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Seabed Mining

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3.1 Introduction

3.1.1 Challenges for Offshore Mining

The surface of the planet is approximately 71% of water spread over five oceans: the Arctic, Atlantic, Indian, Pacific and Southern ocean. In fact, it represents the largest habitat for life on Earth[1]. The deep ocean beyond the continental shelf is the most difficult to access but also very promising in available resources, like biodiversity and ores. These includes minerals like gold, silver, nickel, cobalt, Rare Earth Elements (REEs), phosphorytes and gas hydrates (Scott et al., 2008; SPC 2013a, b, c, d; SPC 2016; EPRS, 2015; Rogers et al., 2015; Petersen et al., 2016).

Ores are currently being mined in coastal waters. Sand and gravel are already in exploitation e.g. for use in coastal defence and use for infrastructural works such as roads and the production of concrete. Metal ore sands and precious stones such as tin in Indonesia, gold in Alaska, or diamonds in

[1]This diverse habitat is largely unknown. Biodiversity, general ecology, natural dynamics, responses to natural and human drivers are hardly studied.

Namibia are exploited as well (Cronan, 2000; Baker et al., 2017; Hannington et al., 2017).

Due to the nature of the deep ocean (the immense pressure, the hard to reach bottom, the lack of data and the offshore character), the exploration and especially the exploitation of the resources on the seabed pose immense technical and environmental challenges. The initial euphoria of the 1970s was generated by high prices combined with relatively easy access to minerals available at that time. Then a collapse in world metal prices and new land-based mines dampened interest in seabed mining. However, after decades 'on hold', there is renewed interest in the potential for commercial exploitation of marine minerals from the private sector and governments alike (SPC 2013a, b, c, d; Ecorys, 2014; Lange et al., 2014; Arezki et al., 2015; Rogers et al., 2015; Worldbank, 2016).

Deep seabed mining (as a sector) must therefore be considered a significant new and emerging use of the global ocean. It was included in the project of MARIBE as a form of Blue Growth. To completely understand its functioning and promote the development of seabed mining, this chapter aims to provide an extensive overview of the social and economic drivers that influence the performance of the industry (including industry lifecycle and structure, socio-economic impact and regulatory framework, among others). The purpose is that investors, governments, operators and other interested stakeholders generate insights for future developments.

Numerous reports already exist on the analysis of the metallurgic ores that are found subsea (e.g. SPC, 2013a, b, c, d; SPC 2016; Ecorys, 2014). This study therefore aims at adding to this discussion by comparing metallurgic ores with the other major deep seabed resources phosphorites and gas hydrates. Comparing the subsectors could yield additional insight and information.

The considered subsectors face more or less similar challenges and technical demands. The challenges for a viable offshore mining industry are to deliver products at competitive prices given a volatile market, high costs, low levels of development, and anticipated major environmental impacts. A major discussion point is to tackle an investment gap; is development of small-scale innovations by adapting existing vessels and gear sufficient or are thorough innovations needed?

3.1.2 Definitions and Demarcation

Major issues for mining of marine resources are depth and distance. The general rule of thumb is the further away the deeper. And the deeper one has to mine, the more complex the techniques. Some geological and practical definitions are introduced here as a general setting and to support the definitions used.

- Limits of conventional dredging: the depth of –150 m is the theoretical limit where the conventional dredging equipment like trailing suction hopper dredgers (TSHDs) can still be used without major accommodation ('business as usual'). In practice this depth appears to be –80 m. Below that –80 m, a degree of innovation of the equipment is needed or excessive amounts of energy need to be applied making the deeper dredging a new business case. From –80 m till –200 m adapted regular exploitation vessels can be used. E.g. in the diamond mining industry the type of underground determines whether conventional techniques (vertical mining with a rigid large diameter drill) or Remotely Operated Vehicles (ROVs, horizontal mining) are used (Scott et al., 2008[2]).
- An important limit is that of the continental shelf towards approx. –200 m depth (SPC, 2013d; Rogers et al., 2015). Beyond that the depth strongly increases from the continental slope to the abyssal plains at approx. 4000 m and deeper: the deep sea.
- Potential of river deposits: The sea-level fluctuations due to ice ages are normally till –130 m ($\pm$10 m; Liu et al., 2004; Cronan, 2000). In general riverine deposits are measured and exploited till that depth (Cronan, 2000). However, in southern Africa beach planes and riverine deposits (like sand, diamonds and ore sands) can be found till at least –500 m due to tectonic movements, lowering erosion ridges and former beach planes to deeper regions. Possibly similar tectonic movements can also be valid for Australia (Siesser & Dingle 1981; Gurney et al., 1991; Cronan, 2000).

A distinction can be made between nearshore mining and offshore mining. The words offshore and nearshore represent the distance component and illustrate the differences between the business cases we describe. Taking these limits and the aspects of depth and distance we define:

Nearshore mining, ranging from –0 till –200 m still on the continental shell as a measure for both distance and a markedly chance in geology (from plane to abyss). Typically riverine deposits can be found here.

Offshore mining starts from –200 m downwards. Till –500 m exploitations could still be profitable with adaptation of existing ships and technologies,

[2]https://www.debeersgroup.com/en/explore-de-beers/mining.html (d.d. 03-11-2015).

which implies low investment costs, and high exploitation costs with lower economic revenues (using e.g. TSHD with a flexible trailing head and an extended (and partially flexible) suction tube to dredge the nodules. Schulte, 2013[3]). From –500 m and deeper more adaptions seem to be required.

The seabed offers a variety of resources like i) polymetallic manganese nodules (nodules), ii) polymetallic seafloor massive sulphide (SMS) deposits, iii) polymetallic cobalt crusts (cobalt crusts), iv) phosphorites, polyphosphates and phosphate sands, v) gas hydrates, vi) metal ore sands, vii) sand and gravel, viii) precious stones ix) shells x) other chemicals (Baker et al., 2017). Offshore mining encompass an elaborate scale of potential resources, which differ from location to location. Some demarcation is necessary to limit the scope of this study, as given in the following sections. The sector needs to be a new developing business (Blue Growth), and not an established business (Blue Economy). To limit the vast field of ores the following resources are studied (defined as subsectors):

1. Nodules, SMS deposits and cobalt crusts because of their potential and the fact that they are part of a developing economy (SPC, 2013a, b, c, d; Ecorys 2014; Lange et al., 2014).
2. Phosphorites and polyphosphate sands are also an upcoming mineral and a developing economy (USGS, 2017 and e.g.[3]).
3. Gas hydrates are considered interesting because the reserves are estimated to exceed known petroleum reserves and governments are highly interested for geopolitical reasons (Lange et al., 2014).

3.2 Market – Investigating Market Trends

In this section market trends are described for the different subsectors. As dealt with in Section 3.3.2, the number of exploration licences issued by the International Seabed Authority (ISA)[4] or individual countries within their Exclusive Economic Zone (EEZ) is limited[5]. The number of licenses for exploitation is even scarcer, if any. Despite the low number of licenses, the claimed surfaces for exploration are rather large. Offshore mining demands high technological development and high capital expenditures (CAPEX) and operating expenses (OPEX) costs making it high-risk for commercial exploitation (see Section 3.3). On the other hand there is a general feeling that

[3]http://www.rockphosphate.co.nz/ (d.d. 16-07-2017).
[4]Responsible for the international area of the deep seabed (the Area).
[5]https://www.isa.org.jm/deep-seabed-minerals-contractors (d.d. 13-07-2017).

despite all the draw backs on the economic and commercial domain, offshore mining could be important in the future. Main pulling factors are cobalt and REEs supply, excessive environmental impacts of land mining (Section 3.4) and local needs and interests of countries lacking independent reserves or other means of income such as the Pacific States for metals (SPC, 2013d; Worldbank, 2016), Japan and Korea for gas (Lange et al., 2014).

Also having and demonstrating a leading position in dredging technology and abilities could be a driving force to be first (EPRS, 2015; Worldbank, 2016).

The challenge is to find those spots where concentrations and availabilities of ores are high enough to have commercially viable exploitation despite the low TRLs and resulting high costs of equipment and techniques. This results in a strong competition for suitable concessions.

Phosphorites can now be produced at normal market prices and are thereby in competition with the land-based producers (Schilling et al., 2013). When the distances are far between consumers and land-based operators, local nearshore production is especially interesting (Don Diego, 2015). Gas Hydrates are not yet commercially produced.

3.2.1 Market Trends, Product Demand, Prices

This section and its subsections give the general trends and interpretation of the different resources.

3.2.1.1 Metals

Table 3.1 presents an overview of metal resources and reserves on land for crusts and nodules and an example of SMS type deposits. Also the estimated yearly world production is given in absolute figures and as a percentage of the currently economically minable deposits today on land. The yearly production is ranging between 0.005 and $\sim$6% of the currently economically minable deposits on land. The three bulk metals manganese, copper and nickel consume yearly $\sim$3% of the reserves (meaning enough reserves for $>$30 years for most resources, not taking into account the sub-economic deposits on land (Table 3.1). In a global observation, the economic minable reserves are around 30 years for all metals. Thirty years is the normal financial horizon used by banks and other financial institutions. Mining companies will be reluctant to invest more in exploration beyond a 30-year stock/reserves (Arndt et al., 2017). Hence, based on Table 3.1 and Arndt et al. (2017), the economically minable reserves can be expected to be much larger than a 30-year stock.

Table 3.1 Metal resources and reserves on land and seabed for crusts and nodules (millions of tonnes) and an example of sulphide type deposits (data from Hein et al., 2013; Lange et al., 2014 unless stated differently). Also estimated amount of SMS deposits are given without Atlantis II and the estimates from Sulphide rich sediments Atlantis II separately

Location Elements	Cobalt Crusts in the Prime Crust Zone (PCZ)	Global Reserves on Land (Economically Minable Deposits Today)	Global Reserves and Resources on Land (Economically Minable as Well as Sub Economic Deposits)	Manganese Nodules in the Clarion-Clipperton Zone	Estimated Amount of SMS Deposits without Atlantis II[d]	Atlantis II Sulphide Rich Sediments[e]	Estimated Yearly Worldwide Production in 2016[f]	Estimated Yearly Worldwide Production in 2016 as a Percentage of the Economically Minable Deposits Today on Land
Manganese (Mn)	1714	630	5200	5992		3.8–4.3	16.0	2.5
Copper (Cu)	7.4	690	1000+	226	10	0.74–0.81	19.4	2.8
Titanium (Ti)	88	414	899	67				
Rare earth oxides	16	110	150	15				
Nickel (Ni)	32	78[f]	130[f]	274			2.3	0.3
Vanadium (V)	4.8	19[f]	38	9.4			0.076	0.04
Molybdenum (Mo)	3.5	10	19	12			0.0002	0.002
Lithium (Li)	0.02	13	14	2.8				
Cobalt (Co)	50	7[f]	13	44		0.0053	0.123	0.16

Tungsten (W)	0.67	3.1	6.3	1.3				
Niobium (Nb)	0.4	4.3[f]	4.3[f]	0.46			0.064	1.5
Arsenic (As)	2.9	1	1.6	1.4			0.0365	3.7
Thorium (Th)	0.09	1.2	1.2	0.32				
Bismuth (Bi)	0.32	0.3	0.7	0.18				
Yttrium (Y)	1.7	0.5	0.5	2			0.005–0.007	1–1.4
Platinum group	0.004	0.07	0.08	0.003				
Tellurium (Te)	0.45	0.025[f]	0.05	0.08			>0.000108	>0.4
Thallium (Tl)	1.2	0.0004	0.0007	4.2				
Gold (Au)		0.05–0.057[a,b,c,f]	0.1157[c]	0.000095	0.00102	0.000046	0.0031	5.4–6.2
Silver (Ag)		0.57[f]		0.0036	0.069	0.0065	0.027	4.7
Zinc (Zn)		220–230[b,f]	1900[b,f]	13	20[d]	3–3.8	0.012	0.005

[a]Estimate based on booked reserves in mining companies http://www.bullionmark.com.au/how-much-gold-is-there (d.d. 09-09-2015).
[b]USGS (2015).
[c]http://www.visualcapitalist.com/global-gold-mine-and-deposit-rankings-2013/ (d.d. 09-09-2015).
[d]Hannington et al. (2010, 2011): estimated total 600 millions of tonnes. In Hannington et al. (2011) copper and zinc are presented summed together 30 millions of tonnes. Based on Hannington et al. (2010) a simplified 1:2 Cu: ZN ratio is presented here.
[e]Bertram et al. (2011); Lange et al. (2014); Laurila et al. (2015).
[f]USGS (2017).

In general land-based mining is an inflexible economy. The investments in and cost structure of the mining infrastructure is so huge that they cannot flexibly react to market developments. This results in typical fluctuations between a state of oversupply and supply shortage. In Figure 3.1 an example is given of the price developments of the resources, showing largely stable prices with a peak in prices in the 1970's and another peak starting from approximately 2005 and going down after 2011. For the recent past, three trends can be distinguished:

1. An increase in demand of metals since the early 2000's due to economic development raising prices. Economic development of Brazil, Russia, India and China (the BRIC countries) has led to a higher demand. China is particularly consuming more and more metals. In addition, technological development (smartphones etc.) has increased the demand for special metals like cobalt and rare earth elements (REEs) (Worldbank, 2012 and 2016; SPC, 2013d; Ecorys, 2014; Arezki et al., 2015).
2. The financial crises in 2008, which started with the bursting of the United States housing bubble in 2004–2006 (Tully, 2006; Worldbank, 2012) and that lead to both raising and lowering of prices.
3. A decrease in the quality of ores by the end of the 1990, early 2000's leading to higher prices (Worldbank, 2012; Mudd et al., 2013; SPC, 2013d).

3.2.1.2 Phosphorite

The same patterns in price development and demand that occur for metal ores occur for phosphorites as well. Prices remained stable around €30 to €50 per metric tonne from 2000 till 2007 (Figure 3.1). Around the time of the financial crises, prices rose sharply to almost €300 per metric tonne and then descended till a fluctuation plateau of €70 to €150 per metric tonne. In 2007–2008, world agriculture increased due to growing world population and associated food demand, leading to a strong rise in demand for phosphate-derived fertilizers. Currently economically minable deposits on land are 68,000 Million metric tons with a yearly consumption of 261 Million metric (0.4%). 74% of this reserve is located in Morocco and Western Sahara. Large phosphate resources have been identified on the continental shelves and on seamounts in the Atlantic Ocean and the Pacific Ocean. Total world resources of phosphate rock are more than 300 billion tons. There are no imminent shortages of phosphate rock (USGS, 2017).

Increasing concerns on both the supply market being dominated by a few suppliers (especially Morocco) which seems to become more extreme

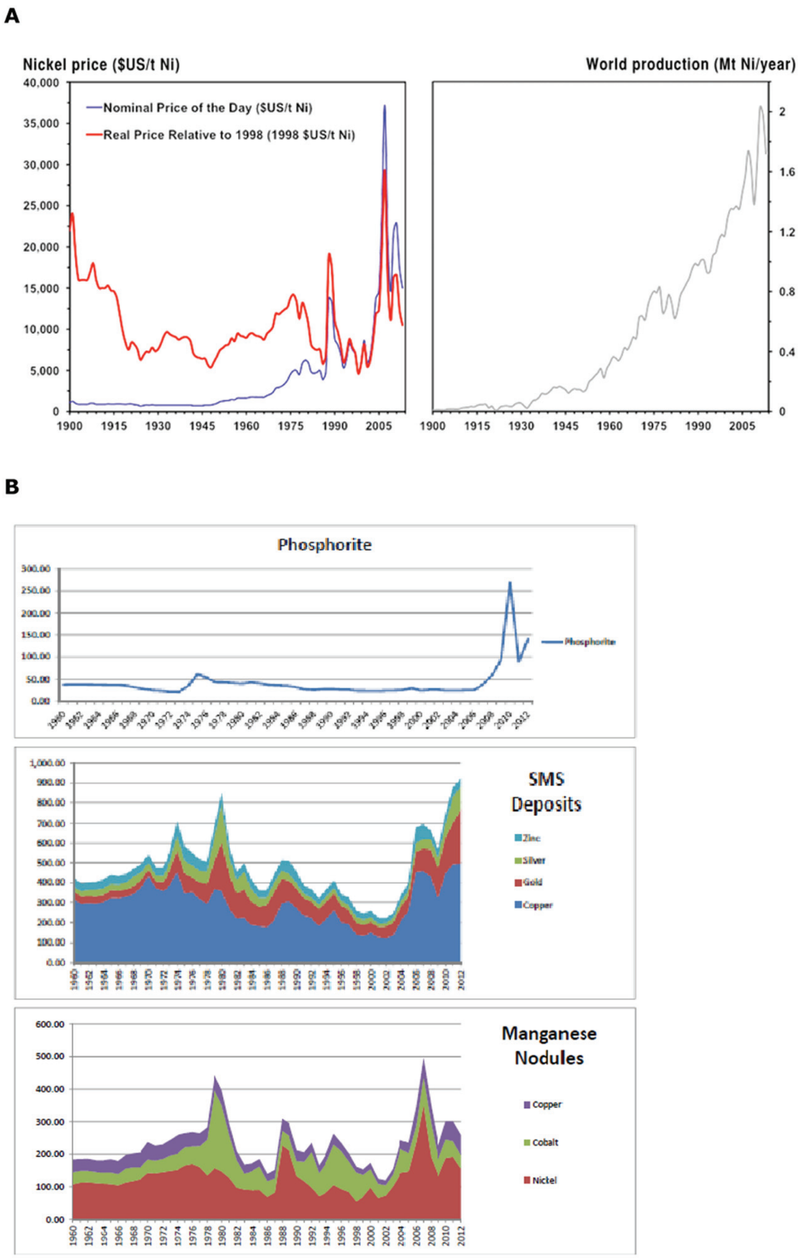

Figure 3.1 (A) Long term development of nickel https://theconversation.com/queensland-nickels-demise-yabulu-a-relic-refinery-53368, (d.d. 10-02-2017). (B) Price development of minerals, corrected for inflation, in Euro per ton till October 2012 (Schulte, 2012).

in the future and a need for phosphate rock with a lower cadmium content (de Ridder et al., 2012), urge for new supply source where offshore mining can offer options. Also the exploitation of local phosphorites can mean local employment and export potential for the region and even reduce the carbon footprint.

3.2.1.3 Natural gas

The price developments of gas depend on location (Figure 3.2) (BP, 2016). In the US, which is self-sufficient in gas-supplies, prices remained relatively stable (around $ 5 for a million British Thermal Units (mmBTU) except in the period of the financial crises. In Europe and Japan prices tend to be higher around $ 7–$ 10 for a mmBTU (probably reflecting the dependency of the import) (ECB, 2014).

The prices of natural gas depend on many factors, including macroeconomic growth rates and expected rates of resource recovery from natural gas wells. Natural gas prices, as with other commodity prices, are mainly driven by supply and demand fundamentals. However, natural gas prices may also be linked to the price of crude oil and/or petroleum products, especially in continental Europe. Higher rates of economic growth lead to increased consumption of natural gas, primarily due to gas usage in housing, commercial

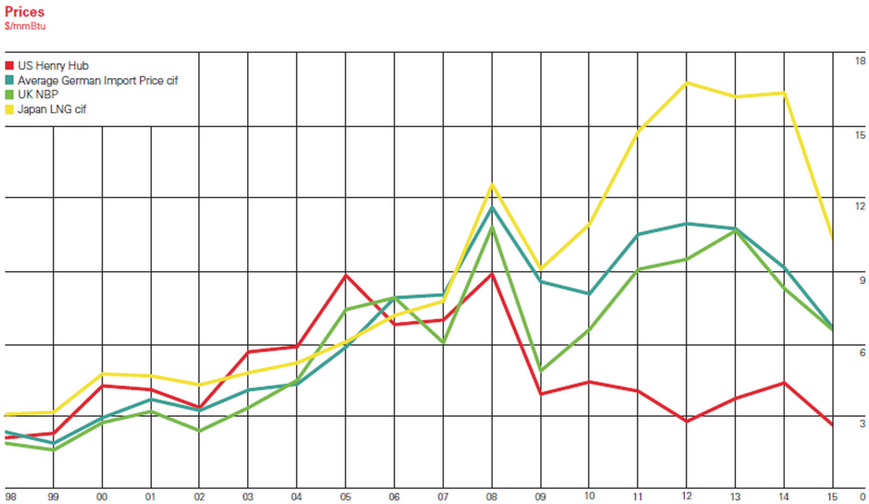

Figure 3.2 A long term overview of the price of natural gas (mostly methane) in $ per million British Thermal Units (mmBTU) for different regions in the world (BP, 2016).

floor space, and industrial output. Also an event like the earthquake in Japan leading to less nuclear energy and trust in nuclear energy can be noted in an international context. Weather conditions can also have a major impact on natural gas demand and supply. Cold temperatures in the winter increase the demand for space heating with natural gas.

3.2.1.4 A general model

De Ridder et al. (2012) developed mathematical models to explain the price development for phosphorites, which seem quite suitable for metals as well. In general ore production was insufficient, causing greater derived demand for ore. Meanwhile, supply tightened (ore degradation), with production and transport costs going up. This resulted in a higher price. Eventually, higher prices made more exploration and recycling activities economically feasible. It therefore became possible to restore supply. As demand remained stronger than before, new prices reached a slightly higher level than originally (de Ridder et al., 2012).

3.2.2 A View of Future Supply and Demand

3.2.2.1 Metals

The previous section described price developments and the drivers on supply and demand. It emphasized the demand by economic developments and the influence of price. Despite steadily increasing demand, the onshore deposits will in most cases continue to satisfy our growing appetite for metals and minerals (SPC, 2013d; Lange et al., 2014; Ecorys, 2014) (Figure 3.1, Table 3.1). Indeed, with an increasing political stability worldwide new land-based reserves are discovered in emerging market and developing economies (Table 3.1) (Figure 3.3, Arezki et al., 2015). Section 3.6 performs a sensitivity analysis for global prices and revenues. The analysis concludes that global metal prices are currently low, making offshore mining of metal ores unlikely in the short term. Metal prices will need to rise substantially before making offshore mining commercially viable.

On the long run the combination of increased absolute and relative demand combined with geopolitical issues can limit the availability of some metal resources. New technological developments demand more and more of special metals and REEs. A lot of these resources for new technology are situated in a few countries only, often with a political instable climate making it a geopolitical issue of availability. Geopolitical issues can make offshore mining an interesting option despite the high costs. Examples of components of geopolitical concern are the supply of cobalt (dominated by the Democratic

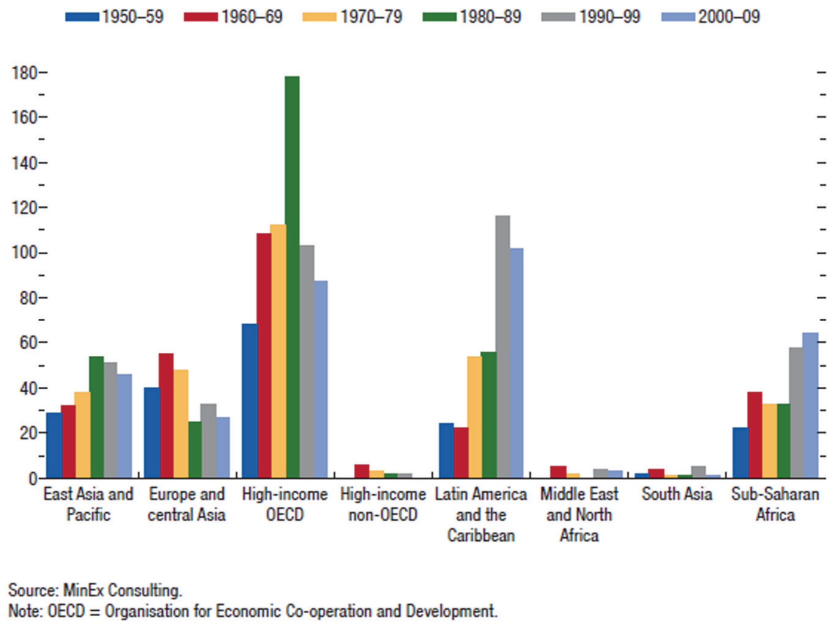

Figure 3.3 Number of metal deposit discoveries by region and decade (Arezki et al., 2015).

Republic of Congo), phosphorites (Morocco), as well as gas hydrates (Hein et al., 2013; de Ridder et al., 2012; Lange et al., 2014; USGS, 2015 and 2017). In addition, environmental concerns on land-based mining could turn the table towards seabed mining (Section 3.4). Currently, China is considered the only supplier of REEs. However, numerous large reserves have been discovered and are available in Australia (Mount Weld), Greenland (Kvanefjeld), Chili, Bolivia (Uyuni Salt Flats), and Afghanistan[6], as well as Brazil, India, Russia and Vietnam (USGS, 2017). With fluctuating market prices these mines open and close with profitability.

3.2.2.2 Phosphorites

With an increasing population, food production and phosphate demand will increase. In addition a need has arisen for phosphate with less calcium

[6]http://geology.com/usgs/ree-geology/, http://www.australianrareearths.com, http://www.ggg.gl, https://www.masterresource.org/electric-vehicles/rare-earth-and-lithium-supplies-cloud-renewables/, http://www.popsci.com/science/article/2010-06/us-geologists-uncover-staggering-1-trillion-cache-unmined-mineral-resources-afghanistan, (all d.d. 27-03-2017).

concentrations. World stocks can easily meet the demand on phosphate; the calcium content is a different topic (USGS, 2017, De Ridder et al., 2012).

3.2.2.3 Gas hydrates

World consumption of gas is steadily increasing. Global proved natural gas reserves in 2015 were estimated to be 186.9 trillion cubic metres, sufficient to meet 52.8 years of current production (in most cases not taking shale gas into account). Proven gas reserves were dominated by the Middle East (43%). Also Russia holds large proven reserves (~17%). Other countries have substantial reserves. It appears that every ten years more proven reserves are determined (BP, 2016). Reserve estimates change from year to year as new discoveries are made, as existing fields are more thoroughly appraised, as existing reserves are produced, and as prices and technologies evolve. Sources also differ in actual estimates. It is estimated that there are about 900 trillion cubic metres of "unconventional" gas such as shale gas, of which 180 trillion cubic metres may be recoverable (another ~50 years).

Recent estimates of worldwide amounts of gas hydrate, which attempt to consider all of these aspects, are on the order of 5 to 15 times the land-based reserves (Lange et al., 2014).

3.2.2.4 Potential influence of offshore mining ores on global markets

The Ecorys study (2014) made some assumptions and calculations of the potential influence of offshore mining ores on global markets. As mentioned before, only a limited number of metals seem interesting and from those copper, gold and silver are the targets for SMS deposits and copper, cobalt and nickel for the crusts and nodules. The impact on the world market can only be estimated with assumptions since there is no production at this moment.

Taking the target metals: for **gold and silver** a production by offshore mining was estimated at ~3% and ~1% of the yearly terrestrial production respectively (USGS, 2015; Ecorys, 2014). These volumes are very small. In addition, metals like gold and silver are characterised by low production concentration and existing market exchanges, which however are only marginally influenced by physical demand and supply. Therefore offshore mining is not expected to have an influence on the price.

Currently, global annual production of **copper** is 18.7 million tonnes from different sources (USGS, 2015). Looking into an initial reachable estimated annual volume of 0.1 million tonnes of copper (~0.5%) from a typical offshore mining operation (Ecorys, 2014) it is unlikely to have a substantial impact on global prices. The same is valid for **nickel**.

In the case of **cobalt** (8 thousand tonnes, Ecorys, 2014) the impact on price may be more substantial as global annual production is around 112 thousand tonnes (USGS, 2015). An estimated annual output of ∼8% could have an impact on market prices and price fluctuation, particularly in view of cobalt's supply risk due to geopolitical reasons. Congo (Kinshasa), a potentially unstable country, has ∼50% of the world production. Any substantial new source will influence the market. The same line could be valid for the **REEs** as well (Ecorys, 2014; Worldbank, 2016).

Annually, 261 million tons of **phosphate** is produced. Namibia's offshore **phosphorite** mining aims at ±10% market share of the traded phosphate market of 30 million tons a year[7]. Taking into account the potential impact of Don Diego (Mexico) and Chatham Rise (New Zealand) exploration, the seabed mining of phosphorites can have a substantial impact on world prices.

For **gas hydrates** it can be expected that once in full operation it will have a substantial impact on local and world prices (Lange et al., 2014).

3.3 Sector Industry Structure and Lifecycle

The polymetallic (manganese) nodules, cobalt crusts, SMS deposits, phosphorites and gas hydrates have different distributions over the world and in depth. Moreover, different techniques are required to harvest them based on depth and origin. This gives rise to distinct industries and sectors involved in the development of offshore mining.

3.3.1 Worldwide Offshore Resource Distribution

Resources for offshore mining are spread all over the world in both the deeper national waters and the international seas and oceans. The most interesting sites for exploration are not found in European waters. Below, information is presented on the presence of the considered deposits worldwide.

3.3.1.1 Nodules

Nodules occur widely on the vast, sediment-covered, plains of the abyssal ocean at depths of about 4,000 to 6,500 m (Hein et al., 2013; SPC 2013b). The greatest concentrations of metal-rich nodules occur in the Clarion-Clipperton Zone (CCZ), which extends from off the west coast of Mexico to as far west as Hawaii (map B, Figure 3.4). Nodules are also concentrated in the Peru

[7]http://www.namphos.com/project/sandpiper.html (d.d. 16-07-2017).

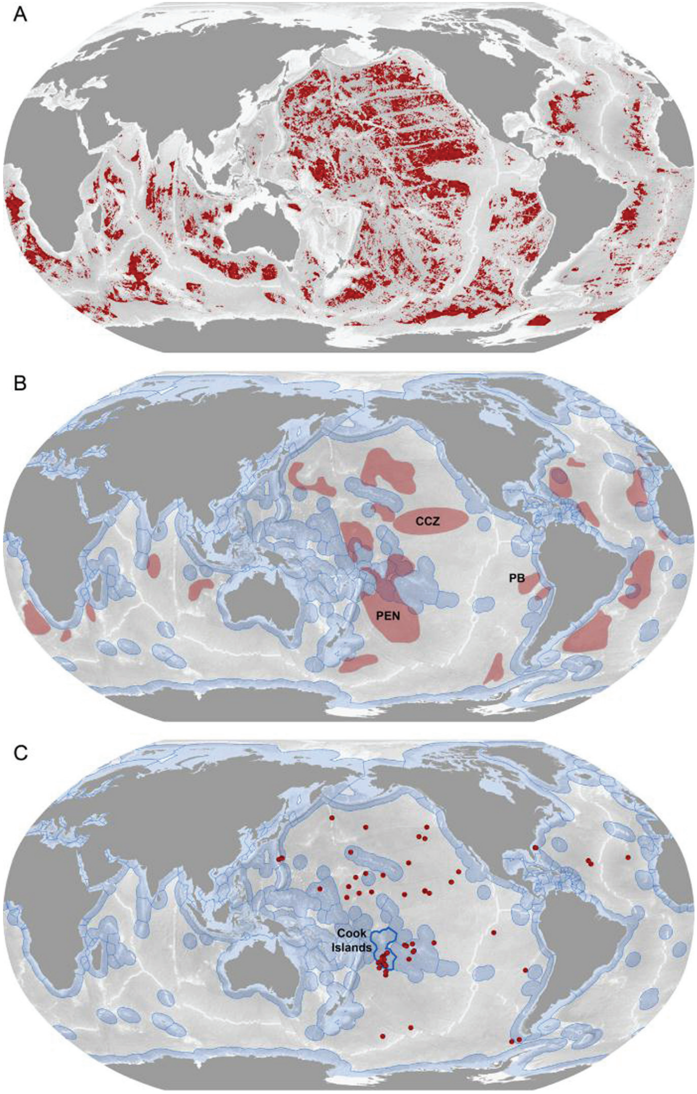

Figure 3.4 (A) Locations of areas within the abyssal plains that are important for manganese nodule formations based on seafloor classification, seafloor age (older than 10 My), sediment thickness (<1000 m), sedimentation rate (<1 cm/1000 years), and water depth (between 3000 and 6000 m). Note the lack of data below 70°S and above 80°N. (B) Areas with highest Mn-nodule potential based on seafloor morphology, age of crusts, and metal input. Light blue areas delineate the EEZ. Abbreviations: CCZ = Clarion-Clipperton Zone, PB = Peru Basin, PEN = Penrhyn Basin. (C) Location of manganese nodule samples in the ISA database with Co concentrations above 0.5 wt% (N = 211). Note the large number of Co-rich samples in the EEZ of the Cook Islands. (Petersen et al., 2016).

Basin, near the Cook Islands, and at abyssal depths in the Indian and Atlantic oceans (Hein et al., 2013 and 2015). In the CCZ, the manganese nodules lie on abyssal sediments covering an area of at least 9 million square kilometres (Figure 3.4).

No relevant concentrations of polymetallic (manganese) nodules have been found in basins within the scope of the MARIBE project (Atlantic, Baltic/North Sea, Mediterranean, and Caribbean). However, some spots with substantial amounts of nodules were discovered recently in the tropical Atlantic (north of French Guyana and west of Africa (Devey, 2015[8]). These findings await publications or reports that putting them into perspective. In addition in the Galicia Bank region (northwest Iberian margin, NE Atlantic), a complete suite of mineral deposit types was encountered including (1) phosphorite slabs and nodules, (2) Fe-Mn crusts and strata bound deposits, (3) Co-rich Mn nodules, and (4) Fe-rich nodules. The Galicia Bank nodules are exceptionally rich in cobalt (Gonzalez et al., 2016). Quantities for commercial exploitation need to be assessed.

3.3.1.2 SMS deposits

SMS deposits are rich in copper, iron, zinc, silver and gold. The total accumulation of sulphides is estimated to be on the order of 600 millions of tonnes (Hannington et al., 2010 and 2011). As compared to nodules and terrestrial reserves the amounts deposited in SMS are far less (Table 3.1, Figure 3.5), although the amount of precious metals is substantial. Gold and silver, together with copper, appear to be the commercially most interesting metals (Boschen et al., 2013, Ecorys, 2014).

Deposits are found at tectonic plate boundaries along the mid-ocean ridges, back-arc ridges and active volcanic arcs, typically at water depths of around 2,000 m for mid-ocean ridges (Figure 3.5). These deposits formed over thousands of years through hydrothermal activity, which is when metals precipitate from water discharged from the Earth's crust through hot springs at temperatures of up to 400°C. Because of the black plumes formed by the activity, these hydrothermal vents are often referred to as 'black smokers'.

SMS deposits can potentially be found in the Mediterranean, near the Azores (Marques & Scott 2011; Lange et al., 2014; Ortega, 2014) and in Norwegian waters at the Mid Atlantic Ridge. Future exploration is needed to get more indication of their values.

[8]http://www.geomar.de/en/news/article/tiefseetiere-gesucht-manganknollen-gefunden/ (d.d. 15-07-2017).

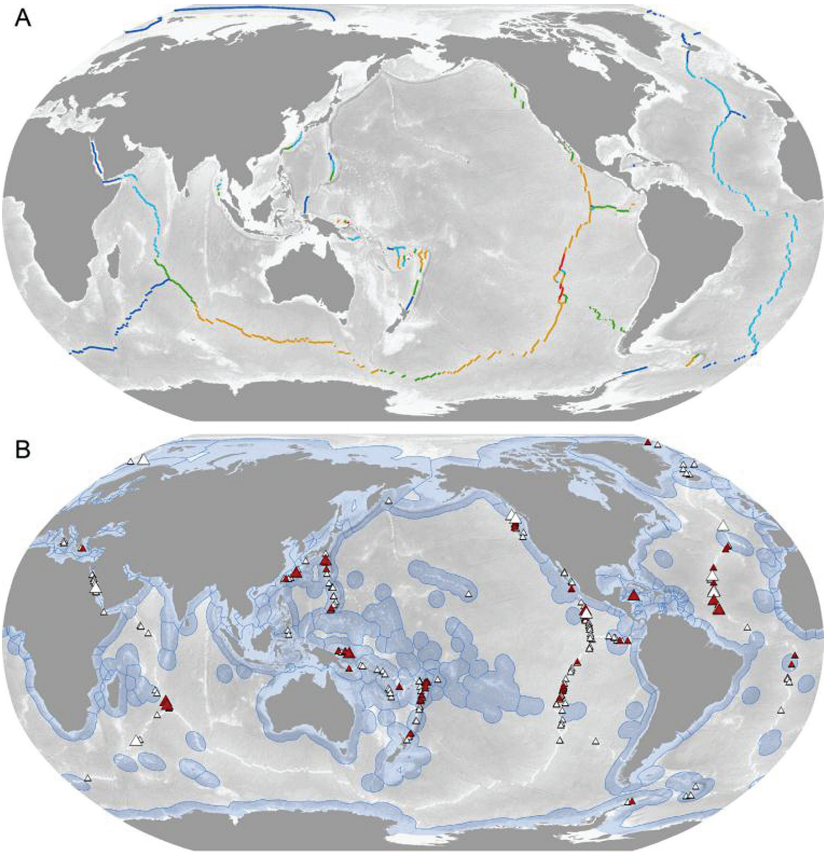

Figure 3.5 (A) Locations of mid-ocean ridges and back-arc spreading centres important for the formation of seafloor massive sulphides. Colours denote the spreading rate of each segment. Dark blue = ultra-slow spreading <20 mm/yr); light blue = slow spreading (20–40 mm/yr); green = intermediate spreading (40–60 mm/yr); orange = 1/4 fast spreading (60–140 mm/yr); red = ultra-fast spreading (>140 mm/yr). (B) Location of high-temperature seafloor hydrothermal systems and associated seafloor mineralization, where red colour indicates occurrences with economically interesting metal concentrations (average grade of the deposit is either 45 wt% Cu, 415 wt% Zn, or 45 ppm Au) and large symbols indicate occurrences with size estimates above 1 million tonnes. Using these criteria, only a few occurrences of economic interest have been identified. Note that geochemical analyses are commonly only available for surface samples that are not representative for the entire occurrence. A quantitative resource assessment for seafloor massive sulphides is only available for two occurrences (Solwara 1 and Solwara 12, both within the EEZ of Papua New Guinea). Light blue areas delineate the EEZ. (Petersen et al., 2016).

3.3.1.3 Cobalt crusts

Cobalt crusts accumulate at water depths of between 400 and 7,000 m on the flanks and tops of seamounts. They are formed through precipitation of minerals from seawater. The crusts contain iron, manganese, nickel, cobalt, copper and various rare metals, including rare earth elements (Table 3.1). They vary in thickness from <1 to 260 mm and are generally thicker on older seamounts. Because cobalt crusts are firmly attached to the rocky substrate, they cannot simply be collected on the bottom like manganese nodules. They will have to be laboriously separated and removed from the underlying rocks. (Hein et al., 2013; Lange et al., 2014; Petersen et al., 2016).

Globally, it is estimated that there may be as many as 100,000 seamounts higher than 1,000 m, although relatively few of these will be prospective for cobalt crust extraction. As compared to the terrestrial reserves, cobalt crusts represent a substantial portion. The commercially most important metals seem to be copper, cobalt and nickel (Table 3.1) (Ecorys, 2014).

The world's oldest seamounts are found in the western Pacific. Accordingly, many metallic compounds were deposited here over a long period of time to form comparatively thick crusts. This area, around 3000 kilometres southwest of Japan, is called the Prime Crust Zone (PCZ) (Figure 3.6) (Hein et al., 2013; SPC, 2013b; Petersen et al., 2016).

For Europe some potentially commercially exploitable crusts can be found on seamounts near Madeira, the Canary and Azores islands, the Galicia Bank, Iberian margin and one sample from the western Mediterranean Sea (between –750 to –4,600 m). The resource potential of Fe-Mn crusts within and adjacent to the Portuguese EEZ is evaluated to be comparable to that of crusts in the central Pacific, indicating that these Atlantic deposits may be an important future resource (Muiños et al., 2013; Conceição et al., 2014; Gonzalez et al., 2016). The resources at the Galicia Bank, Iberian margin need to be evaluated in a commercial perspective. They are not as enriched in cobalt as the nodules from the Galicia Bank (Gonzalez et al., 2016; Hein et al., 2013).

3.3.1.4 Phosphorites

Phosphates are found in areas of oceanic upwelling and riverine deposits. They are most commonly formed off the western margin of continents and on plateaus (zones of upwelling, Figure 3.7). In this sense they are the result of marine and oceanographic processes and not (direct) land run off and deposits. Europe has some deposits at the continental shelf of Portugal

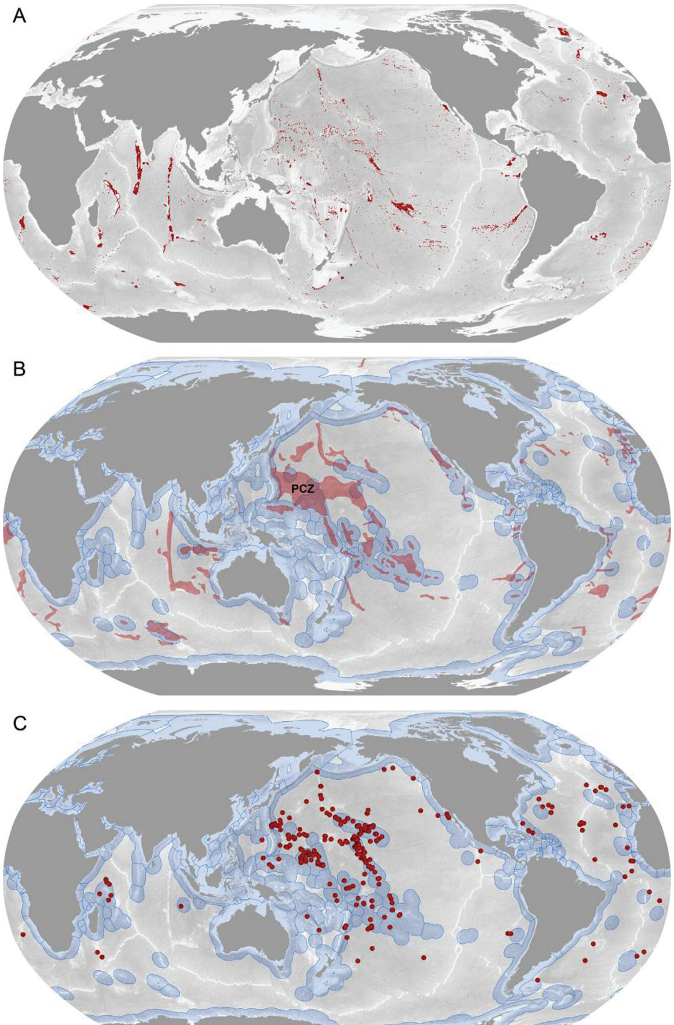

Figure 3.6 (A) Locations of seamounts, guyots, and oceanic plateaus that are important for the formation of ferromanganese crust based on seafloor classification, seafloor age (older than 10 My), sediment thickness (<500 m), sedimentation rate (<2 cm/1000 years), and water depth (peaks between 800 and 3000 m). Note the lack of data below 70°S and above 80°N. See text for details. (B) Area with highest ferromanganese crust potential based on morphology, age of the crust, and metal input. Light blue areas delineate the EEZ. Abbreviations: PCZ = Prime Crust Zone. (C) Location of ferromanganese crust samples from the ISA database with Co-concentrations above 0.5 wt% (N = 465). Note that most Co-rich ferromanganese crust samples lie in the western Pacific (Petersen et al., 2016).

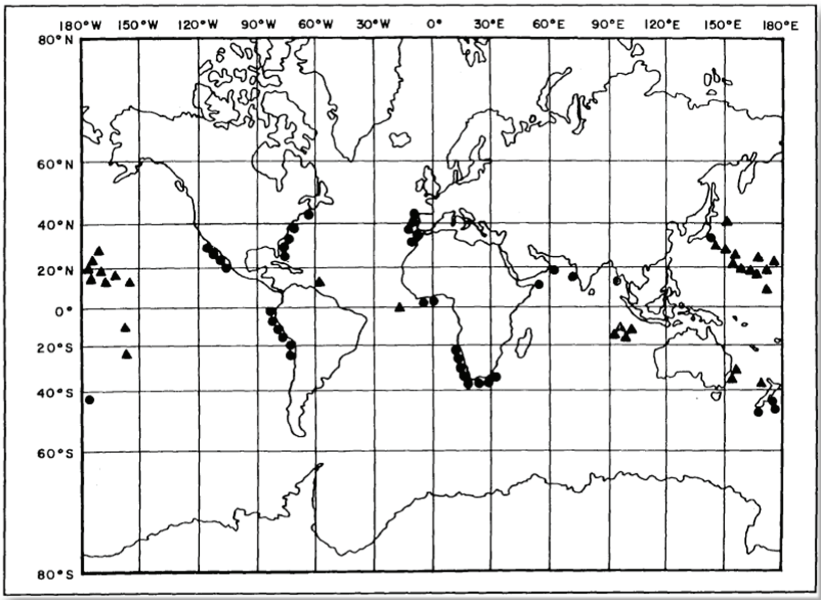

Figure 3.7 The presence of Phosphorites and other resources according to the status in 2008. Dots: continental shelves; triangles: seamounts.

Source: Thiel et al., 1998.

(measured ~–400 m till ~–2000 m Gaspar, 1982) and Spain (Galicia Bank, measured ~–750 m till ~–1900 m) (Gonzalez et al., 2016).

3.3.1.5 Gas hydrates

Methane is formed by the metabolisation and decomposition of dead biological material by anaerobic bacteria or by chemical decomposition by earth heat starting from –300 m to –3000 m. When gas molecules are trapped in a lattice of water molecules at temperatures above 0°C and pressures above one atmosphere, they can form a stable solid. These solids are gas hydrates which are trapped in the pore of the sediments (Boswell & Collett, 2011; Lange et al., 2014).

Methane hydrates develop in permafrost regions on land or beneath the seafloor. They are usually covered by a layer of sediments. Their formation under the seafloor requires an environment of sufficiently high pressure and low temperature. Thus, in the Arctic, methane hydrates can be found below water depths of around 300 metres, while in the tropics they can only occur below 600 metres. Most methane hydrate occurrences worldwide lie at water

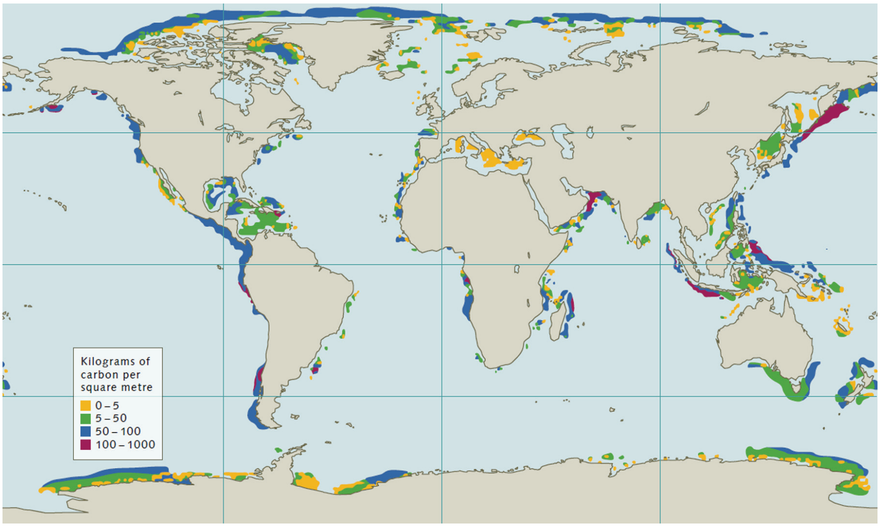

Figure 3.8 The occurrence of biogenic gas hydrates. Gas hydrate forms when methane and water combine at pressure and temperature conditions that are common in the marine sediments of continental margins and below about –200 m. The figure only shows biogenic gas hydrates. The amounts of thermogenic methane are not taken into account (Fig. from Lange et al., 2014).

depths between 500 and 3000 metres at the continental margins. According to current estimates the largest deposits are located off Peru and the Arabian Peninsula (Lange et al., 2014; Figure 3.8).

3.3.2 Centres of Offshore Activity

3.3.2.1 International areas

To date (20-07-2017), a number of contracts signed with the ISA for the *exploration* for mineral deposits are currently into force: 17 for polymetallic nodules, 6 for polymetallic sulphides, 4 for cobalt-rich crusts (Figure 3.9)[5]. Three States have notified the ISA of their prospecting activities (Fiji, Tuvalu, Samoa). There is no application or contract for *exploitation* of minerals as of yet in international areas.

3.3.2.2 National areas

Metallurgic deposits

In relation to metallurgic deposits, Nautilus Minerals Inc. holds a license for exploration and exploitation of SMS deposits at the Solwara site in

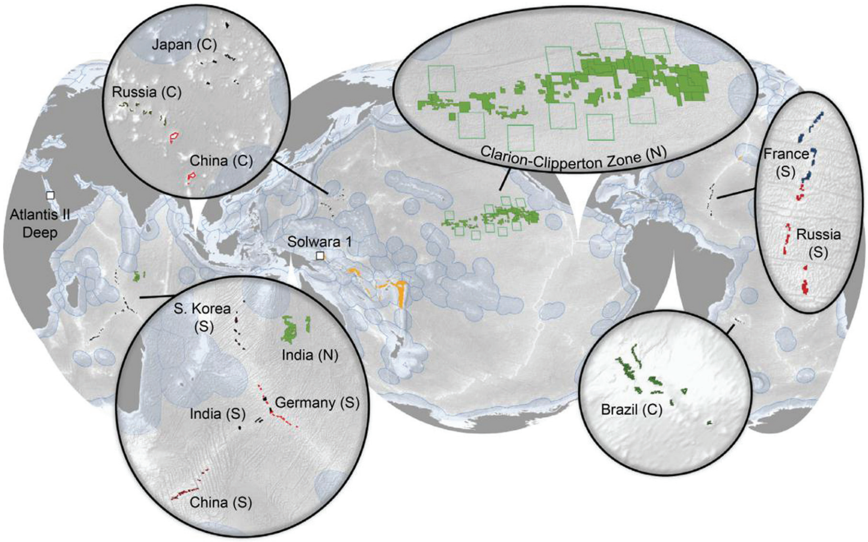

Figure 3.9 Locations of global exploration licenses for manganese nodules (N), Co-rich ferromanganese crusts (C) and seafloor massive sulfides (S) for licenses within "the Area", orange for licenses within EEZs. The locations of the only two seabed mining licenses (Atlantis II Deep in the Red Sea and Solwara 1 in Papua New Guinea) are indicated by the white squares. The location of the protected "Areas of Particular Environmental Interest" (size of 400 km by 400 km each) in the CCZ is provided as rectangles with a green outline (Petersen et al., 2016).

Papua New Guinea. For mining the Atlantis II Deep in the central Red Sea, positioned in the common EEZ of the Kingdom of Saudi Arabia and the Democratic Republic of the Sudan, the Diamond Fields Ltd. of Canada and Manafa of Saudi Arabia consortium has received a 30-year license for exploration and exploitation (Thiel et al., 2013; Petersen et al., 2016, Figure 3.9[9]).

Neptune Minerals[10], a company registered in the USA, is also conducting exploration for SMS since 2005. The company holds (or has held) prospecting and exploration licenses in Japan, Papua New Guinea, Solomon Islands, Vanuatu, Fiji, Tonga and New Zealand.

[9]http://www.diamondfields.com/s/AtlantisII.asp (d.d. 20-07-2017). Atlantis II Deep contains hot brines with metallurgic content. The upper 10 metres of sediment in the Atlantis II Deep at ~2200 m, contains economically highly valuable metal deposits.

[10]http://www.neptuneminerals.com/ (d.d. 20-07-2017).

Phosphorites

There is no phosphorite nor gas hydrates exploration going on in international areas. Currently three regions are in various stages of exploitation: phosphate rich sands in Namibia (–180 m to –300 m, two companies), nodules in Chatham Rise (–250 to –450 m, New Zealand), and phosphate rich sands in the Don Diego deposit (–50 m to –90 m, offshore Baja California, Mexico). They are all currently on temporary hold due to environmental considerations. Environmental impact estimates are questioned by stakeholders fearing the impacts of large-scale exploitation (Sharma, 2017).

Offshore deposits located off Florida and Georgia in the south-eastern U.S. have been drilled, fairly well characterized and seem promising for exploitation (Scott et al., 2008).

Gas hydrates

Japan and South Korea are at the cutting edge of the exploration and exploitation of gas hydrates. In the coming years these two countries will carry out additional production tests on the seafloor. Significant efforts are also being undertaken in Taiwan, China, India, Vietnam and New Zealand to develop domestic gas hydrate reserves in the seafloor. A major technical barrier is the development of methods best suited for production. For this reason large amounts of money continue to be spent on research. To date, close to 1 billion US dollars have been invested in gas hydrate research worldwide. The first resource-grade gas hydrates in marine sands were discovered in the Nankai Trough area off Japan in 1999. In 2013, methane was produced there for the first time from a test well in the sea (Lange et al., 2014). This resource exploitation is still in an experimental phase.

3.3.3 Ownership

In general most of the exploitation of offshore metallurgic and gas resources is in the hands of governmental related companies[5]. Commercially exploitable, high grade phosphorites concessions seem more in the hands of private investors combined with national authorities, as further explained below.

3.3.3.1 Governmental companies

In most of the projects in international waters, the main contractors are governments (Korea, Russian Federation, India) or companies sponsored and funded directly or indirectly by governments through public funding. It is the case, for example, of KIOST (Korea), COMRA (China), JOGMEC102 and

DORD (both Japan) and the Federal Institute for Geosciences and Natural Resources (BGR, Germany)[5]. In the case of nodules, out of 16 contractors, nine are directly or indirectly government related, three operators and a science institute with potentially a strategic interest; only 3 private investors are involved.

Depending on the country, governmental institutes perform a more supporting task for a ministry (the final contract holder with ISA), or manages the contracts with ISA itself. The distinction is the relationship of the contractor with the governmental department, as well as the degree of (in)dependency.

3.3.3.2 Private companies

Private companies are encountered at two levels: operation and investment. Typically in metals most private companies provide services in the value chain (Figure 3.10). In the case of profitable phosphorites, private companies are investors as well.

The value chain of mining operations includes exploration and resource assessment, mining and extraction as well as processing (smelters) and distribution (Figure 3.10). The tendency for large aggregations is typical of more mature land-based mining rather than seabed mining (Ecorys, 2014). In offshore mining, smaller companies (as compared to the broader mining industry) can conduct exploration activities. However, specialised companies like Fugro and GSR (exploration) are bought by larger dredging firms like Boskalis and DEME, demonstrating vertical integration and the aggregation tendencies of maturing industries.

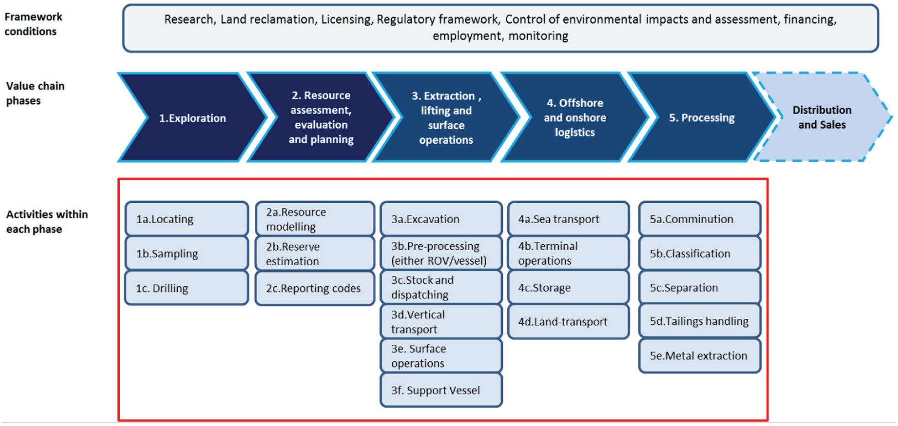

Figure 3.10 Value chain phases and activities of offshore mining (Ecorys, 2014).

The companies can be owned or are supported by investments of three groups of investors:

1. Large mining firms acting as investors (e.g Nautilus).
2. Large generalist investors (like Levi Levine and Namibia Marine Phosphate (NMP) for phosphorites).
3. Dredging companies and offshore construction companies.

3.3.4 Integration

Both vertical integration and horizontal integration takes place in the value chain of nearshore and offshore mining. Integration of different types of expertise also appear necessary to allow offshore mining to occur.

3.3.4.1 Vertical integration

A clear case of vertical integration is that of the Phosphorites mining companies in Namibia and Mexico. NMB and the Leviev group want to have their own refinery factory to increase the ore grades to commercially interesting grades (downstream) (Benkenstein, 2014). The Mexican Don Diego project also foresees a form of local, on site, processing of the ore to a more refined ore reduced in volume in order to reduce transport costs, e.g. a factory ship that refines the raw ores working next to a TSHD.

3.3.4.2 Horizontal integration

Horizontal integration is shown in the fact that dredgers offer their service to all kinds of marine resources: sand and gravel; phosphorites, metal ore sands etc. Exploration companies like Odyssey explore the oceans of the world locating valuable treasures and resources, archaeological sites and shipwrecks. Bosch Rexroth designs materials for both offshore mining and offshore oil and gas industry. Offshore knowledge, capacity and capability is highly valuable and adapted for new purposes. The dredgers have rather recently entered the offshore wind energy installation market. The key value here is general offshore knowledge (Rozemeijer et al., 2015).

3.3.4.3 Highly specialised operators

Because offshore mining is located in open seas, it is by definition a capital-intensive sector. All commercial activities on seas and oceans require high-end knowledge, extensive experience and large investments. Offshore and adapted nearshore mining represent an extremely demanding environment, which has to deal with both the very harsh conditions and remoteness of the open ocean and the extreme environment of the deep sea. In the role of operators, only established companies with a long history of operation can operate there, having developed a balanced view on investment, revenues, logistics, innovation etc. (Ecorys, 2014; Lange et al., 2014; EPRS, 2015). These companies operate in an international, global setting. Europe has some major players in the fields: renowned international dredgers and offshore-installation producers.

3.3.4.4 Buying in knowledge and reducing risks

More often than not, major companies buy in extra technology or local market knowledge of procedures with the local government and local stakeholders. For Don Diego, Boskalis is investing in Odyssey Marine Explorations and in a second Mexican company Dragamex, thereby getting access to knowledge on exploration techniques as well as the local governance procedures and stakeholders. Odyssey currently owns 54% of the outstanding shares of its subsidiary, Oceanica Resources S. de. R.L. (Oceanica). Oceanica itself owns Exploraciones Oceanicos, S. R.L. de CV, the Mexican operating company with the mining concession containing the Don Diego phosphate deposit. Next to buying in knowledge, it protects the mother company and implies minimal investments for maximum influence (staged 54% majority shareholding).

Similar combinations or networks of expertise also exist, e.g. around Chatham rise Phosphorites projects. Odyssey Marine Exploration has minority ownership stakes in Chatham Rock Phosphate Ltd. Once more, Boskalis is the operator for the Chatham rise concession. Odyssey Marine Exploration also has minority ownership stakes in Neptune Minerals. They are all companies controlling exclusive mineral licenses for areas believed to contain high-value ocean floor mineral deposits.

Both Boskalis and DEME bought in exploration knowledge with the smaller companies of respectively Fugro and GSR.

A network of interdependent investors and operators ensures the conservation of investment and essential knowledge.

3.4 Working Environment

In this section, attention is given to the various factors impacting the lifetime of a seabed mining project as well as the interactions of said project with the surrounding environment in its widest sense. This includes the governance and societal implications of project development, the employment aspects, the economical context and ecological concerns.

3.4.1 Employment and Skills

Although the typical ores extracted through offshore mining are in general not present within European waters, the interest of EU-based companies in the sector is of primary importance. The relevant experience in specific vessel design, construction and operations of extracting seafloor resources are mostly of European origin and Europe-based until today. Indeed, it is the European dredging and offshore construction industry – mainly concentrated in the Netherlands, Belgium and the UK, which is particularly involved in applying their knowledge and experience arising of nearshore dredging and mining around the globe (Rozemeijer et al., 2015).

The long-term employment opportunities that should arise from offshore mining are expected to be limited to a few hundred of high skilled positions per project, which is relatively low when compared to the sectors of land-based mining or recycling. This is explained by the need for technological tools rather than workforce on board mining vessels, requiring expertise from mainly crew, technicians, managers and other indirectly involved staff. However, when looking at the entire value chain, treatment and processing factories on land as well as commercial phases should open the door to a greater need for labour supply. Even though, the EU offshore industry has been qualified as marginal in terms of job creation by several studies (SRK Consulting, 2010; EPRS, 2015).

Despite the low impact on employment, this type of activities also has the potential to become an important driver for technological development and innovation (EPRS, 2015; Worldbank, 2016). Universities, public-private partnerships in R&D, and EU funding programs like H2020[11] play a consequent role in pushing and pulling this leading position in technology development, engineering, and adjacent fields such as environmental optimization, ecological impacts and sustainable governance.

Research on governance, policy and legal development is of particular interest to future mining projects. Indeed, the assessment of their impact on such projects, as well as the associated costs and liabilities, is rendered challenging by the status of the legislation which is still, to date, under development.

[11] https://ec.europa.eu/programmes/horizon2020/en/draft-work-programmes-2016-17 (d.d. 13-07-2017).

3.4.2 Rules and Regulations

The deep seabed spreads both over areas within national jurisdiction (EEZ, Continental shelf) and the Area. There are thus two different levels of regulatory framework depending on the specific location of mining activities:

1. International law: Part XI of the *United Nations Convention* on the *Law of the Sea* (LOSC, 1982), applicable to the Area and where the ISA is responsible to administer and regulate mining activities through the development of its Mining Code.
2. Domestic law: the legislation of the coastal State applicable to the seabed within its national jurisdiction.

3.4.2.1 International law

The Area and its mineral resources are reserved for the Common Heritage of Mankind, as provided in Part XI of the LOSC. The ISA is mandated by the LOSC to adopt rules and regulations to ensure that prospecting, exploration for and exploitation of minerals in the Area is conducted in accordance with the economic and environmental principles set forth in the LOSC. To this aim, the ISA has started drafting a Mining Code[12]. Components of this Mining Code on exploration have since then been adopted and implemented, but the exploitation phase remains to be regulated. Since 2015, the ISA has effectively begun the drafting process of exploitation regulations that will be incorporated into the Mining Code[13]. Their adoption is expected by 2018 or 2019. As it stands in its incompleteness, the current regime under which these resources are administered may be described briefly as follows:

- While scientific research is largely free of restrictions, prospecting may be conducted only after the ISA has received notification, accompanied with a written undertaking that the proposed prospector will comply with the LOSC and the ISA rules, regulations and procedures, and will accept verification of compliance by the ISA. This solely implies requirements on environmental and human safety considerations, and respect for other activities taking place in international areas.
- Exploration and exploitation may only be carried out under a contract with the ISA and are subject to its rules, regulations and procedures. Contracts may be issued to both public and private mining enterprises

[12] Available at (d.d. 13-07-2017): https://www.isa.org.jm/mining-code
[13] Updates on the drafting process are available at (d.d. 13-07-2017): https://www.isa.org.jm/legal-instruments/ongoing-development-regulations-exploitation-mineral-resources-area

provided that they are sponsored by a State Party to the LOSC (the Sponsoring State) and meet certain standards of technological and financial capacity. Although the contractual form allows for more flexibility than permitting or licensing, which is the traditional mean of authorization for land-based mining, most of the contract clauses are pre-set by the Mining Code.

The ISA has also emphasized provisions relating to environmental protection and safeguards (Benkenstein, 2014), although the requirements for the exploration phase are rather light. In March 2017, the Federal Institute for Geosciences and Natural Resources (BGR) and the German Environment Agency (UBA) held an expert workshop jointly organized with the ISA on environmental standards for seabed mining. In the current context where the ISA is still developing the Mining Code's part on exploitation, international experts participating in the workshop advocated for systematic environmental protection in offshore seabed mining both at project and policy level[14]. Experts also recalled the compelling need for a comprehensive assessment of both the chances and risks of future seabed mining, as well as the obligation to apply a precautionary approach[15]. Major, stricter and more detailed requirements are hence expected with the coming regulations for exploitation.

Current requirements in the Mining Code for exploration include:

- Prevention, reduction and control of pollution and other hazards to the marine environment, applying a precautionary approach. Ecosystem-based management, monitoring and mitigating strategies, and more generally best environmental practices, even though part of the discussion at policy level, remain to be set in further details and standards.
- Gathering of environmental baseline data against which to assess the likely effects on the marine environment of a future seabed mining project.
- Establishment of comprehensive programs for monitoring and evaluating environmental impact.
- Determining of 'impact reference zones' (areas that are sufficiently representative to be used for assessment of impact on the marine environment).

[14]Workshop Towards an Environmental Management Strategy for the Area Berlin, 19 to 24 March 2017, the ISA Secretary-General's opening statement (d.d. 13-07-2017): https://www.isa.org.jm/sites/default/files/documents/EN/SG-Stats/remarks.pdf

[15]http://www.umweltbundesamt.de/en/press/pressinformation/deep-sea-mining-germany-lobbying-for-high (d.d. 13-07-2017).

- Determining of ‘preservation reference zones’ (areas in which no mining shall occur to ensure representative and stable biota of the seabed in order to assess any changes in marine biodiversity).
- Preparation of prior EIAs before any test mining such as large scale extraction or equipment trials; small scale test mining is considered as part of exploration activities and is hence included in the scope of an exploration contract.

The role of the Sponsoring State is to guarantee that the contracting entity will respect the ISA rules, regulations and procedures. In other words, the sponsoring State ensures that the relevant rules of international law apply to public and private entities that are not States. To achieve this, the Sponsoring State has the obligation to adopt national measures, in the form of legally binding instruments. The current state of legislation of EU states is summed up in Table 3.2.

3.4.2.2 Domestic law

Within national jurisdiction, Coastal States are sovereign and can regulate seabed mining occurring on their continental shelf. However, in doing so, they also have to respect the international obligations deriving from global and regional treaty law, including the standards set or to be set by the ISA. While there are thus a variety of different legislations and approach already in place, they tend to be derived from the same principles. For example, the Secretariat of the Pacific Community has developed a framework based on sound legal principles and practice to aid Pacific States in adopting their own legislation[16], while ensuring a high level of requirements and harmonization of the law in the region (Makgill & Linhares, 2015).

In addition, EU member states also have to abide by the relevant and applicable regional conventions and EU law. Environmental rules and procedure in Europe are particularly developed and might add to the ISA requirements, even though EU law is often a form of implementation of international obligations. For instance, the EIA directive (85/337/EEC) and the environmental liability directive (2004/35/EC) can be applied, as well as the EU maritime safety directives and regulations aimed at ensuring safety and environmental protection by EU flag states[17]. An overview of the status of EU states’ laws both within and beyond national jurisdiction is provided in Table 3.2.

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[16]http://dsm.gsd.spc.int/public/files/2014/RLRF2014.pdf (d.d. 13-07-2017).

[17]https://ec.europa.eu/transport/modes/maritime/safety/actions_en (d.d. 13-07-2017).

Table 3.2 Oversight of the national legislation for offshore mining in Europe. CS: Continental Shelf

State	Legislation Adopted – Relevant Acts	Area		EEZ/CS
		Draft	In Force	
	EU Sponsoring States			
Belgium	Belgian Act related to prospecting, exploration and exploitation of the resources of the deep seafloor and subsoil thereof beyond national jurisdiction (17th August 2013)		X	
Czech Republic	Act No. 158/2000 on Prospecting, exploration for, and exploitation of mineral resources from the seabed beyond limits of national jurisdiction (18th May 2000)		X	
France	Mining Code of 20th January 2011			X
	Ordinance No. 2016-1687 of 8 December 2016 relating to the maritime areas under the sovereignty or jurisdiction of the Republic of France		X	X
Germany	Seabed Mining Act (6th June 1995, amended in 2010)		X	
UK	Deep Sea Mining Act 2014, amending Deep Sea Mining (Temporary provisions) Act 1981 (14th May 2014)		X	X
	Other EU Member States – Not Sponsoring			
Denmark	Mining Code Act of 24th September 2009			X
Malta	Malta Resources Authority Act nr XXV of 2000; Continental Shelf Act of 8th August 2014			X
Netherlands	Mining Act of 2002			X
	Note verbale dated 26 March 2013 from the Permanent Mission of the Netherlands to the United Nations.	X		
Portugal	Decree-Law on research and exploitation of minerals, 15th March 1990 (on-going amendment)	X		X
Spain	Law on Mines of 21st July 1973 (last amendment 2014)			X

3.4.3 Societal Impacts and Concerns

Exploration and exploitation of offshore resources could also have serious societal impacts, such as consequences for the livelihoods and well-being of coastal communities in particular for nearshore mining projects. So far no exploitation activities have taken place, which poses uncertainty with respect to the actual impacts of offshore mining.

3.4.3.1 Possible societal impacts

When it comes to offshore mining, the most relevant social impacts will likely be associated with several key changes during mining life cycle, which is likely to be relatively long (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 where the absence of conservation areas to protect the unique and little known ecosystems of the deep-sea, and sometimes the lack of an adequate regulatory regime, is striking. Public and local communities participation is also frequently lacking from the project's process and the authorities' decision-making (Franks, 2011; SPC, 2013d; EPRS, 2015, Baker et al., 2017), although trends in legal developments around the globe seem to be heading towards more transparency.

Table 3.3 below presents the potential societal impacts due to offshore mining built upon examples from terrestrial mining as a proxy (EPRS, 2015).

Table 3.3 Overview of potential societal impacts of offshore mining (EPRS, 2015, adapted from SPC, 2013d)

Category	Benefits	Disadvantages
Socio-Political	• Health and safety, • Working conditions, • Remuneration ... • Opportunities for other development options, • Strategic position of metal providers in the global arena	• Social inequalities at local scale • Political and strategic conflicts or inequalities: land-based mining vs offshore mining policies.
Economic	• Employment, • Flow of money, • Training, • Local business expansion, • Community development and social programs, • Equitable distribution	• Change in industrial landscape and composition, • Dominance of foreign entities
Socio-environmental	• Compensatory measures in favour of local communities • Compensatory measures in favour of the scientific world • Increased knowledge of habitat and ecosystem through data, surveys and trials' results	• Access to Marine Resources and competition between users of the sea • Fisheries • Cultural practices, • Environmental damage

Table 3.3 solely lists the societal impacts applicable to offshore mining that are considered likely to have a significant effect as things currently stand. It is an attempt at balancing positive and negative effects.

From a socio-political point of view, impacts can be both positive and negative. For example, labour features as described in Section 3.4.1 may increase remuneration in a given locality because of the higher skilled workforce, as well as ensure good working conditions and health and safety standards. However, this may also increase the social inequalities especially when a project happens in a developing state where communities depend on lower skilled jobs. In Papua New Guinea, one of the main concerns of local communities was the impact that the Solwara 1 project would have on fisheries.

On a bigger political and strategic scale, seabed mining represents opportunities for states or regions in terms of direct growth, but also indirectly through the development of other industries and sectors (e.g. development of industries using the produced metals, service providers, R&D ...). For the reasons earlier explained in Section 3.2, this could also help global strategies and alliances between states or regions. On the other hand, the rise of big and small, new offshore players might affect the economy and political stability of players depending on land-based mining, potentially creating tensions or conflicts.

Economically speaking, while there are a number of benefits directly arising from the sector's growth (e.g. employment, cash flow, community development ...), it might also bring some challenges requiring adaptation. The rise of seabed mining in a state that may be new to the sector, or that already has land-based mining activities occurring on its territory to balance it with, will change the industrial organisation of its system. Inevitably, this will require an adaptation phase, potentially with a new organisation of the sector or even the broader economical balance. In developing states, one of these changes will most likely occur from the arrival or increase in foreign entities joining an economical system, potentially disrupting a pre-established balance.

The socio-environmental impacts of seabed mining are perhaps more difficult to balance. It appears rather obvious what ecological concerns might mean for people worldwide and even so for local communities: lesser access to marine resources for those competing users of the seas (shipping routes, cables, scientific campaigns ...), impact on fisheries, or more generally, the environmental damage undeniably arising out of seabed mining (see Section 3.4.4 for more details). However, as compensatory measures, the sector has the potential to offset those impacts by bringing value back to society, through scientific opportunities on-site, the gathering of data and knowledge on these poorly known environments, or direct benefits to local communities through funding of local infrastructures, training opportunities, etc.

3.4.3.2 Societal impact relevant for the EU

Due to the increasing importance of the topic in the immediate future and the necessity for the EU yet to define a policy on this matter, the European Commission launched a Stakeholder Consultation (including civil society, NGOs, Member States and some private and public consultancies) on offshore mining. The main outcomes of this consultation showed that[18]:

- Commercial mining is not an option unless regulations are in place.
- The drafting and adoption of regulations must be transparent and participatory and any benefits widely shared.
- More emphasis on reuse and recycling of materials rather than on offshore mining is required.

On the other hand, the interviews with industry stakeholders point out the fact that before making any conclusions, the opponents of offshore mining, scientists and governments should look at the overall risk and impact of offshore mining vis-à-vis terrestrial mining, and allow things to go forward.

As further explained in Section 3.4.5, the land, nearshore and offshore mining impacts can be compared and they also diverge for clear reasons. High risk and actual damages already occur on land, and the sole recycling and reuse of metals will not satisfy the increasing need for mineral resources. Hence, it is important to weigh the pros and the cons and to balance environmental risks with the potential for benefits, all the while making sure that the right framework is in place to enable sustainability (EPRS, 2015).

3.4.3.3 Mitigation of societal impacts

Lessons learnt from terrestrial and nearshore mining are provided below together with past relationships between mining companies and Pacific Island communities that have been characterized by complexities, tensions and contradictions (Franks, 2010; SKR Consulting, 2010; EPRS, 2015):

- Use ecological (systematic) approach.
- Be aware that legal limits and scientific data may not be aligned with community expectations.

[18] http://ec.europa.eu/dgs/maritimeaffairs_fisheries/consultations/seabed-mining/index_en.htm (d.d. 13-07-2017).

- Societal changes can be indirect, often of economic/political in nature.
- Socio-environmental concerns are very important (use of coastlines, deep-water pollution and disturbance).
- Access to, use of and ownership of land 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 is needed to understand communities' positions.

3.4.3.4 Safeguarding financial revenues for the future

An offshore resource (like any other resource) only has a limited stock and has an end to exploitation at a given time point. After exploitation ends, so does the source of substantial income. As far as international seabed mining in the Area is concerned, the LOSC provides that all mining activities (whether at the exploration or the exploitation phase) shall be carried out for the benefit of mankind as a whole. Hence, some of the provisions in Part XI of the LOSC ensure benefit-sharing in several forms, including non-monetary, particularly in favour of developing States. The sharing of financial and other economic benefits is one of them, although it has not really been implemented yet since exploitation has not started. The LOSC does not give much detail as to how this benefit-sharing should be operationalized, but it does prescribe that a contractor's payment to the ISA shall not be higher than the rates in land-based mining in order to avoid inequalities in the sector. Major discussions are currently talking about rates of 4–6% of the potential revenues (ISA, 2016).

Before granting exploitation concessions, mineral funds should be considered and set up, especially considering that the Area represents the Common Heritage of Mankind and thereby of all nations. Countries like Alaska, East Timor, Norway and São Tomé et Príncipe offer examples and inspiration for their structure and organisation (SPC, 2013d).

3.4.3.5 Safeguarding scientific revenues for the future

Other than financial benefits, the LOSC also provides for the dissemination of marine scientific research results, cooperation with developing states in research programs and training, technology transfer, access to reserved areas of exploration reserved for developing States at lesser costs. During the Berlin workshop in 2017[15,16], it was urged to combine all ecological and physical non-sensitive data and to make it publicly available. This is a matter that should be, and that is to a certain extent, regulated, but more importantly that should be effectively implemented in the future.

3.4.4 Ecological Concerns

3.4.4.1 Potential direct ecological impacts

Various studies emphasize that the ecological impacts of offshore mining are a point of major concern. Amongst others, SPC (2013a, b, c), Ortega (2014), and Sharma (2017) concluded that the impact of offshore mining is expected to be in the various forms of:

- loss of substrate,
- loss of benthic communities,
- loss of biodiversity,
- sediment plumes on the seafloor,
- increased turbidity in the water column, and
- addition of bottom sediments to the surface.

Such impacts would result in changes to the food chain and thus to the marine ecosystem, but impacts on the surface as well, owing to collection, separation, lifting, transportation, processing and discharge of effluents should not be overlooked. Oebius et al. (2001), Ramirez-Llodra et al. (2015) and others described the impact of sediment clouds as a result of other human activities, providing clues and background knowledge from which the impact of seabed mining plumes could be extrapolated. Boschen et al. (2013) describe more specifically the impact on a range of habitats and time scales for SMS deposits.

Mining nodule areas seem especially sensitive, since these deep areas are cold and hardly receive energy input: a standstill world with high and complex biodiversity. The nodules themselves harbour an epiphytic biota distinct from the surrounding sediments. In one CCZ locality, roughly 10 per cent of exposed nodule surfaces were recorded as being covered by sessile, eukaryotic organisms (mostly foraminiferan protozoans) carrying an unique mini-ecosystem themselves (SPC, 2013b; Vanreusel et al., 2016).

The seamount areas of cobalt-rich crusts host biodiversity rich habitats such as deep water coral reefs. Water currents are enhanced around seamounts, delivering nutrients that promote primary productivity in surface waters, which in turn may promote the growth of fish and animals such as corals, anemones, stars and sponges, but also creates an oxygen-minimum zone that inhibits the growth of some organisms (SPC, 2013c). FAO designates seamounts as Vulnerable Marine Ecosystems, a protective status for fishing activities[19].

Hydrothermal vents and SMS deposits are associated ecosystems composed of an extraordinary array of animal life. Chemosynthetic bacteria, which use hydrogen sulphide as their energy source, form the basis of the vent food web, which is comprised of a variety of giant tubeworms, crustaceans, molluscs and other species, with composition depending on the location of the vent sites. Many vent species are considered endemic to vent sites and hydrothermal vent habitats are thus considered to hold intrinsic scientific value (Van Dover, 2008; SPC, 2013a).

Technical and scientific studies have found that there is a general lack of data to make thorough environmental impact assessments (SPC 2013a, b, c, d; Lange et al., 2014; Ecorys, 2014; Rogers et al., 2015). Phosphorite mining examples show how uncertainties and gaps in knowledge and data actually lead to major delays in project development (Baker et al., 2017), in particular due to major discussion on EIAs, potential economic impacts, government shares and social acceptance. Societal protest is due to the fact that phosphorite mining can be nearshore, within the range of fisheries and rich biodiversity (see e.g. Benkenstein, 2014; EPRS, 2015; Baker et al., 2017; Sharma, 2017).

3.4.4.2 Potential indirect ecological impacts

On a more general level, one could state that offshore mining hampers the evolution towards a circular economy (recycling, eco-design, sharing, repairing, etc.), since new resources are reclaimed instead of recycling discarded products. On the other hand, Ecorys (2014) indicated that recycled contents remain rather low, not fulfilling the needs. It also shows that offshore mining can provide a part of the additional new ores that will be needed on the market.

Gas hydrates are thought to influence ocean carbon cycling, global climate change, and coastal sediment stability (issue under serious debate, e.g. Bosswell & Collett, 2011; Lange et al., 2014). In addition the mobilization of gas hydrates as a new, potentially cheap energy source will contribute to

[19]http://www.fao.org/in-action/vulnerable-marine-ecosystems/en/ (accessed 13 July 2017).

additional CO_2 in the atmosphere, a cheap new source can also hamper the development of renewable techniques.

3.4.4.3 Mitigation of ecological impacts

Concerns about the ecological impact of offshore mining are recognized by the ISA, who have subsequently taken various actions to describe and support good practices. This includes training – including biodiversity monitoring and development of environmental management systems.

Integrated governance based on the ecosystem approach will be necessary in developing deep-sea mineral policies. Ecosystem-based oceans management strategies, laws, and regulation for seabed mining would include provisions for (SPC, 2013d, ISA):

- Collecting adequate ***baseline information*** on the marine environment where mining could potentially occur.
- Establishing ***protected areas*** where there are vulnerable marine ecosystems, ecologically or biologically significant areas, depleted, threatened, or endangered species, and representative examples of deep sea ecosystems.
- Adopting a ***precautionary approach*** that, in the absence of compelling evidence to the contrary, assumes offshore mining will have adverse ecological impact and that proportionate precautions should be taken to minimize the risks.
- Applying ***adaptive management*** in which different hypotheses on exploitation and impacts are formulated and tested during exploitation in order to switch to different management strategies.

Processes at the deep seafloor require lots of energy, e.g. for transport of raw material to the surface and for processing and transport on board of vessels and platforms. Therefore, the use of on-site renewable energy sources may be considered to reduce the supply and costs of fuels, and emissions of CO_2. Especially when combined with floating or fixed platforms, wave energy and wind farms could possibly be used. To this end, innovation and R&D in the seabed mining sector is a crucial and on-going step.

3.4.5 Comparing the Impacts of Land-based Mining versus Offshore Mining

Aside from sediment plumes being dispersed in the water column at different depths with different consequences, seabed mining will also undoubtedly destroy the habitats and biodiversity locally and in the case of nodules most likely permanently, on the sites where the mining occurs. However, these two impacts (plumes and habitat destruction) need to be relativized when compared to land-based mining's social and environmental footprint.

On land, mining tailings could be the equivalent of sediment plumes. Mining tailings are often dumped directly in the surrounding environment, may it be grounds or rivers, and are more often than not charged with chemical and heavy metals remaining from minerals processing into commercially exploitable metals. While the dumping of sediment tailings has significant effects on the surrounding environment comparable to the ones of underwater plumes, contaminated tailings flowing into the water cycle – groundwater, watercourses and eventually the sea – is quite worrisome, to say the least (Hein et al., 2013; Ramirez-Llodra et al., 2015; Rogers et al., 2015).

With seabed mining, contaminated sediments plumes in the water column are not only unlikely because on-board processing methods differ, but they are also legally forbidden. Not only the LOSC and ISA standards do not and will not allow it, but maritime practice and customary rules built upon the relevant IMO conventions have long been applied, monitored and effective (IMO, 1972; IMO, 1996). Even though to date IMO conventions are not directly applicable to seabed mining, the ISA, following the International Tribunal for the Law of the Sea's advice, is taking steps to avoid the emergence of "sponsoring States of convenience" in the seabed mining sector, meaning that States will be treated equally irrespective of their status or capacity when it will come to compliance with Part XI of the LOSC and the ISA Mining Code (ITLOS, 2011). This is also of relevance considering that land-based mining often occurs in places where, even when environmental safeguards are in place, their effective application is often lacking. Indeed, major extracting activities happen on the territory of developing States that are at best, unable to monitor and enforce and at worse unstable and corrupted (e.g. China, Congo).

Hence, even though the geographical scope of sediment plumes is likely to be larger than onshore mining due to the size of exploitation areas and oceanic currents and dynamics, measures to maintain turbidity at an acceptable level and to prevent the use of contaminants will be effectively applied and monitored by several levels of authorities (sponsoring States, ISA, IMO). A major concern is still the definition of what is acceptable and what is harmful impact in this offshore environment[8].

Comparison of habitat destruction onshore and offshore bears different concerns. Seabed mining is likely to occur on areas much larger than typical land-based mine sites. The exploration area of GSR is three times the size of

Belgium[5]. Even if they are likely to actually exploit only a small proportion of it, that could represent up to a third of said country. However, the direct impact of extraction will have a superficial impact on the seafloor (Hein et al., 2013). Indeed, whichever mineral is targeted (nodules, sulphides or crusts) will not require deep-cutting excavation methods. Because of the formation of such minerals either from superjacent water deposit or subsoil volcanic and geologic activity which are specific to their oceanic environment, mineral extraction does not require much more than scraping the seafloor's surface of a few meters deep only (Hein et al., 2013). When compared to land-based mining, where entire mountains can be taken down or underground mining can go too deep as to weaken stability and provoke slides (e.g. Chile), seabed mining's negative impact on the seafloor habitat may appear minor from a geological point of view. From an ecological point of view, habitat, biodiversity, genetic information and ecosystems concerns are not fully addressed and compared yet (SPC, 2013a, b, c, 2016; Ecorys, 2014; Rogers et al., 2015[20]).

Last but not least, working conditions on board will without a doubt be a lot better than conditions of onshore mine workers. Indeed, the technicality of seabed mining operations and the restrictions of having to sail on the high seas require limited and higher trained workers and seafarers, as opposed to the potentially terrible conditions of miners' populations often abused by corporates and governments (e.g. Congo) in terms of salary, health and safety rules[21].

In summary then, it is difficult to compare the environmental impacts of land based mining with seabed mining because one is a mature, large scale, destructive industry and the other has only limited information. As a consequence in all individual cases decision makers would need to evaluate independently – taking into consideration the market and environmental conditions of the individual minerals at the moment of deciding and in the future – whether the integrated economic, social and environmental footprint of seabed mining is acceptable and preferable or that land-based mining provides a better solution to meet the standards for the integrated economic, social and environmental footprints.

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[20]http://dosi-project.org/ (d.d. 13-07-2017).

[21]http://www.economist.com/news/middle-east-and-africa/21705860-can-ambitious-mine-make-difference-eastern-congo-richest-riskiest (d.d. 13-07-2017).

3.5 Innovation

Innovation needs are firstly introduced using the guiding principles of LCA and the value chain and next described in more detail. The value chain for offshore mining, irrespective of the specific resource, can be considered to include six main stages (Figure 3.10; Ecorys, 2014):

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

The current state of technology can be assessed on the basis of Technology Readiness Levels (TRL). The TRL levels for offshore mining value chain have recently been assessed and reported (Ecorys, 2014), and this section builds on the results of this study that was commissioned by the EU, and by the SPC study (2016).

3.5.1 Lifecycle Stages

The concept of business lifecycle considers how industries and firms were not in a steady state and appeared to evolve over time. The general value chain of nearshore and offshore mining is given Figure 3.10. For each sector and segment information for the LCA is given throughout the document. Per subsector more information on the most conspicuous features is given in the next sections. The most dominating aspect at the moment is the interpretation of exploration results, extraction and ore processing (steps 2, 3 and 5 in Figure 3.10) where the TRL of most aspects is still fairly low.

3.5.1.1 LCA of nodules, SMS deposits and cobalt crusts

The LCAs of nodules, SMS deposits and cobalt crusts are discussed in combination since they experience the same driving forces. The main drivers of the interest in offshore mining of metals seems to be the high market prices of the resources at stake at a certain moment in combination with the high exploitation costs vs geopolitical concerns on flows of essential ores.

Typically, TRL levels are lower (range 1–4) for technologies required on the seabed (collectors like cutters and scavengers) and for vertical transport (lifters). The on-board processing of ores for metal extraction -in order to reduce material loads to be transported- also needs to be improved. Technologies required at sea level (ship/platform and associated equipment, logistics) and onshore are more mature as they have similarity to applications in other sectors already existing. In addition the refined metals have their long established markets (Ecorys, 2014).

Innovation is expected to reduce the exploitation costs. Since these prices are highly dynamic and innovation costs are high and time consuming, major developments in activities are not expected at the moment (except for a few exceptions with high concentrations of resources).

3.5.1.2 LCA of phosphorites

A first remark is that extensive reviews are scarce on marine phosphorite mining. Only limited information is available. Most informative are websites. Given the high potential of this resource a more elaborate study is welcome.

Contrary to the metals, phosphorites can have valid business cases in the three projects in Namibia (two companies), Don Diego, Mexico and Chatham rise New Zealand. Several aspects make these business cases alive:

1. The large local demand for phosphates (Don Diego, 2015);
2. High global market prices (Figure 3.1);
3. Reasonable exploitation costs (Table 3.4);
4. Potential export and a share in the global market (Benkenstein, 2014).

Whereas they are imported now, rich relative shallow concessions are available and investors are willing to make the necessary high start-up investments. Amongst other reasons, problems with land-based ore qualities, increased demands, and geopolitical concerns (de Ridder et al., 2012), a more stabilized higher price and presumably technological developments will have altered the business case.

For phosphorites the business case seems more viable: large concessions can be found in the easily reachable nearshore and the shallow offshore. This enables the use of standard equipment what only has to be adapted to a minor extend (Schulte, 2013). As a result preparations have been made to exploit the resources with substantial interest expected (like being able to deliver 10% of the global market for phosphates). Environmental considerations have blocked the actual exploitation until further evaluations partly due to the fact that this type of bottom destruction in this zone has not been attempted before and e.g. impacts on bottom-life and associated fish communities are feared (Benkenstein, 2014; Rogers et al., 2015; Baker et al., 2017, Sharma, 2017)[22].

[22]See e.g. the continuing discussion on the Namibian NMP Sandpiper project (accessed 13-07-2017): https://southernafrican.news/2016/11/07/namibia-u-turn-on-phosphate-mining/

Table 3.4 CAPEX, OPEX costs and IRR of metal ores (Ecorys 2014) and an example phosphate project[7]. The metals used for calculations and the relative contribution to price: SMS: copper, gold, silver (70:28:2). Nodules: copper, cobalt, nickel (25:11:63). Including processing, however assumed to exclude processing of manganese. Cobalt crusts: copper, cobalt, nickel (4:63:33). Including processing, however assumed to exclude processing of manganese

	SMS Deposits	Polymetallic Nodules	Cobalt Crust	Phosphate
CAPEX ($)	1,000,000,000	1,200,000,000	600,000,000	400,000,000[a]
Years of operation:	15	20	20	20
Linear depreciation $/yr:	66,666,667	60,000,000	30,000,000	
Yearly production (tonnes crude ore):	1,300,000	2,000,000	450,000[1]	3,000,000
CAPEX per tonne crude ore($):	51	30	37	7
OPEX Cost excluding processing $/tonne crude ore:				60
OPEX Cost including processing $/tonne crude ore:	70–100	85–300	95–310	
Revenue (excluding manganese) $/tonne crude ore:	718	306	216	
Total OPEX per project	3,315,000,000	7,000,000,000	3,200,000,000	3,600,000,000
Total Revenues per project	14,001,000,000	12,240,000,000	3,456,000,000	7,500,000,000
Net profit per project	9,686,000,000	4,040,000,000	–344,000,000	3,500,000,000[b]
IRR % (excluding manganese)	68	2	no positive cash flow over period	23.6
IRR % (including manganese)		109	46	

[a]Estimated for total project.
[b]at $125/tonne.

3.5.1.3 LCA of gas hydrates

According to current estimates, global hydrate deposits contain about 10 times more methane gas than conventional natural gas deposits. There is a strong urge to make the exploitation of gas hydrates viable. In particular, highly developed countries without their own sources of energy are investing in this sector. The technology needs to be developed since it is a whole new substance type for exploitation. There are some doubts whether it can be exploited in a profitable approach. It remains to be seen whether hydrate extraction at great depths is economically viable at all.

Continuing on the specific stages in the value chain (Figure 3.10):

3.5.2 Resource Assessment

During the last decade, stage 1 has been developed up to a reasonable level to proceed with the actual exploitation phase. In stage 2 Planning, deep-sea geotechnical site investigation and evaluation methods and procedures for pit design, including slopes and ground conditions as well as for predicting extraction efficiencies are the subject of current R&D projects[23]. However, the extraction methodology still needs to be validated in lab and real environments. Since offshore and onshore logistics are already well developed, the critical stage in the value chain from a technology perspective is stage 3. It will be considered here.

3.5.3 Extraction

No commercial offshore mining operations have taken place yet, and especially the extraction techniques required on the seabed are not operational yet (Ecorys, 2014, SPC, 2016). The technology to be used depends mainly on the type of deposit. The extraction process for deep-sea minerals starts with the excavation. For nodules the proposed technique for excavation is by making use of collectors, while for SMS deposits crusts cutters are being developed. Some processing may also take place on the seabed. The TRL for proposed extraction technologies is scored low, ranging from TRL2 (formulated concept) to TRL 5 (technology validated in relevant environment). Hence, more development should take place before exploitation from the deep-sea bed can take place. In the summer 2017, GSR[5] will test a nodule harvesting tool for the first time in the Area, showing great improvements in the design and

[23] See for instance the Blue Mining project www.bluemining.eu; or the Blue Nodules project www.blue-nodules.euor MIDAS: www.eu-midas.net (d.d. 13-07-2017).

preparation of a future exploitation project. Nautilus will also be undertaking submerged trials in PNG[24].

The availability of the operational gear is a crucial aspect (SPC, 2016). At the time of writing, the most advanced (and applied) technique to raise crude ore from the seabed appears to be the technique as developed by the diamond industry to recover eroded diamonds, deposited on the (nearshore) ocean floor by land runoff and fluvial systems. The maximum reported commercial and full-scale operative removal depth reported so far is limited to – 140 m (ROVs and scraping & vertical lifting[2]). This basic technology – as developed for this given mining environment – may amongst others also be applicable to the environments under consideration in the present chapter, although we are here dealing with depths ranging from a few hundred meters for seamount crusts down to –4000 m for nodules. In addition, for the phosphorite concessions of Don Diego and Chatham Rise, an adapted TSHD with trailing technique will most likely be developed to remove ores till depths of –450 m[3]. Cutters need to be tested and optimised for SMS deposits and crusts.

3.5.4 Vertical Lifting

Vertical lifting is another critical part of the mining process. Air lift systems and especially hydraulic systems seem most applicable for use in deep sea mining operations. However, TRL levels for proposed lifting systems is at 5 at the highest, and therefore further development is required. Both require high power input and are so far sensitive to unstable flows, which again given the depths at stake is one of the most critical aspects from a technological and technical point of view. Possibly, techniques being used in the offshore oil and gas sector (transport of drill cuttings and mud) could be adjusted for use in ore transport. For nodules the ROVs or AUVs seem the most promising technique. These have to be tested for operation at depth of 6000 m (real operating environment).

3.5.5 On Board Processing

Once raw material is transported to the surface, a working platform is required for further handling. Support vessels or platforms are proposed

[24] See http://www.tijd.be/nieuws/archief/Knollen-rapen-op-de-zeebodem/9854214?ckc=1&ts=1491349056 and http://www.nautilusminerals.com/irm/PDF/1893_0/NautilusMineralsSeafloorProductionToolsarriveinPapuaNewGuinea (d.d. 13-07-2017).

as dispatching system, storage facility, dewatering and on-board processing facility. Simple dewatering systems can easily be applied on board of vessels and platforms, but further processing on board like concentrating ore and application of metallurgical processing requires further development. Fixed platforms offer better opportunities for processing than ships because comminution, the grinding to smaller particles, is performed by large and heavy equipment.

For efficient use of ships and equipment, use of a platform in a central place with respect to the mining locations should be envisaged. Platforms are very stable, and instability issues like on ships are not important. The technology for such platforms in deep sea is well established in the oil-industry. In addition one can think of floating platforms, as well as of the installation of renewable energy structures in order to reduce the energy costs and carbon footprint.

A central platform located nearby the mining site or halfway to port, and where most of the processing would be carried out, could be more efficient than carrying-out processing on the ship. The ship could transport the retrieved minerals to the platform rather than sailing all the way to port every time, which is particularly relevant in remote cases like the high seas and the Area. Processing of the ore can proceed on the platform and concentrates can then be shipped to on-shore locations (Ecorys, 2014, SPC, 2016).

3.5.6 Final Processing

Due to the large quantities of ore, and – in some cases – complex chemical process involved, the final processing will most likely take place on-shore in dedicated facilities. In general two techniques have been tested: hydrometallurgy, where the metals are separated with acids (hydrochloric or sulphuric) or basic reagents (ammonia), and smelting. Some ores, especially manganese and cobalt (to a lesser extent) still pose problems and require extensive energy input or use of aggressive chemicals (by methods still in optimisation phase, SPC, 2016).

However, most developments that are currently taking place focus on adapting available techniques to deep-sea environments rather than developing novel techniques and processes specifically suitable for deep-sea deployment. It seems therefore that higher operating expenses (OPEX) are accepted to avoid higher capital expenditures (CAPEX), e.g. for lifting (Schulte, 2012[3]).

3.6 Business Economics and Investment

From a commercial perspective, seabed mining is a small sector, with only few active companies. This section reviews available information on the economic performance of seabed mining, addresses the current status of investment and identifies key concerns among investors.

3.6.1 Economic Climate for Offshore Mining

Land-based mining was developed over a long period of time. Starting with small-scale mining of easily accessible deposits, this sector is gradually increasing in size of operations and targeted less accessible depots. As a consequence, knowledge and investments increased gradually. This development pathway is not foreseen for seabed mining where – particularly for resources at depths exceeding 200 metres – investors need to be fully committed with high initial CAPX costs (near $1,000 million starting, Clark et al., 2013, Rozemeijer et al., 2015, Table 3.4).

Despite of the availability of a lot of documents on the subject, it is hard to dig into the details of the costs involved in offshore mining in order to pinpoint a target for innovation on the basis of CAPEX or OPEX. This is due to the lack of uniformity in the data provided by different authors concerning CAPEX and OPEX. When considering the cost and revenues it is important to remain cognizant of the fact that all costs are based on technology that has been piloted but not proven at the commercial level of operation. Cost estimates are highly uncertain and may change significantly depending on the mining technology that is in place at the time of full-scale commercial operation.

From the assessments described below, the following general picture emerges. Phosphorites exploitation can be profitable at this time. Offshore mining of SMS deposits seem economically profitable, when enough resources can be found clustered to support 15 years of continuous operations. Nodules revenue estimates are subject to serious debate and exploitation of crusts is far from profitable. Gas hydrates are even further from actual exploitation (see Table 3.4).

3.6.1.1 Market price for key resources

It is interesting to study long-term trends of metal prices as the fluctuation in price correlates to the interest in offshore mining. The first wave of offshore mining development took place in the 1970s when resource prices where high

(Figure 3.1, Section 3.2). Likewise, interest in the first decade of the 21st century can be related to high resource prices.

In the mid-2000s, prices for these metals rapidly increased, but then started to decline around the year 2010 (Figure 3.1). Current prices are somewhere in between pre-2000 prices and the highest recorded prices[25].

3.6.1.2 Costs and revenues of SMS deposit mining

SMS deposit mining requires a very high initial investment to start the operations. Initial investments (CAPEX) are estimated at around \$300M–400M for a typical seafloor SMS deposits operation (Birney et al., 2006; Yamazaki, 2008). However based on actual costs developments for the Nautilus Solwara 1 operation, actual CAPEX is likely to be much higher. In practice total CAPEX, including exploration costs, is estimated to be closer to \$1,000M (Table 3.4; Ecorys, 2014; EPRS, 2015). The OPEX of seabed mining, including transport to shore, are estimated to be between \$70–140/tonne crude ore based on the above sources. Necessary processing costs increase total OPEX to \$150–260/tonne crude ore.

Boschen et al. (2013), backed by the studies of Ecorys (2014) and SPC (2016), estimated that SMS deposits will be profitable due to the high content in currently highly priced copper, gold and silver (with copper contributing the most ∼2/3). In addition REEs and other metals will contribute also to the revenues. The Ecorys study calculated a potential internal rate of return (IRR) of 68% of total investment. Total revenues are \$14,001,000,000 and net profit \$9,686,000,000 (Table 3.4).

However, there is considerable uncertainty regarding SMS deposits as it is assumed that an operation of 15 years is needed to generate returns on investment, whereas most resources and proven reserves seem to point to smaller sizes, and a strain of operations on different locations needs to be established. The Solwara1 project seems to have only a limited amount of deposits (2 years) (SRK Consulting, 2010; Ecorys, 2014; EPRS, 2015; SPC, 2016). In addition, when comparing all different sources, different values for CAPEX and OPEX are encountered every time (Rozemeijer et al., 2015).

3.6.1.3 Costs and revenues of nodule mining

Nodules mining is expected to be more capital intensive than SMS deposit mining due to the larger depths and more widespread distribution over the seafloor. An initial estimated CAPEX of \$1,200M seems realistic to start

[25] www.infomine.com (d.d. 13-07-2017).

operations (Yamazaki, 2008, Clark et al., 2013). A more detailed estimate– as described in EPRS' study (2015) indicates a CAPEX cost of almost $1,800M. Still according to ERPS, almost half of these capital investments come from investments in a processing facility. Estimates of nodule mining OPEX range between $85-500/tonne, of which costs related to processing form an important component.

Considering copper, cobalt and nickel, Ecorys' study estimated the IRR at 2% (Table 3.4) with nickel being the main contributor ($\sim$1/2). Manganese was excluded from their calculations. Including manganese IRR increases to 102%. For manganese no efficient extraction method is yet available. The manganese residuals could of course be stored till further developments enable costs effective isolation (SPC, 2016). The conclusion of Ecorys (2014) is not consistent with other sources that consider nodules as the most attractive deposits economically (EPRS, 2015). According to SPC (2016), nodules were profitable only in 60% of various scenarios with different CAPEX, OPEX and revenues. Clark et al. (2013) give an IRR range of 6–38%. Note that Martino & Parson (2012) propose that a lower IRR of 15–20% could be advocated since seabed mining is less risky than onshore mining (IRR $>$ 30%).

Rozemeijer et al. (2015) calculated based on different scenarios with copper, cobalt and nickel prices of 2015 and were not able to show profitable exploitation. The assumptions taken on e.g. equipment efficiency and costs are very important in the calculations and vary highly between authors (Rozemeijer et al., 2015; SPC, 2016).

3.6.1.4 Costs and revenues of cobalt crust mining

Only the costs and revenues of a single cobalt crust source have been assessed. Yamazaki (2008) has estimated the CAPEX and OPEX of cobalt crusts based on nodule mining. CAPEX is expected to be some 50% of nodule mining and OPEX stand at 45%. However, assumed production volumes (dry) in these estimate for cobalt crusts stands at some 40% of manganese nodules which makes the CAPEX and OPEX per tonne some 25% resp. 12.5% higher than for manganese nodules. Based on calculations by Ecorys (2014), Rozemeijer et al. (2015) and SPC (2016), it is concluded that under current market prices, there is no viable business case for cobalt crusts mining.

3.6.1.5 Costs and revenues of phosphorites

Namibian Marine Phosphate (NMP) estimates the further CAPEX for a whole project on phosphorite mining will amount to approximately $326M.

In addition, \$50 million OPEX will be spent on the project. The mining licence of NMP has been granted for an initial period of 20 years. Approximately 3 million tonnes of dry product for export are expected to be processed starting from year three, at a price of \$125 per tonne (Table 3.4). This is approximately \$7–7.5 billion for 20 years. It is claimed to be very profitable. The IRR for Namibian Marine Phosphate project Sandpiper is estimated at 24%[7].

Leviev's private company LL Namibia Phosphate (LLNP) plans investing \$800 million in building a mining facility to produce about two million tons annually from an estimated two billion tons at a depth of 300 meters. At a selling price of an estimated \$125/tonne, the revenues are about \$250M a year. Chatham Rock Phosphate expects yearly revenues of \$280M and a yearly profit of \$60M (Schilling et al., 2013).

3.6.1.6 Concerns and uncertainty about economic viability

Doubts can be raised on the economic viability of offshore mining of metal ores. Ecorys (2014) examined the estimated CAPEX, OPEX and market price for metals of seabed mining and concluded that SMS deposits are likely to have the highest commercial viability (to be treated with caution as no actual operations have taken place yet). This is due to the fact that in SMS deposits, copper can be extracted in large amounts from these resources at a moderate market costs. Furthermore, it is possible to extract gold from these reserves (Boschen et al., 2013).

In the calculations presented above, exploitation of nodules and crusts is not commercially feasible. This finding is not consistent with the answers given by some interviewees (EPRS, 2015), who mentioned nodules as the most attractive deposits commercially. This can be due to the fact that mining companies assume an operation of 15 years (20 years for nodules and cobalt crusts) to generate returns on investment, while key uncertainties exist in case of SMS deposits about the resources and reserves which seem to point to smaller sizes (SRK Consulting, 2010; Ecorys 2014). This has been confirmed by the industry stakeholders, mentioning that it is challenging to find and extract SMS deposits as they are more difficult to spot and are relatively small, while the operations are usually calculated with a proven resource for 20 years.

3.6.2 Government Support

Government support for development and commercialisation of offshore mining can take different forms. In a basic form, governments can be catalysts via their membership of the ISA, enabling their national companies to obtain exploration and exploitation contracts with the ISA.

Funding can also stimulate innovation. Offshore mining could use a boost in order to exploit at less energy costs (cheaper) and with less environmental impact, making it economically viable. To this end, national and EU publicly funded research projects related to offshore mining and offshore exploration technologies are carried out. Research is often supported by engineering firms and technology providers, which themselves work closely together with research institutes and universities. Three important EU projects aiming at deep-sea resource extraction are Blue Mining and MIDAS[23]. Blue Mining explores the needs for developing the technologies required for nodule and SMS mining, while MIDAS focuses on environmental impacts from deep-sea activities. Other research efforts are linked with seabed mining, but have a wider scope.

An important programme is the European Innovation Partnerships (EIP). The EIP aims to reduce the possibility that a shortage of raw materials may undermine the EU industry's capacity to produce strategic products for EU society. The EIP on Raw Materials is not a new funding instrument. It aims to bring stakeholders together to exchange ideas, create and join partnerships in projects that produce concrete deliverables. In 2014, 80 commitments were recognized as 'Raw Material Commitments', out of which, six are related to seabed mining (Ecorys, 2014).

3.6.3 Status of Investment in Seabed Mining

The recent history of deep-sea mining is not a story of great commercial success. A number of companies have succeeded in getting listed on various stock markets, including well-known companies such as Nautilus Minerals (Toronto Stock Exchange), Neptune Minerals, Chatham Rock Phosphate (New Zealand) and Odyssey Marine Exploration. However, where common stock-market indexes have risen considerably in the last years, the stock-market value of these companies has dropped sharply between 2013–2015 and is consistently low since then. Traded volumes are also low (see Figure 3.11).

Research on identification of investors in seabed mining, and their interests – carried out under the EU Maribe-project and reported in van den Burg et al. (2017), is illustrative of the low interest of investors in seabed mining.

The inventory of investors active in the various Blue Growth and Blue Economy sectors (van den Burg et al., 2017) identifies 31 investors in seabed

Figure 3.11 Stock market price of Nautilus, listed on Toronto stock exchange https://www.bloomberg.com/quote/NUS:CN (06022017).

mining (out of 244 total investors). The majority of these investors are so-called internal investors; these are companies that invest in R&D in seabed mining, as this can be a future market for their products or services. Examples include shipbuilding companies (Damen, Royal IHC), generic maritime service companies (Kongsberg Maritime, Heerema) and dredging companies (such as Boskalis). Notably absent are private equity investors, business angels and banks. These investors are generally from the UK, USA or the Netherlands, with a few exceptions.

In a survey, investors were asked how important the different Blue Growth sectors are for them (see van den Burg et al., 2017). Seabed mining scores considerable lower than the other sectors, with an average score of only 1.82 (1 = not important, 4 = highly important), see Figure 3.12.

3.6.4 Factors Hampering Further Investment

Research into investor behaviour (see van den Burg et al., 2017) pointed out some of the main concerns of investors. The top 5 risks that stand in the

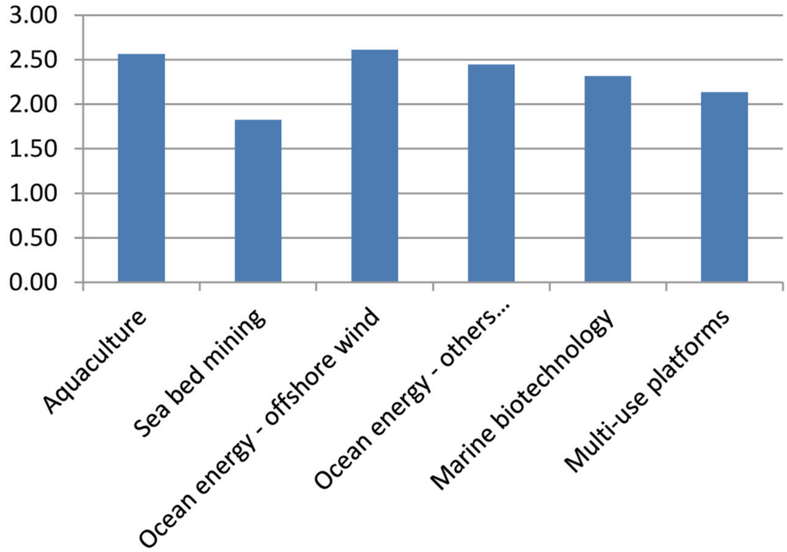

Figure 3.12 Importance of various Blue Growth sectors (from van den Burg et al., 2017).

way of investment in seabed mining are discussed from a seabed mining perspective below.

3.6.4.1 Operational risks

Technologies for seabed mining are under development but in the absence of large-scale mining activities, this remains experimental development. While surveys of deep-sea resources have a long history, the actual mining of these resources has hardly been done before. Uncertainty about the technology to deploy, the risk and associated costs impede investment.

3.6.4.2 Financial risks

Low interest of investors is inextricably linked to doubts about the financial performance of the sector. In Figure 3.1 it was shown that prices of the resources fluctuate significantly over time. In the period 2000–2010, prices for natural resources peaked, increasing interest in the exploitation of deep-sea resources. As mentioned before, copper, gold and silver are the main metals of interest for SMS deposits, cobalt, and nickel (and copper to a very limited extend) for nodules. Crusts seem too costly at this moment. Apart from the overall uncertainty within the assumptions, a specific uncertainty exists regarding potential revenue streams for manganese (Section 3.5.6).

This directly points to the importance of further efficiency increases in mining itself and in processing as well.

3.6.4.3 Regulatory risk

The recent history of seabed mining shows that the risk of (sudden) withdrawal of governmental support is real. This also includes permitting. Chatham Rock Phosphate lost 92% of its stock value in one trading day when it was refused consent to mine from the Chatham rise in 2015. With continued pressure from NGO's and other interest groups to halt further development – also witnessed e.g. in Papua New Guinea – regulatory risks are a key obstacle to investment in seabed mining (Baker et al., 2017, Sharma 2017[3]).

3.6.4.4 Environmental issues

Given the attention the offshore mining industry receives from stakeholders, none of the companies would be willing to add risks to their investment by developing environmentally harming techniques. Before licenses are issued, environmental impact assessments need to be approved, including the techniques and mitigating actions concerning the environment. Therefore, it can be expected that the technologies being developed at the moment are technologies that will mitigate environmental impacts as much as possible. Acting in an environmentally friendly way is a prerequisite for economically attractive operations, as the risk of refusal, suspension or withdrawal of permits is too high. However, standards and protocols for environmentally friendly seabed mining are still under development (sees Section 3.4).

3.6.4.5 Product market risk

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

3.7 Concluding Remarks

Offshore mining is seen as one of the Blue Growth sectors, with a potential contribution to growing the (European) economies. This promise stems from an idea of vast natural resources, available for human exploitation, that are in great demand. The reality is however less bright and shiny. There are not only technological challenges to offshore mining; it is also trapped in a vicious circle of uncertain operations, the need for high capital investments and fluctuating prices for the resources. The target resources for offshore mining are very scarce in the European basins. On a global level, the European sector is of importance though, since the EU has some major operators.

A closer look at the sectors reveals the differences in status and potential. From an economic perspective, the polyphosphate sector is closest to commercial take off, with high enough and stable prices for the products. Offshore mining of metals is less promising, given low resource prices and enormous costs for exploration. Also, the urgency for exploration of new resources has decreased in recent years. Gas methane mining is in the early stages of development and development of this sector is inextricably linked to the development of global energy market. The gas hydrates initiatives are typically lead by governments. These subsectors seems driven by governmental interests for control of strategic ore reserves. The polyphosphate sector seems ready to take the next step in exploitation, licensing and actual exploitation. However, its operations are now hampered by discussions and uncertanties on environmental impact and on impacts on other economic sector activities like fisheries and vulnerable areas like seamounts.

A new balance between sectors with at times conflicting interests has to be found. Governments and international policy makers (such as ISA) will need to develop protocols, guidelines and legislation to settle re-occurring debates. But this is not only a governmental responsibility. In an era of social corporate responsibility and social licences to produce, the nearshore and offshore mining sector needs to justify why marine resources need to be explored and bears responsibility for mitigation of social and environmental impacts.

3.7.1 Moving Forward

Ore prices are the major incentive for market-driven development. When especially nickel and cobalt prices will rise structurally, offshore mining on nodules can be achievable. Further development of the technologies used for mining can strengthen the sector (Figure 3.10, exploration, collecting, lifting, on board handling, on land extraction of ores).

Market driven technological development is hampered by the large uncertainties and ample availability of land-based ores and recycling. Today, most of the exploitation of offshore metal and gas resources is in the hands of governmental related companies. Some private enterprises can be found as well for high grade concessions and for commercially exploitable phosphorites. In view of high investment, technological challenges and economic considerations, private-public cooperation could be an effective means to make offshore mining a success. The EU and individual governments can step in here and stimulate the technological and governmental innovations to achieve lower CAPEX and OPEX and at the same time lower environmental impacts in the sensitive nearshore and offshore seabed and associated systems.

Further support for the development of offshore mining can also be driven by the desire to be front-runner in technological development. Extracting some deposits now, getting acquainted with offshore mining in practice, helps to develop techniques and earn a reputation in this uncertain field. It can be of strategic importance to create a first-move advantage, useful when conditions change and offshore mining becomes profitable.

3.7.1.1 Some considerations

Among the reasons for exploring offshore metal extraction, a potential shortage of natural resources is often mentioned, due to geopolitical reasons or limited availability on land. Resource prices are prone to speculation and not a good indicator for worldwide availability. Various researchers have pointed at the real danger that resources will be scarce in the future, for example for phosphate (Gilbert, 2009), and highlighted different national strategies to deal with future resource scarcity (Bartekova & Kemp, 2016). On the other hand our analysis suggests the contrary, that there are ample land-based stocks of economically minable deposits today for at least 30 years and large stocks which one can expect to become economically minable deposits in due time (Figure 3.3, Table 3.1, see also USGS, 2017). NB; an important intriguing aspect is that reserves (economically mineable amounts) appear constant in amount over time (Arndt et al., 2017). Probably due to reasons of financing prospecting and research, the market gives little consideration to a reserve life sufficient to supply more than 20 to 40 years of present consumption (Arndt et al., 2017). On the other hand there is also the unresolved debate of the differences in impacts of land-based mining vs seabed mining, where land-based impacts are estimated to be substantial. Having at least 30 years of reserves and an immense amount of resources (Figure 3.3, Arndt et al., 2017, USGS, 2017) implies that there is no direct urgency for offshore mining. On the other hand, given the fact that some exploration licenses are ending, bodies like ISA should make steady progress to install the necessary regulations and additional preparations in order to enable seabed mining. Regarding nodules, there appears to be a momentum given a recent workshop[16] despite doubts on profitability.

To add to the discussion, Hannington et al. (2017) pointed out to large ore reserves of all sorts nearshore. Those nearshore reserves could also provide the necessary ores at lesser costs. Considering the fierce environmental discussions about nearshore phosphorites, similar environmental discussions can be anticipated.

Given the fluctuating market prices, technical risk and uncertain environmental impact, private entrepreneurs and companies can be expected to be hesitant to invest significantly. A coherent and stable European policy to support offshore mining can benefit society and the sector. Anticipating now a future need for offshore mining could help in geopolitical stabilisation, be a technological pull for knowledge developments and incentivize European exploiters to further develop technologies for offshore mining.

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