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Report on policy options and associated valuation and appraisal needs and methods

Deliverable 9.5

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¹ Median Sustainability S.L.

30 September 2016
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<tr>
<td>5EAP</td>
<td>European Union 5th Environment Action Programme</td>
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<td>7EAP</td>
<td>European Union 7th Environment Action Programme</td>
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<tr>
<td>ABNJ</td>
<td>Areas beyond national jurisdiction</td>
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<td>APEI</td>
<td>Areas of Particular Environmental Interest</td>
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<td>BAT</td>
<td>Best available technology</td>
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<tr>
<td>BBNJ</td>
<td>United Nations Ad Hoc Open-ended Informal Working Group to study issues relating to the conservation and sustainable use of marine biological diversity beyond areas of national jurisdiction</td>
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<td>BEP</td>
<td>Best environmental practices</td>
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<td>CBA</td>
<td>Cost-Benefit Analysis</td>
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<td>CBD</td>
<td>Convention on Biological Diversity</td>
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<td>CCZ</td>
<td>Clarion-Clipperton Zone</td>
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<td>CNC</td>
<td>Critical natural capital</td>
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<td>COP</td>
<td>Conference of the Parties</td>
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<td>CWC</td>
<td>Cold Water Coral</td>
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<td>DSM</td>
<td>Deep Sea Mining</td>
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<td>EC</td>
<td>European Community</td>
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<td>EIA</td>
<td>Economic impact Assessment</td>
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<td>Environmental impact assessment</td>
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<td>EMP</td>
<td>Environmental management plan</td>
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<td>EMP-CCZ</td>
<td>Environmental Management Plan for the Clarion-Clipperton Zone</td>
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<td>EU</td>
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<td>GVA</td>
<td>gross value added</td>
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<td>IO</td>
<td>Input-Output</td>
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<td>International Tribunal for the Law of the Sea</td>
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<td>LDCs</td>
<td>Least Developed Countries</td>
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<td>Legal and Technical Commission</td>
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<td>Managing Impacts of Deep-sea Resource exploitation (research project)</td>
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<td>MCA</td>
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<td>MPA</td>
<td>Marine protected area SEA Strategic environmental assessment</td>
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<td>NIMBY</td>
<td>‘Not In My Backyard’</td>
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<tr>
<td>NNL</td>
<td>No Net Loss</td>
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<td>NPV</td>
<td>Net Present Value</td>
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<td>PNG</td>
<td>Papua New Guinea</td>
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<td>PP</td>
<td>Precautionary Principle</td>
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<td>PPP</td>
<td>Polluter Pays principle</td>
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<td>PSV</td>
<td>Production Support Vessel</td>
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<td>RALS</td>
<td>Riser and Lifting System</td>
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<td>Real Option Analysis</td>
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<td>SEMP</td>
<td>Strategic environmental management plan</td>
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<td>Sustainable development Goals</td>
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<td>Seafloor-massive Sulphide</td>
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<td>TEV</td>
<td>Total Economic Value</td>
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<td>WTA</td>
<td>Willingness to Accept Compensation</td>
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<td>WTP</td>
<td>Willingness to Pay</td>
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Executive Summary

Deep Sea Mining (DSM) offers a potentially rich source of key minerals. Some deposits lie beneath national waters and are sovereign resources. Many others lie in the Area Beyond National Jurisdiction (ABNJ, ‘the Area’) and access to these resources is regulated by the International Seabed Authority (ISA) under the United Nations Convention on the Law of the Sea (UNCLOS).

Although commercial exploitation has not yet started, there is potential for these deposits to be highly profitable. If shared equitably, the proceeds could fuel social and economic benefits and meet strategic needs for secure supplies. Deep sea deposits are generally richer in mineral content than terrestrial sources, and are on or near the seabed surface, and so can be accessed with creation of much less spoil than terrestrial mines. Together with their location far from human populations, this might make DSM environmentally preferable to terrestrial mining.

On the other hand, DSM activity would inevitably impact on deep sea ecosystems with effects that are highly uncertain and may be long term or irreversible. At the same time, the economic and social impacts of DSM could be highly variable depending on the mechanisms put in place to regulate and tax the activities. Hence, national governments and the ISA face difficult choices regarding the appropriate development and regulation of DSM. The decisions to be taken include broad-scale/strategic decisions about the global approach to licensing exploration, standards and protocols for seeking operational permits, research and monitoring requirements, and benefit sharing. They also include more localised/tactical decisions about specific resource deposits and applications to exploit them.

To make good decisions, it is important to understand the potential economic, social, and environmental impacts, benefits and costs of DSM. This also requires a broad strategic view of DSM and its potential role in achieving sustainable development, meaning that DSM should not be considered in isolation, but as a part of a world economic system that includes terrestrial mining and other alternatives to mining such as recycling and resource substitution. We also need to recognise the full range of values arising from the deep sea, including roles in vital biogeochemical cycles, conservation values, and the potentially huge values of knowledge about deep sea systems and organisms. Finally, we must also understand the different motivations and incentives faced by different actors in DSM and related areas, and recognise the need for policy structures to ensure that private decisions are consistent with socially desirable outcomes. Hence, this report aims to contribute to the debate around the following questions:

1. What are the guiding principles and objectives that should govern the activities and decisions of the ISA and, by extension, other regulatory bodies and actors in DSM?

2. What is the appropriate role of decision support tools in informing these decisions, given the present state of knowledge?

3. Who are the stakeholders with an interest in issues associated with resource supply and DSM, how should they be consulted and involved in the decision processes, and how should conflicts be resolved?

4. What are the policy conclusions following from the answers to the above?
We first consider the drivers for DSM, the stakeholders and their motivations, and the economic, social and environmental impacts. One of the important features of the impacts is that, at present, they are very poorly studied and highly uncertain.

This carries forwards to considering the appraisal and valuation methods available for decision support purposes, and critique existing attempts at applying these. Decision support tools such as economic impact assessment (EcIA), (strategic) environmental impact assessment (EIA), financial/cashflow appraisal, and cost-benefit analysis (CBA) including environmental valuation are widely used in investment and resource management decision making. They are also being applied to DSM. However, the current lack of knowledge of deep sea systems, the substantial uncertainties about the impacts of DSM (especially environmental) and the potential for improbable but nevertheless possible extreme or irreversible damages, render these tools very unreliable as guides to socially desirable decisions. We are in a situation of making decisions under strong uncertainty about the possible consequences.

In the light of this, we then assess the principles of good governance as they apply to decisions relating to DSM. Some of these principles are already present in the DSM governance framework, in particular through the recognition of the need to apply a Precautionary approach, the declaration that the seabed beyond national jurisdiction and its mineral resources are the ‘Common Heritage of Mankind’ (CHM), or the requirement that ISA be responsible for managing DSM activities in the Area “for the benefit of mankind as a whole”. There are also duties under UNCLOS to protect and preserve the marine environment and to conserve and sustainably use marine biodiversity. Legitimacy also requires consultation over the trade-offs and uncertainties involved in resource management. National governments do not fall under a CHM requirement, but have responsibility to act in the interest of their citizens now and in the future. Under UNCLOS, national laws and regulations for mining activities within national jurisdiction are to be “no less effective than” the international rules, standards, and recommended practices and procedures. Hence the regulatory structures that the ISA is putting in place, following the principles, will have far-reaching implications.

In the final section, we draw conclusions regarding the developing governance and policy regimes for DSM. Throughout, our focus is on broad, societal-level debates regarding fundamental strategic choices about DSM (rather than on more tactical issues about appraisal of specific individual projects). This is in turn driven by the important choices facing the ISA in the development of a global governance regime for activities in the Area, but with conclusions that can also inform sovereign decision making regarding resources on territorial seabeds. Combining what we know about the incentives faced by actors, about the environmental, social and economic impacts of DSM, and about the principles that should guide decisions, leads to recognition that the fundamental issue is not only about whether or not to engage in DSM, but also about when, where and how this should take place. Since the environmental damages of DSM are both highly uncertain and in part irreversible, sensible decisions following the precautionary and CHM principles will need to involve a gradual and experimental approach to DSM, including maximum monitoring and learning, such that uncertainties may be reduced and decisions improved over time. The ISA has a clear role in pushing a strategic approach both to enhancing the learning from DSM exploration and eventual exploitation, and to ensuring the wide dissemination of the knowledge which itself can be seen as a manifestation of the CHM.
1. Introduction

Deep seas are generally defined as water and seafloor areas below 200m. Deep Sea Mining (DSM) is the extraction of metal resources from the deep sea bed. There are several different potential sorts of DSM from areas with very different characteristics (Figure 1), though all versions currently under discussion share some common features:

- targeting resources that are readily available on the sea bed;
- generally in richer concentrations than are available in current terrestrial mines;
- using advanced and costly technology to overcome the serious technical challenges of extracting ores at great depth and transporting them to the surface;
- taking place in deep sea ecosystems that are poorly studied and understood

This means that DSM offers a rich source of minerals that can potentially be accessed with creation of much less spoil than terrestrial mines. On the other hand, DSM activity would inevitably impact on deep sea ecosystems with effects that are highly uncertain and may be long term or irreversible. At the same time, the economic and social impacts of DSM could be highly variable depending on the mechanisms put in place to regulate and tax the activities. Hence, societies face difficult choices regarding the appropriate development and regulation of DSM.

These choices need not all be made immediately: DSM has been ‘on-hold’ due to several factors, including current availability of metals from terrestrial sources and their fluctuating prices (Sharma 2011), as well as technological and governance issues. However, progress continues and DSM remains “a rapidly emerging frontier activity both in marine areas under national jurisdiction and beyond national jurisdiction.” (Lodge, 2015). Difficult decisions will have to be made, and probably sooner rather than later, because commercial pressures within the deep sea mining/technology industry, sustainable development concerns for resource owning states, and broader strategic and economic interests at a global scale, all represent drivers for pushing forwards with DSM. Especially given the substantial uncertainties surrounding the environmental, but also the social and economic, impacts of DSM, it is therefore important that we consider now what these choices are, what policy options we have for implementing them, and what methods we have for evaluating and informing choices through appraisal and valuation of the impacts, in order that we can best make appropriate choices in the near future.

Box 1: The “known unknowns”: risks of mismanaging long-term, uncertain impacts on natural resources

“A ‘Public Domain’, once a velvet carpet of rich buffalo-grass and grama, now an illimitable waste of rattlesnake-bush and tumbleweed, too impoverished to be accepted as a gift by the states within which it lies. Why? Because the ecology of this Southwest happened to be set on a hair trigger.”

1.1 Current state of DSM

Unlike widespread and familiar marine oil and gas production, Deep Sea Mining has not yet taken place on a commercial basis, though there are advanced plans in some areas. It has seemed for some years that mining is imminent, in particular for Seafloor Massive Sulphide (SMS) deposits in the territorial waters of Papua New Guinea (PNG) where Nautilus Minerals (http://www.nautilusminerals.com/) has been engaged in exploration for the past decade, with a view to commercial extraction of copper and gold from the SMS deposits. Nautilus was granted its first Mining Lease in January 2011 for Solwara 1, and the Environmental Permit for Solwara 1 was awarded in December 2009. However the company has faced financial difficulties. As of 22 August 2016, Nautilus announced bridge financing and a radical restructuring, stating that: “If the additional required funding is secured by June 2017 and subject to ongoing detailed planning, the Company could be in a position to commence the initial deployment and testing operations at the Solwara 1 Project by the end of Q1 2019”. The work required includes “activities necessary to maintain the good standing of the Mining Lease and Environmental Permit for the Solwara 1 Project”, in particular completion of Environmental Management and Monitoring Plans and community projects in regions of PNG closest to the Project area, to be carried out together with Nautilus’s joint venture partner, “the Independent State of Papua New Guinea’s nominee”.

The proposals have been contentious and are resisted by, for example, the Deep Sea Mining Campaign (http://www.deepseaminingoutofourdepth.org/), a project of the Ocean Foundation (www.oceanfdn.org) and “an association of NGOs and citizens from the Pacific Islands, Australia and Canada concerned about the likely impacts of DSM on marine and coastal ecosystems and communities” and the “Alliance of Solwara Warriors” which “is made up of communities in the Bismarck and Solomon Seas”. The former seeks “to develop an active, broad-based and informed Civil Society response to Deep Sea Mining in the Pacific region” while the latter “seeks a ban on seabed mining in PNG and the Pacific”.

Elsewhere, mining is less imminent, but could commence over the next decade or so. In the Clarion-Clipperton Zone, for example, there is a vast area of abyssal plains with polymetallic nodules, for which there are multiple exploration licenses. Along with the exploration licenses there is a matching
area of “reserved areas” of supposed equivalent commercial interest, set aside for activities of the International Seabed Authority (ISA) or developing States. There is an environmental management plan proposed by the ISA Legal and Technical Commission and first adopted by the ISA Council in July 2012, including areas designated of particular environmental interest (Figure 2).

The issue of whether and how – and when – to mine the deep seas is divisive because DSM will have impacts on all aspects of sustainable development: economic, social and environmental. This includes potential long-term and/or irreversible environmental impacts, about which there are substantial uncertainties and unknowns. There are also unresolved questions regarding sharing the benefits and costs of DSM, and, associated with these, the potential for resource rents to yield long-term social and economic advantages for resource-owning societies, or for long-term social and economic decay (see discussion of ‘resource curse’ and ‘Dutch disease’ below).

These issues could be partly addressed through further research to resolve uncertainties regarding impacts, and through development of robust environmental, social and economic policies to ensure appropriate exploration and exploitation of resources, and fair sharing of benefits. But, there are also opportunity costs associated with delays to DSM, including the potential damages associated with using other (non-DSM) sources of key resources, and/or economic impacts due to restricted resource supplies.
1.2 Governance of DSM

Matters are further complicated by the different governance regimes in place for the exploration and exploitation of the sea bed and its resources. Some likely areas for DSM lie beneath national waters and can be managed as sovereign resources. Many other areas are in the Area Beyond National Jurisdiction (ABNJ, “the Area”), as defined in the 1982 United Nations Convention on the Law of the Sea (UNCLOS). In a radical departure from the tradition of open access and freedom of the high seas, UNCLOS declared the seabed beyond national jurisdiction and its mineral resources as the ‘Common Heritage of Mankind’ (CHM). All mineral exploration and exploitation activities in the Area must be sponsored by a State Party to UNCLOS and approved by the International Seabed Authority (the Authority). The International Seabed Authority (ISA) can be thought of as "the institutional manifestation of the CHM principle" (Jaeckel et al 2016, p. 199). The ISA is responsible for managing DSM activities in the Area “for the benefit of mankind as a whole”, through developing licensing, regulatory and financial policies to ensure a range of outcomes, including environmental protection and equitable benefit sharing. In its 20 years of existence, the Authority has adopted regulations and guidance for exploration activities; in 2013 it began the development of regulations to govern the future exploitation of seabed minerals, starting with polymetallic nodules. The decisions made by the ISA will have wider relevance, however, since under UNCLOS (Article 2008) national laws and regulations for mining activities within national jurisdiction are to be “no less effective than” the international rules, standards, and recommended practices and procedures. Further details of the roles of UNCLOS and the ISA in DSM can be found in the MIDAS brief “The international legal framework for deep sea mining: a primer” 1, and the implications for governance, details of the ISA’s mandate and progress to date are explored further in section 0.

The decisions to be taken include broad-scale/strategic decisions about the global approach to licensing exploration, standards and protocols for seeking operational permits, research and monitoring requirements, and benefit sharing. They also include more localised/tactical decisions about specific resource deposits and applications to exploit them. To make good decisions, it is important to understand the potential economic, social, and environmental impacts, benefits and costs of DSM. To do this, we need information about:

- the geological/mineral resource availability
- mining technologies and costs
- the economies/societies impacted directly by mining activities and indirectly via regional/global resource markets
- the environmental and ecosystem impacts of mining activity and any potential for post-mining restoration
- the counterfactual scenario – what will happen if DSM is delayed or mothballed? This includes consideration of alternative sources of resources, and alternatives to using them

In many areas of economic activity, including primary industries such as terrestrial mining, fossil fuel extraction, forestry, agriculture, and fisheries, there is a long history of using various tools for decision support, including economic impact assessment (EcIA), environmental impact assessment (EIA), financial/cashflow appraisal, and cost-benefit analysis (CBA). Tools of environmental valuation are widely used to attempt to incorporate environmental impacts within CBA, though this can be highly contentious, in particular where impacts are uncertain and long-term, or involve damage to resources that are unique, pristine, or endowed with significant cultural resonance.

Decision support tools are not operated as independent calculations but are applied within the context of a set of broader governance principles that set down the goals of government/society and the

procedures and modus operandi that are considered legitimate and appropriate. In the case of the ISA, we have mentioned the CHM principle. Other principles endorsed by many states and enshrined in various legal structures and international agreements include the Precautionary Principle and the Polluter Pays Principle. Legitimacy also requires consultation over the trade-offs and uncertainties involved in resource management.

The key questions to be addressed, therefore, are:

5. What are the guiding principles and objectives that should govern the activities and decisions of the ISA and, by extension, other regulatory bodies and actors in DSM?
6. What is the appropriate role of decision support tools in informing these decisions, given the present state of knowledge?
7. Who are the stakeholders with an interest in issues associated with resource supply and DSM, how should they be consulted and involved in the decision processes, and how should conflicts be resolved?
8. What are the policy conclusions following from the answers to the above?

In seeking to resolve these questions, we need to recognise that there is great uncertainty and ignorance about the impacts, costs and benefits of DSM. This is partly because DSM is not yet operational anywhere in the world, the technologies are under development, deep-sea ecosystems are poorly understood, the short- and long-term environmental consequences of deep sea disturbances are largely unknown, and valuation research to quantify the implications for human societies has not been carried out. Hence, Pacific Communities (SPC) (2016) present “preliminary economic (cost-benefit) analysis” that is “based on realistic yet hypothetical mining scenarios”. But, as discussed below, quantitative analysis of this sort, relying as it does on heroic assumptions to deal with severe data gaps, may be neither meaningful nor appropriate as a prop for decision making.

We also need to recognise that both opinions and incentives are likely to vary greatly across stakeholders. To some extent, divergent views may reflect asymmetric information that could be addressed through greater discussion, or issues about benefit sharing that could potentially be resolved through negotiation, but there will also be more fundamental disagreements regarding the legitimate principles that should govern action and the appropriate trade-offs and compromises to make across alternative outcomes. Differing incentives, meanwhile, will drive a wedge between socially- and individually-optimal behaviours, and will require policy measures or negotiated agreements to resolve.

The remainder of this report seeks to address the four key questions set out above. In the following section, we consider the drivers for DSM, the stakeholders and their motivations, and the economic, social and environmental impacts. One of the important features of the impacts is that, at present, they are very poorly studied and highly uncertain. This carries forwards to section 3, where we consider the appraisal and valuation methods available for decision support purposes, and critique existing attempts at applying these. The significant uncertainties regarding impacts, and the potential for improbable but nevertheless possible extreme or irreversible damages, result in limits to the applicability of conventional appraisal methods. In the light of this, we then assess the principles of good governance as they apply to decisions relating to DSM, with a particular focus on the Precautionary Principle and the Common Heritage of Mankind. In the final section, we draw conclusions regarding the developing governance and policy regimes for DSM. Throughout, our focus is on broad, societal-level debates regarding fundamental strategic choices about DSM (rather than on more tactical issues about appraisal of specific individual projects). This is in turn driven by the important choices facing the ISA in the development of a global governance regime for activities in the Area, but with conclusions that can also inform sovereign decision making regarding resources on territorial seabeds.
2. Stakeholders, drivers, and impacts

Fundamentally, the choices about governance of DSM, and in particular CHM, requires weighing of different societal risks and benefits, which itself builds on value judgments. These include, for example, the relative values we place on increasing the supply of minerals now as opposed to preserving them for future generations, on preserving ecosystems versus growth and investment in man-made and human capital, and on the damages and risks from DSM and alternative sources of minerals. But at sub-global levels, for individual states and enterprises, the incentives and value judgements may be quite different, leading to a need for governance frameworks and policies to seek to ensure that private decisions do not deviate too far from socially desirable outcomes. Thus, the regulation and management of DSM needs to be grounded in an understanding of the drivers of and barriers to DSM, the economic, social and environmental impacts of DSM and its alternatives, and the incentives and behaviours of stakeholders. There is no natural ‘linear’ way to consider stakeholders, drivers and impacts – rather, the three are inextricably linked – so following sections and the possible overlaps in them need to be understood in this light.

2.1 Stakeholders, drivers and barriers for DSM

The stakeholders for DSM are many and varied. Most obviously, these include the resource owners and extracting businesses, and their employees and customers, and all the agencies and official bodies involved in managing resource extraction and associated health and safety and environmental risks. The owners may be sovereign states, giving the citizens of the state a stake in the way their non-renewable resources are managed. Or, for the resources of the Area, the resources belong to the Common Heritage of Mankind. In essence, the long timescales, high uncertainties, non-renewable nature of the resources, potentially irreversible and wide-reaching effects, and potentially important contributions of deep-sea minerals to economic growth and a ‘green’ economic transition, make stakeholders of all of us – future generations included.

Each of the stakeholders sees the pros and cons differently and is exposed to different potential costs and benefits, and therefore faces different drivers and motivations to action. Such asymmetric incentives are important because, depending on the precise definitions of Common Heritage of Mankind and the Precautionary Principle (see chapter 4 below), there will be more or less of a wedge between incentives for private business decision makers, investors, sectoral authorities, local and national governments, and international bodies. While the international bodies may have remits closely overlapping with a global, multigenerational interpretation of CHM and the PP, this may not match with the incentives of individuals and groups participating in the global bodies. Other actors will face more narrowly defined incentives, and in some cases strong asymmetries can arise. These asymmetries drive a wedge between privately and socially optimal/desirable behaviour. Policies and governance arrangements may then seek to avoid the associated problems, either by directly regulating or preventing specific behaviours (for example through requirements to use best available technologies for avoiding environmental damages, or complete protection of certain sensitive areas) or by intervening to alter the incentives such that private and social incentive better align (for example by implementing the Polluter Pays Principle and requiring environmental insurance deposits/bonds).

- At the global level, all costs, benefits and risks are experienced by somebody. However, their distribution is not fixed. This applies not only to intragenerational distribution, but also intergenerational. The CHM requirements seek to address both issues.

- For private businesses, the downside may be strongly limited compared to society – at worst, total loss of investment – while the upside may be strongly skewed with scope for quite disproportionate benefit from higher than expected returns (depending on how royalties are calculated). Within private businesses, incentives can be further skewed:
- for business decision makers, there may be sizeable remunerations during operations irrespective of results, substantial upside, and ability to walk away from bad outcomes (provided no laws have been broken);

- shareholders/investors, meanwhile, will often be protected by strong diversification (DSM is a small part of portfolios) and the ability to offset losses against tax (there may even be tax breaks on benefits due to policies for high risk / venture capitalism incentivisation);

- Discount rates in private business can be substantially higher than rates applied to public sector investments, due to constraints on capital availability and higher expectations for returns on investment to offset risks that are more pooled at societal scales (though this applies less to small states facing multinational corporations).

This can give incentives to push ahead with developments that might not be desirable from a broader societal perspective, or simply to move faster than might be socially desirable.

- Local populations may or may not have strong benefit potential – in principle jobs and expenditures associated with developments, and royalties, bring economic benefit. In practice much of the potential upside may leak out of the area to investors/shareholders, skilled labour may be sourced from outside, and royalties may disappear into general government expenditure or even corruption. There may also be long-term economic consequences (Dutch disease). At the same time, local populations may face a disproportionate share of possible costs, especially where they rely on marine industries (in particular fishing) that they fear may be impacted negatively. These may all be uncertain effects, but the populations may be disproportionately exposed to these risks – unlike the private investors and decision-makers, they cannot walk away if worst cases are realised. This can give strong incentives to resist developments.

- Local decision makers should in principle reflect interests of their constituencies, but may face divergent incentives due to shorter time horizons (driven e.g. by electoral cycles or career progression) and can also be targets of attempts at corruption.

Similar points arise for national decision makers, at different scales. National pride can also be an important factor, working either for or against DSM, depending on framing – in extreme forms, a DSM project could be presented as a dynamic demonstration of pioneering spirit and global leadership in developing new frontiers in resource development, or as a naïve or corrupt political class allowing international corporations to rape a nation’s sovereign natural resources and leave future generations impoverished).

Roche and Feenan (2013) review the primary and secondary drivers of DSM, as well as the barriers (Figure 3). As explained above, these all vary depending on the scale of analysis. At the industry level, interest is driven by the prospect of high profits for smaller pioneer companies and technology developers, though the substantial uncertainties make this a highly risky strategy; larger players are positioning to move in when uncertainties are somewhat resolved, driven also by increasing cost and difficulty of terrestrial mining (including in some cases rising conflicts around mining operations). At the global scale, economic growth may be the most obvious factor, but specific drivers for deep sea sources include strategic considerations associated with ensuring supplies of resources that may otherwise be dominated by unstable or hostile regimes, and the need for specific metals in substantial quantities to fuel a ‘green economy’ reliant on alternative technologies. For individual countries owning deep sea resources in national waters, the drivers are primarily associated with economic growth, especially in poorer nations reliant primarily on fisheries resources, agriculture and other primary resource exploitation.
Clearly, chief among the primary drivers are the economic motivations for profitability or economic growth. Indeed it can be argued that one of the main reasons DSM has not yet started commercially in territorial waters is that resource price fluctuations and uncertainty, coupled with very high start-up and operating costs, have (until recently, and perhaps still) made DSM too risky a prospect even from a purely commercial perspective. Sharma (2011) presents some approximate calculations for a ‘typical’ nodule area of 75,000 km², expected to yield about 54 million tonnes of metals with a gross in-situ value of c.$21-42 billion over 20 years of mining. To access these resources might require a capital investment of c.$2bn and operating expenditures of $9 bn. Sharma suggests that these large figures, technological challenges and high uncertainty mean that private-public cooperation could be effective – and indeed, for Solwara Nautilus is partnering with an independent nominated representative of the PNG State, and ISA rules require all exploration and exploitation activities in the Area to be sponsored by a State Party to UNCLOS.

Nevertheless, “the majority of investment over the past five years has been from the private sector” (Lodge, 2015). This reflects the greater ‘urgency’ for private sector enterprises seeking to become involved in DSM, especially for smaller, specialist companies. With no other sources of income, DSM specialists need to find finance to continue their exploration, technological development and compliance with governance requirements (e.g. preparation of environmental impact statements and investments in social projects), and this is only possible to the extent that they can demonstrate to

<table>
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<td>State actors: securing access to essential resources, capable of vertical integration of resource extraction and processing with product manufacture</td>
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venture capitalists and prospective shareholders a realistic prospect of strong financial returns in the not-too-distant future.

Larger mining enterprises with substantial terrestrial investments may face less time pressure, for example because they already have stronger cashflow positions and perhaps also because they would not wish to see their existing mines become unprofitable due to influx of cheaper DSM metals. This part of the private sector needs to be in position to exploit DSM if / when the time is right, but may be in no particular rush to advance that time, provided they can be assured of access, for example, through being involved in exploration licenses.

States, meanwhile, face somewhat different incentives. In territorial waters, the resources are not going anywhere; time pressure to extract depends on the income/development needs of the State, but in general discount rates / expected ROI are lower than for private companies in high-risk markets. States are also aware that some of the potential damages could impact on their economies and populations, for example if fishing interests are damaged, and this provides an incentive to proceed more cautiously. In the Area, there is more prospect of a ‘gold rush’, but like the larger companies, the important driver here is the need to be involved in the licensing/exploration process (see e.g. Figure 2) rather than a need to bring resources on-stream quickly. At the national level, the possible flows from DSM generally form small proportions of GDP, except for small developing countries with extensive possible resources in territorial waters. The world average share of mineral rents in GDP from 2006-2015 was 0.7%; the highest OCED figure was 5.7% (Australia) and some developing states have much higher mineral dependence, up to 35.7% (Mauritania) (see Figure 4). In fact the States with most current dependence on minerals are often those with most to lose from DSM, because they have high terrestrial deposits that may be less profitable if DSM leads to price falls – this is the rationale behind the stipulation in the ISA CHM principle of benefit sharing to seek protection against adverse effects of deep seabed mining on land-based mining interests. Overall, the DSM drivers for most States are currently more geopolitical and strategic in nature than due to pressing needs to exploit the economic potential of deep-sea resources.
Partly related to the issue of asymmetric incentives is the issue of asymmetric information that allows different actors to assess the risks differently. Industry, as the developer and implementer of DSM technology, de facto has information that it may not wish to share with authorities, for different reasons. These include commercial confidentiality, to maintain advantages in technological developments and cost reductions, but also incentives to play down any possible environmental impacts. On the other hand, this should not be interpreted as a simple one-shot game: rather, firms and regulators have long-term ongoing relationships. Insights from game theory show that even in quite stark situations of incentives to ‘cheat’, the potential for retaliation can make cooperation the better choice. Nevertheless, there remains an incentive to put the best possible spin or gloss on the information available, and there is clear potential for strategic behaviour in collection, analysis and presentation of data, in particular if private industry is responsible for impact assessment and monitoring, as well as exploration, operations, and developing the technologies for all these tasks. This is rendered particularly problematic by the extreme uncertainties relating in particular to the environmental consequences of deep sea ecosystem disturbances.

One possible implication of consistently applying the precautionary principle (see section 0 below) is to act as an incentive to share information fully. If the burden of proof is placed on prospective miners, then they become incentivised to produce evidence in order to support the claim of no harm. This can motivate greater research and learning, but does not remove the concerns associated with incentives to minimise any evidence of possible damages.

These issues can also be considered as a subset of broader corporate social responsibility (CSR) and the extent to which individual firms ‘buy in’. Trebeck (2009) analyses case studies of Australian terrestrial mining and concludes that uptake of corporate social responsibility depends on responsive individuals in the company, especially senior management, being receptive to pressures for...
responsiveness that appeal to commercial interest. She argues that “civil regulation and increased community participation in corporate decision-making is insufficient to attain the stated aims of particular communities”, highlighting “a role for civil society in maintaining vigilance and sustaining the context that prompts companies to consider communities.” This in turn highlights the importance of developing and maintaining the capacity of civil society to sustain this vigilance. There is a risk that deep sea operations could be more out of sight, out of mind – or at the least, it will be much more difficult for civil society, especially in developing states, to monitor what is going on - suggesting an important role for the ISA and international NGOs in providing this oversight.

2.1.1 Strategic supplies and geopolitical drivers

One of the key factors invoked in pushing for DSM at the national-global scale is the strategic need to secure access to essential resources, to support economic growth, but also for risk-reducing purposes, reducing reliance on particular sources or regimes and associated risks of supply interruptions or price volatility. This applies particularly to the Rare Earth Elements (Figure 5) though there are also longer-term concerns about more widespread resources. Of particular relevance to DSM is the role of China in dominating world supply for certain resources, leading to a geopolitical strategic concern with developing alternative sources. Humphries (2013) reports that for economically recoverable rare earth elements “China holds 50% of the world’s reserves (55 million metric tons out of 110 million metric tons) and the United States holds about 13% according to the most recent USGS estimate.” Other countries such as South Africa and Canada have significant REE potential. In terms of production, China accounts for about 95% of the REE raw materials, about 97% of rare earth oxides, and is the only exporter of commercial quantities of rare earth metals. Thus, even if rare earth production in the US or from DSM sources ramps up, as things stand, much of the processing/alloying and metal fabrication would occur in China.

However, studies examining the role of DSM in supplying critical resources tend to focus strongly on economic impacts and in particular on risks to supplies and consequences in terms of economic vulnerability. Mayer and Gleich (2015) review studies of resource criticality and classify the criteria used (see Figure 6) finding that the primary criteria relate to risks of disruption to supplies, then to the consequences of such disruption. Social and environmental aspects have rarely been taken into account, but are a growing consideration.

![Figure 5: US assessment of short and mid-term criticality (source: IAMGOLD, 2012)](image-url)
2.1.2 DSM as component of the Green Economy

Metals from DSM are sometimes presented as essential to a transition to a ‘green economy’ relying on renewable energy sources, battery technology and so on. These technologies demand large quantities of certain metals such as copper, lithium and silver. This issue is explored by Teske et al (2016) who investigate the impact of a global energy transition towards 100% renewable energy on the demand and supply of copper, cobalt, nickel, lithium, silver and specialty metals (tellurium) as well as rare earths (neodymium, dysprosium). These metals are needed in the renewable energy technologies likely to be important, and could potentially be mined in deep-sea operations. Teske et al proceed by compiling data on current global mine production rates, global reserves and resources, and estimated recycling rates, estimating the metal resource use intensity by technology and application, and applying resource intensity to published future global energy supply and demand scenarios considering different renewable energy technologies and storage devices. They note that their “advanced energy revolution” scenario (100% renewable by 2050) is highly ambitious; even the milder “energy revolution” scenario would require concerted policy effort.

Their results show that even under the most ambitious scenario the cumulative demand to 2050 for silver and lithium is estimated to be less than 35% of known terrestrial resources, whilst the demand for all other metals considered (under all scenarios) is less than 5%. However, with respect to known
reserves (i.e. economically extractible with current prices and technologies), the demand for lithium and silver are estimated at 99% and 94%.

They recognise that future demand will also depend on other factors, and that renewable energy technologies are not necessarily the principal driver of future demand for all these metals. And continued research and development of alternative battery chemistries may change the demand profile. On the other hand, it is also possible that new terrestrial resource discoveries, and/or cost-reducing technological developments, could occur before 2050. The assumption of static recycling rates is conservative, and an increase in recycling (e.g. through wider adoption of policies such as the EU’s WEEE directive\textsuperscript{2} and ELV directive\textsuperscript{3}) could ease pressure on mining production. The supply constraints are well known, and “provide a very strong driver for sustaining strong research and development into alternative technologies that reduce, or eliminate, the use of these metals.” (ibid.)

The authors conclude that “Even with the projected very high demand growth rates under the most ambitious energy scenarios, the projected increase in cumulative demand – all within the range of known terrestrial resources – does not require deep-sea mining activity.” They suggest that “Increasing recycling and continued research and development into alternative technologies that reduce, or completely eliminate, the use of these critical metals are vitally important complementary strategies.” (ibid.)

On the other hand, there is nothing to say that DSM could not provide a more economic, long-term source for key metals – the point is rather that these calculations suggest that the demands of a renewable energy revolution are not sufficient to drive a sense of urgency concerning DSM: we have another 30 years to play with, if need be. That said, it remains possible that DSM sources might provide cheaper metals, potentially driving a green economic transition faster. And, it is possible that DSM could provide metals at lower environmental and social impacts, as discussed further below. Pendleton et al (2013) summarise by arguing that deep sea mining could contribute to a greener economy if the following conditions are met:

- the economic benefits of deep sea mining exceed their economic costs;
- the environmental component of the costs of deep sea mining is adequately understood by all and is incorporated into the decision making of deep sea mining companies (including management of consequences, as appropriate); and
- a sufficient share of the wealth generated by mining (for example, through taxes or royalties) is invested in social and environmental capital in order to ensure the sustainability of wealth creation from finite resources.

These are in principle empirical questions, though the substantial uncertainties mean it is not possible to resolve them with the current state of knowledge. In effect, if these conditions were satisfied it would imply DSM could make a net positive contribution to sustainable development at a micro scale, focusing on the direct economic, environmental and social impacts.

2.1.3 Alternatives to virgin resources

As alluded to above, however, competing sources of virgin materials (land-based mining, reprocessing of land-based tailings) represent only part of the sustainable development calculus. Other alternatives include recycling of metals from electronic waste and building material, but also mineral demand reduction through substitution and greater efficiency, or even de-growth. Target 12.5 of the 2030


Agenda for Sustainable Development seeks to ‘substantially reduce waste generation through prevention, reduction, recycling and reuse.’ (UNGA 2015, p. 22)

Bringing large new sources of minerals on stream could have the reverse effect, putting downwards pressure on resource prices, leading to greater resource use and reduced incentives for efficiency, recycling and substitution. There is also a potential problem of lock-in due to high capital investments that must be recouped, with the short-run marginal cost of DSM production much lower than the long-run average cost including all the exploration, development, licensing and permitting costs.

A similar issue arises with energy from waste schemes – it can be argued that extracting energy from waste through incineration plants is environmentally better than landfilling waste and producing energy from other sources. However, this creates an ongoing demand for waste to incinerate. In both cases, the implication of the lock-in is a disincentive to recycling and efficiency efforts. This need to consider the mid- to long-term dynamic implications of decisions is key to achieving a genuine green economic transition.

This split is seen, for example, in the EC consultation (CEC 2015b), where “civil society stakeholders argued that seabed mining was not compatible with the EU’s resource efficiency drive” while “others felt that whilst increased recycling is indeed a worthy ambition, it is not going to meet all our needs and the choice is rather whether we continue relying exclusively on terrestrial mining or turn to the sea for some of our needs.” (p18)

Jaeckel (2016) moots the possibility that the CHM status of the Area and the requirement to apply the Precautionary Approach could be interpreted as requiring the ISA to participate actively in the broader societal discussion over the need for DSM. This discussion goes beyond the conditions set out by Pendleton et al (above) to take a more strategic and global perspective on the economic and social necessity for seabed mining. In this debate, the risks and benefits of seabed mining need to be considered in light of all potential alternatives, not only alternative virgin sources, and including the need to consider the sustainability of consumption patterns, not only production patterns (UNGA 2016, p.2; WCED 1987, chapter 2 paragraphs 5, 62). Considering alternatives to potentially harmful practices is a requirement of the precautionary approach (CEC 2000, pp 17-18), as discussed further in section 0.

### 2.1.4 Barriers to DSM

There are many potential barriers to DSM, and most of them strongly reflect the high uncertainties inherent in most aspects of mining the deep seas. Martino and Parson (2012) identified price volatility as the most important parameter affecting investment in deep sea mining; they predict that, without technical improvement or falling costs, nodule exploitation might be expected to be delayed for one or two decades, with even greater uncertainty for crust exploitation.

Respondents to the EC Consultation (CEC 2015b, p22) note that for deep mining, the main obstacles were “access to finance, volatility of prices and technology limits.” The uncertainties relating to resource prices and to technological efficiencies and costs, as well as delays due to the licensing and permitting procedures and possible civil society resistance, mean that it is difficult to attract investment for DSM. Technological limits apply not only to extraction, but also to processing – for example, Eurogeosurveys argue that lack of a cost-effective and environmentally sustainable metallurgical processing technique for manganese nodules is holding back mining operations. There is also uncertainty about the location, size, quality, and accessibility of the resources - though UK NOC reports that this is less of an issue for nodules, especially in the CCZ. However this barrier is one that could be addressed relatively easily through ongoing research and exploration.
More fundamental uncertainties arise regarding "our knowledge of the natural histories, life cycles, ecosystem interactions, and ecological functions of marine species and ecosystems. Still less is known about their resilience to human threats and natural pressures." (European Marine Board; other research and civil society groups also flagged these issues). Similarly, the implications for biodiversity and ecosystem services of any environmental changes arising through DSM are poorly understood. This makes it very difficult to make informed decisions balancing the economic benefits of mining with the possible damages, and brings the Precautionary Principle into play.

Leading on from such uncertainty, scientists, NGOs and the general public have expressed concerns about the environmental and social impacts of DSM, and in particular about the levels of uncertainty about these impacts. There is a clear divide between the attitudes prevalent in the private sector and in civil society, as seen in the EC consultation (CEC 2015b, see Figure 7), with the public sector and research community in between. This is discussed further in the section below on stakeholders, but it should be noted here that the disagreement is not necessarily about any matters of fact regarding DSM and its potential economic, social and environmental benefits and costs. Rather, the disagreement is about how society should compromise between the conflicting objectives at stake, given the uncertainties about impacts. This is where a clear understanding of the appraisal needs and options, and about stakeholder incentives and consultation needs, can inform choices about the development of the governance structures and decision-making processes.

![Figure 7: Responses to “Could DSM contribute towards a sustainable and economical supply of raw material for EU industry and agriculture?” (Source: EC 2015)](image)

**2.1.5 The role of the general public**

Although the general public may have little familiarity with deep sea environments, and with the plans and potential for deep sea mining, they may nevertheless have considerable interest and potentially strong views on these matters. The New Zealand Government submission to “Developing A
Regulatory Framework For Mineral Exploitation In The Area: Report To Members Of The Authority And All Stakeholders” responds to the draft framework note that public interests are not immediately identifiable in the Area. New Zealand reports that “there has been significant interest, both domestic and global, in applications for seabed mining activities under its EEZ Act” and argues that “the possibility of considerable public interest in proposed exploitation activities should not be discounted.” Similarly, Ocean Europe responded to the European Commission consultation (CEC 2015b, p21) that “The fact that the main driving interest is technological development is exactly the reason why the EU must regulate this activity. It is not simply because we possess the technology to mine the seabed or because it has now become economically feasible, that we should necessarily do it. It is major societal and political decision that EU citizens have a right, and duty to participate in.”

That some among the general public have strong views on this area is borne out by a recent Avaaz petition (Figure 8) which at the time of writing has attracted around 1 million signatures worldwide. The wording used to promote the petition could be seen as somewhat alarmist (“insane idea that could become a planetary disaster”) and as failing to reflect the procedures for assessing and managing impacts (“corporations unleashed to dig up the ocean floor...far from any scrutiny”) though the text of the petition itself is slightly more measured (“Deep sea mining could be catastrophic for our climate and biodiversity. Our ecosystems are fragile and we simply don’t know the risks posed by this kind of industrial activity.”) This presentation can be seen as a reflection of the important uncertainties coupled with strong endorsement of a precautionary approach. Although the act of signing a petition is very low-effort, the significant numbers point to a widespread (and legitimate) interest in these matters, and it seems likely both that members of the public would wish to have an input to consultation processes, and that the NGO community is likely to promote and facilitate such participation. This could result in substantial response – for example, in the case of the European Commission’s consultation on the review of EU nature conservation legislation (April to July 2015), 552,470 replies were received – the largest response ever to a Commission on-line consultation (CEC, 2015).

New Zealand concludes that, since it is crucial that an open, inclusive and cost-effective process is established, “it is important that the degree of influence public engagement can have on impact assessments and management plans ... is made very clear, so that the expectations of those who choose to engage are appropriate”.

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4 https://secure.avaaz.org/en/png_nautilus_loc_rb/ A somewhat similar petition asking the ISA to call a moratorium “unless and until independent scientists agree it is safe, and the ISA dramatically increases transparency and access for all meetings and reports” has attracted almost 800,000 signatures https://secure.avaaz.org/en/deep_sea_mining_loc/
2.2 Impacts of DSM

All the above stakeholders need to be considered when reflecting on impacts of deep-sea mining activities in the context of the sustainable use of the oceans, and achieving the Sustainable Development Goals (SDGs) more generally. This implies that management practices, and appraisal/decision-support tools, should be holistic “based on an integrated overview of all present and future human uses and ecosystems services” (UNEP et al 2012).

In this section we consider social and economic impacts jointly as from a societal perspective it is both difficult and somewhat artificial to disentangle them – it would be easier, in fact, to distinguish impacts on present and future generations. Environmental impacts are slightly different, and can be treated separately up to a point, but when these impacts are followed through to changes in ecosystem
services, they return to the overall 'sustainability' assessment, impacting on economic processes and social welfare and wellbeing, including cultural heritage and non-use values.

Economics approaches to sustainability through the theory of human welfare, the latter is dependent on flows of goods and services that themselves are dependent on various capital stocks available to society. The capitals are variously defined, but commonly broken down into natural, manufactured, human, social and financial capital. These stocks are, at least in principle, separately measurable, though available methods do not distinguish between human and social capitals, and give an incomplete accounting of natural capital. The methods presented in World Bank (2006 and 2011), “for example, derive estimates of Total Wealth broken down into:

- Produced/manufactured capital: machinery, structures, equipment and urban land.
- Natural capital: agricultural land, protected areas, forests, minerals and energy.
- Intangible capital: this is measured as a residual (the difference between total wealth and produced and natural capital) and implicitly includes measures of human capital and social/institutional capital (factors such as the rule of law and governance that contribute to an efficient economy).

In the World Bank research, the Total Wealth of nations is defined as the present value of future consumption that is sustainable, discounted at a rate of time preference of 1.5 percent, over 25 years. This measure of total (or comprehensive) wealth is based on the principle that current wealth must constrain future consumption. The calculation of total wealth requires adjusting levels of consumption to take account of rates of saving adjusted for depletion of produced and natural capital: when depletion-adjusted saving is negative, countries are consuming natural resources, jeopardizing the prospects for future consumption. Subsoil assets (fossil energy and minerals) can form an important (but non-renewable) part of a nation's natural capital. Through mining, these ‘sterile’ resources are converted into forms of capital that directly contribute to national development. The subsoil assets component of natural capital wealth is calculated as present value of rents from extraction, discounted at 4 percent, over the exhaustion time of the resource, or 25 years, whichever is shorter. This forms an important component of the wealth estimates for many countries. As recognised by UNEP et al (2012), deep-sea minerals are a possible new revenue stream that could support national development goals. For some countries, deep-sea minerals could form a new and important addition to Wealth; for humanity as a whole, under the principle of the CHM, the resources of the Area also represent a potentially important addition to Wealth.

However, this is constrained by the possible damage to other components of wealth that may follow extraction of the resources. In the “wealth” model, sustainable development can be defined in terms of non-declining capital stocks, with different interpretations and conclusions depending on the degree of substitutability assumed across capital types.

‘Weak’ sustainability requires non-declining total wealth. This assumes that these components of wealth are completely substitutable, and in particular that the services of ecosystems are perfectly substitutable by human-made capital. Under this interpretation, human use of the environment is essentially an economic problem, and the costs of environmental degradation can be compensated through building up human-made capital. The assumption of weak sustainability has been widely explored in the literature on non-renewable resources, with a focus on ever-reducing inputs of non-renewable resources (from natural capital) being compensated for via ever-increasing inputs of produced capital, generally via constant elasticity of substitution production functions (see in particular Solow 1974). Neoclassical analysis of this sort leads to conclusions on investment profiles, in particular the ‘Hartwick Rule’ (Hartwick, 1977, 1978) of investing the rents on extraction of non-renewable resources in reproducible capital. There are numerous possible complications associated
with uncertainty, depreciation, technological change and so on, but as Solow (1986) observes, "This seems like a useful rule of thumb for policy", and it is clear that any society that does not invest non-renewable resource rents in produced capital, but instead spends them on current consumption, is likely to following an unsustainable path.

Following in these lines, Pearce and Atkinson (1993) propose the “Genuine Savings” test of weak sustainability. This adds up the value of year-on-year changes in each individual element of the capital stock of a country, valuing these changes using shadow prices which reflect the marginal value product of each stock in terms of its contribution to the present value of aggregated utility over infinite time. Research in environmental economics continues to explore the empirical relationships between genuine savings and sustainability of consumption. Hanley et al (2016) for example find evidence to support the use of genuine savings as an indicator of sustainability over modest time horizons (20-30 years) but suggest longer time horizons require consideration of technological progress.

‘Strong’ sustainability goes further by rejecting the substitutability between different capitals (and in particular natural and produced capitals) and considers different capitals as being separately essential to well-being. This has been less explored for non-renewable resources (since if they are simultaneously essential to production, non-substitutable, and non-renewable, there is no sustainable solution: sooner or later, those resources will be used up, and since they cannot be substituted, production will stop) however we cannot simply assume that infinite substitutability between different types of capital applies. In any case much of natural capital, and in particular the goods and services provided by living ecosystems, is renewable, and potentially (given historic degradation) improvable via ecosystem restoration.

This makes human use of the environment a jointly economic and environmental issue, and focuses concern on the preservation of important and non-substitutable environmental outputs and services (Davies, 2013). But although most debate in this area focuses on the substitutability issue as outlined above, Pearce et al (1989) presented three other reasons why a strong sustainability rule may be required:

- irreversibility
- uncertainty
- intra-generational equity (because the poor are often hit harder by poor environmental quality than the rich).

All of these issues are strongly present in the case of DSM, leading to difficult value judgements and trade-offs for which ‘standard’ appraisal methods are ill-equipped.

### 2.2.1 Social and economic impacts

At the most basic level, economic impacts are often reduced to ‘simple’ financial viability for a particular project (such as a proposed DSM operation). Actually calculating financial viability is in fact quite complex (Figure 9) involving multiple variables, many of which are highly uncertain. Market prices for metals, for example, are subject to large fluctuations that can be considered one of the main barriers to DSM to date (Sharma 2011, Martino and Parson 2012), as noted above. Furthermore, these fluctuating prices are themselves likely to be strongly impacted by expectations about the extent, costs and regulatory and tax regimes of future DSM.

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5 Interestingly, these reasons are also strong justifications to apply a precautionary approach.
The financial calculations may be all that is required from the perspective of a private company, but the economic impact from a social/national point of view can be much more complicated. It depends of course on royalty/tax rates, on where resources are processed, on whether companies invest in local employees and facilities and so on. Beyond that, there are two important phenomena that need to be kept in mind when reflecting on economic impacts of mineral exploitation at the level of a nation: the ‘resource curse’ and ‘Dutch disease’.

The idea of a ‘resource curse’ arises from evidence that some countries where mining is an important part of the economy have not grown as rapidly as other countries. Davis and Tilton (2005) review this evidence and the possible explanations for the phenomenon. While rich mineral deposits provide opportunities for development, decisions about how to use the resources and rents can result in these opportunities being lost. One issue is the instability of commodity prices, and risk of long term declines – in defiance of the Hotelling rule, which argues that, ceteris paribus, resource rents must rise at an exponential rate for market equilibrium. In fact, the markets for primary products, including mineral commodities, show significant instability, with price variations of 30% or more within a year or two not uncommon. And the prices of primary commodities tend to fall relative to those for manufactured goods, in part because primary commodity markets are competitive and so reductions in costs are passed on immediately to consumers in the form of lower prices.

Another problem, potentially related, is “Dutch disease”, whereby rapid expansion of the mineral sector puts upward pressure on domestic wage rates, while at the same time increasing mineral...
exports lead to appreciation of domestic currency. These make other domestic industries less competitive, damaging economic diversification and increasing dependence on the mining sector and exposure to mineral price fluctuations, especially if the processing is carried out abroad. Skilled workers may be brought in from overseas, rather than training local workers. The real extent of the damage then becomes clear when mining runs out, leading to deflation and depression.

Royalties and taxes from minerals could be used to avoid this damage, for example by cutting taxes on employment or profits, and/or by building up investment funds based on the rents, but in some cases this is not done effectively. Rather, mining rents are often captured by political elites, resulting in increasing inequality and rent-seeking behaviours, and exacerbating the negative economic and social consequences outside the mining sector. The environmental and social costs, meanwhile, tend to be borne by local communities.

Pendleton et al (2013) view these problems as stemming from insufficient investment in social capital leading to persistent poverty despite wealth generated by mining, citing the example of Papua New Guinea which despite extensive (terrestrial) mining development “consistently contributing between 10 and 20 per cent of national income over the years” remains among the poorest nations in terms of GDP per capita and the human development index, with ongoing poverty in communities close to mines. They argue that this is due to “inadequate institutional capacity, ineffective management, and inequitable capture and reinvestment of resource rents”, also citing Lal and Holland’s (2010) evidence of corruption preventing local communities from benefitting from the wealth generated from community-owned resources.

Davis and Tilton (2005) conclude in essence that there is no simple answer to these issues – some places have done it well, others badly. The policy question is where and how to encourage DSM, and the policies that are needed to ensure that it contributes as much as possible to economic development. There could be issues here associated with timing and perhaps sharing of resources, for example, to attempt to develop a socially, environmentally and ecologically sustainable and long-term DSM industry that avoids a boom and bust cycle in any particular place.

There may be particular risk of these problems arising in some potential DSM regions. For example, Hanich and Tsamenyi (2009) note that the Pacific Islands region includes some of the smallest countries in the world, many in precarious economic conditions and heavily reliant on the region’s tuna fisheries for both revenue and food security. The SPC-EU EDF10 Deep Sea Minerals Project (Howorth, 2011) argues that DSM “will significantly contribute to reducing their economic vulnerability and expand their narrow resource base by optimizing the benefit from the size and extent of their EEZs and the mineral resource potential that occur on the seabed” (Howorth, 2011).

However, achieving sustainable development for these countries is crucially dependent on their ability to conserve and sustainably manage their natural resources, and effectively invest the proceeds in social and economic development. Their ability to achieve this is “undermined by a combination of economic, governance and institutional weaknesses that make these countries vulnerable to corruption in the fisheries sector.” (Hanich and Tsamenyi, 2009). The problems cited do not all transfer directly to DSM (they include e.g. the migratory nature of stocks and problems dealing with IUU fishing), but the overall message remains relevant. Although any interference with management of sovereign resources is a dangerous area, there could be a role for practical support, including development of appraisal and decision support tools for sustainable management and investment, and enforcement of anti-corruption legislation in the nations whose firms are involved in resource
exploitation, for example through the OECD Convention on Combating Bribery of Foreign Public Officials in International Business Transactions\(^6\).

A second source of social/economic impacts arises through the market effects of introducing new supplies of resources from DSM. According to the Hotelling rule, increasing the economically recoverable stock of an exhaustible resource – for example through technological development enabling profitable extraction of DSM – will result in a decline in the in-situ value of resource stocks. Prices would decline, and quantity demanded/supplied would increase, driving enhanced economic growth, but simultaneously reducing the profitability (rents) of terrestrial mining operations, with particular impacts on societies strongly dependent on terrestrial mining.

This could be exacerbated in certain cases because the production of metals from manganese nodules occurs jointly, with the relative quantities of the metals involved differing from the relative importance of the same metals on the world markets. Thus, DSM could lead to some metals suddenly becoming available in quantities sufficient to flood world markets, leading to major price falls and potentially mine closures. Donges (1985) presents evidence for the cobalt, copper, manganese and nickel markets to argue that such supply-side adjustments in these four metal markets would take place mainly in developed countries (Australia, Canada, South Africa, United States, COMECON-countries) and not in least developed countries (LDCs) as is commonly believed, with the notable exception of the Democratic Republic of Congo\(^7\), which alone would bear about 90% of the costs to LDCs. This leads them to suggest that the introduction of barriers to entry and production quotas, foreseen in UNCLOS as a means to protect LDCs from competition from seabed mining, could turn out to rather protect the big land-based mineral producers, while compensation of LDC losses by the ISA could form an important obstacle to a profitable deep-sea mining.

A further set of highly uncertain economic (and social/environmental) impacts could arise through increased bioprospecting and biomimicry applications, via previously unknown species, genetic resources and information on biological processes, and through technological developments resulting as a side-effect of DSM. Learning by doing and technological developments could reduce the costs/damages of future DSM and potentially spin-off to improve other activities in the deep sea or elsewhere. These are indirect benefits of DSM, and could in principle occur without it, except that Pendleton et al (2013) argue that “it is clear that the costs of conducting research in the absence of commercial exploration, driven by potential mining profits, would likely be prohibitively high”. On this view, at the very least, DSM will bring forward in time the enjoyment of these benefits. But at the same time, the environmental damages of DSM could result in irreversible loss of parts of the genetic ‘treasure trove’ in vulnerable and unique deep sea ecosystems. Much depends on the relative emphasis placed on systematic sampling and learning, damage minimisation, and cost reduction. The distribution of these benefits and costs, meanwhile, will depend on the governance arrangements put in place to determine who owns the intellectual property in any new discoveries, and who pays for any damage caused.

Clearly these issues are worthy of consideration, in particular for the ISA with its charge to manage DSM activities in the Area “for the benefit of mankind as a whole”. This is to be achieved through developing licensing, regulatory and financial policies, and to ensure a range of outcomes, including environmental protection and equitable benefit sharing. This can be read as implying that the ISA should facilitate DSM, in order to extract benefit from the CHM that can then be shared equitably. However the conditions should be interpreted broadly, such that DSM should be encouraged if and only if it is possible to achieve benefits that clearly exceed any environmental, social and economic damages. From an economic perspective, the impacts can be split into efficiency and distributional impacts:

\(^6\) [http://www.oecd.org/corruption/oecdtantibriberyconvention.htm](http://www.oecd.org/corruption/oecdtantibriberyconvention.htm)

\(^7\) Known as Zaire when Donges wrote.
• *economic efficiency* requires that resources be allocated efficiently, here in the sense of equating marginal costs across different sources of minerals – including recycling and substitution options – equating marginal benefits across different uses, and achieving dynamic efficiency through equating the discounted marginal costs and benefits across generations;

• *distributional impacts* are generally ignored or side-lined in mainstream economic appraisal, which focuses on efficiency (see section 0) and accepts changes as improvements provided the ‘winners’ could fully compensate the losers. The requirement for equitable benefit sharing from the CHM can be interpreted, *inter alia*, as requiring *actual* compensation.

The challenge from a narrow economic perspective is to achieve equitable benefit sharing through policies that do not compromise the efficiency criterion too much. It is also worth noting that policies that restrict DSM in order to avoid damage to terrestrial mining interests would have second-order distributional impacts through the effects of higher resource prices, which would be unfavourable to consumers, perhaps especially in LDCs (Donges, 1985). Allowing DSM while taxing resource rents and reinvesting part of the proceeds to offset any distributional damages would involve less market distortion and allow a better compromise between the goals. However, this conclusion must be held in check since it does not address the key issue of the great uncertainty regarding the environmental impacts of DSM, and their possible consequences for ecosystem services and human societies.

### 2.2.2 Environmental impacts

The MIDAS project aimed to improve our understanding the potential impacts of mining on deep-sea ecosystems. Key conclusions from the project are summarised in MIDAS (2016). The direct environmental disturbances of DSM may be many and varied, including (MIDAS 2016; Pacific Communities 2016; Dyment et al 2014):

• Mining related disruptions to the services provided by deep seabed communities:
  o destruction of habitat and associated fauna
  o formation of a plume of fine particles (sediments and ore particles, potential toxicity)

• Discharge of mining waste:
  o bottom water, sediments and ore debris
  o surface water quality impacts due to the discharge of nutrient rich water,

• Additional mining impacts:
  o acoustic, light and electromagnetic emissions;
  o vibration and noise from seafloor, riser and surface operations.

• Risk of unplanned releases into the marine environment during mining or transport operations
  o accidental emissions of oils
  o accidental emissions of chemicals or wastes
  o invasive species associated with ship movements

• DSM mining related increases in carbon dioxide (CO₂) emissions, and

• Impacts relating to the transport and processing of mined materials

The last three of these impact types are not unique to deep sea mining, and are relatively well-studied or familiar. This is not to say there is certainty regarding the risks and impacts: far from it. Unplanned oil releases are inherently uncertain, and there is fundamental uncertainty regarding the impacts of greenhouse gas emissions and resulting climate change. Nevertheless, these impacts are quite ubiquitous and offer no unique/specific challenge for the DSM case, so we do not dwell on them here. Carbon dioxide is a globally mixing pollutant. Though there is uncertainty about the damage cost per tonne of emissions, there is broad agreement that the specific location of emissions has little bearing on the damage. Similarly, the on land impacts of processing and transport will not be particularly
specific to DSM, being similar to those for terrestrial sources, though with possible differences associated with different ore qualities.

The first three impacts, however, are more specific to DSM, although certain other activities, notably deep sea trawling, will also disturb deep ecosystems. It is in habitat destruction, disturbance of organisms and creation/dispersion of sediment plumes in these sensitive ecosystems that DSM could have its most damaging impacts. But estimating these impacts can be very challenging. The deep-sea environment is one of the least understood regions of the planet and we still have a fairly rudimentary understanding of the ecosystem services these environments support (UNEP et al. 2012). Deep-sea ecosystems are highly heterogeneous and host a vast, but poorly surveyed, array of biology, as well as energy, and mineral resources (Ramirez-Llodra et al., 2010). They also play important, but poorly understood, roles in biogeochemical cycles providing vital global functions and services for humanity (van den Hove and Moreau 2007). Knowledge is also sparse on the ways in which human activities are impacting on deep-sea environments, in particular through overfishing (Watson and Morato, 2013) and the effects of greenhouse gas accumulation in the atmosphere and in the oceans.

Even the exploration and study phases of DSM could have important environmental impacts. Dyment et al (2014) stress that, while the main scientific exploration techniques (mineralogical and chemical analyses, hydrodynamic studies, geological and biological sampling, photography, video and acoustical methods) are thought to have negligible harmful impacts when used occasionally, they could have a significant impact if used intensively over a limited area.

The effects of emissions of nutrient rich water near the surface are also highly uncertain. However, they are very unlikely to have serious long-term consequences, but will rather be limited to the period of operations. It may also be possible to avoid the need to calculate these impacts if we follow the approach taken by Pacific Communities (2016), who assume that the best practices that operators must follow require avoiding these emissions. Consequently, their CBA does not seek to value nutrient emissions near the surface, but rather incorporates the costs of technological/operational steps to avoid such emissions into the costs of mining.

For oil releases, a similar point arises in that technological and operational measures should seek to minimise the risk of emissions. However, accidents happen, and the consequences of oil releases are potentially more damaging and long-term. Estimating the impacts involves assumptions about the frequency and extent of releases: Pacific Communities (2016) uses spill frequency data collated by the International Tanker Owners Pollution Federation (ITOPF) and volume estimates. They do not directly calculate ecological impacts but rather rely on published estimates of damage costs (Kontavas and Psaraftis, 2010).

The relative importance of these impacts is likely to be highly variable, since the deep sea systems likely to be impacted by different mining activities, and the technologies to be used, are themselves very different. The main types of mining include seafloor massive sulphides (SMS), polymetallic nodules, and cobalt-rich crusts (CRC). These sources, the associated ecosystems, and the potential impacts of mining, are reviewed by Dyment et al (2014).
Table 1: Ecology and impacts of DSM for three main resource types (source: synthesised from Dyment et al 2014)

<table>
<thead>
<tr>
<th>Resource</th>
<th>Production</th>
<th>Ecology</th>
<th>Impacts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sulphides</td>
<td>Formed quite rapidly by hydrothermal processes along oceanic ridges and at submarine volcanic sites</td>
<td>Dependent on status: active vents have high biomass of specialised extremophile fauna and microbial communities, often with endemic species. Inactive vents are expected to have less abundant and less endemic fauna, with distinct but still abundant and diverse microbial communities. Active systems have high temporal variability due to fluctuating geological processes.</td>
<td>Little is known about community structures/relationships and in particular about connectivity. Extinction/recolonization events are likely to feature in the natural cycles of these systems. For active systems, genetic and molecular adaptations of extremophiles are of great interest for bioprospecting. To the extent that exploitation targets inactive sites, impacts on endemic communities may be minimised. However, “very fragmented knowledge of the communities of inactive hydrothermal areas prevents us from predicting the response of the associated ecosystems. These impacts will lead to changes in ecosystem services. This will include in particular direct impacts on supporting services, notably habitat provision and biogeochemical cycles, and this in turn could lead to consequences for fishery production, loss of genetic and molecular resources, and damage to cultural/non-use values. Dyment et al (2014) stress that “it is not possible at this stage to evaluate the possible economic consequences of these environmental impacts, as the evaluation methodology remains to be defined and systematised.”</td>
</tr>
<tr>
<td>Nodules</td>
<td>Formed very slowly in areas of low sedimentation Vast: nodules of 5-10cm diameter spread over tens to hundreds of thousand km2 on surface of sediments in abyssal plains</td>
<td>Sediments have highly diverse, low biomass fauna. Spread over vast areas, levels of endemism are low. Nodules form islands of rocky substrate on otherwise homogeneous sediments, with attached specialist fauna (corals, sponges). Microbial diversity little is known but likely significant, distinct from sediment communities, and playing a role in metal mineralisation (nodule growth).</td>
<td>Impacts dependent on degree of sediment disturbance. The epifauna and endofauna on nodules, and part of the fauna in the sediment, will be destroyed by exploitation. Pilot exploitation sites have been seen to be recolonised in a few years, but by fauna with a different specific composition.</td>
</tr>
<tr>
<td>Crusts</td>
<td>Formed very slowly on rocky substrates with no sedimentation Several km2 on sea-mounts and inter-plate highs, up to 25cm thick/</td>
<td>Hard substrate areas colonised by fixed, slowly growing, engineer species such as corals and sponges, which in turn host a wide diversity of organisms. Abundance, biodiversity and endemicty of the macrofauna heavily dependent on typology. Fauna specifically on crusts little studied. These areas are discontinuously distributed and endemism could be significant.</td>
<td>Studies of the impact of deep-sea fishing on seamounts confirmed that the associated ecosystems have an extremely low capacity for resilience due to the importance of slow-growing engineer species. The endemic species specific to crusts could be threatened with extinction</td>
</tr>
</tbody>
</table>
There is the potential to learn much more about the possible impacts of DSM activities on deep sea ecosystems. For example, MIDAS research\(^8\) is helping to develop understanding of the impacts of sediment plumes. Mine tailings studies in Norwegian fjords show that sediment burial of more than 1.5 cm causes mortality in nematodes (R15) while sediment deposition of more than 0.5-3cm causes significant impact on benthic metabolism in shallow water experiments on mine tailings. Other MIDAS research suggests that release of metals from fresh sulphides at the seafloor varies from mineral to mineral, but release begins very quickly on exposure to seawater. This means that mining of sulphides at the seafloor will immediately release dissolved metal ions into the environment, decrease pH and lower oxygen, all of which will have an impact on ecosystems. MIDAS research shows that most pelagic fauna are very sensitive to changes in oxygen levels. Particulate sulphides generated by SMS mining that come into direct contact with non-vent fauna may also have a strong toxicity effects, as well as a physical impact on organisms. Cold-water corals die very quickly when exposed to SMS particles, potentially due to elevated copper levels. It should also be recognised that some existing knowledge may not translate directly to DSM conditions – for example, published LC50 values for certain species do not necessarily apply at bathyal and deeper conditions.

Pusceddu et al (2014) review evidence on the impacts of deep sea trawling, and present evidence on biodiversity and ecosystem function impacts from trawled versus untrawled areas in deep waters of the Mediterranean. There are two main sources of impact: sediment disturbance and removal of organic carbon, and destruction of habitat complexity. Carbon removal can represent as much as 60–100% of the input flux, which can have substantial impacts on ecosystem processes, causing “the degradation of deep sea sedimentary habitats and an infaunal depauperation” and “the collapse of benthic biodiversity and ecosystem functions, with potential consequences on the biogeochemical cycles”. Compared with untrawled areas, trawled deep-sea sediments have lower organic C turnover and are significantly depleted in organic matter content, meiofauna abundance and biodiversity, and nematode species richness and individual biomass. These results apply to areas that have been trawled repeatedly over years, with gear designed to remove fish biomass, and so do not necessarily translate directly to likely impacts of DSM. Nevertheless they do indicate that there can be potentially severe ecosystem consequences of practices that cause significant disturbances deep-sea sediments.

MIDAS research suggests that the species likely to be impacted by mining are those that have similar characteristics as those vulnerable to deep-sea trawling, such as longevity and low fecundity. Ecosystem productivity also appears to play a role, and it is expected that recovery will be faster and higher in the higher productivity areas of the CCZ relative to the lower productivity areas. The damages will also depend on abiotic features, in particular tidal movements will affect sediment plume settling patterns.

Although little is known about recovery from DSM disturbances, there is some evidence that long term or even irreversible damages could occur. Sediment compaction caused by mining vehicles, or as a consequence of removing the top layer during mining, may be problematic for recolonization. Removal of the top layer of sediment exposes older sediments that may be less carbon-rich making them less easy to colonise. Where recovery from deep sea disturbance has been studied, it appears to be very slow. Recovery of ecosystem function in soft sediment faunas at DISCOL and CCZ is very slow with not even the microbes appearing to recover. Nematode recovery in 36-year old disturbance experiments is evident in top 1cm of sediment only. Lower depths show depleted levels compared to control site. Bioturbation is probably important in the process of recovery by creating a thicker active layer of sediment. Resedimented areas will have a different "soil" structure to both undisturbed areas and mined areas and nematode communities within and outside tracks at the OMCO site show differences. Diversity of genera in tracks is lower than outside tracks, even taking into account natural variability. Epifauna within track areas show no recovery after 20 years compared to undisturbed areas.

\(^8\) The MIDAS research findings are summarised in the MIDAS final scientific report (soon available on the MIDAS website: [http://www.eu-midas.net](http://www.eu-midas.net)) and in the ‘MIDAS Research Highlights’ Brochure (MIDAS forthcoming October 2016).
nodule/no nodule areas. Recovery depends both on dispersal ability and on the availability of suitable habitat.

While population genetics can be used to predict recolonization scenarios and to monitor recovery, data are available for only a very small number of vent and seep fauna. There are not enough individuals of any one species in most samples to carry out population genetics analysis for connectivity studies. Much more sampling needs to be done to determine if this is a function of rarity. There are also important data gaps in connectivity studies, e.g. for the CCZ where there is no information relating to larval types and dispersal. eDNA sequencing technology can help but needs to be used with extreme caution in connectivity and recovery studies because it cannot distinguish between living and dead organisms, or ex-situ organism traces. There is potential in this technology but it is not yet mature enough for application.

The possibility of cumulative impacts (DSM plus trawling, plus any other disturbances due to other marine uses) should also be considered where relevant, including not only direct overlap of activities but also overlap of plumes generated, and potential cumulative impacts across ecosystems even where direct impacts do not overlap. Mengerink et al (2014) point out that the deep sea “already experiences impacts from activities such as fishing; oil and gas development; waste disposal; and land-based pollution, including greenhouse gases.” DSM and climate change will lead to changes in temperature, pH, oxygen concentrations and carbon fluxes which taken together “will inflict a spectrum of impacts that, if not managed wisely, may irreversibly damage essential ecosystem functions, processes, and services”.

That such cumulative impacts could be damaging is borne out by Thurber et al (2014) who review current knowledge on the functions and services provided by the deep sea, seeking to provide a foundation of knowledge for effective management, while identifying the traits that differentiate deep-sea habitats from other global biomes. They note “the severe lack of deep-sea environmental and biological data, the conceptual challenge of its size, and the unexplored habitats … that likely add heterogeneity and diversity in unknown ways.” Nevertheless, they argue that it is possible to develop “a basic understanding of how the temporal and spatial diversity in the deep sea creates a system with far-reaching linkages both within its realm as well as to society as a whole.” This understanding includes recognition of the vast nature of the habitat, allowing small-scale functions and processes to add up to globally essential cycles. There can be a long separation of function and service within the deep sea, both spatial and temporal: for example, nutrients regenerated in the North Atlantic may not reach surface waters in the North Pacific for millennia.

This situation is highly relevant to the choices faced in DSM governance, including to the comparison with terrestrial sources. Both terrestrial and marine mining cause environmental damages, but in the case of DSM, impacts are much less understood and more difficult to monitor, partly, but not only, because DSM has never been done at an operational scale. Halfar & Fujita (2002) consider the great uncertainty coupled with the potential for serious harm to favour terrestrial sources, arguing that “mining on land has caused environmental devastation, certainly, but environmental risks of terrestrial mining are better known and perhaps could be more easily contained than those of deep-sea mining”. They argue that “a prudent policy approach would consist of: 1) conserving mineral resources, 2) increasing the recycling of minerals, and 3) exploiting land based mineral resources with much greater efficiency and more stringent environmental regulation.”

Others, however, argue to the contrary, saying that environmental and social impacts of terrestrial mining are so consequent that surely mining in the deep sea, which is both enormous in total extent and much more remote from human populations, would be a ‘safer’ option. In the EC Consultation (CEC 2015b, p19) the German Research Centre for Artificial Intelligence put the argument from the somewhat different perspective of environmental constraints, noting that in Europe “access to new
sites for the mining for higher value commodities and rare earth elements as well as a re-use of old sites is difficult due to strict environmental regulations and public perception of mining activities. If done with the right equipment in an ecologically sound way, non-invasive deep-sea mining can be a valid economic alternative.” While the conclusion is fundamentally correct, it would be unfortunate if DSM were to hold an advantage over terrestrial sources merely because environmental regulation and public perception lag behind. The current strict regulation of terrestrial mining is in place due to a long history of damages and accidents. Part of the public perception is due to a NIMBY issue (which might be expected to be much less relevant for remote deep sea operations) but part is also due to growing awareness of the importance of biodiversity and the potential for irreversible losses to natural and cultural heritage through inappropriate economic activity. To avoid following the same path of reactive policy – tightened legislation following damages – it is important that appropriate environmental rules and public consultations are in place from the start.

A related argument holds that the extent of disturbance in DSM is likely to be less than for terrestrial sources, because ores are richer and can be accessed with much less sediment displacement. This is one of several potential advantages to DSM compared with terrestrial mining. Nautilus Minerals (2016) list these as:

- Limited social disturbance: seafloor operations do not require the social dislocation common to land-based operations with the resulting impact on culture or disturbance of traditional lands
- Reusable infrastructure: Operations will be limited to a production support vessel (PSV) and seafloor production tools (SPTs) which can be re-used for future projects unlike many aspects of land-based operations
- Minimal overburden or stripping: the mineralization generally occurs directly on the seafloor and will not require large pre-strips or overburden removal common to many land based mining operations where commonly up to 75% of the material moved is waste
- Minimal footprint: the high-grade of material that will be extracted, along with the minimal amount of overburden, will result in a very small physical footprint
- Limited processing waste: the high-grade material and gold-bearing pyrite by-products present in the material stream mean there will be limited, if any, mineral processing waste
- Increased worker safety: the operation is controlled remotely from the PSV, not requiring operators to be exposed at the cutting face

However, the deep-sea environment is more dynamic/connected and 3-dimensional compared to terrestrial life, restricted to a thin veneer around the surface, and deep sea ecosystems are thought to recover only slowly from disturbance (Billett et al 2015). Although the total amount of sediment moved may be less, plumes from seabed mining may be extensive and move considerable distances both vertically and horizontally (MIDAS 2016). And since there are no physical borders, mining of one area can affect other areas. Halfar & Fujita (2002) point out that this poses particular issues for mining within the EEZs, suggesting that “the international community should be concerned about pollution of international waters by unregulated mining activities within the EEZs of individual countries.” This concern is partly addressed by the UNCLOS (Article 2008) requirement for national laws and regulations to be “no less effective than” the international regime.

Overall, there is a need rapidly to increase our knowledge deep-sea environments, and of the full range of services they support. Determining the “true” value of deep-sea minerals, when additional factors such as possible impacts on ecosystem services are taken into account, is at present challenging (UNEP et al 2012) and this hampers effective decision making. The uncertainty is pervasive in part because research has been limited, compared to more accessible environments, and
mostly focused on ecology (species abundance, distribution and diversity and community structures) (Rex and Etter, 2010).

Recent work has started to study the relationship between deep-sea ecology and ecosystem service, notably Danovaro et al 2008. Knowledge of deep-sea ecosystem services has been reviewed by Armstrong et al (2012) and by Thurber et al (2014), with the latter focusing more on the ecological relationships and the former more on the challenges of valuation.

Multiple frameworks have been posed as the initial step to communicate the ecosystem functions and services provided by different habitats. Generally these frameworks or classifications are traditionally centred around terrestrial assessments, partially owing to the limited availability of data and methods to assess the provision of marine and coastal ecosystem services. It is therefore not surprising that the applications of ecosystem services in marine contexts span a short history (Liquete et al., 2013). Thurber et al (2014) argue that ecosystem services frameworks developed for terrestrial environments, and discussed in the context of deep sea environments by Armstrong et al. (2012), are not well suited to the deep sea due to the low resolution of spatially explicit marine information and the difficulty of quantifying ecosystem functions and processes in the highly dynamic and connected three-dimensional marine environments. Indeed many of the services identified by Armstrong et al are supporting or intermediate services in the deep sea that underpin crucial final services elsewhere in space and time. This does not sit well with recent approaches such as CICES or FEGS, which focus only on the final services. Le et al (2016) meanwhile stress the likelihood for discovery of unknown final and supporting services. Hence, though Liquete et al. (2013) produced an adaptation of the CICES framework to cater for marine and coastal ecosystem services, Thurber et al. argue that they “came up short” in addressing the concerns put forward by Armstrong et al. (2012) and van den Hove and Moreau (2007) and state that it is “imperative that renewed efforts are undertaken to adapt existing ecosystem services frameworks ... or to create new solutions... developing multiple appropriately structured classification systems for different purposes presents an opportunity to enrich our thinking about ecosystem services and find appropriate solutions.”

One specific problem associated with the complexity marine ecosystems, and their connectivity with other systems and services across space and time, is that it makes knowledge transfer very challenging. Jobsvogt et al (2014b) call for new communication tools to increase understanding of ecological values outside the science community. They present the “Ecosystem Principles Approach” attempting to explain the importance of ocean processes via easily understandable ecological principles, derived through a Delphi process with experts. The ecosystem principles describe ecosystem processes, link such processes to ecosystem services, and provide spatial and temporal information on the connectivity between deep and shallow waters. However, while such initiatives are of course valuable aids to communication and consultation, they do not get round the more fundamental issue of great uncertainty and gaps in knowledge about deep-sea ecosystems – this is a research and learning issue, not a communication problem. Nevertheless, there clearly is a gap between scientific understanding of possible DSM impacts and the views of civil society, as borne out by the EC Consultation (Figure 10; CEC 2015b).
2.2.3 Valuation applied to deep sea systems and services

A few studies have attempted to apply valuation methodologies to investigate public preferences for the protection of deep-sea ecosystems. Jobstvogt et al (2014a) present a choice experiment study of Scottish households willingness-to-pay for additional marine protected areas in the Scottish deep-sea. The experiment focused on the elicitation of economic values for two aspects of marine biodiversity: (i) the existence value for deep-sea species and (ii) the option value of deep-sea organisms as a source for future medicinal products. Survey respondents were willing to pay £70 to £77 each to promote deep-sea biodiversity conservation and develop new medicinal products from deep-sea. Wattage et al (2011) report a similar study showing the public of Ireland willing to pay up to €10 each to protect deep-sea corals from trawling, for biomedical raw materials, essential fish habitats and carbon sinks. Jobstvogt et al (ibid, p18) conclude that “policy makers are better off to consider the existence value that people associate with species protection in combination with the direct benefits of marine protection, and that overlooking non-users will necessarily lead to undervaluation of marine ecosystems.”

Aanesen et al (2015) present a study of CWC conservation in Norway. They report that, despite the fact that marine industries such as oil/gas and fisheries could be adversely affected by CWC protection, this did not reduce the respondents' willingness to pay for further protection. The possibility
that CWCs play an important role as habitat for fish was the single most important variable to explain respondents' Willingness to Pay (WTP) for CWC protection. The survey revealed a high degree of preference heterogeneity, with an average WTP for CWC protection in the range of EUR 274–287.

The results are interesting, and somewhat in conflict with those of Falk-Andersson et al (2015) who find in focus groups that respondents were generally not willing to support exploratory closures of fishing grounds while the presence and status of CWCs was checked. This may be to do with the less discursive approach of the choice experiment and the way the fishing/protection trade-off is presented (indeed Aanesen et al note that people value CWC due to its role as habitat for fish not only because fish provides food (and generate income) for them, but also because they care about the existence of fish, and state that they were not able to disentangle these two motives for WTP). There could be a framing issue here that is relevant to the use and interpretation of valuation results.

Hanley et al (2015) review evidence on marine and coastal valuation, asking if it is ‘fit for purpose’. With reference to the deep sea, they conclude that gaps in scientific knowledge mean that it is hard to predict the effects of changes in deep-sea ecosystem management on the delivery of intermediate and final ES. This makes the use of production function methods for economic valuation difficult. Moreover, an almost-complete lack of experience with and understanding of deep-sea ecosystems on the part of the general public creates problems for the use of stated preference methods to estimate non-use values for deep-sea biodiversity, or to estimate WTP for deep-sea protection, since peoples’ preferences for these assets will be highly incomplete. Although stated preference and focus group approaches can be quite holistic compared to the ecosystem services framework – in that they can look at values for protection of whole systems, not individual functions or services – this still begs the question of whether people understand what they are valuing. And whilst the use of valuation workshop methods can help fill knowledge gaps on the part of those sampled, this creates problems in knowing how sample values should be aggregated to the population level.
3. Decision support for DSM

The above discussion has highlighted the complex range of potential impacts of DSM, the different stakeholders and scales affected, and the generally high uncertainty regarding many of the impacts. In the face of this complexity and uncertainty, investors and operators need to make informed decisions about exploration and technology development. National policy makers and international bodies, in particular the ISA, face the difficult task of developing appropriate governance frameworks, licensing and operational requirements, taxation and liability regimes for DSM. And civil society generally faces profound choices about the role of DSM in sourcing minerals, developing a ‘green economy’ and transitioning to a sustainable future.

To help in these tasks, DSM policies and projects can be subjected to appraisal in various ways, depending on the decisions to be taken and the interests and needs of the decision makers and other stakeholders. Below, we review these tools, their advantages and limitations and applicability to the DSM case. We focus primarily on tools that different stakeholders might use for overall appraisal, rather than evaluation of specific impacts – in particular, we do not dwell on Environmental Impact Assessment, because that has been covered in some detail in the MIDAS deliverable 8.2 “Review of existing protocols and standards applicable to the exploitation of deep-sea mineral resources” (Billett et al 2015b).

All of the tools considered should be seen as ways of structuring the available information so as to help decision-makers to understand the trade-offs involved in decisions. They do not provide ‘final answers’ and are an aid to deliberation, not a replacement for it. This caveat applies to all applications, but a fortiori to DSM, where the high uncertainty regarding impacts, and the lack of knowledge of deep-sea ecosystems and their services, place substantial limits on the usefulness of standard decision support tools.

3.1 Appraisal methods

Financial appraisal, economic impact assessment, cost-benefit analysis (CBA) and multi-criteria assessment (MCA) all build on the idea of aggregating information about costs and benefits of different projects (Gamper et al., 2006), and the initial steps are similar. The methods start with a resource allocation problem to be solved within a defined decision context. The different project options and policy alternatives must be developed, as must a ‘baseline’ or ‘counterfactual’ scenario. The boundaries of assessment need to be set out, in particular relating to whose values are to be taken into account – for example assessment may be restricted to impacts on a nation state and its citizens, or a global scope may be chosen. Certain impacts, both negative (costs) and positive (benefits), then need to be identified and where possible measured in comparison to the baseline/counterfactual. The scope of this stage varies: while financial appraisal will be concerned only with cashflow impacts, CBA looks to assess all impacts that influence human welfare, but essentially ignores welfare-neutral ‘transfer’ payments (such as government subsidies or tax payments for example) between entities within the boundaries of the analysis. In most cases, the concerned stakeholders need to be identified and in some cases involved in the assessment. The time and resources available for analysis need to be clarified, and may constrain the level of detail possible or influence the choice of method: when spending public money on assessments, it is important that the level of resources invested be proportionate with the consequences of the policy options.
3.1.1 Baselines

Any form of economic appraisal involves the comparison of different “states of the world” – the state of the world under ‘baseline’ or ‘counterfactual’ conditions (i.e. without the change(s) that are the subject of appraisal), and one or more states of the world with the change(s) or intervention(s) that lead(s) to different outcomes. This can apply to comparisons of total values of whole sectors (though such comparisons do not usually correspond to realistic policy options) as well as to rather more realistic assessments of marginal changes in resource use and access.

When considering comparisons between different uses of resources - such as exploiting deep-sea minerals or leaving them in situ - one essential issue is to compare like with like. Establishing a consistent and appropriate baseline against which comparisons can be made is therefore a key step in providing an accurate assessment of changes in resource allocation.

The baseline has a variety of slightly different definitions, depending on the context in which it is used. HM Treasury in the Magenta Book defines the baseline as “the situation before the policy” is implemented (HM Treasury, 2011). The European Commission (EC, 2009) states that the aim of the baseline is “to explain how the current situation would evolve without additional public intervention – it is the ‘no policy change’ scenario” (EC, 2009). Defra (2010) focuses on the “change in the provision of the policy good” which is the difference between the level of provision without the decision being appraised (the ‘baseline’) and the level of provision with the project or policy. This change can be measured as a quantity change (e.g. an increase in fish catch) and/or a quality change (e.g. an improvement in average fish size), and may be described qualitatively or measured quantitatively. Whilst the three baselines appear to be similar, the EC and Defra are dynamic baselines which suggest that the economic evaluation needs to predict what would happen in the absence of the policy initiative. Thus the economic practitioner might have to predict what the future would look like both
with and without the policy. Since predicting the future is problematic, economic evaluations may develop a number of policy impact scenarios, such as optimistic and pessimistic outcomes. In some circumstances it may also be appropriate to also develop a number of dynamic baseline scenarios, and the simultaneous use of both baseline and policy impact scenarios can lead to quite complex evaluations.

A good baseline should have a strong factual basis and, as far as possible, be expressed in quantitative terms. It should also be set for an appropriate time horizon (neither too long to be practicable nor too short to cover all relevant impacts). The baseline projection has to provide a clear indication of how serious the problem is, or to what extent it would become more serious without immediate intervention, and whether there are irreversible consequences (EC, 2009) that might call for application of the precautionary principle.

However, the choice of counterfactual is not always clear-cut, and under some circumstances, prediction of the baseline scenario(s) can be as crucial and uncertain as the policy impact prediction(s). Many options can be identified, some are easier to define and measure than others, and data requirements differ. The choice of comparison case may depend on the specific question to be answered, and in many cases the most obvious choice is the ‘most likely’ alternative scenario in the absence of a specific policy intervention.

The choice of baseline is perhaps simpler for DSM than for most decisions, since both the historic baseline and status quo – and, arguably, ‘business as usual’ – involve no DSM. Nevertheless, this still presents considerable challenges, largely because so little is known about the deep sea environment, though also because of uncertainties about how needs, demands and values for minerals may evolve. The lack of known environmental baselines forms a major obstacle for appraisal and planning processes, as has been acknowledged by the ISA on numerous occasions.

### 3.1.2 Boundaries of assessment and comparative impacts

In any particular case, additional considerations arise concerning the determination of system boundaries in space and time – essentially, all changes between the counterfactual and the scenario under analysis need to be taken into account, and we need guidelines to ensure the boundaries are set appropriately to allow for this. Changing conditions (such as social, economic, technological and climate changes) mean that this counterfactual is generally not simply a static ‘status quo’ scenario. With a dynamic counterfactual, we need to account not only for current services and changes to them, but also future potential services and changes to them.

This does not necessarily mean that the area under analysis should be extended to encompass all impacts. A national government, for example, may be entirely justified in limiting attention to impacts that occur within their nation, whereas an international body would have to consider wider impacts, leading to a different result. The CBA presented by Pacific Community (2016) assessed impacts “from the perspective of citizens of the host country based on the operation of a single mine site”, but were a similar study carried out on behalf of the ISA it would need to take a global stance. The point is not that either approach is better than the other, but rather that different approaches are appropriate for different questions. Hence, when considering different analyses, it is important to check that like is being compared with like.

Similarly, the time horizon needs to be set in a manner appropriate to the questions at hand. Generally, decision makers are concerned with more than just the immediate impacts of decisions, and so assessment of resource allocation decisions with long-term or irreversible consequences call

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9 ISBA/Cons/2015/1), page 41; ISA, ISBA/21/LTC/9/Rev.1 (3 March 2015), paragraphs 6-7; ISA, ISBA/20/C/31 (23 July 2014), paragraph 10; ISA, ISBA/17/C/13 (13 July 2011), paragraph 6(e)).
for long time horizons in the assessment. Questions relating to more easily reversible decisions, or comparisons of current flows of value, may reasonably focus on immediate or short-term impacts.

Furthermore, as noted in section 0, the same minerals can be extracted from different sources – terrestrial, deep sea, recycling – and supplies can go further through increased efficiency of use, substitution or avoidance. These means of providing the same final service have different costs and benefits in economic, environmental and social terms. A full societal analysis of DSM would therefore need to consider these impacts not only in absolute terms for DSM, but also in comparative terms across the alternatives. This means not simply terrestrial sources for minerals, but also options of recycling, substitution, and reduction, for example through designing for longer product lifetimes and end-of-life reuse.

The extent to which such complex considerations can be included in individual assessments of DSM is of course rather limited in most cases, but these are important strategic considerations in the context of designing a global ‘green’ or sustainable economy, as discussed above. The important point is to recognise that the results of any appraisal will be strongly dependent on decisions made regarding the appropriate boundaries of assessment – so, for example, an analysis demonstrating a positive benefit-cost ratio over the lifetime of a DSM project from the perspective of a single mining State would not necessarily imply a net benefit from an international, longer-term perspective.

3.1.3 Financial appraisals

DSM is a costly prospect and will only be commercially viable if the market conditions are such that the costs can – predictably and reliably – be supported by the benefits. For any investment or project, financial appraisal is always carried out to evaluate the financial viability of the proposal. Even where a public body is using economic appraisal (e.g. cost-benefit) to determine the overall desirability of a project, it will still need to conduct financial appraisal to ensure that the expenditure needs of the project can be met. Financial appraisal is fundamentally different from economic appraisal in scope and methods, focusing on the effects of cash flow associated with the project from the perspective of the investing organisation. Hence, market prices are used (not measures of opportunity cost/economic value), and discount rates reflect the weighted average costs of debt and equity capital (not estimated social opportunity cost of capital or social time preference). Financial appraisal serves to check that an investment will be profitable overall, and that any temporary shortfalls in cash flow (due to delays between investment and return) can be dealt with. It also serves to check that it is the best use of funds in comparison to other possible investments, often achieved by comparing internal rates of return.

Portfolio analysis is an extension of financial techniques, with a focus on defining a portfolio of policies/options to decrease risks and hedge against uncertain future scenarios. A hedge in this context is “a position established in one area in an attempt to offset exposure to the price risk in another area” (Means III et al., 2010). The analysis relies on estimates of probability distributions and seeks to minimise the portfolio variance, a weighted function of the variances and co-variances of ‘assets’ in the portfolio. Alternatively, Monte Carlo simulations may be used to assess overall risks, and strategies for minimising them through hedging.

Real Option Analysis (ROA) is inspired by financial analysis methods combining classic decision analysis and financial theory. A financial option gives an investor the option to buy a financial asset in the future, at a specified price, if conditions are such that he/she wants to. Applied to decision-making under uncertainty more generally, the focus is on explicit recognition of uncertainties and flexibilities in options. A “real option” in the present context is the ability (but not the obligation) to carry out some action such as investing in, delaying, abandoning, expanding or staging of some resource-extracting project. This method is useful for the analysis of flexibility, learning and future information, in the
presence of significant uncertainty. Analysis that ignores the fact that the future exercising of options can be contingent on the resolution of uncertainties can give misleading results: ROA takes explicit account of these contingencies. ROA will tend to favour projects with important near-term benefits, quite a small variance in outcome scenarios, and/or a long period of waiting for information that could have an impact on the investment decision (Watkiss et al., 2014).

Studies have examined the economic prospects for DSM in various contexts. For example Harskamp (2010) looks at DSM of gas hydrates and finds that for mining to be economically attractive, the required gas price would need to be about ten times higher than the price of 4.2 US$/mmBtu. The illustrative example given by Sharma (2011) is discussed in section 0. ECORYS/MRAG (2014) develop a basic economic model of DSM and make tentative commercial viability calculations for different types of deposit, based on assumptions on capital expenditure, operational costs and revenues. Assumptions are based on available sources, but since no actual operations have yet taken place, and technologies have not yet been fully developed and proven, the estimates are uncertain. The results show that polymetallic sulphides are expected to show the highest commercial viability, whereas nodules and crust are only marginally or not commercially feasible. However there is an important uncertainty regarding polymetallic sulphides, since the analysis suggests an operation of 15 years to generate returns on investment, whereas most resources and proven reserves seem to point to shorter operations at specific sites, and a strain of operations on different locations needs to be established.

Uncertainties regarding financial aspects are one of the main barriers to DSM to date. Sharma (2011) reports that deep-sea mining of minerals such as polymetallic nodules “has been ‘on-hold’ due to several factors such as current availability of Cu, Ni, Co, Mn from terrestrial sources and their fluctuating prices”. Fluctuations can be important and very hard to predict: for example, Jo-Hui and Tushigmaa (2012) detect chaotic fluctuations in prices for rare earth metals. Martino and Parson (2012) identify price volatility as the most important parameter affecting investment in deep-sea mining, and predict that it will lead to postponement of nodule exploitation for one or two decades, with greater uncertainty for crust exploitation, unless there is technical improvement or falling costs.

Prices will also influence which techniques of DSM are preferred. Martino and Parson (2012; 2013) explore the relationship between metal prices and the profitability of different DSM options, demonstrating that cobalt crust mining could be reasonably preferred to manganese nodules at cobalt prices of $40–60/kg if the price of nickel fell below $11/kg. However, when the price of nickel passes the $11/kg threshold, the equilibrium between the two ventures can be reached only at a cobalt price greater than $100/kg, causing cobalt crust to become uncompetitive.

Nevertheless, the uncertainty and price fluctuations seem more likely to delay rather than prevent DSM. Humphries (2013) explains that overall, “costs of mineral extraction are increasing because of lower ore grades and increasing capital costs”, in particular flagging that China’s costs of production are likely to rise. This, coupled with global demand growth, will sooner or later put upward pressure on mineral prices. If prices do indeed rise, developing deep-sea resources could be both economic and a strategic response. However this potential is not yet considered a mainstream option in mineral assessments. For example, David Merriman of Roskill Consulting Group gave a 2013 presentation to Royal Society of Chemistry that reviewed the present and future global supply of rare earth elements: there is absolutely no mention of marine sources either as potential future source or as geographical location for deposits, though there is mention of recycling and urban mining.

### 3.1.4 Economic Impact Assessments (EcIA)

EcIA is a quantitative method used to estimate the economic benefits that a particular project or industry brings to the area where the specific project or industry is located. It usually measures
changes of output, gross value added (GVA), employment and tax revenues associated with changes in the level of economic activity resulting from the project or industry being analysed. It also measures changes in business revenue and profits, personal wages, and/or jobs. In general, economic impacts can be estimated at the direct, indirect and induced levels.

An EcIA has to be undertaken with reference to an identifiable constituency, and this is usually a geographical area. For many policy contexts the most relevant constituency is a whole country, but other constituencies are also common – assessments at the regional level, or for a specific administrative region or local community. It is important to remember that the results of an EcIA analysis are sensitive to the constituency selected, so results from EcIAs with different constituencies cannot be compared directly.

EcIA recognises that the various sectors that make up the economy are interdependent. Changes in activity in one sector will have impacts on the sectors that support it through providing inputs. At the same time, changes in incomes will lead to changes in expenditures, with consequences for other sectors. So EcIA covers three different levels of impact:

- Direct impacts related to the specific sector under analysis: for example, jobs and incomes in agriculture;
- Indirect impacts related to other sectors supporting it: for example, incomes and jobs in food processing, distribution and, marketing, incomes and jobs in production and maintenance of agricultural machinery and agrochemicals; and,
- Induced impacts that result from those involved in the sector spending their income within an area in the community: for example, incomes and jobs supported by agricultural workers’ expenditures on goods and services.

These impacts are often estimated using multipliers derived from Input-Output analysis, discussed below. For most simple EcIA applications, the use of published I-O tables and associated multipliers is likely to be the most practical solution. For environmentally extended EcIA, fewer ready-made tables are available, but there are exceptions, notably the EXIOBASE database system that transforms the supply–use tables of individual countries into an international input-output table that can be used for the analysis of the environmental impacts associated with the final consumption of product groups. The next step beyond static IO models is general equilibrium modelling, which may also include environmental coefficients. The methods are applicable wherever one of the questions of interest is the impact on economic activity and employment: they do not directly reveal anything about impacts on human welfare overall.

### 3.1.5 Cost benefit analysis

Cost-benefit analysis (CBA) is a decision support method, widely used in public sector policy appraisal, which compares, in monetary terms, as many benefits and costs of an option (project, policy or programme) as feasible, including impacts on environmental goods and services. CBA is designed to target two of the most crucial appraisal questions: “Is a given objective worth achieving?” and if so, “What is the most efficient way of doing this?” Inevitably, however, there are data gaps and uncertainties in all applications.

CBA is grounded in the TEV framework: in principle, positive improvements are valued through Willingness to Pay (WTP) and deteriorations through Willingness to Accept compensation (WTA), though in practice WTP values are generally used for all changes. Comparisons of cost and benefit streams are made using net present values (NPV) calculated as total discounted benefits minus total discounted costs, expressed in monetary terms:
\[ NPV = \sum_{t=0}^{T} \frac{(B_t - C_t)}{(1 + \delta)^t} \]

where \( B_t \) is the benefit, and \( C_t \) is the cost, in each period \( t \), \( \delta \) is the discount rate, and \( T \) is the time horizon for the assessment (in almost all cases, \( t \) is expressed in years).

One use of CBA is to compare options for resource use in a specific decision or case, for example to estimate a benefit-cost ratio for a proposed deep sea mine. Another use is to rank/prioritise spending possibilities in terms of their internal rate of return, for example to compare alternative sources of minerals. Provided all relevant options are considered, and all costs and benefits can be included in the analysis, the option with the highest NPV is revealed as the economic optimum (in TEV terms). In practice, there are always some non-marketed costs or benefits for which values are not available, so most real CBA is ‘constrained’ by these unpriced impacts that need to be considered separately.

Allocation problems in economics can be broken down into efficiency and fairness components. Efficiency is a matter of maximising value to society, and depends on equating the marginal values of resources to different activities. Achieving efficiency is largely determined by the effectiveness of markets and of policy aimed at correcting market failures (such as open access). Fairness is about distribution of benefits, and is often determined by allocation of property rights, or other rules about the conditions under which different people can access a resource. Efficiency and fairness are in principle separate issues: where efficiency arguments suggest that one user should have more rights to resources (because marginal values are higher), fairness arguments might suggest that those with less access should be compensated.

CBA is based on maximising (the NPV of) TEV. Thus it is not directly concerned with fairness of allocations: a positive NPV shows the winners could compensate the losers, but that does not mean that they do. This applies both across time periods (intergenerational equity) and within a time period (intragenerational equity). In principle, CBA can be carried out with distributional weighting, in order to put more emphasis on benefits to the less wealthy members of society. In practice, however, income weighting is not common for assessments concerned with environmental goods and services, because impacts are rarely identified for separate income groups. Slightly more common is the practise of identifying groups of winners and losers separately from the main CBA results (not necessarily by income group – this can be groups of residents, or groups with shared characteristics (such as ‘tuna fishers’) so that decision makers can take these distributional impacts into account.

It should be noted that, while the principle of the common heritage of mankind (see section 4.3 below) does not dictate specific measures for compensation, it provides a philosophical and broad legal framework to guide decisions and by implication the choice of decision support tools. Desiderata include dealing with uncertainty in a precautionary way, reflecting the interests of future generations, and taking account of distributional issues and benefit sharing. While the Kaldor-Hicks criterion applied in CBA allows for a change to be deemed economically efficient provided the ‘winners’ could fully compensate the ‘losers’ and still be better off, the CHM principle can be interpreted as requiring actual compensation for any harm. This does not in itself rule out CBA for decision support purposes, but does add an additional requirement regarding compensation, both intragenerational and over time.

### 3.1.6 Value judgements in appraisal methods

It is important to recognise that the methods used in CBA, and indeed in all forms of appraisal, are not ethically neutral but rather rest on sets of value judgements about whose values should be considered, and how they are taken into account and aggregated. CBA uses values based on the
Total Economic Value (TEV) framework, grounded in working out how individuals are willing to trade-off between resources. The measure of value used is individual Willingness to Pay (WTP) for an improvement or to avoid deterioration. As money is exchanged for changes in quality and quantity of resources, WTP is a monetary expression of how individuals are willing to trade-off across different goods and services. In all practical cases, it is also necessary to aggregate these values across individuals in society, to provide a monetary measure of society’s preferences for alternative uses of its scarce resources. In effect, social preferences are taken as the aggregate of the individuals’ preferences. So this approach involves five main value judgements or assumptions:

1. What “matters” are the preferences of individuals in society;
2. Individual are the best judges of their own welfare and preferences;
3. Individuals express preferences through rational economic choices via their ‘willingness to pay’ (WTP) or ‘willingness to accept compensation’ (WTA) for goods and services;
4. Since WTP is constrained by ability to pay (wealth and income), the method in effect judges that the income distribution in society (under existing arrangements for redistribution via the tax and benefit system) is in some way ‘fair’ or acceptable; and
5. It is valid to add up individuals’ expressions of WTP (or WTA) to reach societal values.

The defined “society” is usually taken to mean the entire population of a country, though it could be smaller regions or in some cases global population.

These value judgements can all be criticised. For example, most individuals are generally highly unfamiliar with deep sea ecosystems and their services: it takes a great leap of faith to assume that they can judge how uncertain changes in these systems will influence their welfare. And, the highly unequal income distributions within and between nations are widely considered not to be fair; CBA using values based on these income distributions would place much lower weight on environmental impacts to poor communities in developing states than on the same impacts to wealthier populations.

Similar points apply to all appraisal methods – the reliance on value judgements is not unique to CBA. But it is perhaps especially important to flag this dependency for CBA, since appraisals can give the appearance of providing ‘the answer’, particularly when values are expressed in monetary terms. So it is important to recognise that these figures are only valid within the bounds of the assumptions and value judgements used to derive them.

### 3.1.7 Multi-criteria assessment

Multi-criteria analysis or multi-metric decision-making takes a broader approach to evaluating different outcomes, using a range of weighting methods to include a full range of social, environmental, technical and economic criteria, with a focus on quantifying and exploring trade-offs (Chambwera et al., 2014).

This approach deals with the situation where efficiency and benefit are only two criteria among others, such as cultural or ecological criteria, which are difficult to quantify, especially in a single numeraire. Criteria are identified and weighted, and the different solutions that should be compared are assessed following these criteria, making the comparison possible. Criteria may be clustered – for example, a MCA for sustainability might group criteria under the three dimensions of sustainability (economic, social, and environmental). Typical steps in MCA include: (i) definition of options; (ii) selection of criteria; (iii) scoring options against the criteria; (iv) defining weights for the criteria; (v) assessing the weighted sum; and (vi) ranking the options (de Bruin, 2013).

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10 There is also Willingness to Accept Compensation (WTA) as a monetary measure of trade-offs. Individuals may have WTA to forgo an improvement and to tolerate a loss.
The approach can integrate both quantitative and qualitative data in the ranking of alternative options, one of the main strengths of this method, making it applicable where quantification and valuation in monetary terms of costs and/or benefits is not possible (UNFCCC, 2002). But the weightings lack the theoretical underpinning of preference-based valuation, and can be arbitrary, lacking robustness. They are potentially open to manipulation (favouring particular views/stakeholders) and/or introducing assumptions and consequences that are not fully understood or intended by stakeholders. Sensitivity analysis and transparency in process and reporting can partly address these problems.

It is likely that DSM will occur in a relatively small number of areas, such as the Clarion Clipperton Zone in the equatorial eastern Pacific, mid ocean ridge systems and a few selected seamounts. There are many environmental issues that are common to any particular development in all of these areas. However, some potential environmental risks may extend beyond the boundary of a single mining site, while others may lead to cumulative impacts in association with other uses of marine space (such as deep-water fisheries). Environmental risks, therefore, need to be considered at a broad (regional) scale and environmental management procedures may need to be tailored to the resources and ecosystems under pressure. As a result, it is important to develop approaches for environmental management within a Strategic Environmental Assessment.

### 3.1.8 Strategic Environmental Assessment (SEA)

According to Pendleton et al (2013), “strategic environmental assessment is a tool designed to achieve sustainable development by promoting dialogue, mutual understanding, and trust among stakeholders from the grass roots to high-level decision-makers.” This gives a clear distinction from EIA, which focuses on a specific site or project, where SEA takes a broader industry or ocean-wide approach. Billett et al. (2015) note however that SEA is sometimes used rather to refer to broad consideration of environmental and biodiversity issues right from initial planning stages. SEA can also be a combination of these approaches – for example the European SEA Directive (2001/42/DC) (2001) (Annex 19) views SEA as a way of allowing biodiversity and other environmental considerations to be included in the development of new plans, policies and programmes, while taking a broad scope. We think of SEA as an important tool for achieving sustainable development, both in terms of content (strategic-level consideration of full range of impacts) and process (dialogue involving all stakeholders).

Billett et al (2015) refer to various international guidelines and national/regional policies as justifying a SEA approach to managing the marine environment across business sectors and at regional/oceanic scales. Mengerink et al (2014) argue that “single-sector approaches, necessary for managing specific activities, are not sufficient to ensure balanced resource use and sustainability.” They give the example of Chatham Rise in New Zealand, where the site proposed for deep-ocean phosphate mining overlaps with an existing “benthic protection area” that prohibits bottom trawling under New Zealand fisheries requirements. Taking a SEA approach in such situations may help to resolve competing demands for marine space and resources, and take account of cumulative impacts. More broadly, SEA could be used as a formal structure for considering the role of DSM in achieving a green economic transition and sustainable development overall (as discussed in section 0). Such implementations of SEA would have to consider the duration and frequency of environmental impacts, the areas and scales affected, the cumulative or synergistic effects, the timescales of effects and their possible reversibility/recovery, and the full range of uncertainty associated with all of these aspects. Similar consideration would be required for health and safety, social and economic impacts, as well as for the social/economic consequences of the environmental impacts. This could include consideration of the indirect impacts through changes in primary and secondary resource markets.
Further details of SEA, its application to DSM, and various legislation including the EU SEA Directive (2001) and the Protocol on Strategic Environmental Assessment to the Espoo Convention (2003d) (Annex 20) are discussed in Billett et al (2015). They flag the ISA’s use of SEA in adopting the regional (strategic) environmental management plan (SEMP) for the Clarion Clipperton Zone (CCZ), incorporating many of the aspects of an SEA process for polymetallic nodule mining, considering the environmental management of the whole 4.5 million km² area, taking cumulative impacts into account, and setting aside about a third of the seabed area as nine no-mining “Areas of Particular Environmental Interest” in order to protect the full range of habitats and biodiversity. The SEMP provides some flexibility to modify the boundaries based on improved scientific information about the location of mining activity, measurements of actual impacts from mining operations, and more biological data if equivalent protection can be achieved. Billett et al (2015) also report that the United Nations General Assembly invited the LTC to prioritize the development of SEMPs for other regions of mining interest, with a strategy for the development of further strategic environmental management plans being a current priority for the ISA.

### 3.1.9 Dealing with uncertainty and long-term impacts

In standard economic appraisal, risk and time are addressed through the use of expected values and discounting. Calculating expected values requires knowledge of the probability distributions of different outcomes. Where multiple sources of risk exist, Monte Carlo methods are often used to build up distributions of overall outcomes.
However in many situations, and certainly for the case of DSM, we are facing not risk but uncertainty, following the definition of Knight (1921:19), who made the distinction between measurable risk and immeasurable uncertainty, arguing that “it will appear that a measurable uncertainty, or ‘risk’ proper… is so far different from an immeasurable one that it is not in effect an uncertainty at all. We ... accordingly restrict the term ‘uncertainty’ to cases of the non-quantitative type.” This distinction is maintained in much of the economics literature. The distinction is important because, where the distribution is not known, it is impossible to calculate an expected value. In addition, since much of the uncertainty relates to lack of knowledge regarding deep sea processes and ecology, the probabilities associated with specific impacts and sites are not independent, and so would not tend to ‘average out’ across assessments.

Taleb et al. (2014; see Figure 13) demonstrate how increased uncertainty about outcomes should motivate more precautionary policies. An increased chance of ruinous outcomes (thicker left tail) is much more policy-relevant than the increased chance of happy surprises (thicker right tail). This is in effect the mathematical representation of the reasoning used by Halfar & Fujita (2002; see section 0 above) when they argue that the known damages of terrestrial mining may be preferable to the unknown dangers of DSM. Similar points could be made about other options such as recycling.

![Figure 13: Comparison of different levels of uncertainty (source: Taleb et al 2014)](image1)

The use of discounting makes costs and benefits far in the future much less important than present costs and benefits. There is some debate concerning the appropriate use of discounting for ecosystem services, in particular for the far future. Standard economic methods define the social discount rate as a function of pure time preference and consumption growth, via the Ramsey formula, $\rho_t = \delta + \eta \cdot g_t$. This defines the discount rate at time $t$ ($\rho_t$) as the sum of the utility rate of discount ($\delta$) and the rate of growth in consumption between the present and $t$ ($g_t$), weighted by the elasticity of marginal utility of consumption ($\eta$). A recent US EPA expert panel of 12 economists (Arrow et al., 2012) unanimously agreed that “the Ramsey formula provides a useful framework for thinking about intergenerational
discounting.” However, they did not reach agreement on “how the parameters of the Ramsey formula might be determined empirically”, let alone on actual values. They explain this with reference to a long-running debate between a “descriptive” approach (based on behaviour observed in markets) and a “prescriptive” approach (focusing on ethical considerations to set parameters).

So despite its importance, there is no universally accepted way of calculating a discount rate, resulting in a multiplicity of estimates. Discount rates of a few percent, standard for short-term policy appraisal, result in huge discounting of long-term impacts – applying these rates for climate policy would justify a “wait and see” approach. Some authors advocate declining or hyperbolic discount rates (Kirby, 1997) to combat this problem. Others use a low constant rate - the Stern Report (Stern, 2006), for instance, has been criticized (Nordhaus, 2007) for using a very low discount rate (0.1%), a factor of ten or more less than conventional studies (e.g. 4% average in DICE model, Nordhaus 2008).

Faced with this ambiguity, different authors draw different conclusions. Heal & Millner (2014) argue that there are no objectively correct discount rates, just different ethical positions that should all be taken into account: they argue that climate policy analysis “becomes an exercise in social choice” that requires aggregating “the diverse preferences of individuals into a representative discount rate”. Against this, however, one could argue that there is no way to know the preferences of most of the individuals involved, namely future generations. Weitzman (2007) instead recasts the debate by stressing that expenditures to combat global change “should perhaps not be conceptualized primarily as being about consumption smoothing as much as being about how much insurance to buy to offset the small chance of a ruinous catastrophe that is difficult to compensate by ordinary savings.”

The standard approach can also be criticized for failing to account for different attitudes to growth and decline. There is an underlying assumption in most policy/economic circles of continuous economic growth, but situations in which the PP is applicable can include scenarios of substantial economic decline or collapse. Moxnes (2014) reports evidence that, when very long-term sustainability of well-being is threatened, most people’s implicit discount rates do resemble the low estimates used by the Stern Review. Moxnes also reports that standard social welfare functions represent people’s choices well only along steadily increasing consumption paths, but are not able to capture people’s aversion to overshots and fluctuations. Zuber & Asheim (2012) argue for an extended rank-discounted utilitarian (ERDU) criterion in which discounting becomes a simple expression of intergenerational inequality aversion: it discounts the wealthier generations, making it a strong ethical choice, while being equivalent to discounted utilitarianism on non-decreasing consumption paths. Moxnes (2014) proposes the discounted utility of relative growth in per capita consumption, giving a welfare function that is averse to fluctuations and overshoots in the consumption path.

This brief overview of a large and diverse literature suggests that discounting is likely to be particularly controversial for highly risky situations. Dietz (2011) argues that, although welfare estimates do strongly depend on tail risks, for a set of plausible assumptions time preference still matter. These assumptions include, in particular, capping the maximum losses and the assumption that tail risks are both unlikely and distant: these may be appropriate assumptions for general analysis, but do not apply to the cases where strong precaution may be justified. Evidence suggests that standard approaches to discounting do not reflect people’s choices when faced with such situations; where collapse is possible, discounting is ethically very dubious, at best. Certainly, we cannot expect widespread agreement on the ‘best’ approach – even amongst top economists, this is not possible (Arrow et al., 2012). Moxnes (2014) poses the question “could one do without welfare functions and discounting when choosing between policies?”, and reports that people presented with graphs of policy consequences over time are indeed able to make consistent choices.
3.2 Initial appraisal attempts for DSM

The idea of DSM goes back some decades. The controversial discussions under the Third United Nations Conference on the Law of the Sea from 1973 to 1982 (which culminated in the adoption of a new Convention on the Law of the Sea in December 1982) prompted the Kiel Institute of World Economics to launch a major research project (Donges, 1985) focusing on allocational and distributional aspects of the use of ocean resources, split into three parts:

1. the competitiveness of seabed mining compared with land-based mining
2. the potential impact of DSM minerals supply on the world markets for these minerals
3. the income effects expected from deep-sea mining

Key considerations in the research were the strategic importance of certain mineral supplies and the economic efficiency implications of the establishment of the ISA to manage the CHM of deep sea resources, including provisions for compensation to LDCs if their export earnings were damaged by DSM. The UNCLOS / ISA approach was criticised as failing to meet “the minimum requirements for a legal-institutional framework which could operate in an efficient manner” and in particular for failing to “guarantee private appropriability of manganese nodules, because it fails to assign clearly defined, universal, exclusive and transferable property rights to private firms”. (ibid.)

There is a clear 'libertarian' bias in this approach that favours private enterprise over common management, and so it is perhaps unsurprising that the headline conclusions are “that widespread fears in the Third World about the impact of seabed mining have been unduly exaggerated and that the remedy envisaged by the Law of the Sea Convention has no sound economic foundation.” However, the impacts referred to are economic ones, on the mining industries of LDCs, and the ‘remedy’ is barriers to entry/output restrictions. Times have changed, and salient issues today are strikingly broader in remit.

Nevertheless, important conclusions can be drawn from this early study. Part I demonstrates “the strong dependence of deep-sea mining on future factor and mineral prices” and concludes that there is “no such thing as an automatic and everlasting economic advantage of seabed mining over land-based mining”. Part II illustrates that co-production of minerals in different proportions from those common in terrestrial mining could have impacts on markets for metals, though the evidence presented does not suggest that prices would be so depressed as to have major consequences for terrestrial mining. Regarding the distributional consequences, Part III suggests that the changes could be important, though the analysis is 30 years out of date so specifics cannot be relied upon.

Ecorys and MRAG (2014) present analyses looking at the economic viability of deep-sea mining. They develop a basic economic model and present initial commercial viability calculations for a range of DSM options. Since DSM is not yet commercially practised, with technologies and operational plans still under development, the calculations are based on assumptions about capital expenditure, operational costs and revenues, drawn from a range of available sources, and should be treated with caution.

The results show that polymetallic sulphides are expected to show the highest commercial viability, whereas nodules and crust are only marginally or not commercially feasible. Key uncertainty regarding polymetallic sulphides is that it assumes an operation of 15 years to generate returns on investment, whereas most resources and proven reserves seem to point to smaller sizes and a strain of operations on different locations needs to be established.”

Pacific Communities (2016) present initial CBA and EcIA for three case studies of potential mining operations: Seafloor-massive Sulphide (SMS) Deposits in Papua New Guinea (PNG), Polymetallic
Manganese Nodules (MN) in the Cook Islands, and Ferromanganese Cobalt-rich Crusts (CRC) in the Republic of Marshall Islands (RMI). This work has also been written up in a forthcoming Marine Policy article (Wakefield & Myers, 2016).

The scope of the analyses is the impacts on the citizens of the host countries. Hence, the full economic benefits are not assessed – in particular, the costs and benefits to mining companies are not directly included. However they do influence the level of royalties that can be expected, which are included. Similarly, the environmental costs assessed are limited to the impacts on citizens of the host countries.

The results (Table 2) are argued to be “fairly robust to a reasonable range of uncertainty related to input values and discount rates” – with one case showing negative net benefits, and the other two showing benefits one or two orders of magnitude greater than costs.

Table 2: CBA results from Pacific Communities (2016) case studies

<table>
<thead>
<tr>
<th>Country</th>
<th>Resource</th>
<th>Total Costs</th>
<th>Total Benefits</th>
<th>Net Benefits</th>
<th>Benefit-Cost Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>PNG</td>
<td>Seafloor-massive Sulphides</td>
<td>$0.64</td>
<td>$83.3</td>
<td>$82.7</td>
<td>124</td>
</tr>
<tr>
<td>Cook Islands</td>
<td>Manganese Nodules</td>
<td>$27.4</td>
<td>$494</td>
<td>$467</td>
<td>18</td>
</tr>
<tr>
<td>RMI</td>
<td>Cobalt-rich Crusts</td>
<td>$29.3</td>
<td>$39</td>
<td>$0</td>
<td>0</td>
</tr>
</tbody>
</table>

Note 1: This amount is received from royalty payments, however, since neither of the RMI scenarios were economically feasible from the perspective of the miner, the country would not incur any costs nor receive any benefits; therefore, the net benefits and benefit cost ratio are both zero.

Source: Pacific Communities (2016)

Alongside the CBA, an input-output model (IMPLAN) was used to quantify the effects of DSM mining on local communities and on each country as whole by estimating employment effects and value added (total labour and other income) supported by expenditures associated with mining operations. In addition to the cost-benefit analyses, a regional economic impact model was used to assess the local employment and income effects associated with the operation of a DSM mine in each of the case study countries. The results of the models indicate modest employment and income effects relative to annual royalties received from DSM mining.

Insofar as it deals with the likely economic benefits to the local community, the CBA is fairly standard, though of course how any gains would be distributed through society, and across time, remain important policy issues. The research is more innovative in the ways it seeks to tackle the environmental impacts, in the face of severe data constraints. Below we review and then critique the methods and assumptions used.

The external costs associated with changes in services provided by deep-seabed habitat were estimated by:

- Cataloguing the types of ecosystem services likely to be provided by the deep seabed communities at each of the mines,
• Determining the size and magnitude of any DSM mining-related changes in the level of services provided by deep seabed communities, and
• Using willingness-to-pay literature and replacement cost methods to estimate the value of lost ecosystem services

In practice, the costs that were in fact included are:

• the costs of offsetting carbon emissions, based on a report on the State of the Voluntary Carbon Market with low estimate of $3.7, most likely of $5.8, and maximum of $7.4.
• the costs to citizens of oil spills from vessels, based on an estimate of compensating the public for ecosystem services lost following a spill (estimated in Kontavas and Psaraftis, 2010) at $24,000 per tonne multiplied by estimated annual spillage
• costs of discharging nutrient-rich water near the surface, but this is assumed to be zero due to operational measures that remove risk of discharge (at some cost to the companies)
• an estimate of damages to three services (biological control, genetic material, and habitats/refugia) based on assessment of ‘equivalency’ with forests/wetlands as explained below.

Services are assessed “relative to a forest or wetland”:

• 0 implies the deep-sea habitat provides almost no service relative to a forest or wetland.
• 1 implies a level much less than a forest or wetland
• 2 implies somewhat less than a forest or wetland.
• 3 implies a level similar to or greater than a forest or wetland

The omission of additional categories for values much greater than forest or wetland is justified on the grounds that those systems provide substantial services.

The changes in services, which may be positive or negative, are then assessed in terms of their significance to residents:

• 1 implies that the change is unlikely to be perceptible by residents
• 2 implies that the change may be perceived by residents
• 3 implies that the change would most likely by perceived by most residents.

The results are used to compile a replacement cost estimate. The loss estimate is driven by the area impacted and by the proportion of service loss expected.

For PNG, the reports states that “while there would be a temporary and localized increase in turbidity and sedimentation rates the primary DSM mining related impact to deep seabed communities would be related to the levelling and cutting away of the seabed crust in the 14 hectare mining site”. At this small scale, “changes in biodiversity and/or impacts to the limited provisioning or regulating services provided under baseline conditions would not likely be perceptible to PNG residents” and “likely the primary component of any perceptible change in service provision would be associated with reduced cultural value; this change could persist in the longer term.” Damage is estimated as 85% service loss within the environmental footprint, and service levels are assumed to recover after 100 years. The expected loss is estimated using a 7% annual discount rate. Given these assumptions, the expected loss of services, using a 7% real rate of discount is 367 deep-sea vent “DSAYs” or “Discounted Service Acre Years”.

For the Cook Islands case, DSM mining related impacts are related to the proposed nodule collecting system as it lifts and collects nodules from 2,705 km² of seafloor. This is a large area, but only 2% of
the total area of this type around the Cook Islands. Conversion of primarily hard substrate deep seabed to primarily soft bottom deep seabed would result in long term changes to the resident community, but the authors argue “the resulting change in the provision of services is expected to be minor and may, in some instances, be positive”. Hence, material impacts to provisioning or regulating services are not anticipated. The primary impact would be associated with the conversion of hard seabed to soft sediment and the subsequent reduction in nursery services. Assuming nursery services represent one third of the composite service and allowing for a 25% reduction in nursery services to persist from the time of impact in perpetuity, the total loss is calculated to be 445,857 deep seabed DSAYs.

For the RMI case, the 20 year mining footprint covers 470 km² on a single sea-mount. However mining would occur at a number of small sites, leading Pacific Communities to assume “that individual mining sites are widely distributed across the individual sea-mount. This “patchwork approach” maximizes the probability of recolonization and recovery.” It is assumed that supporting services represent the entire composite service and could decline by 50% in perpetuity, leading to a loss of 470,000 deep sea-mount DSAYs at a 7 percent discount rate. This is despite stakeholders suggesting service losses could be 100%, rejected on the grounds that (1) the topographic relief of the seamount would not be materially changed by mining and provides both nursery and feeding services and (2) a large portion of regulating services are provided by bacteria “which would likely recover in a matter of days”.

Since estimating the cost of replacing/restoring deep sea habitats is not feasible, instead the cost of creating saltmarsh is used. The equivalence between saltmarsh and deep sea bed is estimated using the “productivity logic” of Peterson et al. (2007) who established a series of equivalency ratios based on the relative productivity (gC/m²y) of any two habitats. This gives a ratio of 1ha of saltmarsh ‘equivalent’ to 203ha of ‘flat and undifferentiated’ seabed.

For the PNG case, this is then adjusted to allow for the seabed being ‘relatively three dimensional and includes thermal and chemical loading sources’ by reducing the ratio to 1:9.22. The estimated loss of 367 deep-sea vent DSAYs would then be offset by the creation of 40 wetland DSAYs. The cost of creating 40 wetland DSAYs is estimated to be $454,000 based on NOAA et al. (2013). For the Cook Islands case, the assumption of ‘flat and undifferentiated’ is maintained, so the estimated loss of 445,857 deep seabed DSAYs would be offset by the creation of 2,196 wetland DSAYs, estimated to cost $24,928,000 based on NOAA et al. (2002). The same assumption is maintained for the RMI case (although “flat and undifferentiated” seems an odd description for a sea mount) so the 470,000 deep sea-mount DSAYs would be offset by 2,315 wetland DSAYs at a cost of $26,277,000 based on NOAA et al. (2013).

The results are compared to the economic valuation results from Earth Economics (2015), who present what they describe as “the first ever natural capital accounting and ecosystem goods and services framework for seabed mining”, an independent report commissioned by Nautilus Minerals Inc. They report an annual willingness-to-pay for ecosystem services of up to $1,766 per hectare of deep seabed, based on:

- Biological control services valued at $26 per hectare per year.
- Genetic material valued at $277 per hectare per year.
- Provision of nursery habitat valued at $1,464 per hectare per year.

This figure was based on values associated with cloud forests, due to the lack of valuation studies related to the deep-sea vent services. Since “cloud forests are some of the most productive and bio-diverse ecosystems on the planet” the authors repeat the claim for Earth Economics that this “represents a highly cautious (tending to overestimate) approach to valuation.” The Earth Economics
report, discussed below, appears to describe a global willingness-to-pay (whereas the Pacific
Communities CBA only gives 'standing' to national residents), and the value is for total loss of services
without allowing for any residual services and recovery.

Pacific Communities (2016) note for the PNG case that “while both valuations are challenging given
the current level of biological and economic understanding, both methods suggest the present value of
seabed-related changes are unlikely to exceed $650,000.” For the Cook Islands, they note that “the
area to be mined in the Cook Island EEZ is reported to be one of the least productive habitats on
earth” and consequently adjust downwards significantly the Earth Economics figures, assuming zero
for the first two categories, while for the nursery habitat “it is assumed deep seabed nursery values are
similar to the alpine grassland value of $3.38 per hectare per year estimated by Asquieth et al.
(2008)”. They further assume that DSM could reduce that value by 25% in perpetuity (but at a 7%
discount rate) to claim that “the NPV of ecosystem service losses is calculated to be no more than
$1,859,000.” For RMI, they note “the area to be mined in the RMI EEZ is not nearly productive as
active sea vent areas or the cloud forests to which they were compared” and consequently adopt zero,
$6.19 and $8.03 per ha, based on low ends of ranges in the Earth Economics report. Assuming
complete loss of service in perpetuity, at 7% discounting, leads to “NPV of ecosystem service losses is
calculated to be no more than $5,411,000.”

3.2.1 Critique of existing estimates

There are clearly serious difficulties in interpreting - and dangers in using - the figures produced in the
Pacific Communities assessment. The authors have attempted to deal with the paucity of data in
several areas (in particular, the ecosystem services of deep sea environments, the potential damages
from mining, the implications of damage for services, the possible rate of recovery, the values arising
from services) by creating some fairly heroic assumptions about equivalents. This leads to annual
damage estimates that are essentially meaningless in the context of the potential for actual damage –
unless we accept the idea that the assumptions are so deliberately 'conservative' (in the sense of
'assuming the worst') that they provide an upper limit. The report does in effect attempt to claim this,
but the claim does not stand up to scrutiny.

In particular, the assumption that effects are necessarily limited to the direct footprint area may not be
justified, and there seems to be no compelling reason to accept that services overall are directly
related to productivity. Furthermore, the ratio calculated by the authors used the result of Feijtel et al
(1985), which is for primary productivity in Louisiana saltmarsh. We have not been able to find the
original of Peterson et al, but one derived journal article (Wong, Peterson and Pielhler, 2011) explains
the rational for a focus on secondary productivity “as a metric of food web support to evaluate different
estuarine habitats.” As explained in the NOAA memorandum “Conversion factor between offshore
benthic habitat and marsh habitat in the DBL 152 Oil Spill” (Baker and Arismendez, 2011) the
Peterson et al. results for benthic macrofaunal productivity led to NOAA accepting a ratio of 4.5 acres
of offshore benthic habitat to 1 acre of tidal wetland – very different from the 203:1 ratio used by
Pacific Communities (2016).

Secondly, using a 7% annual discount rate means that the impact of any long-term environmental
damage on the CBA would be heavily constrained. For example, a $1m per year loss in perpetuity is
evaluated at just $14.29 million.

The Earth Economics report gives the appearance of being conservative by valuing the deep sea vent
system using values derived for cloud forest, citing the grounds that “cloud forests are some of the
most productive and biodiverse ecosystems on the planet” to justify concluding that “this represents a
highly cautious and "conservative" approach.”
However there are a number of issues that mean this is not necessarily the case. Firstly, the actual assumption is that “the deep seabed is at least as valuable as cloud forests in terms of biological control, habitat & nursery, and genetic resources” (p81, emphasis added). This gives a total estimate of $1,766/ha.y, whereas the value used for all services of cloud forests is $13,351/ha.y. The difference arises because many service categories are deemed not applicable to the deep sea case, in particular energy/raw materials, food, recreation, climate stability, and nutrient cycling. Some of these are appropriate omissions, others debatable.

Secondly, it is far from clear that the ‘habitat and nursery’ service described for forests is at all comparable with the habitat and nursery service for deep sea vents. The deep sea system could be providing nursery, feeding and refugia functions for species that do not spend their entire life-cycle in the habitat, to a much greater extent than we might expect for cloud forest. In addition, the function/service is often discussed in marine studies in terms of supporting fisheries production, which is rather different from the forests case (where food is considered separately). The further assumption is made that “South Su and nearby vents likely hold the same diversity of life for dominant species as at the mine site, and recolonization of the mine site at the conclusion of mining is expected to reflect the genetic structure of the baseline conditions for all numerically dominant species” (p62, emphasis added). This neither adequately reflects the major uncertainties regarding deep sea biodiversity, nor gives sufficient weight to the less common genes and organisms that are important components of biodiversity, and in particular the potential for endemic organisms at vent sites (Dyment et al 2014). In addition it is not clear how the habitats value has been derived for the cloud forest: tracking the value down is challenging, since the reference is incorrectly cited as ‘New Jersey Type A Studies 2006’, but this appears to be Costanza et al (2007) who report a value11 for habitat/refugia services of forests of $923/acre.y (in 2004$ values) citing many of the same studies as on p114 of the Earth Economics report, though it is not clear how this tallies with the $1463.67/ha.y (2014$ values) figure cited. But it should be noted that the studies here are not for cloud forests: the study by Kenyon and Nevin (2001) is for woodlands in the Scottish borders; the Amigues et al (2002) study is for riparian buffer strips on the Garonne River near Toulouse, France; Haener & Adamowicz (2000) is a case study for Alberta; Shafer et al (1993) is an older set of case studies from Pennsylvania. The range of values presented by Costanza et al runs from $1 to $3242 per acre.y.

Thirdly, cultural values generally are rather glossed over, in keeping with the general assumption that “Because Solwara 1 is so remote, the potential for ecosystem service beneficiaries is low.” The report states (p66) “No physical links to cultural or spiritual value were found” and then dismisses the one possible source of conflict found (“Local people expressed concern about the project impacting cultural practices such as shark calling, a cultural event in which people attract and harvest sharks in shallow coastal waters. Due to the distance from the shore, the background noise associated with the North Su volcano on the seafloor and fishing vessel activity in the area, it is unlikely that the mining project will impact shark calling or other cultural practices.” Similarly, “No cultural or artistic inspirational values were noted at the site.” and “mining activity is likely to have an impact on the natural beauty of vents at the mine site, although no local residents will be impacted”. There is no mention of the possibility of wider non-use values for the global general public, which might be out-of-scope from the perspective of a locally-focused CBA, and would clearly also exist for systems such as cloud forests, but could be significant for a global assessment of alternative sources of minerals including reuse, recycling, substitution and reduction.

Under ‘science and education’, the report argues that “Solwara 1 has a unique potential for contributing to a greater scientific understanding of the deep seabed and for examining deep seabed mining impacts and the resiliency of deep sea vent systems.” This is potentially true, up to a point, and

11 Type A are “peer-reviewed empirical analyses that use conventional environmental economic techniques”, type B is “grey literature” and type C is “secondary, summary studies”. For habitat/refugia, only type A studies are found by Costanza et al hence the values for type A and type A-C are identical.
the value of learning could be seen as a benefit of mining provided adequate research and monitoring protocols are put in place. However the timing of developments should be taken into account – it may well be possible to learn more through a more gradual approach, e.g. for better assessment of baseline conditions prior to mining operations. The argument put forward in the report treats a terrestrial alternative site differently (“There is no scientific agenda associated with the Intag mining plan. As Intag is located in a biodiversity hot spot, the potential for loss of scientific information within the project area is high.” p65). Obviously, there may be better ways to study ecosystem functioning in cloud forests than by clear-cutting them for mining, but this is also true for deep-sea environments.

The combined effect of the above is to render the calculated estimates - whether from the value transfer exercise, or from the resource equivalency estimates - largely meaningless from the perspective of assessing the pressing policy question of whether or not commercial DSM is a responsible and appropriate development at present. This is not to say that the conclusions are necessarily incorrect; the PNG site, for example, is indeed on a relatively small area of seabed, exploiting relatively rich copper/gold deposits (compared to terrestrial mines), and it is quite possible that the inevitable environmental damages could be a price worth paying for the economic and (potentially) social benefits of extraction. The point is rather that, at the current state of knowledge, the cost-benefit and value transfer exercises are of basically no use in determining whether or not this is the case.

### 3.3 Appropriate approaches for deep sea mining

As the above discussion shows, we need to recognise both that full expected-value cost-benefit analysis is not currently feasible, and that it is not fully appropriate as a guide to DSM decisions. The second conclusion partly follows from the first, but also from the fundamental nature of the uncertainty (fat tails as shown in Figure 13 and poorly known distributions) and from the legal framework, in the form of the requirement to apply the precautionary principle, and the requirement to avoid ‘serious harm’.

Several methods for policy setting and evaluation rely on the definition of thresholds, with a specific activity, or development in general, deemed ‘sustainable’ provided these thresholds are not breached. These approaches are particularly relevant where there is significant uncertainty regarding adverse outcomes, such as in DSM.

In particular, the ‘safe minimum standards’ approach has been developed to take into account uncertainty and irreversibility within natural resources management. It has been applied, for example, to water quality, agricultural land use and endangered species conservation (Crowards, 1996). The basic principle behind safe minimum standards is to take account of uncertainty regarding future environmental impacts and associated costs by setting mandatory thresholds that should not be breached. These standards are considered ‘safe’ in the sense of avoiding possible serious damages, and ‘minimum’ in the sense that they do not rule out more stringent control efforts. The approach is closely related to the Precautionary Principle and to the ‘maximin’ rule (i.e. setting policy so as to maximise the ‘payoff’ under the ‘worst case’ scenario). Great emphasis is given to the long-term benefits of preserving nature, compared to any current benefits of development. The safe minimum standard approach is thus a conservative, risk-averse method.

A particular form of safe minimum standards, defined with respect to a baseline rather than with an evaluation of likely consequences, is to require No Net Loss (NNL) of particular important habitat types. This is appropriate where uncertainty is high, loss is ongoing and it is recognised that serious impacts or thresholds could be reached without knowing it. NNL has been developed primarily in the context of biodiversity conservation. The EU biodiversity strategy to 2020 (CEC, 2011) for example, aims to ensure “no net loss of biodiversity and ecosystem services” (target 2, action 7), with the
intention to propose by 2015 a supporting initiative, perhaps using compensation or offsetting schemes.

An alternative but related approach requires the definition of ‘critical natural capital’ that must be maintained. Critical natural capital (CNC) is usually defined as that part of the natural environment that performs important and unique functions, and therefore ought to be maintained in any circumstances for present and future generations. In policy terms this represents a form of safe minimum standard: the idea of critical natural capital reflects the view that there is some level of natural capital that is ‘essential’ and provides important ecosystem services that cannot be substituted by other forms of capital, such as human or social capital (de Groot et al., 2003; Dietz & Neumayer, 2007). Depending on the scale, this could mean anything between globally essential, e.g. to continuing human life on the planet, and locally essential, e.g. a minimum level of accessible green space for psychological well-being, and anything in between. Typical examples include essential ecosystem services, such as freshwater resources, climate regulation and fertile soils (Ekins et al., 2003).

In economic terms, this can be conceptualised as an area of perfectly inelastic demand for natural capital below a certain level of provision; it is a natural extension to consider gradually increasing demand elasticity above the absolute threshold (Figure 14, Farley 2008). There are limits to the use of economic methods where marginal values rise steeply, and a recognition that critical natural capital cannot be traded-off. Identifying critical natural capital is partly outside the remit of economics (a matter of biophysical science) but can also depend on ethical deliberation and how minimum thresholds of acceptable outcomes are defined. For example, it is possible to argue on cultural/ethical grounds that particular sacred sites should be accorded critical status, and excluded from trade-off, though this has nothing to do with ecology or natural functions. This can go some way to addressing the concerns relating to incommensurability of values, by setting ‘hands off’ areas where trade-off is not permitted.

![Figure 14: The demand curve for natural capital (Farley, 2008:3)](image)
3.3.1 Using the concept of ‘serious harm’

In the specific context of DSM, defining critical natural capital is difficult, perhaps impossible, given present knowledge, since we know so little about deep sea ecosystem functions, and the possible impacts that DSM could have on them.

Similarly, No Net Loss is difficult to apply, since we know very little about prospects for restoring deep sea habitats. Restoration of deep sea habitats would clearly be challenging, expensive and perhaps impossible. There is some evidence that restoration could work in some cases. Strömberg et al (2010) report experiments in which CWCs from northeastern Atlantic grown in laboratories and reintroduced to the sea floor had 76% of corals surviving after three years. Barbier et al (2014) cite UK efforts to develop ‘coralbots’, swarms of autonomous undersea vehicles that could transplant and monitor coral fragments in the deep sea to combat habitat damages. They also note, however, that restoration of freshwater and coastal environments shows that systems do not recover full function, or at least not very quickly. Restoration of deep-sea environments is likely to suffer similar problems, but would be hugely more expensive due to the challenges of working at depth. Van Dover et al (2014a) suggest a cost of up to US$75 million to restore one hectare of trawled coral seabed at the Darwin Mounds hummocks, for example. Overall, we know very little other than that it would likely be extremely expensive and long-term, and we are certainly not in a position today to roll out restoration to compensate for losses/damages from DSM. The EU-funded MERCES12 project will start to address this evidence gap, exploring restoration potential in deep-sea environments.

Under UNCLOS and the ISA mining code, the notion of avoiding serious harm is invoked, although it remains vague and requires further discussion and definition. In effect, the requirement to avoid serious harm recognises the widespread uncertainties and is very similar to the establishment of a Safe Minimum Standard. The question is begged, however, of how, exactly, to define ‘serious harm’? Do we have enough knowledge for that? And how does ‘serious harm’ interact with the Precautionary Principle: what should be the standard of evidence required to establish a risk of serious harm, and where should the burden of proof lie?

Currently, serious harm is defined as “any effect from activities in the Area on the marine environment which represents a significant adverse change in the marine environment determined according to the rules, regulations and procedures adopted by the Authority on the basis of internationally recognized standards and practices” (ISA Regulations (nodules), 2000; ISA Regulations (sulphides); 2010, ISA Regulations (crusts), 2012)). The ‘standards’ in question are required to ensure the application of “best environmental practices” and the precautionary approach (ISA, 2010 Regulations 31(2); ITLOS, 2011).

There are various provisions under UNCLOS making use of the ‘serious harm’ concept (Articles 162(2)(w),(x) and 165(2)(k),(l)) (see e.g. Levin et al, in press). In particular, “where substantial evidence indicates the risk of serious harm to the marine environment” the ISA has the power to:

- set aside areas where mining will not be permitted
- deny a new application for a contract to conduct seabed mineral activities
- suspend, alter or terminate operations via emergency orders
- hold the contractor and its sponsoring state liable for any environmental harm if it ensues.

This also applies to national laws and regulations for mining activities within national jurisdiction, since those rules are to be “no less effective than” the international rules, standards, and recommended practices and procedures (UNCLOS article 208).

“*The Commission shall develop and implement procedures for determining, on the basis of the best available scientific and technical information… whether proposed exploration activities in*

http://www.merces-project.eu/
the Area would have serious harmful effects on vulnerable marine ecosystems … and ensure
that, if it is determined that certain proposed exploration activities would have serious harmful
effects on vulnerable marine ecosystems, those activities are managed to prevent such effects
or not authorized to proceed.” (ISA Regulations 2000, 2010, 2012 (nodules 31.4; sulphides
33.4; crusts 33.4))

On the face of it, these are reasonably strong powers. However, the definition of ‘serious harm’ begs
the question of what constitutes a ‘significant’ adverse change. Furthermore, the strength of the
condition is rather weakened by the qualifier “where substantial evidence indicates…” Nevertheless,
Jaeckel (2015) notes a strengthening of the requirement to avoid serious harm in the most recent
nodules Exploration Regulation, where the text evolved towards a "threat of serious harm" being
sufficient to trigger action:

"[For] those activities which under the Exploration Regulations require a higher likelihood of
harm, the probability threshold has been lowered in the more recent Exploration Regulations.
For example, the original Nodules Exploration Regulations, adopted in 2000, provided for
emergency orders in case of an ‘incident resulting from or caused by a contractor’s activities in
the Area that has caused, or is likely to cause, serious harm to the marine environment.’ In
contrast the later Exploration Regulations require emergency orders for an incident ‘that has
caus[ed], is causing or poses a threat of serious harm to the marine environment.’ These
changes were based on the LTC’s considerations ‘that the use of the term “likely to cause
serious harm” as a trigger for action to be taken in pursuance of a precautionary approach
implied a degree of certainty that was incompatible with the precautionary approach, which
requires that there be only a threat of serious damage.” (Jaeckel 2015, p. 154)

Le et al (2016) recognise that the definition of “serious harm” is still under debate within the ISA. They
propose that in the context of DSM, "ecosystem services can serve as one measure for identifying
serious harm, e.g. if an activity will result in the loss of ecosystem services sufficient to affect mining
decisions". This, they argue, because ecosystem services link environmental health to human well-
being.

Compared to other requirements under UNCLOS and / or ISA, such as e.g. ISA required to ‘ensure
effective protection’, ‘best environmental practices’, or even the precautionary approach, the concept
of avoiding ‘serious harm’ is different because serious harm can constitute a trigger for liability. This
makes a clarification of the definition all the more necessary. (Levin et al. forthcoming)

Provided a definition of serious harm can be agreed upon, and available knowledge and data can
ensure that it is respected, this can be seen as establishing the ‘sustainability’ boundaries within which
more conventional appraisal may be seen as relevant. In other words, anything that risks causing
‘serious harm’ would be ruled out; for remaining options, we would still need to carry out financial and
cost-benefit appraisal to check that the projects would be both commercially viable and beneficial to
society. But some of the fundamental objections to the use of economic appraisal methods, in
uncertain and long-term environmental contexts, as discussed above, would be partly neutralised by
the requirement for all projects, individually and together, to ensure no serious harm.

3.3.2 Accountability and process

The very definition of the precautionary principle involves value-laden language (SREP 2011). Taking
the EEA definition (see Box 4), such elements include: ‘serious or irreversible threats’, ‘appropriate
strength’, or ‘pros and cons’. The precautionary principle calls for a consideration of the pros and cons
and specifically stresses both action and inaction, to recognize the asymmetry that may exist in
making a type 1 or a type 2 error, that is, between (i) forbidding an action based on supposed risks
which turn out not to exist and (ii) authorizing an action based on supposed absence of risks which turn out to be present. The principle includes the objective of going beyond narrow cost-benefit considerations and embracing the broader picture, both in terms of who benefits or loses (private companies, countries, societies, ecosystems...) and by taking a broader perspective than mere financial value.

Operationalising the precautionary principle therefore calls for participatory processes whereby stakeholders can contribute to identifying the values and stakes to which the principle may be applied. Yet, though these processes are necessary, they may not be sufficient, as they may not provide for capturing some dimensions and in particular aspects operating at very long time scales. Here, ideas such as creating custodians or advocates for future generations could be considered (Read, 2012).

Scobie (2015) present research on the discourses around deep-sea exploitation for petroleum products, involving environmental, social and economic issues very similar to those arising in the DSM debate, reporting that the most common themes emerging around accountability came down to process. "It was about involving the public in decision-making, at all stages of the process." Scobie argues that "accountability is providing a credible story about what is happening now, what could happen next, how one will respond, and why an activity should or should not go ahead." He points to two opposing narratives competing to appeal to public opinion, both generated by powerful coalitions, and appealing to fundamental aspects of human behaviour, prosperity and compassion, but with completely different implications:

- The industry/government camp pushes the “can’t turn off the tap” and “way of life” argument, combined with the promise of economic prosperity and “hospitals, schools and jobs.”
- The activist/opposition camp pushes the ecological and social justice argument of having to act now in order to ensure a prosperous future for “the Other”. By “the Other”, Scobie means species, the natural environment, and future generations. This is combined with a different promise of economic prosperity through investing in alternative forms of energy and transportation.

One is powerful in terms of political position and financial resources, and the alternative is because of the effective use of storylines laced with morality, designed to appeal to core-human values. This arena, like many others is a constant argumentative struggle where actors try to make others see the problems in their own specific way, presenting seemingly technical positions that in fact conceal normative commitments (Hajer, 1995). This is not to argue that the dominant economic discourse is wrong, necessarily, but rather that it is incomplete. There are clearly potential economic benefits from DSM: the unresolved and contentious issue is whether the benefits outweigh the risks.

How society defines accountability is crucially “dependent on the ideologies, motifs and language of our times” (Sinclair, 1995, p. 221). Economics is “a powerful and parsimonious analytical technique, yet, more and more, we are taking it as a doctrine of behaving, of choosing and of being” (Roscoe 2014, p. 14). But the body of theory, arguments and tools that form neoclassical economics is “not ethically neutral, but rather ascribes moral justice to self-interested actions by equating these actions with the provision of the collective good” (Shearer, 2002, p. 565). The assumption held by supporters of exploration - that increased investment by government and industry will drive future benefits for the general population through wealth accumulation and “trickle down” - is “a normative commitment concealed by economic discourse” (Scobie, 2015). The narrative of neoclassical economic efficiency driving growth is easy to grasp and repeat, but the ways in which wealth accumulation “trickles down” to wealth distribution and social outcomes is much less intuitive and obscured by complex calculations and models. Scobie argues that data “cherry-picked” from such arcane practices “makes it the perfect story-line for particular sectors of society to advance their own interests.”
As a result of competing forces seeking to mobilise public opinion using “issue amplifiers” (such as the “hospitals, schools and jobs” motif), opinion on appropriate responses to risk becomes polarised. Renn (1992) points to two entrenched positions:

- ‘no compromise’: no risk should be taken if there is any danger whatsoever – an extreme form of the precautionary approach.
- ‘no free lunch’: any risk is justified as long as it leads to progress - a rather less extreme form of the “maximise expected value” decision rule.

The challenge for progressive actors in the DSM debate, and in particular for the ISA, is to steer a course between these extremes through open and inclusive consultative processes, guided by the principle of the Common Heritage of Mankind.

**Box 2: Kaitiakitanga**

Kaitiakitanga is a Māori concept of guardianship and stewardship of the land. It has been included in some New Zealand legislation, including the Resource Management Act 1991 which seeks sustainable management of environmental resources and states that people managing resources under the Act must take kaitiakitanga into account. The act defines kaitiakitanga as “the exercise of guardianship by the “tangata whenua” (“person or people of the land; people belonging to a tribal region of an area”) in accordance with tikanga Māori in relation to natural and physical resources; and includes the ethic of stewardship’. Kaitiakitanga was also included in the Foreshore and Seabed Act 2004, where it has the same meaning.  

Kaitiakitanga is the value most frequently presented in the literature as being able to inform Western governance, accounting and business (Craig, Taonui & Wild, 2012; Kamira, 2003; Schneider, Samkin, & Pitu, 2012). It loosely translates to imply guardianship, protection, care and vigilance (Kamira, 2003). It also introduces the idea of an intergenerational responsibility and obligation to protect, rather than implying ownership (Kamira, 2003). Rae & Thompson-Fawcett (2013) suggest that kaitiakitanga is the most commonly cited principle adhered to by iwi when developing policy. It is defined as an ancestral obligation to collectively sustain, guard, maintain, protect, and enhance mauri (life being or force) (p. 16). An actor who carries this responsibility is called a kaitiaki and the obligation of the kaitiaki is embodied in resource management practices. The relationship between the kaitiaki and the resource is seen as reciprocal. Social, economic, and political benefits are obtained through resources but the resources must be cared for and even improved. Kaitiaki are genealogically linked to the resources and derive rights and responsibilities through whakapapa.  

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14 Papa-tū-ā-nuku (Earth Mother) represents the close relationship that Māori share with the natural environment through the concept of whakapapa (genealogy). Whakapapa establishes people as an inseparable part of nature, and says that all things - human and environment - are related through ancestry (Rae & Thompson-Fawcett, 2013). According to Māori culture, all people are descended from the union between Papa-tū-ā-nuku and Rangi-nui (Sky Father) (Royal, 2015)
4. Principles of good governance

4.1 Visions for sustainability

Governance for deep-sea mining, and indeed for any human activity with potential positive and negative ecological, societal and environmental consequences, is best framed in the broader context of a societal vision - some form of understanding of where a society is aiming to get in the long term. This vision may be developed and formulated in different ways depending on the scales in question. Private enterprises and civil society organisations may have mission statements setting out their aspirations for their role in society. National governments have objectives for growth and development for their populations, often set by a ruling party, and that may be formally stated and in some cases put to an electorate in the form of a political manifesto. At supranational scales, the objectives of international and global bodies are generally developed through processes of negotiation and agreement.

In the European Union, a vision of sustainable development has gradually been constructed and codified. The Treaty on European Union (1992; OJ C 191 of 29.07.1992) added the objective ‘to promote economic and social progress which is balanced and sustainable’ to the Community's tasks, while the Treaty Establishing the European Community (1992; OJ C 224 of 31.08.1992) added the objective of ‘sustainable and non-inflationary growth respecting the environment’ (Article 2), and created ‘a policy in the sphere of the environment’ under Article 3. Mainstreaming was also mandated in Article 130r, which includes the line: ‘Environmental protection requirements must be integrated into the definition and implementation of other Community policies.’ The Amsterdam Treaty (1997; OJ C 340 of 10.11.1997) enshrined sustainable development in the preamble and objectives of the EU Treaty.

The periodic Environment Action Programmes articulate a more detailed vision of sustainable development: currently, the Union’s 7th Environment Action Programme (7EAP) intends that “In 2050, we live well, within the planet’s ecological limits. Our prosperity and healthy environment stem from an innovative, circular economy where nothing is wasted and where natural resources are managed sustainably, and biodiversity is protected, valued and restored in ways that enhance our society’s resilience. Our low-carbon growth has long been decoupled from resource use, setting the pace for a safe and sustainable global society.”

However, there is a long history of tension between the holistic vision of balanced sustainable development across social, economic and environmental objectives and a narrower focus on “growth and jobs”. Notably, the Lisbon Strategy (Lisbon Presidency Conclusions; European Council 2000) envisioned the EU becoming ‘the most competitive and dynamic knowledge-based economy in the world capable of sustainable economic growth with more and better jobs and greater social cohesion’, by 2010. The following year, the Sustainable Development Strategy (SDS) (Gothenburg Presidency Conclusions; European Council) (re-)emphasised the need to balance the three pillars of sustainable development, and adopted the CBD’s 2010 Biodiversity Target as the headline objective for managing and conserving natural resources. This tension has remained central to the European polity, but the Lisbon emphasis on innovation, growth and jobs became the dominant political focus (Steurer and Berger, 2010), and continued to hold by far the greater weight in recent years, and especially in the Juncker Commission, as evidenced by its stated political priorities.

At the international level, interest in Sustainable Development dates back to the Brundtland report “Our Common Future” (United Nations, 1987), which set out the “analysis, the broad remedies, and
the recommendations for a sustainable course of development”, defined by the report as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs.” This vision has been mainstreamed and updated to the extent that Sustainable Development has become the overarching global aspiration for the future. The UN General Assembly, in its resolution 70/1 on the Sustainable Development Goals (SDGs) 'Transforming our world: the 2030 Agenda for Sustainable Development' adopts an extensive sustainability vision (Box 3).

Box 3: The UN vision underlying the 2030 Agenda for Sustainable Development

Our vision

7. In these Goals and targets, we are setting out a supremely ambitious and transformational vision. We envisage a world free of poverty, hunger, disease and want, where all life can thrive. We envisage a world free of fear and violence. A world with universal literacy. A world with equitable and universal access to quality education at all levels, to health care and social protection, where physical, mental and social well-being are assured. A world where we reaffirm our commitments regarding the human right to safe drinking water and sanitation and where there is improved hygiene; and where food is sufficient, safe, affordable and nutritious. A world where human habitats are safe, resilient and sustainable and where there is universal access to affordable, reliable and sustainable energy.

8. We envisage a world of universal respect for human rights and human dignity, the rule of law, justice, equality and non-discrimination; of respect for race, ethnicity and cultural diversity; and of equal opportunity permitting the full realization of human potential and contributing to shared prosperity. A world which invests in its children and in which every child grows up free from violence and exploitation. A world in which every woman and girl enjoys full gender equality and all legal, social and economic barriers to their empowerment have been removed. A just, equitable, tolerant, open and socially inclusive world in which the needs of the most vulnerable are met.

9. We envisage a world in which every country enjoys sustained, inclusive and sustainable economic growth and decent work for all. A world in which consumption and production patterns and use of all natural resources – from air to land, from rivers, lakes and aquifers to oceans and seas – are sustainable. One in which democracy, good governance and the rule of law, as well as an enabling environment at the national and international levels, are essential for sustainable development, including sustained and inclusive economic growth, social development, environmental protection and the eradication of poverty and hunger. One in which development and the application of technology are climate-sensitive, respect biodiversity and are resilient. One in which humanity lives in harmony with nature and in which wildlife and other living species are protected.


Specifically for the marine environment, the UNCLOS (1982) defines the rights and responsibilities of nations with respect to their use of the world’s oceans, establishing guidelines for businesses, the environment, and the management of marine natural resources, and providing roles for organisations including the International Maritime Organization, the International Whaling Commission, and the
International Seabed Authority (ISA) that was established by the Convention. The preamble\textsuperscript{17} includes elements of the societal vision:

- Recognizing the desirability of establishing ... a legal order for the seas and oceans which will facilitate international communication, and will promote the peaceful uses of the seas and oceans, the equitable and efficient utilization of their resources, the conservation of their living resources, and the study, protection and preservation of the marine environment,

- Bearing in mind that the achievement of these goals will contribute to the realization of a just and equitable international economic order which takes into account the interests and needs of mankind as a whole and, in particular, the special interests and needs of developing countries, whether coastal or land-locked,

- Desiring by this Convention to develop the principles ... that the area of the seabed and ocean floor and the subsoil thereof, beyond the limits of national jurisdiction, as well as its resources, are the common heritage of mankind, the exploration and exploitation of which shall be carried out for the benefit of mankind as a whole, irrespective of the geographical location of States,

- Believing that the codification and progressive development of the law of the sea achieved in this Convention will contribute to the strengthening of peace, security, cooperation and friendly relations among all nations in conformity with the principles of justice and equal rights and will promote the economic and social advancement of all peoples of the world, in accordance with the Purposes and Principles of the United Nations as set forth in the Charter,

Realising these visions requires the development and implementation of various policies and actions. These policies and actions necessarily build on a series of governance principles, often set out within the visions, which can be understood as bridges between underlying values and actions. However, there are often tensions or inconsistencies between visions at different scales, for example between corporate and societal objectives, between competing political and civil society visions for a society, or between national interests and international obligations. There can also be tensions between principles and even between visions for any given organisation – as discussed above, the European vision in the 7EAP and the actual political priorities of the Commission, for example, may not be entirely compatible.

It is important, therefore, both to unpick the guiding principles and objectives of societal visions to understand how they shape governance and policy options for DSM, and to explore how differences across competing visions can be understood and perhaps reconciled through consultation and negotiation in appropriate forums, which may need to be developed as part of the governance framework.

4.2 European stance

As discussed briefly above, European environmental policy has followed a gradual path of enhanced focus on sustainability and stronger environmental protection, though this emphasis has weakened in recent years, with the strongest environmental focus coming in the 5EAP (1993-2000: Towards Sustainability'). The policies have been built on a number of guiding principles set out in treaties. The 1987 Single European Act was a turning point for EU environmental policy (SEA, 1986; OJ L 169 of 29.6.1987), because the title ‘Whereas environmental protection requirements shall be a component of the Community's other policies’ was added to the Treaty establishing the European Community. This was not so much a radical change, but rather a codifying of existing principles. Nevertheless, it

\textsuperscript{17} \url{http://www.un.org/Depts/los/convention_agreements/texts/unclos/preamble.htm}
gave Community environmental measures a legal basis, defining objectives and guiding principles, and putting economic and ecological objectives on a more equal basis (Haagsma, 1988). The rationale was not fully one of environmental sustainability, however, since harmonisation of environmental standards at 'high level' remained a priority, to avoid distortions of free trade and maintain global competitiveness (Haagsma, 1988).

Article 191 (2) of the Treaty on the Functioning of the European Union\(^{17}\) states that: "Union policy on the environment shall aim at a high level of protection taking into account the diversity of situations in the various regions of the Union. It shall be based on the precautionary principle and on the principles that preventive action should be taken, that environmental damage should as a priority be rectified at source and that the polluter should pay."\(^{19}\) This incorporates the four key principles of environmental governance: the precautionary principle, prevention, rectification at source and polluter pays.\(^{20}\)

In the Synthesis of its report ‘the European Environment: State and Outlook 2015’ (EEA 2015, p 156s), the European Environment Agency identifies four prevailing, interrelated and complementary approaches in current environmental policy: mitigate, adapt, avoid and restore (Figure 15). The report suggests that considering these four approaches together both in terms of policy implementation and for future policy design could accelerate the transition to a green economy and sustainability. It is interesting to note that there is no one to one correspondence between these four modes of action and the four environmental principles of the EU Treaty stated above. Yet different types of action (mitigation, adaptation, avoidance and restoration may build on different principles or a combination of them.

\[\text{Figure 15: Modes of strategic approaches to transformation}\]

\(^{17}\) Formerly the Treaty of Rome, amended and renamed as the TFEU by the Lisbon Treaty 2007, entered into force in 2009.

\(^{19}\) Those four principles were already present in the 1992 Maastricht Treaty on European Union (Art. 130r)

\(^{20}\) It is interesting to note that, as recognised by the EU institutions, "(...) in practice, the scope of this principle is far wider and also covers consumer policy, European legislation concerning food and human, animal and plant health." (http://europa.eu/legislation_summaries/consumers/consumer_safety/l32042_en.htm)
Applied to the case of DSM, the natural position for Europe would be to seek to see these same principles adopted in the global governance framework, and by European businesses involved in DSM activities. This follows partly as a matter of principle, but also because sustainability can only be achieved at a global scale, due to the interconnectedness of the supply chain (including DSM resources) and of the global environment and biogeochemical cycles (where deep sea disturbances could have planetary scale consequences).

4.3 Governance principles for Deep Sea Mining

This section focuses mostly on ABNJ but is relevant also for mining in EEZ since under UNCLOS (Article 2008) national laws and regulations for mining activities within national jurisdiction are to be “no less effective than” the international rules, standards, and recommended practices and procedures. Hence international regulations will set the standard for national regulations and States will be asked to revisit their regulations to make sure they follow guidelines of the ISA.

At the international level, some key principles govern deep-sea mining. Some are spelled out in the UNCLOS, others in the ISA mining code and other ISA documents and reports. An examination of those principles may help contextualise the discussion about DSM. Ultimately it brings us back to the questions “Why and under which conditions should we mine in the deep-sea?”

One of those principles is the precautionary principle or approach. The exploration regulations of ISA specifically oblige all actors (the ISA, sponsoring states, and mining operators) to apply the precautionary approach (Jaeckel 2015). In those regulations, explicit reference is made to Principle 15 of the Rio declaration which spells out a precautionary approach (see below).

Other key governance principles for DSM include the Common Heritage of Mankind (CHM) and the Polluter Pays Principle, and the overarching framing goal of sustainable development. These build on the unequivocal obligation under UNCLOS to protect and preserve the marine environment (Article 192). There are also a series of obligations of a more procedural nature, including obligations to:

- use best environmental practices;
- carry out prior environmental impact assessment;
- ensure transparency and participation.

We will examine these principles and obligations briefly before focusing in more detail on the precautionary principle, which is especially applicable to the case of DSM.

4.3.1 Common Heritage of Mankind

The 1982 United Nations Convention on the Law of the Sea declares the seabed beyond national jurisdiction (‘the Area’) and its mineral resources as the ‘common heritage of mankind’ (CHM). Jaeckel et al. (2016) stress how this principle informs every aspect of the international seabed mining regime and establishes a legal distinction between the Area and the water column, the latter still being governed by the principle of the freedom of the High Seas. A central aim of the inclusion of this
principle was to ensure that developing States, which may not have the technical and financial
capacity to mine in the deep sea, would also access some of the benefits (ibid.). Hence the
International Seabed Authority (ISA) can be conceived as "the institutional manifestation of the CHM
principle" (ibid, p. 199). However the operationalisation of this principle is not provided for by UNCLOS
and the relevant implementation agreement26. This is a task that was left to ISA.

Jaeckel (2016) identifies a series of elements composing the CHM (Table 3) and stresses that "whilst
the common heritage of mankind principle requires the sharing of benefits, these can take various
forms, such as financial, environmental, developmental, and/or technological benefits. In addition, the
CHM principle requires the taking into account of not only the interests of present generations, in
developing states and elsewhere, but also of future generations" (ibid).

Table 3: Elements of CHM (Source Jaeckel 2016)

<table>
<thead>
<tr>
<th>ELEMENT</th>
<th>EXPLANATION</th>
<th>SOURCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-appropriation</td>
<td>All rights in the resources of the Area are vested in mankind as a whole and no state can claim sovereignty or sovereign rights over the Area and its resources.</td>
<td>Art. 137</td>
</tr>
<tr>
<td>Common management</td>
<td>All seabed mining activities in the Area are organised and controlled by the ISA on behalf of mankind as a whole.</td>
<td>Arts. 156-185</td>
</tr>
<tr>
<td>Regulated utilisation</td>
<td>The rules, regulations and procedures adopted by the ISA are binding on all member states, regardless of individual consent.</td>
<td>Arts. 137(2), 153(1)</td>
</tr>
<tr>
<td>Environmental protection</td>
<td>The ISA is required to protect and preserve the marine environment from harmful effects of seabed mining, including for future generations.</td>
<td>Art. 145</td>
</tr>
<tr>
<td>Benefit sharing</td>
<td>Activities in the Area must be carried out for the benefit of mankind as a whole, taking into particular consideration the interests of developing states. The ISA is to provide for equitable sharing of financial and other economic benefits derived from activities in the Area. Other distributive mechanisms include equal participation of all states, transfer of technology (to enable equal participation), preferential treatment of developing states, and protection against adverse effects of deep seabed mining on land-based mining interests.</td>
<td>Arts. 140, 144, 148</td>
</tr>
<tr>
<td>Marine scientific research (MSR)</td>
<td>MSR in the Area is to be carried out exclusively for the benefit of mankind as a whole. The ISA and its member states must support the research capacity of developing states, support the transfer of technology and scientific information relating to seabed mining, and provide for the effective participation of developing states in the seabed mining regime.</td>
<td>Art. 143, 144, 148; IA, annex section 5</td>
</tr>
<tr>
<td>Peaceful purposes</td>
<td>The Area is open to use exclusively for peaceful purposes by all states.</td>
<td>Art. 141</td>
</tr>
<tr>
<td>State responsibility</td>
<td>States parties must ensure that activities in the Area are carried out in conformity with the international regulatory framework. Damage caused by failure to comply with these responsibilities entails liability.</td>
<td>Art. 139</td>
</tr>
</tbody>
</table>

Jaeckel and colleagues (2016) conclude that the current governance framework for deep seabed mining is not yet consistent with the CHM principle. They stress in particular:

- the lack of transparency in the operations of ISA and of the contractors;
- the uncertain mechanism to ensure that developing nations are provided with effective access to deep-sea mineral resources;
- the lack of a fiscal mechanism for financial benefit sharing; and,
- issues related to intergenerational equity and to insufficient consideration of the potential loss or ecosystems and their services.

The CHM principle implies not only the equitable sharing of benefits with current interests but also with future generations (Jaeckel et al. 2016 p. 203). Benefit sharing also implies preserving the ecosystem services provided by the deep ocean for present and future generations (Jaeckel 2016). Yet the principle remains somewhat vague, especially when it comes to its practical implementation, and it is still subject to diverging interpretations by various actors. Jaeckel et al note (p 203) that while it would appear that the CHM principle implies that a significant percentage of the Area's resources should be left for future generations, there is no explicit requirement for this in the Convention, the Implementing Agreement or the Mining Code. The most valuable areas have been licensed on a first come, first served basis with no areas explicitly set aside for future generations. In addition, “there has been little discussion as to whether enjoyment of this financial capital is to be the exclusive preserve of current generations, or whether a portion of it should be set aside for future generations” (ibid).

This discussion can be advanced by recognising that the reach of the Common heritage principle could be interpreted differently depending on the type of heritage considered. In particular, does the CHM cover just economically saleable aspects of natural resources, or productive capital generally, or individual components of capital? And, is the time horizon for sharing one of fair distribution within the current generation, or equitable distribution across generations? Table 4 illustrates the different governance requirements associated with different interpretations.

Table 4: Different requirements of CHM depending on interpretation

<table>
<thead>
<tr>
<th>Common Heritage</th>
<th>Current generation</th>
<th>Multiple generations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resource stocks</td>
<td>Distribution of proceeds</td>
<td>Reinvestment of royalties: Solow golden rule. Sovereign funds.</td>
</tr>
<tr>
<td>All capital stocks together</td>
<td>Distribution of proceeds and impact of immediate effects on incomes</td>
<td>Long-term distribution of effects; non-declining capital stocks (weak sustainability)</td>
</tr>
<tr>
<td>Natural capital and other capitals</td>
<td>Distribution of proceeds and impact of immediate effects on environmental quality and incomes</td>
<td>Long-term distribution of effects; non-declining natural capital (strong sustainability)</td>
</tr>
</tbody>
</table>

Although it seems fairly clear that the intention behind CHM is to ensure that the resources benefit multiple generations, on a narrow interpretation it can be argued that whatever we can extract as rent is benefit to all mankind, since it will contribute to the general process of growth and development. This line of thinking would say that we do not need to concern ourselves with the mechanisms through which the CHM resources are passed to the future – we just need to ensure that the benefits are shared, and let individual countries take care of their own investments of the proceeds.
On a broader interpretation, the CHM could be seen as requiring not only that future generations should receive a fair share of unexploited resources, but also that the ISA would have a legitimate interest in ensuring that the current rents are invested sustainably (and not spent on subsidising present consumption). This is more politically sensitive, in particular if we are prepared to assume that economic growth and technological developments will make future generations wealthier than today’s, on average across the globe – which, despite extensive work on planetary boundaries (e.g. Steffen et al 2015) and recognition of severe problems of global change and biodiversity loss, remains the mainstream political view and vision. Under this view, it would be difficult to justify any requirement for reinvestment of royalties that prevented – for example – use of the rents to deal with present day medical and sanitation needs for impoverished populations.

The CHM principle does appear to compel a high standard of care for the natural environment for the present and future generations, and this intergenerational dimension links the principle to sustainable development (Jaeckel 2016). Furthermore, CHM creates a responsibility for all actors involved to maintain integrity and effective functioning of the ecosystems in the Area (Jaeckel et al, submitted). The extent to which any residual damage can be viewed as an acceptable cost of extracting benefits depends, again, on the precise interpretation of the principle, and in particular on whether a strong or weak sustainability stance is adopted. The high uncertainties inherent in interference with the deep sea environment, and relating to human dependence on it, provide a justification for application of the precautionary principle, and for favouring interpretations that include strong sustainability. As such it constitutes a normative framework for DSM and provides a useful context in which to frame DSM both from a legal and from an operational perspective, even if (as stressed by Jaeckel et al) a lot remains to be clarified in both dimensions.

Another important element stemming from the concept of CHM is that the increase in knowledge concerning the heritage of mankind (in this case the deep sea environment and the goods and services it provides to humans) can itself be considered as one important societal benefit (See Jaeckel 2016, p.5). So in our efforts to prevent serious harm, research is of key importance and constitutes an important cultural service to present and future generations. It is not the idea that knowledge is valuable that is particular to the CHM – that could be the case even for a private resource owner motivated by short-term private benefits – but rather that the benefits of knowledge for future generations must be taken into account. This also means that some present losses (i.e. the costs of research plus perhaps some unavoidable environmental damage through research) can be accepted if the future knowledge benefits justify them. At the same time, it can be argued that there are option values associated with deep sea knowledge, and the potential to learn from these systems in the future – perhaps using improved research technology and methods – gives a motive for conserving them and delaying any exploitation and even potentially damaging research.

The benefit sharing aspects of CHM, meanwhile, can be taken as implying that knowledge derived from DSM-associated activities should be made available to all. There will be a trade-off here, since investors in research and exploration may expect or require a return on investment in the form of patentable technology or bioprospecting discoveries, and the governance regime will need to strike a balance between facilitating research activities that develop the value of the knowledge derived from CHM while ensuring that the benefits are shared fairly. Hence, the ISA is given the role of promoting, coordinating and disseminating the results of research and analysis (UNCLOS Article 143). Jaeckel et al (2016) argue that in fact very few data have been made available, so far preventing realisation of this potentially important benefit.
4.3.2 Polluter Pays Principle

Barbier et al. (2014) argue that a key feature of a global strategy for protecting and restoring the deep sea should be the ‘polluter pays’ principle (PPP). In their view this means that “stakeholders who are most responsible for damages should fund deep-sea ecosystem reserves, research and restoration”. The polluter pays principle is not mentioned explicitly in the legal and other relevant documents governing deep-sea mining. However, as early as 1972, OECD countries agreed that the polluter pays principle should be a guiding principle in relation to the International Economic Aspects of Environmental Policies (OECD 1972 & 1974). It is also the 16th principle of the Rio Declaration: “National authorities should endeavour to promote the internalization of environmental costs and the use of economic instruments, taking into account the approach that the polluter should, in principle, bear the cost of pollution, with due regard to the public interest and without distorting international trade and investment.” (UN 1992).

Hence, the PPP has long been a key principle of environmental policy, at international and national levels, and, as such, it can indeed be argued that it should be considered as an implicit principle in DSM governance. A further justification for this stems from the CHM principle: if mineral resources in the Area should be managed to the benefit of mankind as a whole, then any operator who would be polluting and not paying for the pollution would de facto receive a form of ‘subsidy’ which would be to the operator’s private benefit but not to the benefit of mankind as a whole. Now if the polluter pays principle is to be applied to DSM, the question remains how to operationalise it, given that the damage may be highly uncertain at present, and may only become observable over the long term – perhaps even long after the cessation of mining activities at a particular area, and/or as a consequence of cumulative impacts.

One option is insurance schemes and targeted funds. Barbier et al. (2014) call for a new fund to manage ecosystem conservation and restoration research, development and implementation for the deep sea in areas beyond national jurisdiction. They propose that it should be part of the implementation efforts of the new biodiversity-conservation agreement to UNCLOS which is currently under development. They propose three mechanisms to aliment the fund: contributions by operators, taxes or an international finance facility.

4.3.3 Other key obligations enshrined in DSM governance

Beyond the principles explored above, there is also a series of other obligations, which are sometimes described as principles, but are rather obligations of a procedural nature that can be argued to stem from the other principles, and that apply to ISA and operators in DSM exploration. As part of the duty to protect and preserve the marine environment, these include the obligations to apply best environmental practices; carry out prior environmental impact assessment; conserve and sustainably use biodiversity; transparency and participation; and ecosystem-based management. Principles and obligations are spelled out in various documents and reports, often with little precision on their definition.

The obligation to apply best environmental practices (BEP) is integrated in the exploration regulations for sulphides, crusts and nodules. It applies to the ISA, sponsoring states, prospectors and contractors (Jaeckel 2015; SDC 2011). Best environmental practices are defined in ISA (2012, p.33) as “generally [referring] to widely-accepted norms or customs of environmental and risk management”. The report also stresses the link with the precautionary principle: “Where there is incomplete information and no
established best practices, best environmental practice requires that the precautionary approach be applied.” (ibid.)

The Clarion Clipperton Zone (CCZ) Environmental Management Plan (ISA 2011), identifies six principles that should guide the management of seabed mining. These include:

- two key principles: CHM and precaution
- two environmental protection duties: the duty to protect and preserve the marine environment and the duty to conserve and sustainably use marine biodiversity
- and two more procedural requirements: the prior assessment of activities that may have significant adverse impacts on the environment, and transparency and participation.

Furthermore, the plan also includes the goal to "manage the Clarion-Clipperton Zone consistent with the principles of integrated ecosystem-based management" (ISA 2011, IV 25 (d)). This is another procedural requirement which can be seen as an expression of a principle of systemic approach to human interactions with ecosystems.

Similarly, during a 2011 workshop on 'Environmental Management Needs for Exploration and Exploitation of Deep Sea Minerals' organised by ISA, the Government of Fiji and the SOPAC Division of the Secretariat of the Pacific Community (SPC), participants identified a series of obligations under international law as overarching principles that should be incorporated in any statutory framework for offshore mining (see Box 4).

**Box 4: Obligations under international law as overarching principles that should be incorporated in any statutory framework for DSM (Source: ISA 2012)**

<table>
<thead>
<tr>
<th>The Working Group identified the following obligations under international law as overarching principles that should be incorporated in any statutory framework for offshore mining:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Duty to protect and preserve marine environment (Article 192, UNCLOS);</td>
</tr>
<tr>
<td>Precautionary approach (Principle 15 of Rio Declaration; ITLOS Advisory Opinion; ISA Mining Code);</td>
</tr>
<tr>
<td>Duty to prevent, reduce and control pollution from seabed activities (Article 208, UNCLOS);</td>
</tr>
<tr>
<td>Best environmental practice (ISA Mining Code, ITLOS Advisory Opinion);</td>
</tr>
<tr>
<td>Duty to prevent transboundary harm (Part XII, UNCLOS; ITLOS Advisory Opinion: Rio Declaration);</td>
</tr>
<tr>
<td>Duty to conserve biodiversity (Article 3, CBD);</td>
</tr>
<tr>
<td>Prior EIA of activities likely to cause significant harm (Article 206, UNCLOS);</td>
</tr>
<tr>
<td>Ongoing monitoring of environmental impacts (Article 204, UNCLOS);</td>
</tr>
<tr>
<td>Sustainable development and integrated management (widely implemented in existing domestic legislation of countries within the region, e.g. Fiji, Cook Islands, New Zealand and Australia).</td>
</tr>
</tbody>
</table>

The following principles might also be included:
- ‘Polluter pays’ principle (Rio Declaration);
- Regional cooperation/integration in monitoring, processing and capacity-building (Articles 276-277, UNCLOS);
- Identifying mechanisms of capacity building (Part XI, UNCLOS);
- Accountability and transparency (Aarhus Convention).

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27 The MIDAS project produced a review of best practice environmental management across the deep-sea mining and allied industries (Billet et al. 2015).
4.4 A close up on the precautionary principle

Principle 15 of the Rio Declaration is referred to in the ISA mining code. The Principle mentions a precautionary approach: “In order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation.” (UN 1992). But the Precautionary Principle admits many possible definitions and interpretations, some weaker (allowing for preventive measures to be taken in the face of uncertainty without strictly requiring them, with the burden of proving harm falling on those advocating precautionary action, and costs of action taken into account) and others stronger (requiring precautionary measures whenever there are risks of potential serious and/or irreversible harm to health, safety, or the environment, even if the supporting evidence is speculative and even if the economic costs of action are high, and often establishing liability for residual environmental harm). Stewart (2002) extracted four main versions of the precautionary principle:

- Scientific uncertainty should not automatically preclude regulation of activities that pose a potential risk of significant harm (Non-Preclusion PP).
- Activities should be limited below the level at which no adverse effect has been observed or predicted (Margin of Safety PP).
- Activities that present an uncertain potential for significant harm should use best available technology to minimize risk of harm (unless proponent demonstrates that they present no appreciable risk of harm) (BAT PP).
- Activities that present an uncertain potential for significant harm should be prohibited unless the proponent shows that it presents no appreciable risk of harm (Prohibitory PP).

The questions then become (1) which condition of PP is to be applied to DSM by the ISA and other actors? and (2) how is it to be achieved in practice?

Which interpretation is used depends on the issue at hand, context, culture and power relationships and evolves over time. Some for instance see an evolution towards stronger forms of precaution, as illustrated by the following quote: “Over time, there has been a gradual transformation of the precautionary principle from what appears in the Rio Declaration to a stronger form that arguably acts as restraint on development in the absence of firm evidence that it will do no harm” (Cameron, 2006).

Precaution is an approach that is more thoroughly justified is situations where uncertainties and ignorance prevail, and stakes are high, and impacts are irreversible. Looking at the four versions of the PP spelled out above one can see that the appropriateness of each version will depend on the level of uncertainties, the stakes and the irreversibility of the potential impacts. Only the prohibitory version of the PP is applicable to situations of extensive uncertainties, high stakes and potentially irreversible impacts.
Table 5)
Table 5: Plotting appropriateness of PP version to levels of uncertainties, stakes and irreversibility

<table>
<thead>
<tr>
<th>Version of the precautionary principle</th>
<th>High variability in impacts</th>
<th>High Uncertainties about impacts</th>
<th>High Stakes</th>
<th>Irreversibility of Impacts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-Preclusion PP</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Margin of Safety</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>Best Available Technology PP</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>Prohibitory PP</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
</tbody>
</table>

We saw in the section on Serious Harm above (section 0) that a requirement to avoid serious harm can be conceived of as quite similar as the concept of safe minimum standard (and variations of it such as no net loss or critical natural capital) and is closely linked to the precautionary principle. In the case of DSM, one could have a high expected return but still prefer to delay investment because the consequences are so uncertain that the risk of ‘ruin’ is unacceptable, ‘ruin’ meaning that we have passed a threshold and come to an irreversible state.

4.4.1 DSM: A case in point for precaution?

Following the EEA working definition of the precautionary principle (Box 5) deep-sea mining appears as a human activity for which application of a precautionary approach is highly justified. This stems from the nature of the activity and of the environments in which it would take place, and the level of knowledge of, and experience with, those environments, the activity itself and its potential impacts. Indeed, as confirmed by research carried out notably in the MIDAS project, for deep-sea mining there is still high scientific uncertainty and ignorance about potential environmental impacts, their likelihood, spread and irreversibility (see above sections on impacts). It stems from uncertainties about both the ecosystems and the technologies.

Box 5: EEA working definition of the precautionary principle

The precautionary principle provides justification for public policy and other actions in situations of scientific complexity, uncertainty and ignorance, where there may be a need to act in order to avoid, or reduce, potentially serious or irreversible threats to health and/or the environment, using an appropriate strength of scientific evidence, and taking into account the pros and cons of action and inaction and their distribution.

Source: EEA 2013

When contemplating mining in the deep oceans, we are confronted with highly complex ecosystems, for which the possibility of unpredictable behaviours inherent to the system exists. Furthermore, there are a series of uncertainties and unknowns relating to:

- Ecosystems, their functions, the services they provide, fragility and vulnerability, recovery rates,…
- Potential impacts of mining operations at various spatial and temporal scales, including potentially serious or irreversible threats to the environment;
- Potential negative socio-economic impacts such as e.g. impacts on local communities, resource curse…);
- Technologies, demands, economic and social values;
• Indirect threats to the environment and human health, due for instance to the fact that more of these minerals would be extracted and uses.

A specific line of justification for the application of a precautionary approach to deep-sea mining builds on the fact that we cannot sufficiently identify, let alone quantify, the ecosystem services provided by the potentially affected environments. Hence there are huge uncertainties associated with nature and extent of impacts on the provision of those services and potential irreversibility of those impacts while some of these services may well be key to human well being. This is particularly the case for supporting services, as the role of these ecosystems in providing supporting services is barely understood (Le et al. 2016; Armstrong et al 2012; see also section 0).

Precaution is also justified by the fact that, even if damages would be technically reversible, in the sense that human-induced restoration would be an option, such operations in deep-ocean ecosystems are bound to be hugely expensive (see above section 0). This demands a precautionary approach that at a minimum includes appropriate protection of areas that are representative of targeted habitat as well as ecologically, biologically, and scientifically important.

4.4.2 Arguments against precaution

Opponents to precautionary approaches often present precaution as irrational, arbitrary, and anti-science, and claim that ultimately it slows down or even stops innovation and progress (for a full discussion see e.g. EEA 2013 chapter 27 and Bourguignon 2016). Yet as indicated by the numerous case studies analysed in EEA (2001 & 2013), "the timely use of the precautionary principle can often stimulate rather than hamper innovation, in part by promoting a diversity of technologies and activities, which can also help to increase the resilience of societies and ecosystems to future surprises" (EEA 2013, p. 673).

For DSM, Hedrick (2010) presents arguments that could act against a precautionary approach, by making the case that there are extreme risks associated with security of supply and vulnerability to this – stating, for example that "China is likely to cut off REE supply at any time, it should be recognized as an unreliable and fragile source" Although this has not yet happened, the fear behind it remains, and precedents (such as OPEC-driven oil price shocks) justify concern regarding the potential economic impacts. This remains the largest driver behind the ‘geopolitical/strategic’ argument for DSM (see section 2.1).

There is also a subjective element to the PP, as precaution can often mean different things to different actors and at different scales, depending on the temporal and spatial boundaries put on impacts of interest, even if generally there is a presumption that the spatial scale is broad and the timescale long. A key issue here is that different actors have different motives, objectives, information, incentives and risks. An understanding of drivers and justifications of different actors may help to understand decisions and offer insights for resolving conflicts and reaching socially beneficial outcomes; participatory methods will be useful for such understanding. In particular, there is disagreement over the appropriate burden of proof. Although for DSM it seems clear that the prohibitory form of the PP ought to apply, placing the burden on operators to demonstrate absence of serious harm, the issue has also been framed (see e.g. Pacific Communities 2016) in terms of the relative environmental harm from terrestrial and deep marine sources. Under this view, the requirement is to show that there is probably less harm from DSM.

However, this ignores the greater uncertainty associated with DSM and the possibly ‘fat tails’ of serious consequences, contrasted with the relatively known damages of terrestrial mining (Halfar & Fujita 2002), and also ignores alternatives to virgin resources. As stressed by David Gee, "The PP
Box 6: Previous precautionary approaches: the case of Antarctica

The Convention on the Regulation of Antarctic Mineral Resource Activities (1988) was never brought into force, and was replaced by the Protocol on Environmental Protection to the Antarctic Treaty (the Madrid Environmental Protocol) applicable to all activities in the Antarctic Treaty Area, with a decision to ban mining activities for at least 50 years. However, the original provisions make interesting reading and could provide a useful model for environmental regulations, including EIAs and decision-making rules for approving seabed mining and beyond. In particular, they promote the precautionary idea that there can be no mining unless there is sufficient information to make informed judgments. The provisions in the Madrid Protocol are somewhat weaker. It also bears noting that the fundamental reason why DSM was ultimately banned may not have been principally for environmental reasons, as a precautionary measure, but rather for geopolitical ones. The 1959 Antarctic Treaty essentially froze the territorial claims to Antarctic territory, in effect avoiding the risk of costly conflicts by agreeing not to discuss who owns which parts of Antarctica at all. And, for so long as no state seeks to extract resources on the continent, it makes little practical difference who Antarctica belongs to. So the agreement was that Antarctica would be used for scientific research, and a multilateral body was established to guide and govern that research. If seabed mining were to be allowed in Antarctica, dormant territorial claims would surface, with risks of political conflicts or worse. Along with the facts that mining the deep seabed in the icy waters of the Southern Ocean would be extremely challenging and costly, and that there are alternative, more cost-effective sources available, there is no present economic opportunity cost to delaying any exploitation of the Antarctic.

In practice, as pointed out by Jaeckel 2015 p. 230, the stronger form of the PP does not appear to be applied in current DSM governance arrangements. In particular, “(prospective) contractors do not have to prove an absence of risk. In fact, Article 162(2)(x) LOSC, for example, provides for the prohibition of mineral exploitation in a specific area only ‘in cases where substantial evidence indicates the risk of serious harm to the marine environment.’” She further stresses that: “(…) closing an area for mineral exploitation work requires the presence of ‘substantial evidence’ for the risk of serious harm. Neither the UNCLOS nor the Exploration Regulations define what is meant by substantial evidence. In any case, such evidence would likely be acquired through the compulsory EIAs and monitoring programme required during the exploration phase. However, the same standard of evidence applies to prospecting activities, which although regulated by the Exploration Regulations, is largely conducted freely in the form of marine scientific research. Requiring ‘substantial evidence’ in the prospecting context sets a high evidentiary threshold which appears impracticable given both the early stage of the activities and the high degree of uncertainty over deep sea ecosystem processes. In fact, setting a high evidentiary burden could be argued to defeat the purpose of the precautionary approach because the very nature of the approach implies the existence of uncertainty, arguably rendering it impossible to provide substantial evidence. This holds true especially for a preliminary activity such as prospecting. The notion of evidence implies the need for prospectors to carry out some form of EIA to be able to determine whether serious harm might arise. However, neither do the Regulations require future prospectors to undertake such EIAs, nor would it always be feasible to
acquire such data given the early stages of deep sea scientific research. As of 2015 no areas have been disapproved either for prospecting, exploration, or exploitation, not least because the exploitation phase is yet to commence." (ibid. p. 144-5)

Therefore, if a precautionary approach is appropriate for DSM, as argued for above, and as recognised by the ISA, the challenge remains of how to implement such an approach in practice. We will now examine this question and how the PP links to the other relevant governance principles and obligations for DSM.

4.5 Implementing the precautionary principle

The 2011 workshop on 'Environmental Management Needs for Exploration and Exploitation of Deep Sea Minerals' mentioned above (ISA 2012) identified a need for more guidance on how to operationalize the precautionary approach in the context of DSM and provided some examples of how the precautionary approach might be incorporated into decision-making:

- Regular reporting of data on environmental impacts and pre-emptive action to avert serious harm to the marine environment.
- Ensuring the conservation of biodiversity through the creation of marine protected areas in proximity to the mining footprint; establishing corridors outside the mining areas and environmental compensation (i.e. protecting biodiversity of equal or greater value in a different location).
- Adopting an incremental test bed approach to a mining activity where impacts are uncertain, e.g. authorize test mining rather than immediately authorizing commercial-scale activity

Taking a somewhat more systematic approach, some procedural elements can be identified which appear as necessary to making the precautionary principle operational for deep-sea mining. They include aspects related to the evidence (or absence thereof), the decision processes and ensuring adequate implementation.

4.5.1 Dealing with evidence of harm / no harm

In cases where evidence is limited, stakes are high and potentially irreversible and uncertainties are ubiquitous and not necessarily reducible, procedures to deal with the evidence, or in many cases the absence thereof, are needed.

Identifying gaps in knowledge

There needs to be procedures for identifying gaps in knowledge (and in particular absence of evidence) and potential risks. This will require a lot more emphasis on ensuring availability of scientific and monitoring data held by all actors, in particular contractors, the ISA and the scientific community (see also Ardron, in press). It also necessitates continued research on the ecosystems of the deep sea as well as on the potential impacts of DSM on these systems and on the services they provide.

Uncertainties, strength of evidence and weak signals

Procedures are also needed for recognising, qualifying and, where possible, quantifying uncertainties. Notably one should be transparent about where uncertainties appear to be strongest, and clear about the extent to which it would be possible to reduce such uncertainties, at what cost, how confident one can be with the uncertainty analysis, and how the uncertainties and their treatment play on the decision processes.
One important confusion, often seen when in uncertain situations is that the 'absence of evidence of harm' can too easily be taken by the proponent of an activity as 'evidence of no harm', which from a scientific point of view is of course totally untenable (see EEA 2103 Ch 27 & 28).

Work on uncertainties should also comprise procedures to define how to assess what strength of evidence can be considered as appropriate in a particular case. In particular, lower strengths of evidence should be considered as appropriate to indicate potential risks, based on the argument that in situations of high stakes and potential irreversibility, it may be more appropriate from a societal well-being point of view to make a type 2 error (false positive) than a type one error (false negative). Hence, the acceptable strength of evidence always needs to be defined in relation to the stakes and the potential irreversibility of the impacts. When entering the legal realm such lowering of strengths of evidence required corresponds to a lowering of the standard of proof (See Jaeckel 2015 pp46s).

In this regard, when stakes, scope and potential irreversibility of impacts are expected to be significant, procedures should to be put in place to allow for the identification of weak signals indicating potential harm.

**Research to address knowledge gaps and assess serious harm**

Once gaps in knowledge and uncertainties are identified and prioritised, procedures need to exist to stir the production of new knowledge to address the gaps. As the MIDAS project and other research efforts on deep-sea ecosystems in potentially mineable areas have shown, for most deep-sea ecosystems, we lack even basic information about ecosystems, their functions, their vulnerabilities, the service they provide, and so on. One way to develop the requisite knowledge base is to establish funding mechanisms as part of leasing, licensing, mitigation, and liability systems under national and international frameworks. There will however remain an important issue relating to the timing of research. The ISA proposed a 'Seabed Sustainability Fund' which would allow the ISA to direct further large-scale research activities and to contribute to the development of a strategic and more independent research agenda (ISA 2015). However, as stressed by Jaeckel (2016, p.6), "(…) timing is a challenge. If such a fund is established in the future exploration regulations, to come into effect during the commercial mining phase, this will arguably be too late for fundamental research into the environmental effects of deep seabed mining". The point is that if a precautionary approach is de rigueur, then there is a strong case for ensuring that the research into the ecosystems and the impacts is funded and carried out before exploitation is allowed.

One particular point of attention in defining and implementing research strategies is to ensure that the definition and assessment of ‘serious harm’ is one key objective of the research (Jaeckel 2015). It is also important that it is defined in a transparent, open and participatory way, not behind closed doors. And defining serious harm requires a baseline as well as a relatively good knowledge of the ecosystems, their functions, and the services they provide. It may also be more relevant to produce such definition in presence of a clear conservation objective, which should be spelled out notably by the ISA. As stressed by Jaeckel (2015, p. 4): "A major shortcoming is that the Mining Code does not articulate a conservation objective. As a result, it is impossible to assess whether a protective measure, even if adopted specifically to give effect to the precautionary approach, is effective in and proportionate to precautionary management aims.”

Increasing our knowledge of deep sea environments, DSM and its potential impacts will partly reduce, the uncertainties discussed above, but they will never be completely eliminated as we are confronted with complex ecological (and indeed socio-ecological) systems that will likely display nonlinear feedbacks and/or density-dependent relationships that may be highly sensitive to initial conditions and therefore difficult or impossible to predict, and/or strong dependence on variable environmental factors. These conditions lead to irreducible uncertainties. It may become more possible to ‘bracket’ the possible outcomes if we can learn the ranges over which such stochastic and internal system...
features may move, although developing this knowledge may take many years or decades of observation.

Although at present just about any data from deep sea environments will expand our knowledge, such is the extent of our ignorance, in the longer term effective learning of the sort outlined above will not be achieved through an ad hoc approach. To identify knowledge needs and design a research strategy around DSM in the framework of a precautionary approach, starting from the EEA working definition of the precautionary principle (Box 5) and identifying for each element what it means in terms of knowledge production approach, would be a useful exercise. This is done in Table 6 which shows that the types of research questions stemming from a precautionary governance stance on DSM necessitates integrated research bringing together natural, social and technological sciences in a genuine transdisciplinary effort to address the complex social-ecological issues at hand.

Table 6: Knowledge needs: Unpacking the PP definition (Source: van den Hove and Tinch 2015)

<table>
<thead>
<tr>
<th>Precautionary principle</th>
<th>Deep-sea mining questions</th>
</tr>
</thead>
<tbody>
<tr>
<td>...situations of scientific complexity, uncertainty and ignorance</td>
<td>What are the uncertainties, the stakes, the unknowns? Which are the reducible and irreducible uncertainties (unpredictable behaviours inherent to the system)?</td>
</tr>
<tr>
<td>... may be need to act to avoid, or reduce</td>
<td>What available actions? How do they compare?</td>
</tr>
<tr>
<td>... potentially serious or irreversible threats to health &amp;/or environment</td>
<td>What environmental and societal risks? Is the harm potentially serious (nature and extent)? Is it reversible?</td>
</tr>
<tr>
<td>... using appropriate strength of scientific evidence</td>
<td>What do we know? vs. What do we need to know?</td>
</tr>
<tr>
<td>... taking into account pros and cons of action and inaction</td>
<td>What are the arguments for and against mining / waiting?</td>
</tr>
<tr>
<td>...end their distribution</td>
<td>Who benefits and who loses if we mine and if we do not mine?</td>
</tr>
</tbody>
</table>

Procedures to integrate new knowledge as it becomes available

The knowledge production mechanism should be complemented by effective mechanisms of science-policy-society interfaces through which the knowledge held by different actors is exchange in a dynamic, iterative manner, to allow the decision and implementation processes to take place based on the best available evidence. (Sarkki et al. 2014, 2015; Young et al. 2013a & b). This should also be integrated within the broader consultation, accountability and co-decision methods developed as part of the governance framework.

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28 By transdisciplinary approaches we understand work that “moves beyond the domain of disciplinarity, generating new approaches to scientific knowledge production that either transcend the formalism of a discipline altogether and/or operationalize integrative collaborations between academics and non-academics, such as local communities and/or policy-makers, as a core part of the scientific work” (Farrell et al. 2013, p. 36).
4.5.2 Shifting the burden of proof

As discussed in Jaeckel 2015, in the ISA context, the general burden of proof is not reversed in a strict sense, even though the assumption of harm is incorporated into the regulatory framework. According to that author, it is the absence of agreed conservation objectives that undermine the application of a precautionary approach since it is necessary to assess harm or absence thereof, whoever bears the burden of proof (ibid. p. 230).

It is worth stressing however that attributing the burden of proof to the proponent or the opponent of an activity which is potentially harmful to the environment and/or human well-being is not neutral. Indeed, because of the asymmetries mentioned above (e.g. private mining companies have potential very high benefits and relatively low risks – such as going bankrupt but still being in a position to start another activity elsewhere or in another sector – while potential downsides for societies and environment can be very high – e.g. irreversible contamination or destruction of life-supporting environmental services – and because of externalization of negative effects from the private sector to societies and/or the environment, there is a rationale for reversing the burden of proof from regulatory authorities to mining companies and sponsoring states. This means that companies and the sponsoring state would have to give sufficient proof that the mining activities will NOT negatively impact the environment to be authorized to operate rather than authorities having to proof that the mining activity will have a negative impact to be able to prevent or restrain the operation.

4.5.3 Establishing procedures in advance of need

One key aspect of implementing the PP is that the earlier procedures for its implementation are discussed and established, the better. It is indeed much more difficult to argue for, and implement, a precautionary approach once actors have started investing in a technology and its deployment. As stressed by Halfar & Fujita (2002), "Even though mining for polymetallic sulfides may not take place for several years, precautionary performance standards, environmental regulations, and the establishment of Marine Protected Areas may help guide the marine mining industry toward a goal of minimizing environmental impacts. Once substantial investments in prospecting and exploring a potential mining site are made, implementation of environmental regulations may prove to be much more difficult." When procedures are established in advance and a clear signal towards precaution is given, actors are more likely to take a more precautionary approach in their business strategies and related technological development. In this way concerns for sustainability in all its dimensions can be upstreamed in decision processes of actors. And in fact, this will be of considerable benefit to investors/operators, since one of the key areas of risk they face disproportionately (i.e. that impacts strongly on them, and much less so on society as a whole) is associated with uncertainty about the governance and regulatory structures. Far better to know in advance what specific data, environmental impact assessments and compliance work will be required, and when, than to discover this late and need to adjust plans and financing in unexpected ways.

4.5.4 Taking a broad perspective

As stressed in the introduction of this chapter, governance principles help us contextualise discussions about DSM and ultimately should take us back to the fundamental question: "Why and under which conditions should we mine in the deep-sea?". Applying a precautionary approach to wide-scale, highly uncertain and potentially highly impacting activities such as DSM forces actors to take a broader perspective and contextualise the issue. As we saw in the section on DSM and the green economy, the real issue for humanity is to make the appropriate trade-offs between environmental, social and economic sustainability, aware of the fundamental asymmetry stemming from the fact that a healthy environment is our only path to sustainability along the other dimensions. This requires a reflection in terms of needs of current and future generation and of intra- and intergenerational equity.
4.6 DSM and the Sustainable Development Goals

Since 2015 the 2030 UN Agenda for Sustainable development spells a plan of action for people, planet and prosperity (UN 2015). In section 4.1, Box 3, we saw the transformational vision underlying the SDGs. The vision is ambitious for all aspects of "shift[ing] the world onto a sustainable and resilient path", from the ecological to the human, social economic aspects. The Agenda is made up of 17 Sustainable Development Goals and 169 associated targets which are "integrated and indivisible, global in nature and universally applicable" (UN 2015, § 55). As such they constitute an international governance setting in which to frame DSM.

Box 7: Sustainable Development Goals (Source: UN 2015)

<table>
<thead>
<tr>
<th>Goal</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>End poverty in all its forms everywhere</td>
</tr>
<tr>
<td>2.</td>
<td>End hunger, achieve food security and improved nutrition and promote sustainable agriculture</td>
</tr>
<tr>
<td>3.</td>
<td>Ensure healthy lives and promote well-being for all at all ages</td>
</tr>
<tr>
<td>4.</td>
<td>Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all</td>
</tr>
<tr>
<td>5.</td>
<td>Achieve gender equality and empower all women and girls</td>
</tr>
<tr>
<td>6.</td>
<td>Ensure availability and sustainable management of water and sanitation for all</td>
</tr>
<tr>
<td>7.</td>
<td>Ensure access to affordable, reliable, sustainable and modern energy for all</td>
</tr>
<tr>
<td>8.</td>
<td>Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all</td>
</tr>
<tr>
<td>9.</td>
<td>Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation</td>
</tr>
<tr>
<td>10.</td>
<td>Reduce inequality within and among countries</td>
</tr>
<tr>
<td>11.</td>
<td>Make cities and human settlements inclusive, safe, resilient and sustainable</td>
</tr>
<tr>
<td>12.</td>
<td>Ensure sustainable consumption and production patterns</td>
</tr>
<tr>
<td>13.</td>
<td>Take urgent action to combat climate change and its impacts*</td>
</tr>
<tr>
<td>14.</td>
<td>Conserve and sustainably use the oceans, seas and marine resources for sustainable development</td>
</tr>
<tr>
<td>15.</td>
<td>Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss</td>
</tr>
<tr>
<td>16.</td>
<td>Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels</td>
</tr>
<tr>
<td>17.</td>
<td>Strengthen the means of implementation and revitalize the Global Partnership for Sustainable Development</td>
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</tbody>
</table>

* Acknowledging that the United Nations Framework Convention on Climate Change is the primary international, intergovernmental forum for negotiating the global response to climate change.

Scanning the SDGs (Box 7), it is quite apparent that DSM can potentially contribute to achieving (some of) the SDGs but that it can also potentially go against some of them. Goal 14 for instance — *Conserve and sustainably use the oceans, seas and marine resources for sustainable development* — since DSM would only be acceptable if sustainable use of the mining resource is achievable and if oceans and seas are conserved. This leads to the question of the feasibility of sustainable use of a non-renewable resource.

Now it is argued by some that to achieve Goal 7 — *Ensure access to affordable, reliable, sustainable and modern energy for all* — the extraction of mineral resources from the deep-sea will be inevitable to
develop all the necessary green energy technology. Some however disagree with this vision (Teske et al 2016). The same ambiguity holds for Goal 8 — *Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all* — since, as discussed above, DSM could contribute to economic growth for those countries which would benefit from it, but the inclusivity and sustainability of the economic benefits over the long term depend on how DSM is implemented from an economic but also a social and an ecological perspective.

As for Goal 9 — *Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation* — as discussed above, a precautionary stance towards DSM could lead to more innovation and more sustainable industrialisation than an immediate rush for the resources, that raises the risk of creating lock ins in technologies that use particular minerals. Similarly, aiming for Goal 12 — *Ensure sustainable consumption and production patterns* — imposes a transformation towards a green and circular economy whereby exploitation of non-renewable resources is limited and framed in a long term perspective.

Coming to the end of this section, it appears that we do have quite a complete and appropriate array of governance principles to guide decision-making on DSM. Two key lessons can be derived from the above discussion. First these principles should be implemented in a holistic manner, taking into account the interdependencies between the principles and framing the stakes in the broader picture of societal needs and ecological constraints. Second, putting into practice the key governance principles mentioned above in the framework of the existing visions for sustainable development at various governance levels will require a systematic and systemic examination of whether the decisions made on DSM bring us collectively closer of farther from reaching some SDGs.

29 See above section on the green economy.
5. Conclusion: Policy implications

For deep-sea mining, the dominant policy questions are whether, why, where, when and how to authorise or even encourage DSM, and which are the needed policies to ensure that DSM contributes as much as possible to fulfilling societal needs, including economic development, in the context of a broader societal vision of sustainability, as articulated for example in the Sustainable Development Goals. In answering these questions, there are value judgements to be made. In particular, should DSM be considered as something to implement, value judgements are associated with timing and intra- and inter-generational sharing of resources, for example, to attempt to develop a sustainable/long-term DSM industry that avoids a boom/bust cycle in a particular place.

The same questions arise, but with slightly different scope, at all scales in DSM governance. Nevertheless, the stakes, boundaries and constituencies vary according to the decision makers. The ISA has a mission to manage DSM activities in the Area “for the benefit of mankind as a whole” and must do so while respecting a wide range of legal obligations and governance principles (see Box 4). The European Union aims to effect a transition towards Sustainability, and to be a world example in this transition, leading to pressing questions regarding the role of DSM in achieving a broader societal purpose and vision. For individual States, the stakes are similar but the details can be very different – in particular in the case of certain less developed states for which DSM resources may form a substantial component of their national wealth – and a narrower focus on the well-being of national (not global) populations may mean many of the risks are discounted. The same holds a fortiori for individual contractors and investors, unless instruments can be put in place to internalise the external risks and costs. Therefore a further set of concerns relate to achieving coherence in decisions made at different scales – notably, decisions about DSM in the Area and the valorisation of the CHM, and decisions made by national governments about management of their sovereign deep sea mineral resources. In a broader sense, coherence is also desirable with strategic decisions about management of terrestrial minerals, recycling, reuse, substitution, research and development, and investment in promoting Circular and/or Green Economies. It is time to recognise that the arguments of the form "we should mine because we can do it" or "we should mine because it will happen anyway" are not intellectually robust answers to these pressing questions, which need to be addressed in a thorough, democratic and participatory way.

5.1 MIDAS findings relevant to designing DSM decision processes

Research throughout the MIDAS project has advanced evidence and findings that are relevant to the design and implementation of decision processes for strategy and policy to resolve the above questions. 30 These findings by no means resolve the substantial uncertainties about the pros and cons of DSM, but serve to demonstrate how research activities can contribute to this long term goal, and start to identify a precautionary and adaptive strategy for research and exploitation.

Major gaps were identified in current guidance for deep sea mining around regional/strategic environmental assessment, project environmental assessment, baselines assessment, data management, environmental management plans, review of project documentations, transparency and linking technology to the environment.

Filling these gaps will be facilitated by better knowledge generation and sharing. Most fundamentally, contractors need to share their environmental data with researchers and authorities. Levels of confidence in predictions vary with the scale models: it is necessary to understand local physical

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30 The MIDAS research findings are summarised in the MIDAS final scientific report (soon available on the MIDAS website: http://www.eu-midas.net) and in the ‘MIDAS Research Highlights’ Brochure (MIDAS forthcoming October 2016). This section brings together some of the key findings which are relevant for DSM decision making processes.
dynamics in order to successfully model local conditions with accurate boundary conditions. However, this will be difficult to achieve at decent resolution at larger (regional) scales, where there can be orders of magnitude of uncertainty. Scale is vitally important in understanding deep sea ecosystems, for example through connectivity studies in order to understand larval dispersal and genetic flow, and the role of microbial communities in benthic ecosystem functioning (e.g. carbon and nutrient cycling) is important over regional scales in the CCZ. Habitats in CCZ are highly variable in terms of nodule densities and terrain, so it is important that preservation reference zones are chosen to reflect this variability (Vanreusel et al 2016). However, biogeographic information, on appropriate scales, is scarce in most areas targeted for mining (vent and seep megafauna are exceptions to this); without this information, connectivity is impossible to assess.

Decision processes need to ‘embrace’ this large scale uncertainty. The requirement for collaboration between operators and sharing data is clear, as it is the only way to build up the regional picture and to help to validate the smaller-scale models generated by individual contractors. The great uncertainty and lack of data make new data especially valuable. There is therefore a strong public good nature to data developed by contractors. Steps may be required to ensure data sharing – for example through conditions on licensing – to avoid contractors treating data as commercially confidential. One specific recommendation related to this is that a new EIA should be required each time operations move to a new area within a block, and when original bases of assessment change such as changes to mining operations, technology used, or new scientific information becomes available. This ensures always working on the basis of best available information, and always seeking to learn from actions.

Furthermore, there is a need for independent scientists to be involved in any industrial-scale mining trial, and the ISA should establish or sub-contract an independent science body to ensure this. This is especially clear given the observations above about divergent incentives, and in particular to industry incentives that may point towards more rapid development than might be socially desirable, highlighting a need for checks and balances. Similarly, licence contract approval and inspectorate functions within the ISA need to be independent of each other to ensure an independent re-evaluation of past decisions and to reduced risks of regulatory capture.

An adaptive and strategic approach to management suggests the need for a nested approach to management planning, with three levels:

1) Large-scale regional assessment/plan;
2) Medium scale assessment/plan for the licence block; and,
3) Local assessment/plan for the mined area(s)

All plans need to be adaptive and include the provision for regular reassessment. The ISA needs to take the responsibility for the top level of regional planning, as well as for a more global strategic reflection on the future role of DSM in a transition to a sustainable global economy. On the side of valorising the knowledge component of the CHM, this links back to the proposal to establish an independent scientific body, which should be able to take a strategic view at the oceanic/global scale to ensure that research is organised in such a way as to yield most useful results and feed in to adaptive management, including designing the nested assessment plans with a view to active experimentation and strategic learning.

The project phase (pre-mining/baseline study, mining, post-mining/recovery) and the impact/effect that is addressed (e.g., plume dispersal or changes in biodiversity) have to be considered when planning monitoring strategies (sensors and platforms; duration, frequency, replication, spatial coverage of observation etc.). This adds a layer of complexity to regulations since regulations will need to address both mining and post mining periods and will need to make sure that all relevant impacts and their effects are appropriately covered. MIDAS (2015a) describes the current state of individual monitoring
technologies and their workflows. The appropriateness of the different technologies to detect mining/disturbance-related impacts needs further testing and demonstration. From assessing the state of the art in data acquisition and analysis (MIDAS 2015b), it seems that habitat mapping technologies have highest potential for routine application, offering rapid, high-grade automatization in data acquisition and analysis. Thus, environmental sensing and sampling capabilities should be added to imaging platforms (AUV, towed camera etc.) for integrative habitat mapping. The potential to use habitat characteristics (natural, disturbed) as proxies of ecosystem status (faunal communities, functions) needs further research, and a definition for visual assessment of the "good environmental status" of deep sea habitats needs to be developed. While such faster monitoring technologies will have the highest acceptance by industry, methods for monitoring of many expected impacts and effects are available – at least in academia – and mostly operational. This means that (in spite of the uncertainty) there is no good reason why we should not be able to monitor and measure most of the impacts. There is therefore (because of the uncertainty) no reason why we should not make this a condition of activity, except possibly if the cost are deemed excessive. However, the likelihood is that new data are highly valuable at present, and financial solutions should be sought to ensure that all monitoring options are taken up rigorously. This may not be necessary in the long run, as we learn more – i.e. we might, through learning, be able to determine which specific impacts need to be monitored and are management relevant.

Although the nature and importance of damages remains uncertain, it is likely that damage to mined areas will be irreversible and unrecoverable in the sense that the post-mining system will remain very different from the original. There is a need for monitoring of mined areas after extraction, but areas adjacent to the mined areas should also be subject to regular monitoring to determine impacts at local, regional, and global scales, and in order to determine cumulative impacts. Not only are off-site impacts possible, they could also be indirect and delayed, for example arising not through the mining operations, but rather as a later result of the damage on-site, for example through food-web/metapopulation impacts or bioaccumulation of toxic substances. This motivates monitoring and concern for cumulative impacts at large scales.

Related to this, while contractors can reasonably be expected to carry out on-site and adjacent monitoring (and should be required to do so), there could be arguments for the ISA, or an independent science body nominated by it, to take on the role of large scale monitoring of cumulative impacts. A proportion of revenue raised by mining could be channelled towards scientific research to address conservation issues that are beyond the responsibility of individual contractors to address, including cumulative impact assessment, regional and global impacts. Since these damages are uncertain, potentially longer term and not limited to the mined and immediately surrounding areas, provision must be made for dealing with these costs that cannot be linked directly to specific activities. Research that could lead to better future management is one possibly valid use for funds raised. Indeed, as noted above, the knowledge deriving from deep sea exploration and monitoring of exploitation can itself be considered an important component of the CHM. There could even be an argument for subsidising some parts of the costs of monitoring for individual contractors, in early years, if the costs are considered disproportionately high but likely to provide a high ‘public good’ source of knowledge valorising the CHM.

Other uses for funding streams include the potential to use a liability fund to compensate for any damages or losses. Barbier et al (2014) moot the potential for “an international finance facility, which would mobilize resources for deep-sea restoration from international capital markets by issuing long-term bonds to be repaid by donor countries over 20–30 years.” As noted above, restoration may not be possible, or may be prohibitively expensive, in which case compensation through other investments of social and environmental interest may be a more beneficial use of liability funds.
5.2 Strategies for addressing the governance challenges

The fundamental issues facing DSM governance are widely recognised, both in terms of the underlying trade-offs and the implications of radical uncertainty, but there is as yet no consensus on how to resolve them, or what the implications for DSM should be. The same observation arises in terrestrial mining (Scobie, 2015) where the way different actors talk and engage “is actually more cohesive than anticipated”, specifically in the sense that actors with different roles and perspectives share common perceptions and languages regarding the risks. Where they differ is in how they believe these risks should be managed. While all Scobie’s participants agreed that accountability involves much more than “traditional” financial accounting, the tension arose between issues of inter versus intra generational equity – “accountability to current or future generations, as well as anthropocentric versus non-anthropocentric accountability”.

DSM governance faces exactly the same situation. As stressed in UNEP et al (2012), "The imperative is on society to decide whether to focus on maximizing short term financial return or on longer term economic objectives, which balance social goals, including developing sustainable livelihoods, and the preservation of ecological parameters against inequitable, unfocused and unsustainable growth".

Similarly, the SPC-EU EDF10 Deep Sea Minerals Project Inaugural Meeting (Howorth 2011) recognises the challenge of ‘sustainable economics’ arising from the finite nature of DSM deposits, suggesting (amongst many other proposals on environmental management, benefit sharing and so on) that, to secure long-term sustainable benefits, policy should seek to:

- balance the economic imperative for intensive/efficient extraction with the precautionary approach to scale up production,
- optimise revenue streams and benefits to cater for national development priorities and a mechanism for future development needs,
- enhance long term economic stability through savings of mining revenue,
- avoid the potential impacts of the "Dutch Disease".

One way forward is to consider both the scale and the timing of action and the decision-theory / game-theory rules that could be applied to decisions. As represented in Figure 16 below, one could decide to allow DSM immediately everywhere (bottom-left quadrant), never and nowhere (top-right), immediately or soon in several selected but limited places (top left) or to delay decision until more knowledge is acquired (bottom right).

The first option (bottom-left) corresponds to a maxi-max type of strategy that we might characterise as “Fools rush in”. In decision theory, this optimistic or ‘aggressive’ decision making rule under uncertainty states that the decision maker should select the course of action whose best (maximum) gain is better than the best gain of all other courses of action possible in given circumstances. This corresponds to a situation where one aims at maximising the benefits of a best case scenario with little regard for long-term risks or consequences. This approach can be suitable for an optimistic or ‘risk-seeking’ investor, who seeks to achieve the best results if the best happens. In DSM, this could make sense for individual entities who stand to benefit disproportionately and can avoid or escape from the risks. Depending on governance and legal systems and measures, this could include some investors and some political elites. At a broader scale, it could apply to any state/contractor able to ‘free ride’ on the risks their actions could impose on the rest of the world and posterity. The strategy could also make sense for groups who feel they have little to lose, for example impoverished communities with few other resources. The analysis presented above indicates that today such an approach cannot reasonably be adopted by any body with concerns for broader scale and longer term impacts, due to the high level of uncertainties and ignorance around the technology and its potential societal, ecological and economic impacts.
The opposite of this approach (top right) corresponds to a maxi-min or 'better the devil you know' type of strategy. Under this decision rule, the decision maker would look at the worst possible outcome for each decision, and select the highest one. This results in choosing the outcome which is guaranteed to minimise losses, but entails losing out on any opportunity of making potentially substantial gains from other options. It corresponds to the strategy whereby one would prohibit DSM everywhere and for an unlimited time, or at least unless and until it can be demonstrated that the damages of DSM are less than those of alternatives including terrestrial mining and recycling/reuse/substitution options (and it is hard to see how this could be achieved without testing DSM in practice). Halfar & Fujita (2002) propose something along these lines, as discussed in section 0. If the first strategy was over-optimistic, this one is over-pessimistic, and it disregards the fact that a transformation towards sustainability will imply exploring which trade-offs need to be made, where and why. Nevertheless this strategy could be adopted by those implacably opposed to human exploitation of pristine environments ('deep-green' views), or by communities who stand to bear disproportionate risks but see little prospect of benefits (e.g. tuna fishing communities).

![Strategies for DSM: scaling and timing of action. (Source: original)](image)

An alternative decision rule that in practice would imply a similar result for DSM is the mini-max regret strategy. This requires selecting the decision that minimises the maximum regret, defined as the opportunity loss through having made the wrong decision. This may be more appropriate for a risk-neutral decision maker. Under this criterion, it is possible that the chance of very high benefits if DSM turns out to be economically profitable and environmentally/socially relatively benign could outweigh the potential for high losses. This might apply for organisations and nations who fear 'missing the boat' on DSM, and this could explain why many states and contractors are keen to be involved in licensing and exploration, without any immediate rush to commercial exploitation, though by and large individual states / contractors may be relatively sheltered from the full extent of environmental damages, where they are global and long term in scope, but face rather the economic risk of investing in new and unproven technology).
However, before applying mini-max regret it is essential to recognised that there is an important asymmetry in the decision. While a decision to engage in DSM involves non-recoverable costs and possibly irreversible damages, a decision not to engage is entirely reversible, with the exception of the ‘missing the boat’ reasoning outlined above. In fact the question can be better couched in terms of delay rather than a firm decision not to mine. Broadly, there are two strategies that correspond to this framing.

The direct correspondence is a ‘look before you leap’ strategy, in other words of waiting and learning (bottom right). This would correspond to an entirely precautionary approach. The benefits include a better understanding of deep sea systems, better technology, potentially lower costs of operation and reduced risks of damages. Yet this strategy requires investment in R&D with no current corresponding flow of benefits, and uncertainty about future mining returns. Thus this strategy reduces the prospect for private sector finance of R&D activities, and may also imply less effective R&D, in the sense that some knowledge of the effectiveness and effects of DSM technologies can only, or best, arise from trying out the techniques.

An alternative approach that enables minimax regret is to consider a staged strategy (top left quadrant in the figure), where we decide to exploit resources with lower risks in a limited number of small sites and to learn as we go, subsequently deciding whether or not to continue exploiting and to exploit in other areas, deliberately opting for an adaptive strategy. This would reconcile a precautionary approach with an approach driven by a sense of urgency conveyed by several stakeholders who stress the needs/demand for the resources and the geopolitical/strategic ‘imperatives’. In doing this, we not only ‘hedge our bets’ in the sense that we mine in the deep sea in different yet contained places and ways (i.e. where the lowest estimated risks are estimated to be, with slow and gradual increase in intensity and heaving monitoring), we also pursue research and development in many directions – on the one hand, enabling a rapid switch to DSM if this proves less damaging and strategically necessary, while on the other, exploring alternative paths which may allow avoidance, substitution, reduction, reuse or recycling. This could reduce the need for virgin resources and allow DSM to spread over a much longer future.

This strategy by definition implies an adaptive approach, recognising the possibility of surprise and accepting from the start that some choices may turn out to be ‘bad ideas’ and that in such cases, stopping an operation may be necessary. As stressed in the Late Lessons from Early Warnings report: “Keeping options open and following multiple paths means that a particular option can be terminated if it turns out to pose high risks, and avoids situations of technological monopolies such as those experienced, for example, in the cases of asbestos, CFCs and PCBs.” (EEA 2013 p. 673)

An adaptive approach is already, to some extent, advocated in the framework of the ISA. For instance, the 2011 workshop on ‘Environmental Management Needs for Exploration and Exploitation of Deep Sea Minerals’ mentioned above stressed that “Adaptive management is one example of the precautionary approach, and should form part of the Act [Deep seabed minerals legislation]. Adaptive management allows the proponent of a mining activity to fill the vacuum (where there is not an established practice) with a novel methodology. Adaptive management can be implemented by the mining operator through monitoring and assessing the operator’s activities, and by amending or improving the plan of work (including methods of mitigation) in cases where new information calls for a different approach.” (ISA 2012, p. 33)

MIDAS work also concluded that the very process of designing legislation for DSM should be adaptive, in the sense that mining protocols and mining legislation should be iterative. Early experiences should inform improvements of legislation, this in turn requires formal mechanisms for collecting and analysing data at large scales, and feeding this back into legislation design and management. It is important to avoid lock-in in management tools/positions wherever possible.
5.3 Summary

The analysis presented in this report indicates that a combination of the two strategies represented in blue in figure 16 is probably an acceptable way forward for DSM today. It would correspond to a precautionary approach whereby one allows some space for trials and learning on a limited scale, in limited sites and under strict control conditions. Of course, the idea of learning as we go with regard to DSM is not new. PrepCom advocated as much in 1990, stating that “some delegations were of the view that since the start-up of deep sea-bed mining would be delayed, this would provide ample time for careful research aimed at protecting the marine environment. Some views stressed the potentially serious problems that could be posed by deep sea-bed mining. It was held that since deep sea-bed mining might not occur for many years to come, the Preparatory Commission should map out a strategy for preserving the sea-bed environment and not merely establish a set of formal procedures. This view also called for the mobilization of public opinion and governmental awareness and suggested that an ad hoc group of experts be set up to make recommendations in that connection.” (Preparatory Commission for the ISA and ITLOS, LOS/PCN/L.79 (28 March 1990), paragraph 14).

But much remains to be achieved, and the ISA has a clear role in pushing a strategic approach both to enhancing the learning from DSM exploration and eventual exploitation, and to ensuring the wide dissemination of the knowledge which itself can be seen as a manifestation of the CHM.

Learning from decision processes around other technology development and deployment (see e.g. EEA 2001, 2013) we summarise that decision-makers in charge of DSM governance and operators of DSM should design and implement a precautionary approach to DSM through the following ingredients:

- Assessing the economic and social necessity of DSM, including assessment of the risks and benefits of DSM in the light of potential alternatives (avoid, substitute, reuse, reduce, recycle, terrestrial mining), and clarification of ethical dilemmas and trade-offs at different temporal and spatial scales;
- Recognising the uncertainties and ignorance regarding potential economic, social and environmental impacts, acknowledging the possibility of surprises and the potential irreversibility of impacts;
- Committing to monitor, experiment, learn as we go, and disseminate knowledge transparent and dynamic;
- Designing inclusive consultative processes that enable all views to be understood and considered in reaching decisions;
- Designing and implementing mechanisms to ensure equitable (inter- and intragenerational) benefit sharing, including application of the polluter pays principle, building on plural, conditional and systemic assessments that account for the full range of ecological, social and economic dimensions over appropriate timescales;
- Designing decision processes which allow for staged, adaptive and iterative implementation of mining, applying the precautionary principle when uncertainty and ignorance prevail and stakes are high;
- Avoiding lock-in via adaptive governance that allows diversity of solutions to build resilience, and avoid lock-ins by allowing decisions and choices to be revised, keeping open the options of expanding or stopping DSM depending on learning and evidence.
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