable.

Marine genetic 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 type. For both seafloor massive sulfides (SMS) and manganese nodules, technologies are there (at least the blue-prints) to start mining. For crusts, the case is slightly different due to the hard character of the seafloor in which the deposits are situated. European companies are at the forefront of exploration technologies, however, they are a bit lagging behind in terms of exploitation technologies. Nevertheless, more research and technology development is going on in this field (e.g. via FP7 or Horizon 2020 projects).

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 in knowledge and risks appears to be associated with what one interviewee termed "**the social and environmental license [for companies] to operate**". Very little is known about the environmental impacts on marine ecosystems and societal impacts on local communities. 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).

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, which scares off investors (see next section). In case of marine genetic resources, legal framework gaps are even larger to non-existent.

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

Most of the deep sea resources examined in the 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. EEZ areas are under the responsibility of the coastal States, which have exclusive rights over these zones. To date, there are no DSM activities in the EEZ of EU Member States, however, negotiations are going on in Portugal. 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 at the international level. 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 including the EU and its Member States) with some notable exceptions, such as the United States of America, 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 currently still under development.

The International Marine Minerals Society (IMMS) made an attempt, following a request by the marine mining industry, to regulate the environmental considerations in relation to responsible marine mining, developing the Code for Environmental Management of Marine Mining. This code tries to integrate environmental considerations for responsible marine mining by seeking to provide environmental principles and guidelines to complement national and international marine mining environmental regulations in place.

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 are currently safe-guarded by a rigorous international patent-system under the TRIPS (Trade-Related Aspects of Intellectual Property Rights) 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 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 (BBNJ) took place. In the meeting it was agreed to develop a new legally binding instrument on BBNJ under UNCLOS.

5. What are the main technologies for exploration and exploitation?

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 are central. For the exploration, there are already several such ships in operation, often linked to national research institutes and geological surveys. Research cruises are expensive and a vessel costs around 50,000–100,000 euro/day in operation.

For raw materials, each resource type presents its own technological challenge:

- **SMS** consist of hard rock and therefore require significant force to extract, and are situated in areas with cumbersome topographical terrains hindering the operability of a Remotely Operated Vehicles (ROVs) which cannot handle steep slopes.
- **Polymetallic nodules** are simply spread across the seabed and can be excavated through a gathering mechanism such as a suction system or rake. The main difficulty is the location of the nodules at depths exceeding 3,000 m and wide area of distribution.
- **Manganese crusts** present similar challenges as SMS. The key difficulty is removing the thin layer of crust while leaving the waste rock behind.

Consequently, three different ways of extraction are required. Seafloor Massive Sulphides (SMS) would be collected by ROVs on the seafloor and then piped up to the surface awaiting ship for further processing (see Fig 1). The readily available manganese nodules can be collected through an ROV functioning like vacuum-cleaner (see Fig 2). Manganese crusts can be collected by large ROVs that grind through the hard crust, creating a mixture containing the valuable minerals which would then need to be piped to the surface (see Fig 3).

Figure 1 Schematic of deep sea mining of Seafloor massive sulphides

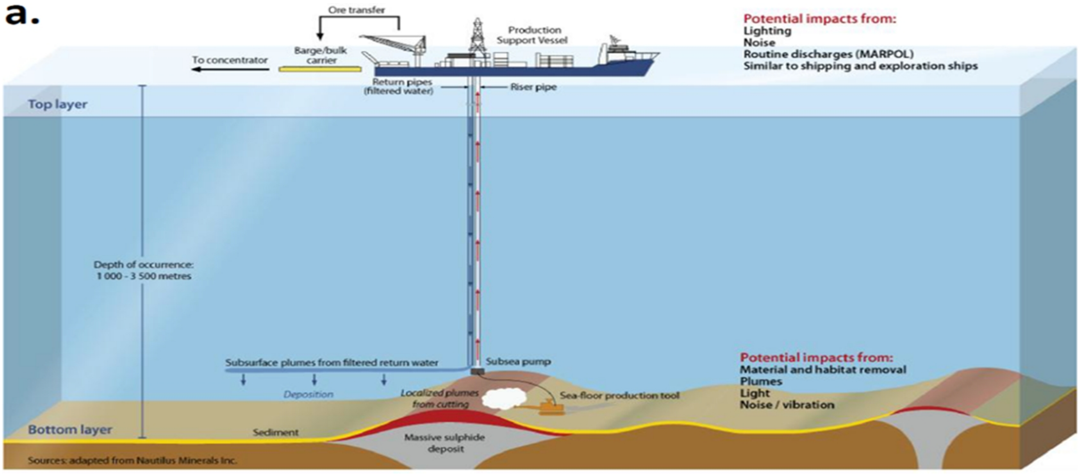


Figure 2 Schematic of deep sea mining of Manganese nodules

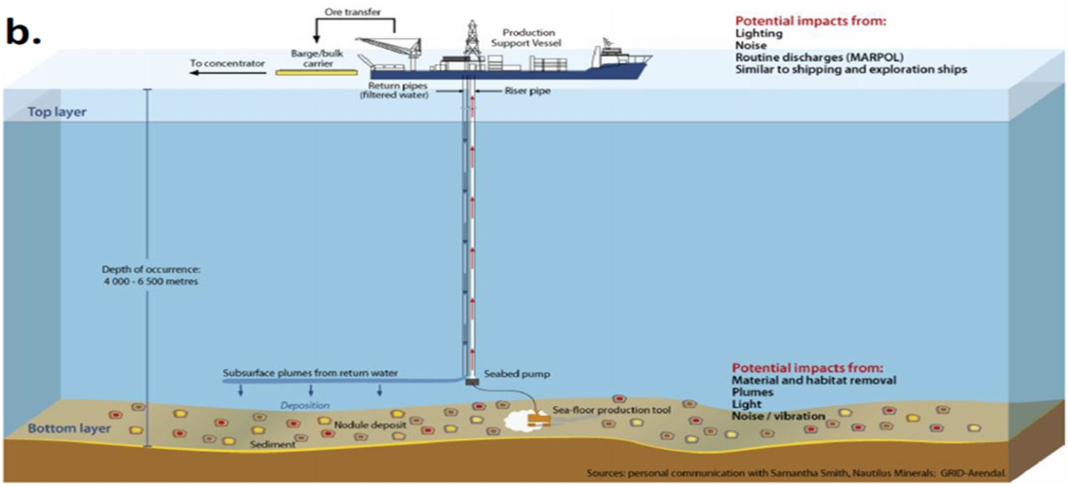
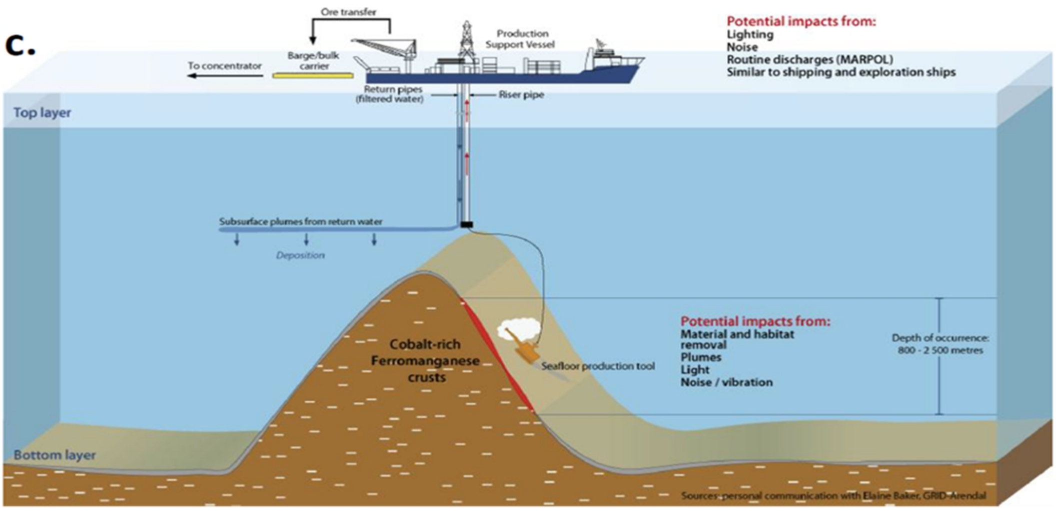


Figure 3 Schematic of deep sea mining of Manganese crusts



Source for the three figures: Clark & Smith (2013)

To assess the readiness of the different technologies to be put into action, the main report includes an overview of the "technology readiness level (TRL)" of each component. Overall, for the exploration phase, where mapping and drilling plays the major part, the TRL is fairly high and well-developed. In terms of exploitation on the other hand, the TRL is fairly low with several of the technologies in the value chain needing further development.

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

The business case for deep sea mining and biological resources follow 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, is substantive. Not all projects are commercially viable but decisions to go offshore are in many cases strategic (e.g. to develop and use innovative technologies and investigate new areas of mining). 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 of land sites (the mining infrastructure in the deep sea is mobile, i.e. can be moved from one deposit to another) and the cost of labour on land can make mining deposits in deep sea attractive for industry and investors.

In the main report, an overview of the **deep sea mining** value chain, the technologies and the estimated costs is provided. Exploration costs more than $100,000 a day; most exploration trips need a budget of at least $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, these are mainly the market value of the specific resource at the time of sale and the cost savings deep sea mining can generate *vis-à-vis* terrestrial mining. These cost savings include for example, much lower processing costs in the deep sea, no waste digging costs, lower energy costs and no ground moving costs (mobile infrastructure).

The table below provides a breakdown of the main costs related to exploration.

Table 1 Overview of the main costs for exploration activities, mineral resources

Value chain	Technology	Cost estimate
Exploration		
Exploration in general	Ship time	1 ship around €1billion; most expensive part of exploration: around $50,000 -100,000 per day, if 60 days needed → $3-5 million in total
	ROV	$50,000 – 100,000 a day
	SMS exploration	Nautilus spent $150-200 million, high cost per tonne of deposit as low amount of deposits found
	Nodules exploration	Cca. 20 months of cruise needed to identify the nodules. 1 month with the right equipment costs €10-15 million.
Locating	Mapping (SMS deposits)	Neptune spent more than $100 million to map
	Mapping (nodules)	$5-7 million cost for mapping time (30-60 days); $30-35 million to map resources
Sampling	Deep sea vehicle going down and back to the surface	Up to US$ 1 million per day, excluding maintenance costs
	Analysis of the samples	Less costly than ship time

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. Instead, the largest costs are in the analysis, research and development of applications for the biotech and pharmaceutical industry, which overall has a high risk/high return structure. The product development cost is the highest cost element (hundreds of millions to billion and high risks), not the discovery stage. Due to the high cost of marine scientific research and the slim odds of success (only 1-2% of pre-clinical candidates become commercially produced), the potential for making profits is rather small according to one interviewee, which limits the involvement of industry. Only a handful of companies succeeded in putting a product originating from deep sea marine genetic resources on the market. One of these success stories is Pharma Mar (from Spain), which managed to produce three marine organisms for less than $1 billion.

7. What are the main environmental and societal impacts?

The deep sea is the largest ecosystem on earth and scientists have estimated that as many as 10 million species may inhabit the deep sea. However, it remains among the least explored areas on earth and human activities such as bottom trawling are already showing having negative impacts. It is still **difficult to fully estimate the real environmental impact** of deep sea mining exploration and exploitation activities as no mining has taken place yet. Due to the fragility of these ecosystems, the unknown resilience of this system and the unknown effectiveness of the anticipated efforts to assist natural recovery, it is predicted that these activities will have significant effects if not properly regulated. Regarding bioprospecting of marine genetic resources, the environmental impact cannot really be compared with deep sea mining due to the different techniques to extract the resource and the dimension of area considered. However, since it consists of merely collecting samples in small quantities, the environmental impact is expected to be much lower than from mining.

To bridge the knowledge gaps on environmental impact issues, research on the deep sea continues. Surveys discover new geological features, species and ecosystems, including new hydrothermal vents and their unique biodiversity. The European Commission has funded a number of research projects focused on enhancing knowledge of the deep sea (e.g. Hermes; Hermione; DeepFishman; CoralFish; MIDAS), which should improve our understanding of how the deep sea may be affected by large disturbances. 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, the International Seabed Authority does not publicise the scientific information collected by contractors, which have obtained licenses 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 test 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 is starting.

In terms of **societal aspects**, the most relevant impacts will likely be associated with the (land) mining life cycle, which lasts approximately 20 - 30 years and may apply to different stakeholder groups at household, local, regional, national, and international level. Current exploration is often lacking sufficient participation of the local 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 (Exclusive Economic Zone 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. In addition, the society will benefit from new technologies, research and innovation (and development of new medicine/ drugs in case of bioprospecting).

8. Conclusion: What are the next steps and what could the EU do?

Harvesting resources from the deep sea clearly comes with a number of technological, legal, environmental, economic and social knowledge gaps and challenges. For **marine raw materials**, technology needs to prove itself capable of yielding commercially viable returns without damaging the sub-marine environment beyond acceptable levels. The legal framework needs to be developed to provide a safe investment environment and protect people and places affected by the social and environmental impacts of mining. Research needs to improve our knowledge-levels on the environmental effects of deep sea mining, aid regulators and companies to devise the best possible policies and methods. Also, the economics of deep sea mining needs to prove itself worthy of the large financial and environmental risks associated with deep sea mining, in particular in comparison to land mining. Lastly, the opportunity cost of investing in deep sea mining needs to be compared to other strategies for dealing with resource scarcity and volatile markets. Recycling for example, could provide the same goods in many cases, and should thus be part of the deep sea mining equation.

For **biological resources**, there is simply a large knowledge gap in the deep sea ecosystems and what organisms could be of value and use for human applications. This gap makes any venture extremely risky in financial terms and scares off investors. Consequently, the overall need for a better understanding of what the world looks like in the deep seas is valid for both mining and bioprospecting.

There are several policy options that the EU and its institutions could take to address these challenges (see Policy Options brief published alongside the study in a separate document) and it starts from a rather good position in terms of both exploration and exploitation of deep sea resources.

In terms of mining, EU-members such as France, Germany, the UK and Belgium have licences with the ISA to conduct exploration activities. Portugal also has a forefront position due to its possible deposits in the waters of the Azores. For technological development, research institutes (e.g. IFREMER) and companies (e.g. IHC Merwede, Technip) 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 also 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. This type of funding appears essential if the deep sea ambitions and potentials are ever going to bear fruit.

Besides continued support for research, other policy options identified in this study are:

- Improve communication between and across sectors and raise awareness on the topic among civil society in order to better understand and manage the opportunities and challenges with deep sea exploration and exploitation.
- Improve the knowledge base and address the environmental impacts by, for example, participating and negotiating EU position in any working group established by the ISA or by setting up an ad hoc temporary committee at the European Parliament.
- Support the adoption of a complete legal framework to ensure that environmental and social requirements are clear for policy makers and investors enabling a more stable and certain cost-benefit analysis to be applied.
- Support a pilot mining project that is transparent to develop the knowledge and knowhow on what mining actually does and means, taking into account environmental and social impacts.
- Further investigate recycling as an alternative to deep sea mining which could yield similar gains as extracting new resources and adopt a stronger position on this matter taking into account that some non-EU countries will continue DSM.
- Address the societal impacts on local communities to ensure that people affected by resources extraction done by EU and other companies are also adequately protected. Further studies on this topic should be encouraged.

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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