EUROPEAN UNION

Pacific Community
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An Assessment of the Costs and Benefits of Mining Deep-sea Minerals in the Pacific Island Region

Deep-sea Mining Cost-Benefit Analysis

Cardno
Shaping the Future

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Suva, Fiji, 2016

Original text: English

Pacific Community Cataloguing-in-Publication Data

SPC Technical Report SPC00035

An Assessment of the Costs and Benefits of Mining Deep-sea Minerals in the Pacific Island Region: deep-sea Mining Cost-Benefit Analysis / Pacific Community

1. *Mines and mineral resources – Management – Oceania.*
2. *Mining – Oceania.*
3. *Marine mineral resources – Oceania.*
4. *Ocean mining – Oceania.*

I. Title II. Pacific Community

549.95 AACR2

ISBN: 978-982-00-0955-4

This project was implemented by the Pacific Community's Deep Sea Minerals Project – a partnership between SPC and the European Union – and this project report was prepared for the Pacific Community (SPC, Suva Regional Office, 241 Mead Rd., Nabua, Fiji) by Cardno (121 Continental Drive, Suite 308, Newark, DE, 19713) for the Deep-sea Mining Cost-Benefit Analysis project (E515004700) (Project Manager - K Myers).

2016

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Acronyms

APC	African, Caribbean and Pacific Group of States
BCR	benefit-cost ratio
BP	British Petroleum
BPA	biodiversity protected area
CAPEX	capital expenditures
CBA	cost-benefit analysis
CEPA	Conservation and Environmental Protection Agency
CLC	Civil Liability Convention
CNMI	Commonwealth of the Northern Mariana Islands
CO_2	carbon dioxide
CPI	consumer price index
CRC	cobalt-rich crusts
DSAY	discounted service acre year
DSM	deep-sea minerals
DTPY	dry tonnes per year
DWT	dead weight tonne
EEZ	exclusive economic zone
EIA	environmental impact assessment
EIS	environmental impact statement
EPRI	electric power and research industry
EU	European Union
FIFO	first in first out
FSRU	floating storage and regasification unit
GDP	gross domestic product
GHG	greenhouse gases
GSD	Geoscience Division
GW	gigawatt
HEA	habitat equivalency analysis
HCL	hydrochloric acid
HFO	heavy fuel oil
HPAL	high pressure acid leach
IMPLAN	Impact analysis for Planning
I-O	input-output (as in model type)
INCO	International Nickel Company

IOPCF	International Oil Pollution Compensation Funds
ISA	International Seabed Authority
ITOPF	International Tanker Owners Pollution Federation
JICA	Japan International Cooperation Agency
KORDI	Korea Ocean Research and Development Institute
lb	pound
LNG	liquefied natural gas
LPC	local purchase coefficient
MA	millennium assessment
MMJ	Metal Mining Agency of Japan
MN	manganese nodules
MoA	memorandum of agreement
MRA	Mineral Resources Authority
NMSA	National Maritime Safety Authority
NOAA	National Oceanic and Atmospheric Administration
NPV	net present value
NRDA	natural resource damage assessment
NSB	net social benefits
NZD	New Zealand dollars
OMZ	oxygen minimization zone
OPEX	operating expenditures
PAL	pressure acid leaching
PNG	Papua New Guinea
PPI	producer price index
PSV	production support vessel
PV	present value
RALS	riser and lift system
REEs	rare earth elements
REYs	collective term for the 14 rare earth elements including Yttrium
REIA	regional economic impact analysis
RMI	Republic of the Marshall Islands
ROV	remotely operate vehicle
SBMA	Seabed Mineral Authority
SMS	seafloor massive sulphides
SPC	Secretariat of the Pacific Community
SSLP	subsea lift pump
STV	shell and tube vaporizers

SWF	sovereign wealth fund
U.S.	United States
USD	United States dollars
VMS	volcanic massive sulphides
WCSMLOA	West Coast Seabed Mining Land Owners Association
WCPFC-CA	Western and Central Pacific Fisheries Commission Convention Area

Executive Summary

This report describes a preliminary economic (cost-benefit) analysis of deep-sea minerals (DSM) mining in the Pacific Island region. Since mining has yet to occur anywhere in the world, the analysis is based on realistic yet hypothetical mining scenarios developed for three mineral deposits thought to have a high potential for economic viability:

- 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).

In each country, costs and benefits are assessed from the perspective of citizens of the host country based on the operation of a single mine site. To the extent possible, costs and benefits are quantified and monetised in order to estimate the net social benefit (NSB) to the people of the host country. Where costs and benefits could not be monetised, they are identified and discussed qualitatively.

Table E-1 summarises the preliminary estimates of the total social costs, total social benefits and net social benefits (total social benefits minus total social costs) in each of the case study countries.

- Dollar figures in Table E-1 represent the present value of costs and benefits that accrue during and/or after mining operations.
- While multiple mining alternatives were considered in the Cook Islands and RMI, Table E-1 reports only the scenario with the greatest net benefits.

Table E-1 Summary of Total Net Benefits by Case Study Country (in millions USD, 2015)

Country	Resource	Total Costs	Total Benefits	Net Benefits	Benefit-Cost Ratio
PNG	Seafloor-massive Sulphides	$0.64	$83.3	$82.7	124
Cook Islands	Manganese Nodules	$27.4	$494	$467	18
RMI	Cobalt-rich Crusts	$29.3	$39[1]	$0	0

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.

Table E-1 suggests that DSM mining activity in both PNG and the Cook Islands has the potential to make the citizens of the host country better off.

- The present value of the total monetised benefits in PNG is $83.3 million (U.S. dollars [USD]). Given the two -year mining timeframe in PNG, this equates to an undiscounted annual average amount of $44 million (USD) to the PNG government.
- The present value of the total monetised benefits in the Cook Islands is $494 million (USD). Given the 20-year mining timeframe, this equates to an undiscounted annual average amount of $47 million (USD).

In contrast, given current technology and market conditions, the benefits associated with DSM mining activity in RMI are unlikely to exceed the costs.

In all cases, conclusions are fairly robust to a reasonable range of uncertainty related to input values and discount rates. 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.

1 Introduction and Background

Scientists have identified high concentrations of metals and rare earth elements deposited on the seafloor. These deposits occur at a limited number of locations, several of which are within the national jurisdiction of Pacific Island states.

As land-based reserves of metals and rare earth elements are depleted and as world demand continues to rise, there has been an upsurge in interest related to the retrieval of these deposits from seafloors. This interest persists despite two facts:

1. These deposits are often found at depths between 1,000 to 6,500 metres and their retrieval requires specialised and costly equipment that can withstand the pressure and environmental conditions of the deep-sea.
2. There are a variety of complex legal and environmental considerations associated with the extraction and mining of deep-sea minerals.

It was within this context that the 15 Pacific states of the African, Caribbean and Pacific Group of States (ACP)[1] requested assistance from the Secretariat of the Pacific Community (SPC) as they considered development of a marine minerals industry. This request ultimately led to the development of the SPC-European Union Deep-sea Minerals (DSM) Project, which is currently being implemented by the Geoscience Division (GSD) of the SPC in collaboration with the European Union. The main objectives of the DSM Project are to provide assistance in developing regional and national legal frameworks for DSM activities; to organise capacity-building initiatives; and to share DSM information that enables Pacific ACP States to make informed decisions and meaningfully participate in DSM mining activities.[2]

To empower the Pacific ACP States in this regard, the SPC has organised and facilitated a variety of technical workshops and meetings, addressing a wide spectrum of DSM topics ranging from scientific and environmental aspects to financial and legal implications. During a recent DSM stakeholder consultation workshop, one of the key recommendations to DSM Project staff was to have countries conduct DSM activity cost-benefit analyses (CBA) to assist with making DSM-related decisions.

As a first step, Cardno, on behalf of SPC, conducted three preliminary CBAs:

1. Retrieval of seafloor-massive sulphides (SMS) from seafloors in the Papua New Guinea (PNG) Exclusive Economic Zone (EEZ),
2. Retrieval of manganese nodules (MN) from seafloors in the Cook Islands EEZ, and
3. Retrieval of cobalt-rich crusts (CRC) from seafloors in the Republic of the Marshall Islands (RMI) EEZ.

In addition, Cardno used an input-output model (IMPLAN) to quantify potential labour and secondary effects (i.e. indirect benefits) associated with each of the three scenarios.

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[1] The African, Caribbean and Pacific Group of States (ACP) is an organisation created by the Georgetown Agreement in 1975. It is composed of 79 African, Caribbean and Pacific states, with all of them, save Cuba, signatories to the Cotonou Agreement, also known as the "ACP-EC Partnership Agreement" which binds them to the European Union. There are 48 countries from Sub-Saharan Africa, 16 from the Caribbean and 15 from the Pacific. (http://www.acp.int/content/secretariat-acp, Accessed June 4, 2015.

[2] More information about the DSM Project can be found here: http://gsd.spc.int/dsm.

To the authors' knowledge, these are the first publicly available CBAs of DSM mining in these countries and, therefore, represent a new application of the method. Despite the limited focus on three countries, the CBA will provide important findings and considerations that are applicable to nations with similar mineral resources.

1.1 Report Objective

This report addresses a key DSM Project goal: to conduct a preliminary economic (cost-benefit) analysis of DSM mining. Since mining has yet to occur anywhere in the world, the analysis is based on a realistic yet hypothetical mining scenario developed for each of the three countries.

For each country, the CBA focuses on the operation of a single mining site. The results of this preliminary analysis will provide decision makers with a better understanding of the costs and benefits likely to be associated with DSM mining. This report also includes a desktop-level identification of those who bear the costs and those who receive the benefits of the mining activities (that is, it evaluates potential distributional effects).

In addition, Cardno uses an input-output model (IMPLAN[3]) to quantify the effects of DSM mining to local communities and to each country as whole by estimating employment effects, and value added (total labour and other income) supported by expenditures associated with mining operations.

The goal of the analysis is to organise information into a standard framework that facilitates informed decisions and management plans related to DSM mining in the three case study countries, while providing general lessons learned for government consideration at broader regional and international levels.

1.2 Report Organisation

Section 2 provides a detailed description of the various sources of data used in this report. It also reviews the methods used to identify, quantify and monetise (where possible) the various social costs and benefits[4].

Sections 3 through 5 present the results of the cost-benefit analyses and regional economic impact analyses for each of the case study countries, PNG, Cook Islands and RMI.

Section 6 summarises the results and key considerations. This is followed by the concluding remarks and policy recommendations in Section 7.

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3 See Section 2.4 for further information.

4 Social costs and benefits are defined to include impacts on project participants via expenditures, revenues, and income, as well as impacts to members of society who are not otherwise participating in the project. Such impacts can arise if a project alters the environment, changes social and/or cultural norms, or has secondary effects that ripple through the economy.

2 Overview of Data and Methodology

Data availability and quality are key components of both CBA and regional impact analysis. As mining for DSM has yet to commence anywhere in the world, the analyses are built upon a combination of secondary data compiled from an exhaustive review of relevant literature, primary research including conversations with stakeholders in each of the case study countries and consultations with SPC staff, and economic relationships embedded in IMPLAN[5]. Sections 2.1 and 2.2 provide a detailed description of the data used in the analyses.

The data description is followed by a discussion of the basic steps in conducting a CBA and a discussion of the regional impact modelling methods.

2.1 Secondary Data

Secondary data were derived from articles in peer-reviewed journals, unpublished technical reports, proceedings and presentations from conferences, government reports and statistics obtained through stakeholder contacts, and proceedings and technical reports of the International Seabed Authority (ISA).

Secondary data were used to inform the development of both baseline and "with-mining" scenarios and to provide a range of estimates for the majority of the inputs used in the CBAs and regional economic impact analyses (REIAs). In some cases, site-specific information for the country of interest was not available. In these instances, assumptions were derived from studies of similar areas and resources. In all cases data are documented and information is provided on the underlying assumptions.

For discussion purposes, secondary data were broken into three categories:

1. Geological and mineral resource assessments,
2. Mining technology and costs, and
3. Environmental impacts.

2.1.1 <u>Geological and Mineral Resource Assessments</u>

As previously indicated, the three primary deposits of interest are SMS, MN, and CRC. Table 2-1 identifies the data sources used to characterise key input parameters including:

- Potential size (in square kilometres [km^2]) and duration (i.e., years of operation) of a single mining operation,
- Total resource potential (estimated tonnage of raw material extracted each year),
- Expected metal content in the deposits on the seafloor, and
- Estimated amount of metal that can be recovered out of the mineral deposits.

Together these inputs largely determine the viability and profitability of a DSM mining operation. For PNG and the Cook Islands, the CBA uses site-specific information for all of the relevant inputs. For RMI, the CBA uses a combination of information from site-specific studies and studies describing conditions at the outer boundary of the seafloor within the national jurisdiction of Japan.

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5 IMPLAN is a well-recognised economic input-output (I-O) modelling software package used to conduct the regional economic impact analyses.

Table 2-1 Summary of Data Sources Related to Geological and/or Mineral Resource Assessments

Author and Year	Source Type	Mineral Resource	Location of Study	Information Provided
Hein et al., 2015	Peer reviewed journal article	MN	Cook Islands	> Metal content > Size of mine site > Duration of operation
Thorburn, 2014	PowerPoint presentation	MN	Cook Islands	> Metal content > Resource potential > Metal recovery rate > Size of mine site
Hein et al., 2013	Peer reviewed journal article	CRC, MN	Clarion Clipperton Zone, Fe–Mn crust zone in the central Pacific	> Geological characteristics of seamounts > Resource potential
SPC, 2013 (a,b,c)	Technical report	SMS, MN, CRC	Cook Islands, RMI, PNG	> Metal content > Resource potential > Metal recovery rate
SPC, 2013	Information brochure	CRC	RMI	> Metal content > Resource potential
Agarwal et al., 2012	Report published through Lloyd's Register Educational Trust (LRET) Series	MN	Clarion Clipperton Zone	> Metal content > Resource potential > Metal recovery rate
Harrington et al., 2011	Peer reviewed journal article	SMS	Various	> Geographic characteristics of SMS deposits
Sharma, 2011	Peer reviewed journal article	SMS, MN, CRC	Various	> Metal content > Resource potential
Hoagland et al., 2010	Peer reviewed journal article	SMS	Various	> Potential size of SMS deposits
Goto et al., 2009	Conference proceedings	CRC	Japan	> Metal recovery rate
SRK Consulting, 2010	Cost study	SMS	PNG	> Metal content > Resource potential > Metal recovery rate > Size of mine site
Hein et al., 2009	Peer reviewed journal article	CRC	The Area	> Size of mine site > Geographic characteristics of CRC deposits

Notes: SMS = seafloor massive sulphides; MN = manganese nodules; CRC = cobalt-rich crusts

2.1.2 Mining Technology and Costs

Mineral deposits vary in composition, location, and depth. As such, the mining technology and ultimately the costs associated with extracting each resource will also vary. The CBA assumes technology has been optimised for each deposit based on recommended engineering systems as of the year 2015. However, it is important to remain cognizant of the fact that all costs are based on technology that has been piloted but not proven at the commercial level of operation. Cost estimates are highly uncertain and may change significantly depending on the mining technology that is in place at the time of full-scale commercial operation.

Estimation of DSM mining costs is based on several elements:

- A description of the preferred or most technologically efficient mining model and engineering system (in terms of capital equipment) as of the year 2015,
- Estimated equipment costs,
- Annual operating and maintenance costs (i.e., labour, wages, fuel, power, etc.),
- Annual transportation costs, and
- Onshore processing cost (capital and operating costs).

Table 2-2 identifies the sources of mining technology and cost information. For PNG, the CBA uses site-specific cost information that was prepared for Nautilus in 2010, while cost data for the Cook Islands and the Republic of the Marshall Islands are based on feasibility studies for MN in the Clarion Clipperton Zone and for mining crusts in the EEZ of Japan.

Table 2-2 Summary of Data Sources Related to Deep-sea Mining Technology and Costs

Author and Year	Source Type	Mineral Resource	Location of Study	Information Provided
ECORYS, 2014	Report written for European Commission – Maritime Affairs and Fisheries	SMS, MN, CRC	Various	> Capital cost > Operating and maintenance cost > Processing cost
Thorburn, 2014	PowerPoint presentation	MN	Cook Islands	> Capital cost > Transportation cost > Operating and maintenance cost > Processing cost
Agarwal et al., 2012	Report published through Lloyd's Register Educational Trust (LRET) Series	MN	Clarion Clipperton Zone	> Preferred mining technology > Capital cost > Operating and maintenance cost > Processing cost
Sharma, 2011	Peer reviewed journal article	SMS, MN, CRC	Various	> Capital cost > Operating and maintenance cost
SRK Consulting, 2010	Cost Assessment prepared for Nautilus	SMS	Papua New Guinea	> Capital cost > Transportation cost > Operating and maintenance cost

Author and Year	Source Type	Mineral Resource	Location of Study	Information Provided
Goto et al., 2009	Conference material	CRC	Japan	> Capital cost > Transportation cost > Operating and maintenance cost > Processing cost
ISA, 2008	Workshop proceedings	MN	Various	> Capital cost > Transportation cost > Operating and maintenance cost > Processing cost
Yamazaki, 2006	PowerPoint presentation	CRC, MN	Clarion Clipperton Zone and Japan	> Capital and operating costs for mining, ore dressing, transportation and processing
Soreide et al., 2001	Peer reviewed article	MN	Cook Islands	> Capital and operating costs for mining, transportation and processing
Premchan and Jana, 1999	Peer reviewed article	MN	India	> Capital and operating costs of processing
Ham, 1994	Peer reviewed article	MN	Various	> Capital and operating costs of processing
Lenoble, 1990	Peer reviewed article	MN	Various	> Capital and operating costs of processing
Hilman and Gosling, 1985	Peer reviewed article	MN	Various	> Capital and operating costs of processing
Andrews et al., 1983	Peer reviewed article	MN	Various	> Capital and operating costs of processing
Dames and Moore, Inc., and E.I.C. Corp., 1977	Book	MN	Various	> Capital and operating costs of processing > Inputs needed for high pressure acid leach facility
Notes: SMS = seafloor massive sulphides; MN = manganese nodules; CRC = cobalt-rich crusts				

2.1.3 Environmental Impacts

The identification and quantification of DSM mining environmental impacts requires both engineering data describing the physical effects of mining and biological data which is used to characterise baseline conditions and evaluate mining related changes to the environment.

Literature was reviewed to determine the:

- Total area of potential environmental influence,
- Composition of biological communities and level of ecological productivity within the area of potential influence,
- Physical conditions within the area of potential influence,
- Type of disturbance or contamination that may arise as a result of DSM mining activities, and

> Type and duration of environmental impacts that may result from DSM mining related disturbance or contamination.

Site-specific data were generally available for PNG. The Cook Islands and RMI characterisations rely on a mix of site-specific and regional data (Table 2-3).

Table 2-3 Summary of Data Sources Related to the Environmental Impacts of Deep-sea Mining

Author and Year	Source Type	Mineral Resource	Location of Study	Information Provided
Earth Economics, 2015	Report prepared for Nautilus	SMS	Solwara 1 Project Site	> Biological characteristics and ecosystem services at mine site
ECORYS, 2014	Report written for European Commission – Directorate General Maritime Affairs and Fisheries	SMS, MN, CRC	Various	> Habitat and biodiversity > Potential impacts of mining
SPC, 2013 (a,b,c)	Technical report	SMS, MN, CRC	Various locations	> Composition of biological community > Potential impacts of mining
Collins et al., 2012	Peer reviewed journal article	SMS	PNG	> Habitat and biodiversity > Potential impacts of mining
Coffey Natural Systems, 2008	Environmental Impact Statement	SMS	Nautilus sites in PNG	> Site-specific characteristics and potential impacts to biological community
Hein, 2004	ISA Workshop proceedings	CRC	N/A	> Described general characteristics of seamount communities
ISA, 1998	Technical report	MN	Clarion Clipperton Zone	> Composition of biological community > Environmental characteristics
Markussen, 1994	Technical report	MN	Hypothetical at depths of 4,000 – 5,000 metres	> Environmental consequences at each mining phase

Notes: SMS = seafloor massive sulphides; MN = manganese nodules; CRC = cobalt-rich crusts

2.2 Primary Data

Cardno conducted onsite meetings with key stakeholder groups in each of the case study countries. The purpose of the stakeholder meetings was to gather country-specific information that could not be obtained through secondary sources and to understand how each stakeholder viewed the prospect of DSM mining. A secondary purpose was to determine if the citizenry hold any unanticipated concerns related to DSM mining and what, if any, challenges they perceived in moving forward with mining operations.

Table 2-4 lists the affiliations of each of the stakeholders interviewed during in-country visits, as well a brief summary of the key issues raised during the discussion.

Table 2-4 List of Stakeholders and Key Issues by Case Study Country

Affiliation	Key Issues and/or Topics of Discussion
Papua New Guinea	
Minerals Resource Authority	> Current revision of legislation and incorporation of Extractive Industries Transparency Initiative (EITI) principles will facilitate management of offshore mineral projects > "Coastal Area of Benefit" to identify which local communities should benefit from offshore mineral activities > Solwara 1 project is relatively small in terms of scale in comparison with on-land mining operations > Provided details on approvals process and current status of Solwara 1
Department of Commerce and Industry	> DSM mining may provide short term, quick economic gains, without many of the complexities of terrestrial mining > Fisheries generate a significant proportion of non-mining related industry in PNG > Unknown environmental impacts are of concern
Nautilus Minerals	> Nautilus has been working closely with all Government agencies over a long period of time to ensure the Solwara project maximises benefits and minimise environmental, social and economic costs > Nautilus is voluntarily involved in a range of social and infrastructure programs in PNG > The short-term nature of proposed projects (e.g. Solwara 1 – 1 to 2 years of operation) can provide challenges and benefits in terms of social engagement, and impact identification and management > SMS deposits are typically small in area and volume in comparison to terrestrial deposits, but may have concentrations in the order of 10x magnitude > Mining vessel and equipment currently in construction. Production to commence in 2018. Equipment would be amortised over several projects > A large number of studies have been undertaken in regards to potential fisheries impacts; findings indicate low material impacts > Potential impacts associated with storage and tailings indicate it is most efficient to export product directly to processing facilities in other countries > Fuelling would be required to be done through offshore bunkering due to inadequate capacity at Rabaul > Data provided on mineral resource and cost details formed the basis of the hypothetical mining scenario

Affiliation	Key Issues and/or Topics of Discussion
Department of Mineral Policy & Geohazard Management	> PNG governance system allows the government to become equity partners in mining projects > There is a high level of knowledge regarding potential DSM impacts > Insufficient copper production within PNG to warrant development of in-country smelting facilities > Benefits would be maximised by having at least some storage / processing on shore > Major challenge is effective distribution of national government revenues to local and regional infrastructure and programs
Institute of National Affairs	> Fishing companies are nervous about the potential impacts associated with DSM mining > Lack of national capacity (in terms of available resources and technical skill) to monitor and audit operational activities on the sea floor and on-board vessels
PNG Chamber of Mines and Petroleum	> Nautilus Minerals are a significant contributing member to the Chamber of Mines and Petroleum
PNG Ports Corporation	> How will the volume of export be controlled if ore is loaded directly from a production vessel to an export vessel? Insufficient policing of resources for marine activities at the moment > Offshore bunkering would be required. Vessel may need to come directly from Singapore
PNG Ports Corporation – PNG Harbours Management Services	> Harbour management likely to be involved and generate fees through supply vessels for mining operations > Direct exportation of ore from a mining vessel would lower the whole of life cost of the project > Pollution risks and damage to environmental systems of high concern
Conservation and Environment Protection Agency	> Environmental Permit issued in 2009 for Solwara 1. It is likely that each individual mine site would require its own Environmental Permit (and Environmental Impact Assessment [EIA]) even though operation at each site is likely to be only for one or two years > Awaiting revised environmental and management monitoring plans for Solwara 1 > Solwara 1 viewed as a “test case” > Cumulative impacts will need to be considered in the future if Solwara 1 is seen to be successful (e.g. the impact of one DSM operation may be minimal but may pave the way for many operations) > Concerns that PNG does not have the capacity (in terms of available resources and technical skill) to monitor and audit operational activities on the sea floor and on-board vessels > Biodiversity Offsetting Policy in development that may be applicable to DSM mining activities

Affiliation	Key Issues and/or Topics of Discussion
National Fisheries Authority	> The concept and design of Solwara 1 is sound > Breakage / spillage from the riser pipe is seen as the main risk to fisheries > Short term nature of project and short population generation time of key species reduces the long term risk to fisheries. > Impacts in fisheries may be driven through perception of adverse impacts rather than actual impacts (e.g. bioaccumulation, mercury poisoning) > Fisheries account for approximately 8% of gross domestic product (GDP) > Most fishing in the area of Solwara 1 is likely to be artisanal fishing
National Maritime Safety Authority (NMSA)	> NMSA responsible for implementation of the International Convention for the Prevention of Pollution from Ships (MARPOL) and London Convention in territorial waters > Key concerns are around ore spills and oil spills generating impacts and ballast water of vessels coming in to pick-up ore directly from the mining vessel > Solwara 1 location is associated with an international shipping lane, increasing the risk of crash > PNG may not have the facilities to respond to large oil spills and may rely upon assistance from neighbouring countries
Cook Islands	
Ministry of Finance and Economic Management	> Discussion of fiscal regime > Discussion of logistics, DSM mining related equipment may come through Cook Island port
Ministry of Marine Resources	> Current location of initial mining leases will not have an impact on fisheries in the south > DSM policy should encourage multiple use and sustainable development
Ports Authority	> Biggest concern is logistics and need to communicate effectively with Seabed Mineral Authority > The only port large enough to support container vessels is in Rarotonga > Storage space is limited
Seabed Mineral Authority	> Processing likely to occur offshore in Mexico, Korea or China > Provided mineral resource and cost details for hypothetical mining scenario > First exploratory lease likely to be issued in 2015 > Provided detail on metal content, resource potential
Natural Heritage Trust	> Ensure no net environmental impact by establishing equivalent BPAs (Biodiversity Protected Areas) > Prevent noise/acoustic impacts to marine life
Ministry of Finance	> Wants Cook Islands to be engaged as far along the mining value chain as possible > Targeted areas for improvement based on revenue from mining include education, housing, and healthcare > No intention of processing on Cook Islands

Affiliation	Key Issues and/or Topics of Discussion
Te Ipukarea Society	> Concerned that knowledge of potential economic benefits will outweigh environmental impacts > Issue licenses one at a time
Marae Moana	> Working to establish marine protected areas around each island (100 nautical miles [nm])
National Environmental Service	> Wants to use first license to learn risks and challenges from biological perspective before moving forward > Environmental laws need to be revised before DSM mining begins > Limited capacity for monitoring and compliance with permit conditions
Ministry of Foreign Affairs and Immigration	> Foreign workers should be considered where capacity is lacking
Infrastructure Cook Islands	> Need to improve awareness and communications in the outer islands > Infrastructure development based on 5-year plans
Office of the Prime Minister	> Should wait to proceed until the market is ready
Miro Consultants	> Thinks demand for infrastructure/housing will increase
Cook Islands Investment Corporation	> Forms state-owned enterprise for mining in the Area (i.e., joint ventures)
Queens Representative	> In the process of establishing sovereign wealth fund based on Norwegian model
Traditional Leaders	> Concerns over ownership of the seafloor – believe it belongs to tribes/native people, not the government > Need balance between wealth and environment > Concerns about return of Cook Islanders living overseas > Concerns about corruption in government
National Council of Women	> How will mining impact violence toward women? > Will there be hands-on training opportunities for young women in mining-related jobs? > Not enough awareness and training for people living on outer islands
Republic of Marshall Islands	
National Seabed Minerals Management Board (National Offshore Minerals Committee)	> Communication and education of potential impacts associated with DSM is important
Office of Environmental Planning and Policy Coordination	> Potential for impacts to RMI fisheries, potential for invasive species and the loss of unique biodiversity are of high concern > Availability of resources (water, energy etc.) may pose constraints to any DSM mining activities
Ministry of Finance	> DSM mining activities represent good revenue opportunity for RMI > Risks and costs associated with establishing regulatory bodies and legislation for DSM mining if it is not considered viable by private operators > Foreign workers and foreign investment (e.g. Joint Ventures) have not always been favourable for RMI > Sovereign wealth fund may be of value to RMI

Affiliation	Key Issues and/or Topics of Discussion
Majuro Local Government	> Community support is likely to be strong if employment benefits are visible > Foreign workers and foreign investment (e.g. Joint Ventures) are not always well received by the community
Ministry of Public Works	> Any onshore activities would place pressure on water, energy, and waste systems > A sovereign wealth fund may be of value > Infrastructure on remote islands limited and needs maintenance > Equitable distribution of benefits
Chamber of Commerce	> Establishment of the right agreement between Government and mining operator is essential > Concern that the rights to DSM may have previously been sold > Chronic unemployment within RMI
Ports Authority	> Majuro harbour is currently being re-developed > Offshore operations are unlikely to lead to vessel delay and capacity constraints > Capable of receiving vessels of 40,000 tonne capacity > Refuelling would need to be done by offshore bunkering as there is insufficient capacity
Environmental Protection Agency	> Customary land-ownership extends to materials taken from below ground > Recovery time of deep-sea habitat and sediment dispersion of importance > Artisanal fishing makes up a large proportion of diet in some communities. Unlikely to extend more than 10 nm offshore > An opportunity to obtain economic independence
Republic of Marshall Islands Marine Resources Authority	> Management of offshore catch and ship-to-ship transfer is an issue for fisheries and may be for DSM mining activities > Risk to fish stocks from DSM mining include unhealthy fish stocks and lower catch rates
Office of Commerce and Investment	> Greatest barriers to foreign investment include the current regulatory framework, active government support, state of infrastructure (particularly airports and ports) > Potential DSM mining activity environmental impacts and impacts to fisheries are a concern
Coastal Management Advisory Committee	> Potential for impacts to tuna fisheries and potential for pollution events to arise as a result of DSM mining > The advancement of scientific knowledge about the deep-sea environment would be a key potential benefit
Economic Policy – Planning and Statistics Office	> There is a large non-cash economy and artisanal fishing plays an important role > Islands serviced by regular boat and plane supply services > If a DSM mining project is undertaken offshore what benefit will the community receive?

2.3 Cost-Benefit Analysis Methodology

CBA is a framework for evaluating the potential impacts of a proposed project[6] on society as a whole. In addition to evaluating a project's impacts on project participants via expenditures, revenues, and income, a CBA takes into consideration a broad range of potential costs and benefits, including environmental and cultural changes that may impact members of society who are not otherwise participating in the project (i.e., project stakeholders). It is because of this broader focus on society that CBA is often referred to as *social* cost-benefit analysis.

The main goal of a social CBA is to determine whether an activity has the potential to make society, as a whole, better off. A key element of that is defining society. The most inclusive definition of society is from a global perspective and it encompasses all people regardless of national and state boundaries. However for the purposes of a CBA, most practitioners define society at the national or state level. The justification for this is that residents of a country share a common constitution that sets out values for making collective choices, and accept that people of other countries have their own constitutions, beliefs and values that make them distinct societies.

The CBA process includes cataloguing and assigning monetary values (where possible) to a project's positive (benefits – i.e., increasing overall social well-being) and negative (costs - i.e., decreasing overall social well-being) impacts. When all benefits and costs are expressed in present value monetary terms, the comparison of benefits and costs can be facilitated using metrics such as the net social benefits (NSB) and the benefit-cost ratio (BCR).

- NSB equals total present value of benefits minus total present value of costs.
- BCR equals total benefits divided by total costs.

When the present value of social benefits exceeds the present value of social costs, the NSB will be positive and the BCR will be greater than one. Such projects pass the "benefit-cost test" and the adoption of the project has the potential to make society better off relative to the status quo or "do-nothing" scenario. Conversely, when the present value of social benefits does not exceed the present value of social costs, the NSB will be negative and the BCR will be between zero and one. Such projects fail the benefit-cost test and implementation of the project will make society worse off relative to the status quo.

In some circumstances not all of the potential benefits and costs can be monetised, and will not be directly reflected in NSB or BCR metrics. In such cases, CBA identifies and discusses these non-monetised benefits and costs so they can be considered by decision makers. Likewise, CBA often does not directly incorporate distributional (fairness) issues instead presenting a discussion of these potentially important considerations.

In practice, CBA is applicable in a variety of settings and has a deep-rooted history informing decisions related to public policy. In the United States, CBA is most often used in evaluating the impact of proposed federal regulatory changes and has also been used in evaluating public policies associated with water development, land use, health care, and public education. Internationally, CBA is most frequently used in evaluating investment in transportation, such as highways, bridges, and airports. Its application in evaluating natural resources and activities and/or regulations that affect the environment has also gained momentum in the past 40 years. These applications include but are not limited to the evaluation of disposal of hazardous wastes, the mode of electrical energy generation (coal, gas, wind, etc.), decisions about land use and water quality, and evaluation of programs or policies aimed at reducing greenhouse gases and improving air quality.

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6 In the context of a CBA, the term project can be interchanged with similar terms such as policy, or regulatory action since they all imply some sort of change from the current state of the world (i.e., status quo).

2.3.1 Steps in Conducting a Cost-Benefit Analysis

Conducting a CBA can be broken into eight basic steps (Figure 2-1).

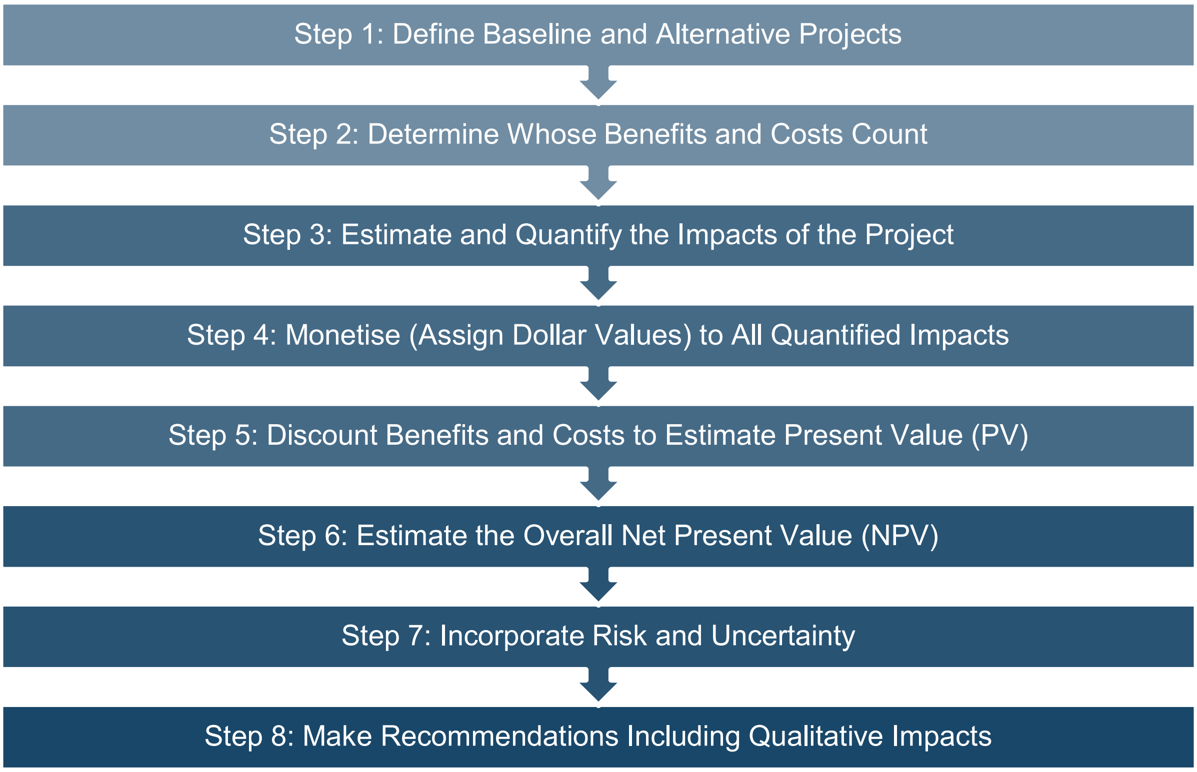

Figure 2-1 Basic Steps in Conducting a Cost-Benefit Analysis[7]

Step 1 Defining Baseline and Alternative Projects includes an effort to describe the state of the world to which the proposed project will be compared. This is often described as the baseline or counterfactual. Step 1 also includes defining the alternative scenario(s) with which benefits and costs will be associated.

> *This assessment evaluates three DSM mining scenarios: collection of SMS in PNG, collection of MN in the Cook Islands, and collection of CRC in the RMI. Unless otherwise specified, each "with-mining scenario", the host country enters into an agreement with a DSM mining company owned, operated, and home ported*[8] *in a country outside the Pacific Community. These scenarios are compared to a base case, in which case DSM mining does not occur.*

Step 2 Determining Whose Benefits and Costs Count requires a determination of who has standing, or the geographic scope over which the benefits and costs will be counted. That is, will costs and benefits be evaluated from a global perspective or at a national, state, or local level?

> *This assessment focuses on costs and benefits accruing to the country in which mining would occur: PNG, the Cook Islands, and the RMI. Thus only citizens of the host country are considered to have standing in each of the CBAs.*

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7 Boardman, Anthony. *Cost-Benefit Analysis: Concepts and Practice*. 2nd Edition. New Jersey: Prentice Hall Inc., 2001. Print.

8 Pacific Island countries may require for the foreign owned mining company to be incorporated in country and/or have a subsidiary with a local physical address and staff.

Step 3 Estimate and Quantify the Impacts of the Project requires the identification of the project's physical impacts, defines them as costs or benefits, and assigns units of measurement. The list of costs and benefits considered depends upon how the project affects the people with standing. In other words, different costs and benefits may be considered depending upon who is determined to have standing. Since the analysis is conducted at the level of the host country only those costs and benefits affecting the citizens of the host country are included.

In this assessment, costs are divided into two categories: private and external.

Private costs are imposed on:

> *The host country government in the form of administrative costs which include wages paid to government workers. These are incorporated into the CBA because they represent a real cost to the host government.[9] Since each scenario is based on the productivity of a single mine site, the cost of developing a national policy and regulatory framework is pro-rated accordingly. All other ongoing administrative costs are based on the wages paid to the number of government workers required to monitor, enforce and report the day-to-day operation of a single mine.*

> *Foreign DSM mining companies in the form of capital expenditures and operating costs. Based on the definition of standing, these costs are not directly incorporated into the CBA. However, DSM mining costs are estimated and indirectly incorporated through the assessment of the economic viability of a mining operation. This is important because if the DSM mining company is not profitable, lease revenues and royalties flowing from DSM mining companies to the government will not exist.*

External costs are those imposed on host country citizens via environmental and cultural change. These costs are directly incorporated into the CBA because they represent a real cost to host country citizens. Environmental costs are monetised; cultural costs are qualitatively addressed.

Benefits are also divided into two categories: private and external. Under an assumption of full employment in the host country, private benefits accrue to:

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9 In developing this analysis stakeholders asked if the rapid injection of wealth in the form of taxes and royalties into a relatively small, isolated country, may have adverse effects that might not arise in the context of a larger or more economically integrated host country? Generally, the answer is no.

If the host government immediately distributes the tax/royalty money to host country citizens in the form of direct payments that are constant across households, short- and longer-term outcomes may be as follows:

> In the short term, when the supply of goods is fixed, the wealth injection leads to an increase in prices. Benefits accrue almost entirely to those who produce or own the goods that will be sold in that time period. Consumers are relatively unaffected as the payments they receive from the government are effectively lost to higher prices.

> In the longer term, production and import activity would increase, prices would trend back toward a global equilibrium, and the benefit associated with the tax and royalty payments would accrue largely to consumers; producers and importers would be left somewhat better off as their profit per unit returns to baseline but the number of units sold remains elevated.

That said, if the government allocated tax and royalty payments to only a subset of households, short-term benefits would still accrue to the individuals who produce or own the goods that will be sold in that time period, and the welfare of those who receive payments would remain largely unchanged. However, the welfare of those who do not receive payments would decrease, as their income would remain unchanged but they would face higher prices. In the longer term, prices would again trend toward global equilibrium, benefits would accrue primarily to consumers who receive payments, and the welfare of producers, importers, and consumers who do not receive payments would be largely unchanged.

A second question arises that is related to the potential for external costs associated with inflation that is driven by an increase in the demand for, and a commensurate rise in wages among, host country labour. DSM-related demand for host country laborers is expected to be modest and is not associated with an increase in host country labour rates and associated inflationary pressure.

- *Foreign DSM mining companies in the form of revenues. Based on the definition of standing, these are not directly incorporated into the CBA. However, similar to DSM mining costs, DSM mining company revenues are incorporated indirectly through the assessment of the economic viability of the mining operation, because, if the DSM mining company is not profitable, royalties and taxes flowing from DSM mining companies to the government will not exist.*
- *Host governments in the form of royalties and/or tax revenues. These are directly incorporated into the CBA as a private benefit to the host country because they represent a transfer of wealth into the country.*

External benefits are those that accrue to host country citizens not otherwise involved in DSM mining via DSM mining related technological and biological advances. These are incorporated into the CBA in the form of a qualitative discussion.

Step 4 Monetising assigns values (in USD) to each of the quantified impacts. Converting each of the costs and benefits to a common unit allows for the direct comparison of costs to benefits (Step 6).

In this analysis costs and benefits are expressed in USD in the base year of 2015.

Step 5 Discounting Benefits and Costs to Estimate Present Value (PV) adjusts the costs and benefits that occur at various times throughout the project into a single time period so they are directly comparable to one another. This process involves what economists call discounting or calculating a present value. Discounting acknowledges individuals' tendency to place more weight on costs and benefits that occur early on in a project rather than later.

Because some uncertainty exists as to the appropriate rate of discount, this assessment considers a range of discount rates and evaluates the sensitivity of conclusions to these discount rates. The base case, to which the sensitivity of the results is tested, uses a 7% discount rate. This is rate suggested by the United States Environmental Protection Agency's Guidelines for Preparing Economic Analyses (USEPA, 2010). (See also Step 7.)

Step 6 Estimating the Overall Net Present Value (NPV) is equivalent to estimating the net social benefit of the project. This is calculated as the present value of the benefits minus the present value of the costs (NSB = PV Benefits − PV Costs).

In this analysis a net social benefit greater than zero (NSB > 0) suggests the project has the potential to make citizens of the host country better off. A net social benefit less than zero (NSB < 0) suggests the project will leave host country citizens worse off.

Step 7 Incorporating Risk and Uncertainty requires the sensitivity of outcomes to be evaluated.

In this analysis, Monte Carlo simulation[10] is used to evaluate the sensitivity of outcomes to uncertainty associated with a variety of the factors used directly in the estimation of costs and benefits. Each CBA also includes a separate sensitivity analysis post calculation to test the sensitivity of the net benefits to variations in discount rates.

Step 8 Making Recommendations requires consideration of the projects NPV, sensitivity of NPV calculations, and any impacts that could not be quantified and/or monetised.

Summaries and recommendations for each individual country are provided in Section 6. There is also a general policy implications and recommendations section at the end of the document (See Section 7).

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10 Monte Carlo simulation is a problem solving technique used to approximate the probability of certain outcomes by running multiple trial runs (simulations) where inputs are drawn from a distribution using random variables. The technique's application to the DSM analyses is discussed further in Section 2.3.4.

2.3.2 Detailed Cost Methodology

The report quantifies and monetises as many of the potential social costs of DSM mining as possible. These include private administrative costs incurred by the host country's government and external costs incurred by host country citizens related to environmental or cultural change. While private costs incurred by foreign owned DSM mining companies are not directly included in the CBA, (these entities do not have standing) they are quantified as part of a DSM mining viability analysis.

2.3.2.1 Private Cost Methodology

The private administrative costs incurred by the host countries are estimated by:

> Assuming a list of costs that would otherwise not be incurred in the absence of DSM mining. These include (1) development of a DSM mining regulatory framework (pro-rated to estimate the amount that would be associated with a single mining operation), (2) monitoring and reporting of DSM mining activity, (3) accounting costs associated with the collection and potential distribution of DSM mining-related payments to the government, and (4) contract administration.

> Providing estimates of the number of full-time workers needed to carry out the duties described above, as well as the estimated annual salaries of these workers.

> Estimating the PV of the costs over time using a 7% discount rate.

The private costs incurred by foreign DSM mining companies are determined by:

> Selecting the most efficient and/or technologically preferred mining system for each mineral deposit based on the typical value chain of a DSM mining operation (Figure 2-2).

> Using estimates in the literature and information gathered through conversations with various stakeholders to develop a range of cost estimates for the capital and operating expense associated with each phase of the value chain.

> Incorporating uncertainty into the analysis by randomly drawing an input value from a distribution of potential values. This takes into consideration that each value has an equal chance of occurring in the future, allowing (during a Monte Carlo simulation) the cost variable to take on different values, thus producing different outcomes.

> Estimating the PV of the costs over time using a 7% discount rate.

Definition of Social Costs

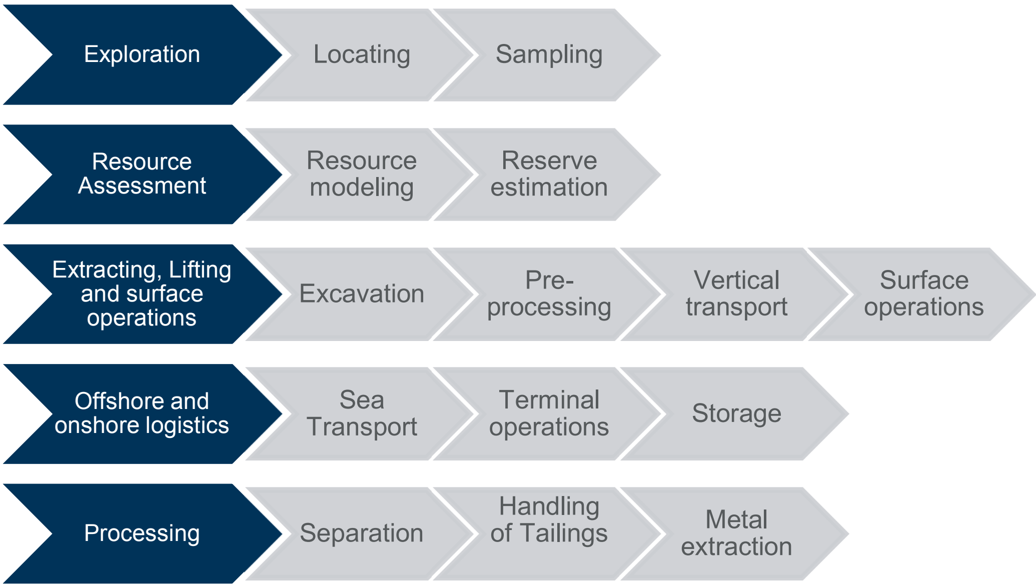
> **Private administrative costs incurred by the host country** – *The government bears administrative costs associated with the ongoing monitoring, enforcement, and permitting activities. These costs are treated as private costs, since the government is voluntarily entering into an agreement with the mining company to sell its mineral rights. The cost of developing a national regulatory framework is pro-rated to better reflect the amount that would likely be attributed to the operation of a single mine site.*

> **Private costs incurred by foreign DSM mining companies** – *While the DSM mining companies do not have standing in our analysis, the costs they incur are estimated because they partially determine the economic viability of DSM mining activities and ultimately affect tax revenue and royalties to the host government.*

> **External costs incurred by host country citizens not otherwise involved in DSM mining** – *These include environmental impacts or cultural changes that negatively affect people's well-being. The external costs identified in the CBAs include:*

- **Environmental costs** – *These costs are incurred if DSM mining results in a reduction in the quality or quantity of services provided by the environment.*
- **Cultural costs** – *These costs are incurred if there is a reduction in the general feeling of well-being due to a project.*

Estimating these costs is relatively straightforward because most involve direct expenditures that are a reasonable measure of the economic value of costs when subsidies and taxes are accounted for.



Source: ECORYS, 2014

Figure 2-2 Typical Deep-sea Minerals Mining Value Chain

2.3.2.2 External Cost Methodology

The external costs likely to be incurred by host country citizens are generally related to environmental changes or cultural changes.

2.3.2.2.1 External Environmental Costs

External environmental costs are incurred if DSM mining activity results in a reduction in the quantity or quality of ecosystem services provided by the environment to host country citizens. Such costs may arise from:

- Mining related disruptions to the services provided by deep seabed communities,
- DSM mining related increases in carbon dioxide (CO_2) emissions,
- Surface water quality impacts due to the discharge of nutrient rich water, and
- Unplanned releases of oil into the marine environment during mining or transport operations.

If mined material were processed within the host country, this activity would impose an additional suite of external environmental costs including but not limited to air emissions, degradation of noise and viewscapes, consumptive and non-consumptive water use, and site contamination risks.

Figure 2-3 identifies these impacts along with their associated phase in the mining value chain.

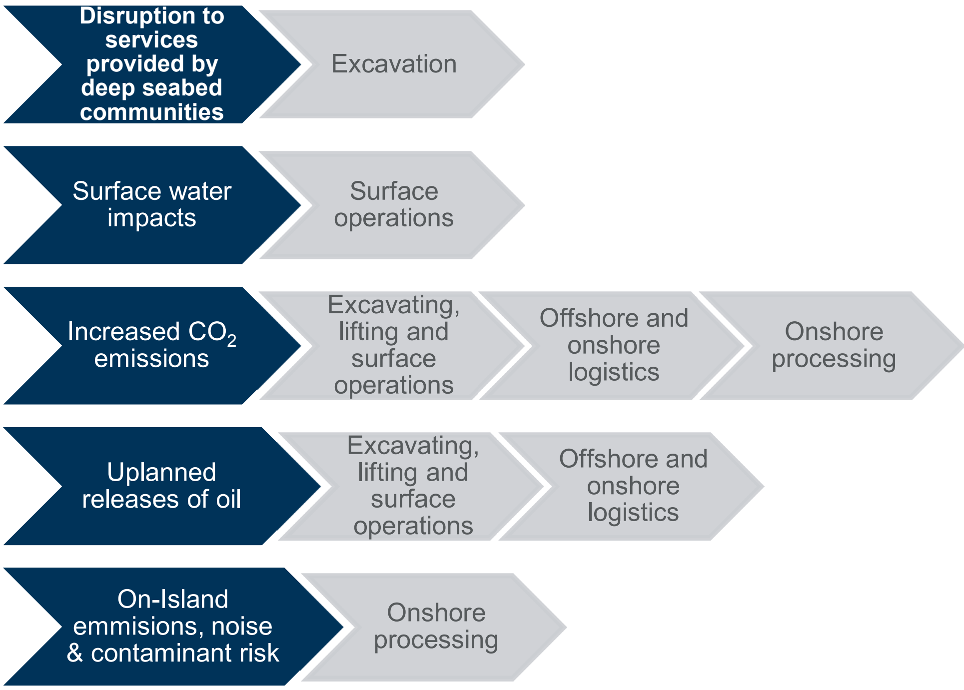


Figure 2-3 Potential Environmental Impacts of DSM Mining Activities by Phase in Mining Value Chain

DSM Mining Changes in Ecosystem Services Provided Deep Seabed Habitats

The external costs associated with changes in services provided by deep-seabed habitat are 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[11] to estimate the value of lost ecosystem services.

Introduction of Nutrient Rich Water

Each CBA assumes that the potential for adverse effects resulting from the introduction of nutrient rich water to the ocean surface can be eliminated via technological requirements. As such, this potential environmental externality is discussed but eliminated as a direct social cost. Instead these costs are internalised by requiring the DSM mining company to invest in operational technology that eliminates the source of the potential impact.

[11] The methods are described in Appendix A.

Carbon Dioxide Emissions

The ecological changes associated with CO_2 emissions are thought to have the same effect on host country citizens regardless of the actual emissions location. That is, CO_2 emitted in the United States is thought to have the same effect on Pacific Island States as would CO_2 emitted within the Pacific Island States.

In this context a complete CO_2 valuation requires an understanding of the effect of DSM mining activity on global metals production.

- If DSM production essentially adds to global metals production, DSM mining related CO_2 represents an addition to the global emissions.
- If DSM production displaces metals produced at some other site and if that “other site” generates the same level of CO_2 emissions as does the DSM mining operation, global CO_2 emissions remain unchanged.
- If DSM production displaces metals produced at some other site and that “other site” generates more CO_2 than does the DSM mining operation, the global level of CO_2 emissions would decrease.

An analysis of the global metals markets and facility-specific carbon footprints is beyond the scope of this report. Instead, it is assumed that the host countries take a precautionary approach to CO_2 emissions and require the purchase of CO_2 offsets by the DSM mining company[12]. This requirement assures DSM mining activity results in no net increase in CO_2 emissions. This effectively internalises the potential externality by requiring the DSM mining company to invest in operational technology that eliminates the source of the potential impact.

Estimating the cost of this precautionary approach is a three step process:

1. Tonnes of annual CO_2 emissions associated with DSM mining activities are estimated,
2. Annual emissions are multiplied by the per tonne cost of carbon offsets, and[13]
3. Total CO_2 offset expenditures are calculated using a 7% discount rate.

Unplanned Oil Releases

The external cost associated with unplanned oil releases is estimated using a four step process:

1. First, the annual spill probability is calculated for each DSM mining vessel using spill frequency data collated by the International Tanker Owners Pollution Federation (ITOPF).
2. Second, spill volume is set equal to the volume of fuel carried by each vessel. Multiplying the probability of a spill by spill volume, expected release volume is collected.
3. Annual spill costs are calculated as the product of expected spill volume and the cost-per-unit-spilled where cost-per-unit-spilled includes the cost of providing compensatory ecological restoration to assure there is no net loss of ecosystem services through time, and unavoidable social costs (Kontavas and Psaraftis, 2010).

[12] This policy may be driven by host country commitments to international agreements and/or may simply reflect a hedge against potential CO_2 related impacts.

[13] The per-tonne cost of carbon offsets comes from a report on the State of the Voluntary Carbon Market. To incorporate uncertainty, this input enters the analysis as a range in a probability distribution (low of $3.7, most likely of $5.8, and maximum estimate of $7.4). This estimate is caveated slightly as it represents the market-clearing or equilibrium price between the cost of sequestering carbon through projects like reforestation, installing renewable energy systems, etc., and society’s demand for these types of projects. That is, the price reflects an avoidance cost rather than a willingness-to-pay estimate.

4. Annual spill costs are discounted using a 7% discount rate.

On-Island Processing

The external environmental costs associated with potential on-island ore processing were evaluated for the Cook Islands and RMI by:

> Quantifying the annual expected environmental impacts related to the selected metallurgy process. These include but are not limited the carbon emissions associated with the processing of the minerals, the disposal and/or storage of liquid and solid waste, and the loss of marine life associated with the withdrawal of ocean water for use as process water,

> Multiplying the expected annual impact by a per unit cost impact, and

> Discounting the expected annual cost at 7%.

Description of Social Benefits

> **Private benefits in the form of royalties and/or tax revenues to the host country's government** – These payments can be used to enhance education, upgrade infrastructure, or simply increase the well-being of individuals.

> **Private revenues accruing to foreign DSM mining companies** – While they do not have standing, benefits to the DSM mining company are used to determine DSM mining viability and the magnitude of payments to the host government.

> **External benefits accruing to host country's citizens not otherwise involved in DSM mining** – These might arise if DSM mining led to development of some technology that benefitted other sectors of the economy.

2.3.2.2.2 External Cultural Costs

This analysis provides a qualitative assessment of the potential cultural costs based on in-country conversations with stakeholders. With the exception of cultural costs associated with changes in the level of ecosystem services provided by deep seabed habitats, cultural costs are not monetised.

2.3.3 Detailed Benefit Methodology

The report quantifies and monetises as many of the potential social benefits of DSM mining as possible. These include private benefits in the form of royalties and/or tax revenues paid to the host country's government and external benefits accruing to host country residents. While private benefits accruing to the DSM mining company are not directly included in the CBA (these entities do have not standing) they are quantified as part of the DSM mining viability analysis.

Private benefits are determined by:

> Estimating gross revenue of the DSM mining company by applying the expected prices (dollars per tonne) to expected yields (tonnes),

> Applying a royalty percentage and subtracting royalty payments from the total gross revenues to determine the mining company's net revenue,[14]

[14] The exact percentage (in terms of royalties and taxes) applied in each host country will depend on whether a fiscal regime is established. This is discussed in the "Benefits Methodology" Section in each of the case study countries (Section 3.6 for PNG, Section 4.6 for Cook Islands, and Section 5.6 for RMI). Also, in the case of PNG, royalties are estimated differently than the other two countries based on the current agreement between the PNG government and Nautilus Mining, Ltd. This is discussed further in Section 3.

- Applying a cash flow model to determine the mining company's profit,[15]
- The mining company's profit in any given year will determine whether the government receives additional income from taxes, levies and/or resource rent,[16]
- Calculating total payments to the government (royalties, taxes, levies, and resource rent payments) in each year, and
- Estimating the PV of government revenues over time using a 7% discount rate.[17]

A note on indirect benefits

In addition to the direct benefits, DSM mining operations may stimulate the economies of each host country by providing direct employment and by increasing demand for services provided by locally based companies or material providers. For the purposes of estimating social benefits, these secondary effects are not included in the CBA since they often represent a form of double-counting. However, they are estimated independently in a Regional Economic Impact Analysis for each host country and reported in Sections 3.9, 4.9 and 5.8.

As with social costs, the social benefits that are most reliably quantified and monetised are those that are associated with market transactions. External benefits are not as easily quantified and/or monetised, which often leads to a qualitative discussion with a general assessment of the potential magnitude of this change.

2.3.4 Incorporating Uncertainty

Given that many of the inputs used to estimate DSM mining costs and benefits are uncertain, the CBA uses a simulation technique known as Monte Carlo analysis to incorporate uncertainty directly into the CBA. In other words instead of relying on a single, static value for an input like the price of metal, the Monte Carlo simulation randomly draws from a range of likely prices to show how the results (i.e. PV of benefits) might change under different scenarios.

The value for each input listed below enters the CBA as a random draw from a probability distribution. The probability distribution is formed by generating a mean or average value for each input and bounding

15 Profit is equal to the net revenue of the mining company, less the costs associated with capital and operating expenses. In years where profit is positive or provides a return large enough to apply resource rent, a corporate income tax and resource rent (if applicable) is applied and added to the royalty payments in order to determine the total revenue to the government. For a detailed discussion of the cash flow analysis see Appendix B.

16 Resource rent is a term used to describe surplus value after all costs and normal returns have been accounted for. In other words, if there are returns above and beyond what a firm needs to remain viable, the government has the option to take a portion of these "super profits" as additional revenue. Thus far, only the Cook Islands has specifically indicated that they will apply a resource rent in addition to taxes and royalties.

17 As a reminder, profits accruing to the foreign owned DSM mining company are not included as benefits in the CBA. They are evaluated on the sole basis of determining the economic viability of the mining operation. In other words, given a variety of factors such as capital and operating expenditures, prices of metals, expected metal recovery, would the mining operation be profitable, and therefore lead to a decision to undertake the operation. It is also noted that *if* mining were to commence and turn out not to be economically viable, the mining company would still be responsible for rehabilitating any environmental damage associated with the mining operation.

the mean from above and below (i.e. generating a high-end value and a low-end value). The determination of the high and low values are based either on extremes found in the literature, or a +/- 50% deviation from the mean.

Ranges that were built based on high and low values found in the literature include:

> The proportion of the minerals present on the seafloor that can be recovered (i.e. mining efficiency),
> The composition of the product retrieved from the seafloor (i.e. assumed metal grade),
> The proportion of metal that can be recovered after processing, and
> Capital and operating expenses.[18]

In the case of price, the probability distribution is formed based on a range (+/- 50%) around the most likely value (i.e. current market price) to reflect the general volatility and variation in price over time.

With each draw, the NPV of profits to the private DSM mining company and revenue to the government are calculated. This is done over and over again to reveal the distribution of potential outcomes. The distribution is illustrated as a cumulative probability plot.[19]

Figure 2.3 is an example illustrating the NPV profit distribution associated with a hypothetical project.

> The green, black and red lines represent the risk profiles for three different options.
> Focusing on the green line, note that an NPV less than $60 million (£) rarely occurs. Also note that the medium NPV is about $75 million (£) which means that half of the draws were associated with a NPV less than $75 million (£) and the other half of the draws were associated with an NPV greater than $75 million (£). Finally, notice that a NPV greater than $85 million (£) is unlikely.
> Now focus on the black and red lines. Both have the same median NPV of $100 million (£). However, the black line is generally steeper than the red, which indicates that there is less uncertainty associated with Option 1 (the black line) than there is with Option 2.

[18] The only exception is PNG where cost estimates were based on the estimates provided by SRK Consulting for the Solwara 1 project. In this case, the upper and lower bounds are approximately +/- 20% from the estimate provided.

[19] The cumulative probability plot is created by plotting the outcome of each draw on the x-axis against the fraction of all the draws that produced an outcome less than or equal to that value. The plot illustrates the probability of being above or below a particular value, or of being within, or outside, a particular range.

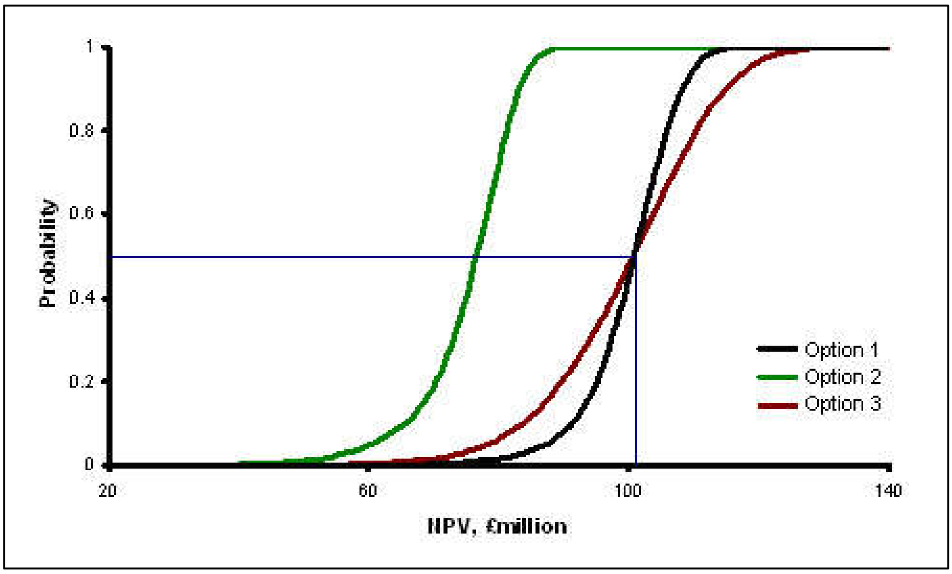


Figure 2-3 Example Output from Monte Carlo Simulation

Associated with each of the case study CBAs is a probability plot illustrating both PV profits to the DSM mining company and PV payments to the host country government. This plot illustrates the range of potential outcomes thus incorporating the high degree of uncertainty in many if not all of the input values.

2.4 Regional Economic Impact Modelling

In addition to identifying, quantifying and monetising the costs and benefits associated with a project, policy makers are often interested in the potential for effects in secondary or support industries. For example, DSM mining may increase demand for helicopter fuel and so increase revenue at helipads. These secondary effects are not generally discussed in cost-benefit analyses because they often represent a form of double-counting. That does not mean that these secondary effects are not important or that they should not be identified and discussed.

Identification and discussion of these secondary effects is facilitated by regional economic impact modelling which provide measures of regional economic growth and activity. Section 2.4.1 provides a basic overview of the economic impact model, and Section 2.4.2 summarises data sources

Regional Economic Impact Modeling Basics

- **Development of economic model –** This involves developing an economic model for the Cook Islands and RMI using IMPLAN software, 2013 IMPLAN data (the most recent data available) and by customising GDP, income, and employment by industry within the IMPLAN model.
- **Development of model inputs –** Project-related expenditure data were collected and evaluated to identify the change in demand for labour and goods and services in each country's economy.
- **Estimation of regional impacts –** Data for mining operations and government royalty outlays were used to estimate direct jobs and income and value added. Once direct impacts were determined, the regional economic impact model was used to estimate the total jobs, income, and value added impacts, including the ripple effects (indirect and induced) throughout other economic sectors as money is recirculated in the economy and/or exported to entities outside the host country.

and assumptions used when applying the model to a DSM mining operation for each study area.

2.4.1 Overview of Economic Impact Analysis

DSM mining operations will stimulate the economies of each host country. Expenditures on materials and labour required to conduct DSM mining may support job and income growth for locally based companies, material providers, other directly related industries, and government.

To understand how a business activity such as DSM mining, affects a regional economy, it helps to understand how different sectors or industries are linked to each other within an economy. For example, DSM mining operations require labour and materials to collect minerals from the seafloor. This labour and material is purchased from firms or contractors which may or may not reside in the host country. In turn, businesses that sell inputs to the mining operation purchase items needed to operate their own industries, and so on throughout the supply chain. These are referred to as backward linkages. In contrast, businesses that purchase raw minerals for further processing are forward linkages in the supply chain. The supply chain ends when a final good or service is either consumed in a regional economy or leaves as an export.

Most businesses import some goods and materials from outside of a local economy. Money spent on imports is a “leakage” from a local economy, which in the case of DSM mining may be large due to the specialised nature of the activity. For example, mine developers are expected to import much of their mining equipment and machinery, which is highly specialised, from outside of the case study countries. Likewise, many businesses export their products to foreign markets. Export revenues are important for economic growth since the foreign payments for exports are new money injected into the regional economy rather than existing money recirculating. Similarly, attracting foreign capital to develop resources in an area such as mineral deposits is new money and grows an economy.

As noted above, new projects affect businesses throughout a region (even seemingly unrelated businesses). This effect is known as a multiplier effect. The size of a multiplier effect or the extent to which new money generated by exports is able to expand the local economy is largely dependent on how much of the money is spent and re-spent in the local economy. A proportion of money received by an industry is spent to procure local supplies, and then these local suppliers re-spend that money. If there are few local suppliers, much of the money will leak from a local economy, and the multiplier effect will be smaller. In other words, the size of the multiplier effect depends on how local businesses are linked and how much leakage occurs in the form of imported inputs.

The household sector is linked to all sectors as it provides the labour and management for local businesses. Changes that affect household income typically have greater impacts on a local economy when compared to changes in the sales in other sectors because households typically spend most of their income locally in retail and service industries.

2.4.2 Economic Impact System and Data

IMPLAN is a software tool and database that allow an analyst to construct economic input-output (I-O) models.[20] I-O models are constructed based on the concept that all industries within an economy are linked together; the output of one industry becomes the input of another industry until all final goods and services are produced. I-O models can be used to both analyse the structure of a regional economy and to estimate impacts of projects or policies. For this analysis, 2013 economic impact models for the

[20] The IMPLAN model consists of commercial software and region-specific economic data, which is maintained and distributed by the IMPLAN Group, Inc. The IMPLAN model was selected for this analysis based on its ability to specify linkages that allow for the determination of the employment, income and GDP benefits directly attributable to DSM operations, and provide a framework to quantify the secondary employment, income and GDP (indirect and induced) effects of DSM operations. In addition, the IMPLAN model is flexible and can be easily customised to the region of interest.

Marshall Islands and the Cook Islands economies were constructed using IMPLAN. The economic impacts of DSM mining in PNG were estimated using a different approach. The economic impact analysis for PNG relies on previous research for large scale resource development projects to approximate the direct, indirect and induced income and employment impacts of DSM mining. Specifically, the analysis relies on research previously completed for the ExxonMobil LNG project and other studies on hard rock mining in PNG. This approach was selected because IMPLAN data for PNG, or a reasonable proxy country, does not readily exist.

Underlying IMPLAN data are not available for the study area countries; however, IMPLAN data are available for the Commonwealth of the Northern Mariana Islands (CNMI). Therefore, given the geographic and economic similarities between CNMI and both RMI and Cook Islands it was assumed, with proper updating and modification, 2013 CNMI IMPLAN data would serve as a reasonable proxy for both of these study area countries. For the underlying IMPLAN model to better represent the economy of study area countries, the CNMI IMPLAN model was customised using the most recent data available for both RMI and Cook Islands.[21] Employment, income, and gross domestic product (GDP) estimates by major industrial sector for the RMI were used to update the underlying CNMI IMPLAN model.[22] Similarly, data recently published by the Cook Islands government was used to update employment and GDP for each major industrial sector in the underlying CNMI IMPLAN model.[23] Recent employee compensation estimates by industry for the Cook Islands are not available; therefore, the REIAs rely upon the average employee compensation (by industry) for the CNMI to derive employee compensation estimates within the underlying Cook Island IMPLAN model.[24]

The key model outputs used in this analysis are employment, income, and total value added. Income is the sum of labour income (including employee and proprietor income and all payroll and benefits) and gross operating surplus or profit. It is equivalent to value added (a measure of the contribution to GDP of a proposed enterprise), less taxes paid. Employment represents the annual average number of employees, whether full- or part-time, of businesses producing output.

IMPLAN has some limitations. One of the most important is that I-O models assume that those who become unemployed or employed due to a change in final demand have no alternative employment. This assumes that increased economic activity associated with the project will increase local employment—when in fact, if existing workers can increase productivity, then new jobs may not be created but output would be higher. For this reason, the analysis uses the number of jobs *supported* by the project, rather than the number of jobs *created.*

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21 Cardno updated the underlying CNMI employment, income and value added to be representative of the Cook Islands and RMI. Please see Appendix D for additional information on specific employment, income and value added data used within the IMPLAN model.

22 Pacific Island Training Initiative, August 2014, Fiscal Year 2013, Statistical Appendices, Website (http://www.pitiviti.org/news/wp-content/uploads/downloads/2014/11/RMI_EconStat_tabs_FY13_publish.pdf) Accessed March 3, 2015.

23 Cook Islands Government, February 2015, Economic Activity and Labour Force of the Cook Islands, Website (http://www.agriculture.gov.ck/contents/pdf-download/national-docs&acts/Economic%20activitiy%20and%20labour%20force%20of%20the%20Cook%20Islands.pdf) Accessed March 3, 2015.

Cook Island Ministry of Finance and Economic Management, 2013, Statistical Bulletin, Website (http://www.mfem.gov.ck/mfemdocs/stats/statistical-series/national-accounts/154-annual-gdp-2013/file) Accessed March 4, 2015.

24 Using this approach, the 2013 average annual employee compensation for the Cook Islands was assumed to be $17,110 (USD). The average wage income estimate of $17,110 is comparable to recent wage income estimates derived by the Secretariat of the Pacific (Cook Islands Investment in Disaster Risk Management, April 2011), which found an average employee compensation of $17,500 NZD (2011) for the Cook Islands or $14,400 USD (2013).

Another assumption is that of fixed proportions—for any good or service, all inputs are combined in fixed proportions that are constant regardless of the level of output. Hence, there is no substitution among production inputs and no economies of scale are possible. Also, each production function incorporates fixed technology, so for example the same proportion of labour and capital are used. This limitation could have implications on the predicted future employment and income estimates if the inputs for the mining industry change over time. I-O models do not incorporate model price effects that might be important to a region. Regardless of the level of production, it is assumed that price and returns per unit of production are constant.

2.4.3 Assumptions Related to Model Inputs

Typically in a regional impact analysis, capital expenditures are included if they are expected to be procured from the region in which the analysis is being conducted. In this analysis, capital expenditures have been excluded given that most of these items are highly specialised and are not expected to be procured from study area countries.[25] Similarly, it is anticipated equipment integration and testing would occur in Southeast Asia and therefore, any labour expenditures associated with integration and testing are assumed to be for non-local workers. The only local employment and income benefits associated with DSM mining are expected to be associated with project operations (i.e. operating expenditures) and are for procurement of project fuel, spares, consumables, and labour.

With respect to the determination of local employment and income benefits, the analysis makes the following assumptions:

- For labour, Solwara 1 estimated a steady state employment of 121 full-time equivalents during operations. Given that the 121-person crew is expected to work a four-week-on-four-week-off rotation, there would be a total of 242 local and non-local workers required for the DSM mining operation. The percentage of local versus non-local labour in PNG is based on research conducted for the PNG mining industry.
- In PNG, local mine hiring practices indicate that 46.1% of mine employees are from the province in which the mine is located; therefore this number is applied in the PNG model. However, it is conservatively assumed that 20% of direct mine employees will be from the local area for the Cook Islands and RMI.
- Total wages paid to local mining employees are expected to average $29,000 (USD) per person annually.[26]
- For spares, consumables, and fuel in the Cook Islands and RMI, Cardno relied on parameters generated using the IMPLAN system and knowledge of local infrastructure constraints to determine the proportion of expenditures that would be made locally. For the PNG, it is assumed that 20% of operational expenditures for local goods and services (i.e. fuel, spares, consumables and miscellaneous) would comprise payments to labour, which is consistent with previous economic impact research in PNG.
- Non-local consumer spending estimates assume each non-local worker would make 12 inbound trips and 12 outbound trips, and subsequently stopover for one night each time

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[25] Various suppliers of the mining equipment are described in the Solwara Cost Study, none of which are located within the any case study country.

[26] The average local mining income estimate ($29,000) was based on the Nautilus EIS employment estimate (242 employees) and income estimate ($6.5 million [2014 dollars] for local employees). With an estimated 91.8 percent of the PNG workforce expected to be local (see Section 3.9.1.2) this equates to approximately $29,000 per local employee. As a comparison, according to the 2012 Hays Salary Guide, this local wage rate for PNG nationals is comparable to recent natural resource extraction wage data estimates for local PNG employees in the oil and gas industry ($29,600). This analysis assumes the same mining wage rate for DSM workers in the Cook Islands and RMI.

traveling through the city hub serving the DSM mining operation. Hotel costs are assumed to equal $50 per night; whereas, food expenditures are assumed to equal $50 each night.

> Operating costs for the Cook Islands and RMI were based on averages from the literature (see Sections 4.5 and 5.5) to estimate the average operational cost. The detailed allocation of operational costs to major cost categories relied on the allocation of operation costs as described for the Solwara 1 project and are reported in each case study country's regional impact analysis separately.

With respect to the allocation of royalty payments, the analysis assumes two separate scenarios for estimating the employment and income effects of government spending of DSM mining royalties and revenue:

> Scenario 1 assumes the government of each case study country will adopt a revenue sharing plan similar to the Norwegian Petroleum Fund, which is often held as a 'best practice' approach in resource revenue management.[27] Under the program, the Norwegian government transfers all of the government revenues obtained from petroleum to the fund. In all, over the 2004-2006 period, 28% of annual resource revenue was consumed by the government, while 76% was saved in the fund. Scenario 1 in this analysis assumes that 25% of total government revenue from DSM mining activities is used by each respective case study country's government is spent equally by each country's government in three industries; health, education and construction.

> Scenario 2 assumes that rather than each government spending the same proportion of their DSM mining revenue in the health, education and infrastructure development, the government revenue is distributed to residents. Subsequently, it is assumed residents will spend this transfer of wealth on local goods and services. It is also assumed DSM royalties will be used to fund government operations. Government revenues for the Cook Islands includes royalties for both mining and (potentially) processing; whereas DSM-related government revenues for PNG reflect royalties from mining alone (see Sections 3.6 and 5.6 for more detail).

[27] Website (http://www.environmentportal.in/files/RFF-Rpt-BenefitSharing.pdf) Accessed August 5, 2015.

3 Cost-Benefit Analysis – Mining Seafloor Massive Sulphides in Papua New Guinea

Papua New Guinea is a group of islands, including the eastern half of the island of New Guinea between the Coral Sea and the South Pacific Ocean, east of Indonesia. PNG is the most densely populated country within Melanesia, with nearly seven million citizens as of 2014.[28] PNG has a total land area of approximately 452,860 km^2 that extends over 130 islands. The geographic spread of its islands is such that its EEZ extends for approximately 2.4 million km^2, including nearly 6% of the world's coral reefs.[29] As prescribed by the United Nations convention on the Law of the Sea (UNCLOS), PNG has jurisdictional rights to the exploration and use of marine resources within this boundary. Figure 3-1 shows PNG's EEZ (area in dark blue), as well as the EEZs of neighbouring Pacific Island states. Within the EEZ, PNG has the sovereign rights for exploring, exploiting, conserving, and managing natural resources, whether living or non-living, of the seabed and the subsoil and of the adjacent water with regard to other activities for the economic exploitation and exploration of the zone, such as the production of energy from the water, currents, and winds. As shown in Figure 3.1, the area in off-white, where the Bismarck Sea lies, is not in the EEZ, but part of PNG's Territorial Sea under UNCLOS, which means that is entirely under PNG's own sovereignty.[30]

PNG has a dual economy comprised of a formal, corporate-based sector and a large informal sector in which subsistence farming accounts for the bulk of economic activity. The GDP in PNG was $16.1 billion (USD) in 2014, of which 26% comes from agriculture, 39% from industry, and 34% from the service sector.

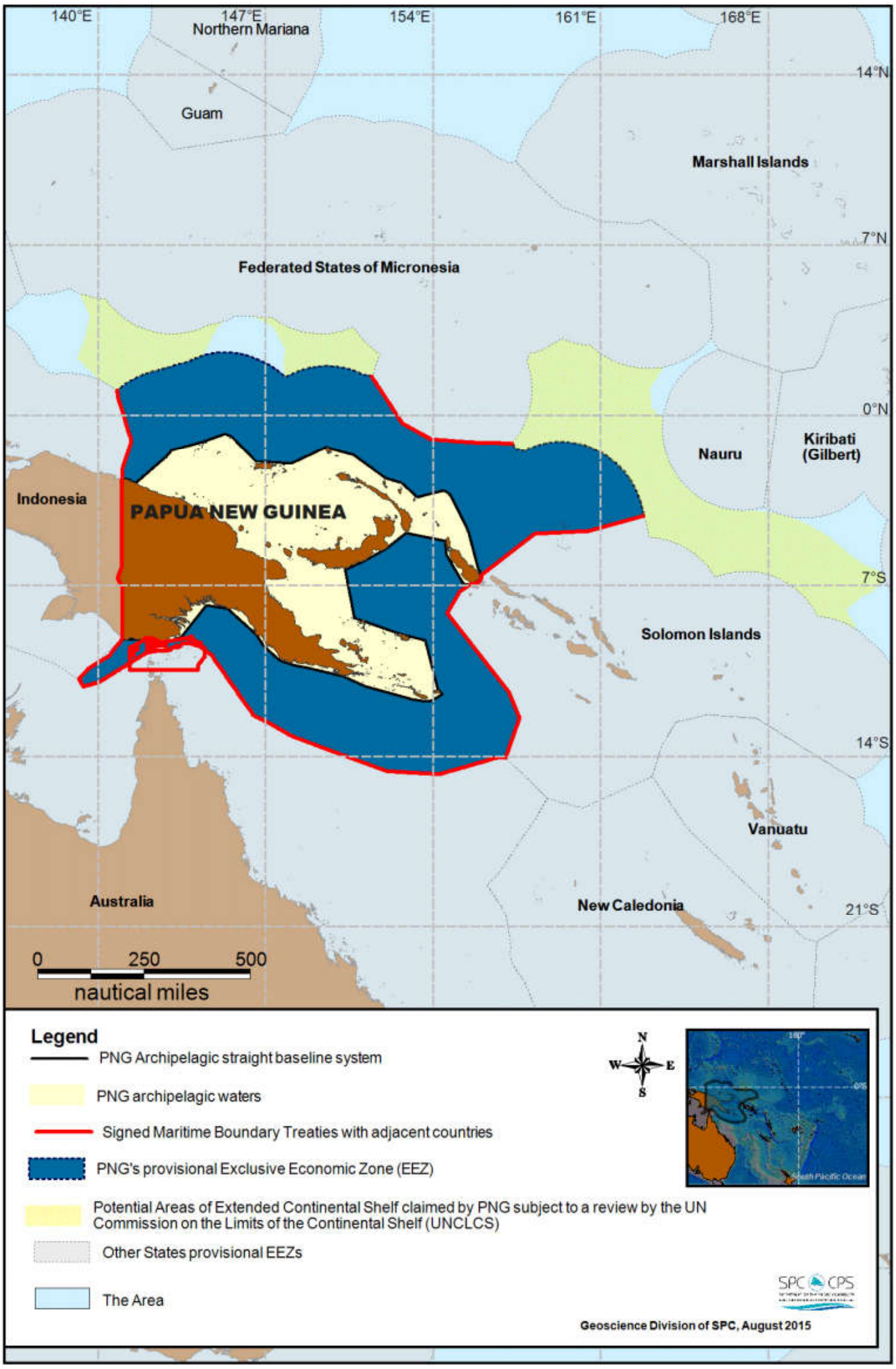
The formal sector provides a narrow employment base, consisting of workers engaged in mineral production, a relatively small manufacturing sector, public sector employees and service industries including finance, construction, transportation and utilities. Mineral deposits including copper, gold, and oil, account for nearly two-thirds of export earnings. Natural gas reserves amount to an estimated 155 billion cubic metres. A consortium led by a major American oil company, ExxonMobil, constructed a liquefied natural gas (LNG) production facility that commenced production of LNG in April 2014 and delivered its first cargo of LNG in May 2014, ahead of schedule. As the largest investment project in the country's history, it has the potential to double GDP in the near-term and triple PNG's export revenue.

The majority of the population is engaged, at least in part, in the informal sector. Agriculture provides a subsistence livelihood for 85% of the people. However, migration to major city centres in the past decade has contributed to urban unemployment and social problems.

[28] https://www.cia.gov/library/publications/the-world-factbook/geos/pp.html Accessed June 23, 2015

[29] http://fishingdown.org/eez/598.aspx (Accessed June 1, 2015)

[30] Personal communication with Nautilus, August 21, 2015.

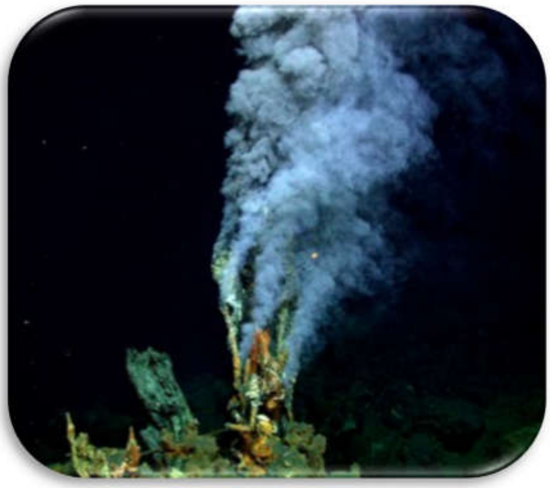


Source: SPC Geoscience Division, August 2015

Figure 3-1 Map of PNG Exclusive Economic Zone (EEZ)

3.1 Description of the Seabed Mineral Resource

Seafloor massive sulphides (SMS) are metal bearing deposits that form in association with sub-sea heat sources. Sub-sea heat sources (e.g. magma) heat sea-water to over 400ºC under pressure, leaching metals out of the surrounding rock in this process. The heated metal rich waters rise rapidly through the rock and out into the water column (typically this occurs at “hydrothermal vent sites”). The heated water rapidly cools, leading to the metals precipitating out of the solution. The precipitate tends to fall within a plume radius from the vent site, often with the vent site itself, forming a deposition chimney of precipitate material.

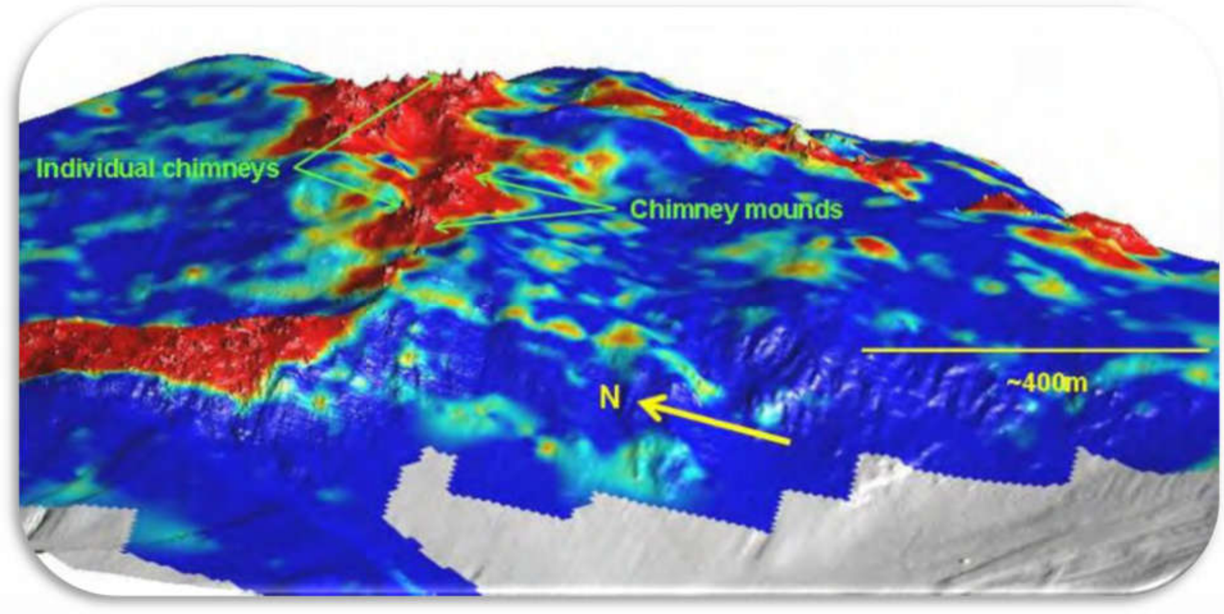


Source: http://science.psu.edu/news-and-events/2009-news/Fisher6-2009.htm (Accessed July 10, 2015)

The sites where this process occurs are typically associated with mid-ocean ridges (e.g. East Pacific Rise) or the back-arc basins and submarine volcanic arcs of the Western Pacific Ocean. The depth of occurrence varies with the tectonics and geomorphology of continental crusts, ranging from 350 metres to 5,000 metres deep. Over 280 potential SMS sites have been identified across the globe, with numerous sites within the territorial waters of Pacific ACP states. Out of the more than 200 sites of hydrothermal mineralisation currently known, only about 10 deposits are currently considered likely to have sufficient size and grade to be of commercial interest of DSM mining. These potential mine sites include the Atlantis II Deep in the Red Sea, Middle Valley, Explorer Ridge, Galapagos Rift, and the East Pacific Rise 13°N in the Pacific Ocean, the TAG hydrothermal field in the Atlantic Ocean, as well as the Manus Basin, the Lau Basin, the Okinawa Trough, and the North Fiji Basin in the western and south-western Pacific.[31] One of these sites, the Manus Basin is located within the EEZ of PNG.

In contrast to MN and CRC formation, SMS deposit formation can develop relatively rapidly, with hydrothermal vent chimneys recorded to grow up to 30 centimetres per day and up to heights of 45 metres. As the zones of geothermal activity are limited and continuously shifting with continental action and movement, multiple chimneys sites tend develop in close proximity to each other (Figure 3-2). As such, it is considered that there is likely to be a predominance of inactive historic vent zones in comparison with active sites. This unique formation process and geographically shifting nature of SMS resources differs significantly from the majority of mineral resource deposits; being more similar to renewable and agricultural resources in some regards.

[31] SPC-EU EDF-10 Deep-sea Mineral Project Information Brochure 6: Deep-sea Minerals Potential of the Pacific Island Region. Available at: http://gsd.spc.int/dsm/public/files/Deep%20Sea%20Minerals%20in%20the%20Pacific%20Islands%20Region%20Brochure%206_V2.pdf



Source: SRK Consulting (2010)

Figure 3-2 Zone of Hydrothermal Vent Activity in Papua New Guinea

The metals of economic interest are predominantly metal sulphides and sulphates including iron, copper, zinc, gold, silver, manganese, nickel, and cobalt. The grades of concentrations within these metals are extremely high, often orders of magnitude greater than terrestrial deposits. However, the location of venting zones is limited, and deposition plume extents variable. In general, the chimneys immediately adjacent to the vent sites have high metal grades. However, once the heated water begins to disperse laterally through the water column, over 90% of metals are lost (SPC, 2013a). Consequently, SMS deposit areas, are small (e.g. generally between 0.1 and 10 hectares of seafloor surface area), but made viable through the high concentration of metals (Hannington et al., 2011).

3.1.1 Papua New Guinea Seafloor-Massive Sulphides Abundance

The potential for hydrothermal vents and submarine hydrothermal sulphides was first identified in the region as part of the U.S. lead Remote Vehicle Moana Wave exploration in 1985. This was followed by a large series of explorations around PNG, particularly around the Eastern Bismarck Sea (Table 3-1). The majority of these surveys were undertaken by research groups funded through a range of national governments (e.g. Australia, France, Germany, Japan, etc.). In particular, research undertaken by Australia's Commonwealth Scientific and Industrial Research Organisation comprises the majority of DSM abundance survey. The majority of the surveys focused on convergent tectonic plate margins and geological formations with the Eastern Bismarck Sea and Manus Basin (Figure 3-3).

Table 3-1 Seafloor Massive Sulphide Exploration History around PNG[1]

Location	Number of Exploratory Cruises	Years
Western Woodlark Sea	3	1986, 1988, 1990
Western Bismark Sea	3	1998, 2002, 2007
Eastern Bismarck Sea	16	1986, 1989, 1990, 1991, 1993, 1995, 1996, 1997, 1998, 1999, 2000, 2002
Central Bismarck Sea	3	1992, 2000, 2005
Southern Bismarck Sea	1	2007
Bougainville – Solomon, Solomon Sea	2	2002, 2009
Goodenough Bay	1	1988
Lihir-Feni Chain	3	1994, 2000, 2002
Manus Basin	3	1994, 2006, 2006
Note 1 - Adapted from SRK Consulting (2010)		

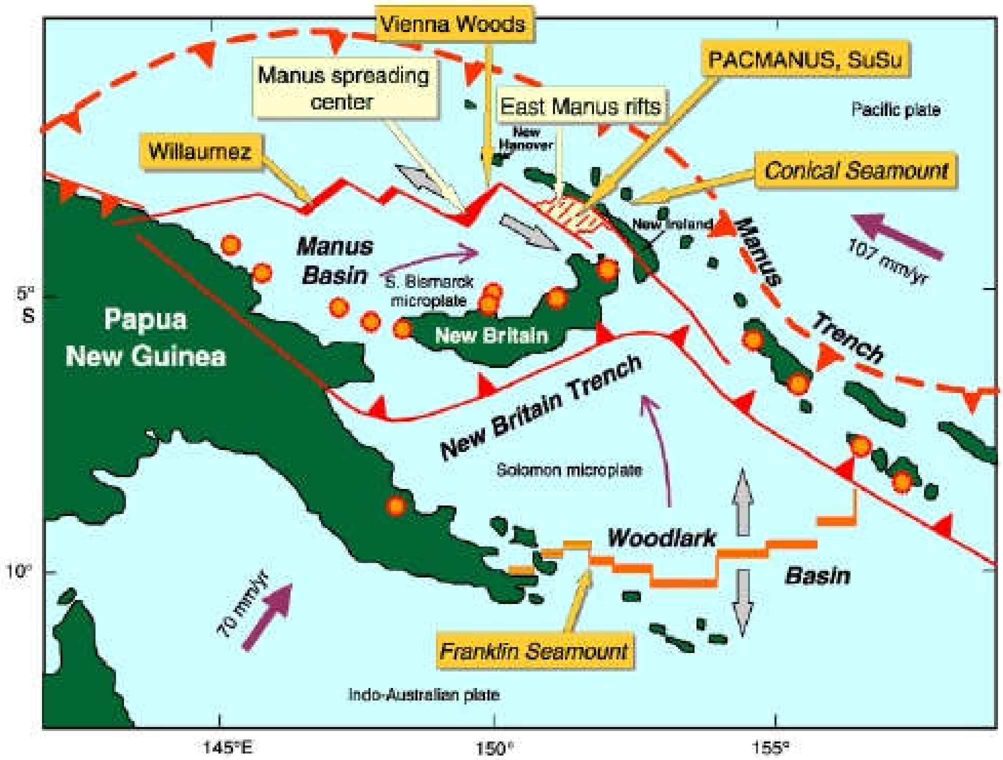


Figure 3-3 Major Geological Features and Hydrothermal Fields of Eastern Papua New Guinea

Despite the extent of survey undertaken, estimates of total PNG SMS deposits are limited due to the variable nature of SMS development and restricted geographic size of deposits. Hannington et al. (2011) identifies high variability in the density and spacing within and between vent complexes. Globally, approximately 33% of deposits are likely to be less than 100m^2, each deposit consisting of multiple chimneys sites within a broader complex (Hannington et al., 2011). Such small deposit areas are considered unlikely to be economically viable in terms of mining. Hannington et al. (2011) also estimate that, of those greater than 100 m^2, a median deposit size of 70,000 tonnes may be anticipated. However, estimates vary widely as Hoagland et al. (2010) suggests a range of one to five million tonnes.

3.1.2 Metal Content of Papua New Guinea Seafloor Massive Sulphides

Within the PNG EEZ, the metals of economic interest within SMS deposits are predominantly copper and zinc, often found in association with valuable trace elements such as silver and gold. Other trace elements (e.g. cadmium, thallium, tellurium etc.) are often present, yet generally not in sufficient concentrations to be of economic interest. In general, sub-sea deposits are considered to have lower values of base and precious metals, with the more exposed seafloor deposits potentially enriched through secondary weathering (SPC, 2013a). Substantial variability in metal values occurs at local and regional scales; and it can be both technically problematic and costly to sample the SMS deposits for size and grade. Therefore, this report presents and uses the concentration results from the Solwara Project as the basis of information for the PNG CBA. The Solwara Project is the most advanced DSM project in the Pacific region with the approval of the mining lease to Nautilus Minerals Ltd issued in January 2011. Based on this agreement, Nautilus has identified 19 SMS deposits within the Bismarck Sea. The extent to which the Solwara Project may be representative of other potential sites within the PNG EEZ is currently unknown.

Table 3-2 presents the concentration results of initial grab samples observed across all Solwara Project sites (estimates are to be considered to be indicative in nature), while Table 3-3 compares the results of the more detailed Solwara 1 and Solwara 12 drilling sampling against other known resources across the globe. It can be seen that the average copper grade across the Solwara Project is approximately 5%, with Solwara 1 reporting copper grades of up to 8% and Solwara 12 grades of 7.3% and 3.6 grams per tonne (g/t) of gold. These are considered to be significantly greater than the grades returned at current land based volcanic massive sulphide mine sites (i.e. less than 2% Cu).

Table 3-2 Average Metal Content by Site from the Solwara Project[1]

Deposit Site	Copper (%)	Zinc (%)	Gold (g/t)	Silver (g/t)
Solwara 1	11	6.6	18.2	215
Solwara 2	1.1	23.8	10.6	340
Solwara 3	0.5	11	30.6	3375
Solwara 4	12.3	19.5	14.1	232
Solwara 5	5.5	7.7	13.9	263
Solwara 6	11.7	18.4	16.1	203
Solwara 7	3.7	15.6	10.9	261
Solwara 8	5.6	31.4	15.6	305
Solwara 9	6.3	10.6	19.9	296
Solwara 10	7.1	14.1	2.3	152
Solwara 11	1.5	15.1	1.3	198
Solwara 12	7	22.6	13.7	425
Solwara 13	9.1	30.7	4.7	546
Solwara 14	1.3	19.2	3.3	97
Solwara 15	N/A	N/A	N/A	N/A
Solwara 16	2.1	18.6	2.8	105
Solwara 17	0	0.1	0	181
Solwara 18	0.3	19.6	0.2	110
Solwara 19	0	0.1	0.6	4

Note 1: Source, SRK Consulting, 2010; Based on averages across various scientific studies throughout time, Table 9-1.

Table 3-3 Comparison of Metal Content at Selected Solwara Sites to Other SMS Sites[1]

Deposit Site	Copper (%)	Zinc (%)	Gold (g/t)	Silver (g/t)
Solwara 1	11	6.6	18.2	215
Solwara 12	7	22.6	13.7	425
Abitibi Belt, Canada	1.47	3.43	0.8	3.19
Whim Creek, Washington State	1.6	1.3	-	8.6
Ok Tedi Mine	0.8	-	1	-
Iberian pyrite belt	0.8	2.0	0.5	26
Abitibi Belt, Canada	1.47	3.43	0.8	3.19

Note 1: Source SRK Consulting, 2010; Table 8-1 and Table 9-1

3.2 Current Status of DSM Policy and Legislation

According to UNCLOS, states are required to take all necessary actions to ensure the effective management of DSM activities (prospecting, exploration, and mining) within their national jurisdiction and beyond. Therefore, before any mining begins, it is important to assess and understand the current policy and legal framework for the sustainable management of mineral resources within the PNG EEZ.

In contrast, to many other Pacific states, PNG has a long history of terrestrial mining and a well-established resource legislature, approvals and management system. Associated with this, PNG has learnt from occasions in which mining has led to significant environmental and social impacts. The Mining Act (1992) is currently being used as the basis of processing both exploration and extraction operations in the onshore and offshore environments, regulated through the Mineral Resources Authority (MRA) and planned through the Department of Mineral Policy and Geohazard Management. The Conservation and Environment Protection Agency (CEPA) is responsible for the issuing of environmental permits for both terrestrial and offshore resource operations under the Environment Act 2000.

The MRA's role is primarily to ensure that any tenement holder/mining developer is compliant with the conditions of the Mining Act (1992) and the Mining (Safety) Act 1977. As of 2012 the MRA had issued over 200 exploration licenses for DSM deposits. It has also issued one mining lease: granting Nautilus the right to undertake extractive activities at the Solwara 1 site. CEPA also issued the associated Environmental License for the Solwara 1 site.

Under the Mining Act, there are two categories of leases that can be issued: a Special Mining Lease (typically for those of sufficient scale to have a significant effect on the PNG economy) and an ordinary Mining Lease (typically for small to medium-sized mineral developments). Under the Act, issue of a Mining Lease requires submission of a Proposal for Development which describes in detail the proposal from a technical, environmental and financial point of view. A key element of this process is the establishment of a Memorandum of Agreement which will detail the distribution of project employment, training and revenues to the PNG government and local communities. Typically these agreements are project specific by responding to the identified potential impacts to local communities and likely revenues generated, and may be revisited over the life of a project (e.g., every five years). The Mining Act also requires that a Compensation Agreement is to be negotiated between the developer and affected landholders.

Through this existing legislation the PNG Government is able to generate revenues in a number of ways, including:

- Royalties and production levies,
- Corporate taxes and export fees, and
- Equity participation.

Royalties and production levies relate to fees receivable on the volume of resource extracted by a mining operation. In contrast, equity participation, involves the government directly investing in the cost of the project and also receiving a proportionate share of the benefits. Currently, the PNG Government has the option to adopt up to a 30% equity stake in extractive industry projects within its EEZ. In the case of the Solwara 1 project, the PNG government has exercised its right to take up a 15% stake in the operation of the project for $120 million. Proceeds from such equity ventures are typically held within the central government, with smaller portions being issued to the relevant affected province(s) (5%) and local community(s) (5%). It is noted that there is some concern regarding government equity ownership where the government is also responsible for regulation of the proposal. At the time of writing, PNG was in the process of developing and updating its Offshore Minerals Policy and the PNG Mining Act (1992).[32] The updates allow enhancement of the Act to better accommodate aspects that differentiate DSM from terrestrial mining practices and strengthening monitoring and auditing requirements of cultural, environmental and fiscal management. In particular, it is understood that the Offshore Minerals Policy will:

- Provide guidance on the structure of the proposed fiscal regimes, including the application of a corporate income tax, a resources rent tax, and tax collection and enforcement mechanisms,
- Detail requirements for environmental impact assessments (EIAs), environmental permits, and monitoring and compliance throughout the duration of the mine,
- Require long-term management plan for mining revenues, and
- Promote capacity building and job opportunities associated with DSM mining activities.

It is understood that the policy will also detail, for the purposes of DSM mining activities, what community stakeholders would be considered to be beneficiaries of offshore resource revenues: the “Coastal Area of Benefit”. This is likely to consist of the closest ward in a direct line to the mine site, and the three wards on either side. The benefit to be distributed to each ward within the Coastal Area of Benefit would be dependent upon the Memorandum of Agreement and any equity partnership option adopted for the specific project in question.

3.3 Description of Baseline Scenario

This section describes the state of PNG in the absence of DSM mining. In other words, it describes the counterfactual (the “Do-Nothing” scenario) to which the proposed project will be compared. The CBA determines, quantifies and monetises, to the extent practical, DSM-related changes to these baseline conditions. For the purposes of the CBA in PNG, the baseline discussion focuses on the deep-sea environment, fisheries, environmentally based tourism, income and employment statistics, and various relevant cultural norms.

3.3.1 Deep-sea Environment

The Solwara 1 Project site in PNG is located approximately 30 kilometres off-shore. The mine site is located 1,600 metres below the surface in an area with several active underwater volcanoes. The natural presence of significant volcanic, seismic and hydrothermal underwater activity causes regular environmental disturbances that are estimated to be comparable in nature to the the type of disturbances likely to be caused by mining activities (Earth Economics, 2015). Currents at the Solwara 1 mine site are relatively weak, while average sedimentation rates are relatively high when compared to open ocean global trends. This may be attributed to the hydrothermal vent activity, combined with the venting of active volcanos nearby that contribute to the discharge of materials in the water column (Coffey Natural Systems, 2008).

Source: Woods Hole Oceanographic Institution

The biological assemblages that surround hydrothermal vents vary with the habitat types present (e.g., soft sediments,

[32] At the time of writing the report, the revised Mining Act and the Offshore Minerals Policy were not available.

hard substrates, active vents and inactive vent features). Active hydrothermal vents are predominantly characterised by unique micro-organisms that use the chemical fluids emitted by the vents to produce energy as photosynthesis does not occur at these depths. These micro-organisms are either digested by larger fauna or have symbiotic relationships with larger species. Many such species have become reliant on the micro-organisms such that they are not able to survive away from the vent sites (Collins et al., 2012). Typical species that can be found in association with active vent sites include tube worms, gastropods, bivalves (like mussels) and crustaceans (like shrimp) (Collins et al., 2012). Studies have shown that it is not uncommon for an active vent site to experience two or more cycles of local extermination and re-colonisation by species due to volcanic and seismic activity. This suggests that, despite the inconsistent and relatively short life-span of hydrothermal venting sites, faunal species have high resilience through their dispersal and recruitment processes, allowing them to move and recolonise new sites relatively quickly (SPC, 2013a).

3.3.2 <u>Fisheries</u>

Commercial fisheries in PNG are dominated by the purse-seine fishery for skipjack, yellow-fin and big-eye tuna, with a smaller long-line tuna fishery focussed on albacore. Total annual catch averages from 150,000 to 200,000 tonnes but it is estimated that the resource could sustain annual catches of 250,000 to 300,000 tonnes.[33] The potential market value is about $365 million (USD) depending on the commodity price.[34] Catch from PNG EEZ waters accounts for 20-30% of the total regional catch and is about 10% of the global catch.[35]

PNG also has a small prawn and lobster fishery that operates in in the Gulf of Papua, the Orangerie Bay and in the Torres Strait. In the Gulf of Papua fishery, total annual catch from all species of prawns is approximately 1,000 tonnes (tail weight) per annum, with an estimated value of $3.6 million (USD). The lobster fishery currently involves more than 500 divers and generates an annual estimated yield of about 80 tonnes, worth approximately $1.5 million (USD) in exports.

Subsistence fisheries in PNG occur along the coast and close to the coral reefs. These fisheries provide food to meet daily needs and surplus fish are sold in local markets. The majority of communities in close proximity to coastal areas rely on fisheries extensively. Landlocked communities also depend upon the coastal communities and local markets to supplement their diets with fish and crustaceans. Along the mainland and high island coasts and in the smaller island communities fishing activities include spear fishing, shallow-water hand-lining from dugout canoes, netting, and trapping in the freshwater reaches of large rivers. In the swampy lowland areas net fisheries for barramundi, catfish, and sharks occur, while in the Gulf of Papua and parts of the Northern Islands Region there are also village-based lobster fisheries.[36]

3.3.3 <u>Tourism</u>

Relative to similar Pacific Island states in the region, tourism in PNG represents a small component of the economy. Currently the tourism industry in PNG is underpinned by the business travel market, which accounts for almost 70% of all visitors and provides the major market for many hotels, as well as the international and domestic airlines. According to the PNG 2011 Visitor Arrivals Summary, holiday travellers represented 21% of arrivals, business travellers represented 44% of arrivals, and employment

33 http://www.fisheries.gov.pg/LinkClick.aspx?fileticket=wBPenkWBv%2BA%3D&tabid=92 Accessed July 6, 2015.

34 Ibid

35 http://www.fisheries.gov.pg/FisheriesIndustry/TunaFishery/tabid/104/Default.aspx Accessed July 6, 2015.

36 http://www.fao.org/fishery/facp/PNG/en Accessed July 6, 2015.

related activities generated 28% of arrivals. Compared to 2010, holiday arrivals increased by 9% in 2011, which marks the seventh year this segment has seen growth since 2003.[37]

The total contribution of travel and tourism to GDP in the year 2013 was $328 million (USD) (2.5% of GDP) and forecasted to rise by 3.9% per annum to $437 million (USD) (2.5% of GDP) in 2024 (World Travel and Tourism Council, 2014). This primarily reflects the economic activity generated by industries such as hotels, travel agents, airlines and other passenger transportation services (excluding commuter services). But it also includes, for example, the activities of the restaurant and leisure industries directly supported by tourists. In addition, the total contribution of travel and tourism to jobs indirectly supported by the industry was 2.1% of total employment (62,500 jobs). This is expected to rise by 1.5% to 75,000 jobs in 2024 (1.9% of total) (World Travel and Tourism Council, 2014).

3.3.4 Distribution of Income and Employment

Due to the complex nature of the PNG economy, which includes a mix of cash and non-cash economies, there is very little published income and employment data. Most of the people in PNG are rural and live in a subsistence or semi-subsistence economy. Therefore, household survey data from a 2008 study is used to provide an illustration of the average monthly income for households in PNG (Finnroad, 2008). Table 3.4 illustrates the distribution of income (i.e. number of households in each income bracket) by province and the average monthly income of each province. From the table, it is evident that East New Britain and West New Britain are the provinces with the highest average monthly income.

Table 3-4 Average Monthly Household Income by Province (in USD)

Monthly Income	Boug[1]	Cen	ENB	ES	Mad	MB	Mor	Ni	WS	WNB
$37 or less	13	1	1	31	23	3	27	32	26	13
$38 to $108	22	33	9	36	46	36	18	39	29	22
$109 to $181	31	34	16	13	23	29	8	11	14	13
$182 to $363	16	29	31	14	7	26	17	12	16	14
$363 to 725	14	3	29	5	0	5	8	4	11	17
Over $725	5	0	14	1	1	1	22	2	4	21
Average Monthly Income	$284	$165	$460	$128	$98	$174	$384	$159	$213	$742

Note 1: Boug=Bougainville, Cen=Central, ENB=East New Britain, ES=East Sepik, Mad=Madang, MB=Milne Bay, Mor=Morobe, Ni=New Ireland, WS=West Sepik, WNB=West New Britain,

In general, there is also a lack of formal labour statistics in PNG. Despite a decade of growth, PNG's formal labour market remains small by regional standards providing livelihoods to less than 12% of the working age population. A much larger informal labour market, centred on semi-subsistence agriculture, forestry, and fisheries, generates livelihoods for most of the remaining working-age population (United Nations Development Programme, 2014).

3.3.5 Perspective of Coastal Communities

Customary land ownership, or land owned by indigenous populations is an important social construct, covering approximately 97% of the nation's land mass (Coffey Natural Systems, 2008). All development is required to consult with and obtain approval of relevant local customary owners. Under existing

[37] Papua New Guinea Tourism Authority. 2011. 2011 Visitor Arrivals Summary. http://www.tpa.papuanewguinea.travel/Papua-New-Guinea-Tourism-Promotions-Authority/Annual-Visitor-Arrivals-Reports_IDL=42_IDT=328_ID=1806_.html Accessed June 24, 2015.

legislation, customary ownership extends 3 nm offshore from the coastline. Outside of 3 nm, the seabed is owned by the State, which includes all resource and minerals therein. Despite this fact, many of the coastal villages who depend on the ocean for their livelihood hold a high regard for the ocean and its resources, often expressing a strong spiritual connection to all components of the ocean environment, including deep-sea hydrothermal vent systems. There is also a movement by the West Coast Seabed Mining Land Owners Association, who view themselves as the landowners of the seabed and want to be recognised as such, to participate and fully benefit from any seabed mining projects.

3.4 Papua New Guinea Mining Scenario

This section describes the size, duration and approximate location of the mining operation under consideration as well as the total estimated resource potential and the expected metal content in the extracted ore. It also includes a description of PNG infrastructure, including identification of infrastructure that may be necessary to support the mining operation.

As previously mentioned, PNG has the most advanced potential DSM mining project in the region through the Nautilus Solwara Project. The mining lease application was submitted by Nautilus Minerals Ltd to the government of PNG in October 2008, and approval was granted in January 2011. Nautilus has identified 19 SMS deposits (of which two, 17 and 19, are sulphate deposits) within the Bismarck Sea as part of the Solwara Project. Of these, only a small number have estimates of deposit tonnages established at this point in time. Solwara 1 represents the most well researched deposit site and is likely to be the first deposit actively mined within PNG. The Solwara 1 site is located on a deep (approximately 1,600 metres below sea level) platform on the eastern edge of the Manus Basin (Figure 3-4).

Source: http://subseaworldnews.com/2011/11/11/canada-nautilus-minerals-release-third-quarter-results/solwara-1-project/
Accessed June 24, 2015

Figure 3-4 Location of Solwara 1 Project Mine Site

3.4.1 Description of Mining Scenario

The scenario includes mining of a single SMS deposit site as envisioned for the Nautilus Solwara 1 deposit. Figure 3-4 illustrates the location of the mine site; critical parameters are reported in Table 3-5. These include:

- Total area of influence (foot print of the mine site),
- Estimated duration of the mining operation, and
- Total resource potential.

Table 3-5 Assumptions Used in PNG Mining Scenario

Category	Assumptions Used
Total mineable area	11 hectares (0.11 km^2) + 3 hectares of overburden
Depth	1,600 metres
Distance from nearest island	<30 km
Nearest processing facility[1]	China
Total estimated resource potential (dry tonnes)	1,957,040[2]
Duration of mining operation	2 years – 1 year and 9 months of ore production, plus a ramp up and ramp down of operations
Collection efficiency	80% to 90%
Metallurgic Processing	> Will occur offsite in China > Nautilus will own the raw material until it is transferred to the shipping vessel for transport to the processor

Note 1: There is a processing facility closer than China, but the CBA is based on the chosen smelter by Nautilus for Solwara 1
Note 2: Based on SRK Consulting (2010) estimate in Table 19-17

3.4.2 Ports and Logistics

The Solwara 1 Environmental Impact Statement (EIS) assumes that the Port of Rabaul would be used to transfer ore from the barges, temporarily store ore in stockpiles, and then to transfer ore from storage to vessels that would transport the ore to the off-site processing facility. Subsequent to the EIS, Nautilus revised its plan to reflect ore being loaded onto an export vessel at the mine site and being taken directly to China for processing. This analysis reflects the most recent Nautilus plan.

3.5 Cost Methodology

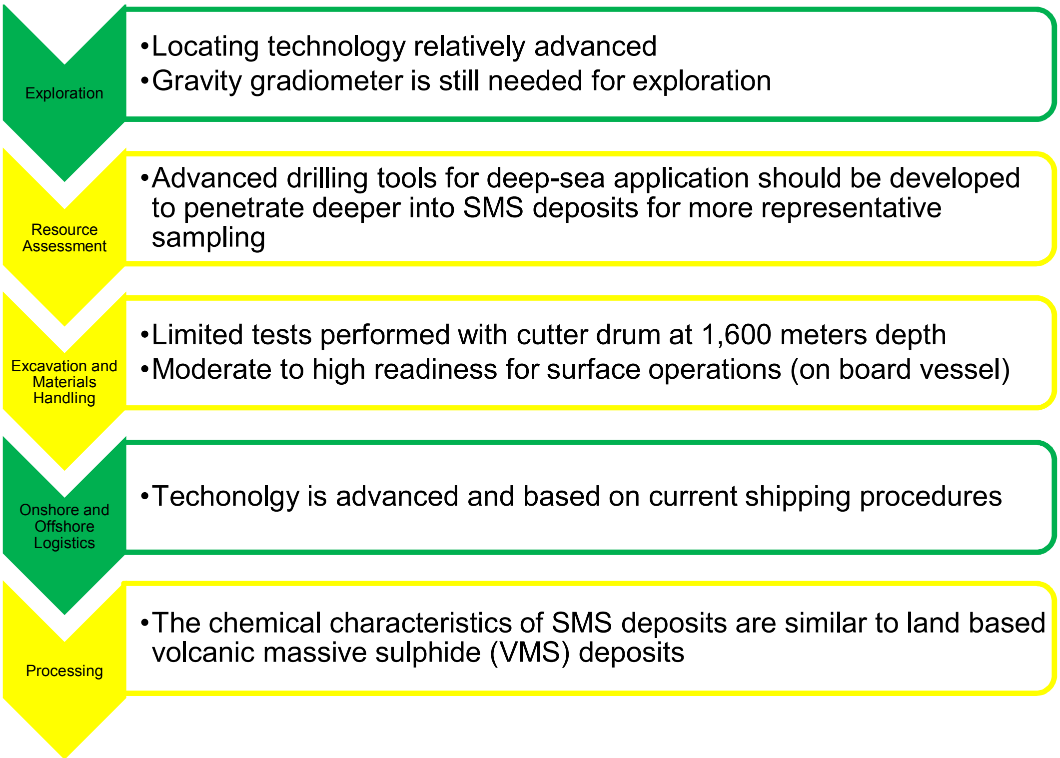
As described in Section 2.3.2, the CBA quantifies and monetises both the private and environmental costs of a single DSM mining operation. Because mining technology is a key determining factor of costs, this section begins with a brief discussion of SMS mining technology and a description of the proposed engineering system. This is followed by a description of costing methods.

3.5.1 Status of Current SMS Mining Technology

Two of the key factors determining SMS mining feasibility are the availability and cost of the technology needed to extract, transport, and process the raw ore at a commercial scale.

Since mining of deep-sea minerals has yet to commence anywhere in the world, the technology required to extract and lift the raw ore has not been proven in a commercial operation. While the majority of the technology required can be adapted from technology used in the offshore oil and gas industry, there are inherent differences that make the mining of deep-sea minerals more complex and costly. These differences are largely driven by the technology required for the vertical transport of raw material from the seabed to the surface.

Figure 3-5 identifies the technological readiness associated with each step in the mining value chain for SMS. Red indicates a low to very low level of readiness, yellow a moderate level of readiness, and green a high level of technological readiness.



Source: ECORYS, 2014

Figure 3-5 Assessment of Technology Readiness in Seafloor Massive Sulphide Mining Value Chain

While the technology associated with each phase of the SMS mining value chain is at a moderate or high level of readiness, opportunities for technological improvements still exist. These include:

> Refinement of commercial-grade cutting and lifting tools,

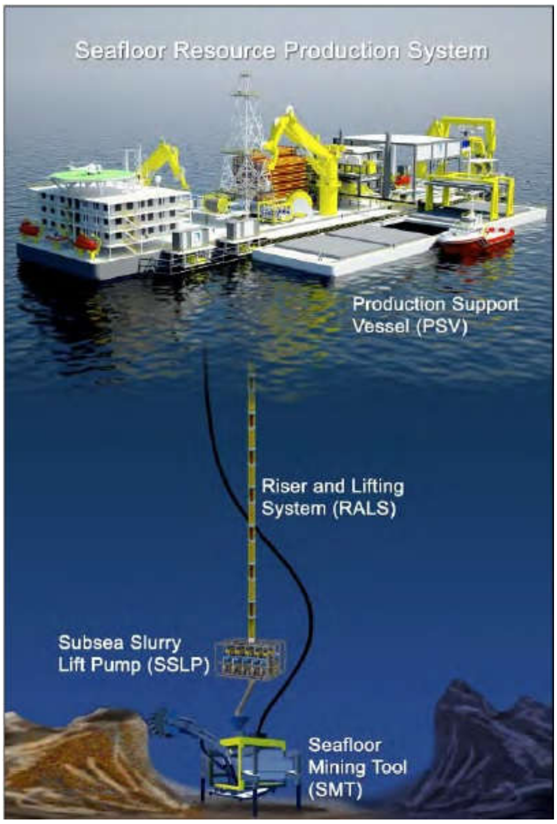
> Refinement of the vertical transport system to ensure it against clogging and wear not common in oil and gas applications where it is currently used, and

> An at-sea demonstration of surface operations.

The technology for offshore and onshore logistics is advanced and commonly used in other industries. Similarly, the process for extracting metals from SMS has been proven at the commercial level via the processing of the very similar land-based volcanic massive sulphide (VMS).

3.5.2 Proposed Engineering System for SMS Mining

The CBA is based on the engineering system originally proposed by Nautilus. The system starts with a production support vessel (PSV), which is the source of power for the entire mining operation, and serves as the platform by which the mining operations are controlled. The PSV is connected to the seafloor mining collection and riser and lift system, which excavates the ores from the seabed and transports it up the riser to the PSV. Wastewater from the pre-processing steps is transported back down the riser pipe to be discharged near the seafloor. The pre-processed ore is transferred to a shuttle barge which delivers it to a processor. Figure 3-6 illustrates the entire production system.



Source: SRK Consulting, 2010

Figure 3-6 Seafloor Massive Sulphide Production System

3.5.2.1 Seafloor Mining Tools[38]

For the excavation of SMS, a cutter system is needed to remove and collect the hard seabed rock in which the metal ores are found. Based on the topography of the mine site (steep slopes and numerous chimneys), Nautilus is proposing the use of three different mining machines known as an Auxiliary Miner (AUX), a Bulk Miner (BM),and a Gathering Machine (GM) (Figure 3-7). In the mining process, the auxiliary miner is the first to be deployed in order to prepare and level the mine site for the bulk miner. The bulk miner is the workhorse of the system, which cuts, grinds and sizes the mineral. Finally, the gathering machine removes the cut ore from the seafloor and transfers it to the riser and lift system (RALS).

Source: Nautilus Minerals

[38] During final review of the document, it was brought to the authors attention that there is now a plan for another Seafloor Mining Tool that was not in the original application, however since all of the cost estimates are based on the capital equipment as described in the 2010 SRK Consulting study, the authors decided to refrain from making any adjustments.

Figure 3-7 Auxiliary Miner (left), Bulk Miner (right) and Gathering Machine (below)

3.5.2.2 Vertical Transport

Ore deposits are transported to the production support vessel using a Subsea Lift Pump (SSLP) and vertical riser system (Figure 3.8). The ore collected by the gathering machine is pumped into the SSLP at the base of the riser and an ore/water slurry is then pumped to the surface.

Source: SRK Consulting

Figure 3-8 Subsea Lift Pump

3.5.2.3 Dewatering and Surface Operations

Before being transported to the processor, the ore is run through a ship-based ore dewatering plant on board the PSV.[39] After the water is removed, the ore is loaded onto barges adjacent to the PSV that will deliver ore to the overseas processing facility at a rate of one barge per day.

3.5.3 <u>Private Costs</u>

This section describes the quantification and monetisation of private costs. These include:

- Costs incurred by the government (a willing participant in the mining operation), and
- An estimate of the capital and operating costs associated with each phase of a SMS mining operation.[40]

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[39] As of 2010, per the SRK consulting cost assessment, the engineering development for the dewatering plant was still in concept phase, with detailed material property testing in process.

3.5.3.1 Administrative Costs to the Government

The PNG government would incur administrative costs not required absent DSM mining. While the PNG has a well-established regulatory system for extractive industries (e.g., the Minerals Resource Authority (MRA) and the Department of Mineral Policy & Geohazard Management) it is currently in the process of updating its legislation and policy to accommodate the nuances of DSM mining[41] and so specific administrative requirements are not known. As such the following assumptions were made:

> The development and updating of existing regulation to better accommodate the unique aspects of DSM mining requires a one-time expenditure of $2,000,000 (USD) in the years prior to the onset of DSM activity. To estimate the share of the cost that is attributable to single mining operation, the CBA assumes that in time, there will be five single mining operations that will eventually use this framework. Therefore, the estimated cost of updating the existing regulation to a single mining operation is a one-time cost of approximately $400,000 (USD).

> The cost associated with monitoring and reporting of DSM activity at the single mining operation is based on the assumption that the PNG government will employ six full-time equivalent workers to provide constant monitoring of DSM mining activities (e.g. PSV on-board monitoring).[42]

  - *$120,000 (USD) annually (salaries, benefits, overhead)*

> The collection and distribution of DSM mining related payments requires one full time equivalent.[43]

  - *$50,000 (USD) annually (salary, benefits, overhead)*

> Contract Administration requires 1 full time equivalent.[44]

  - *$35,000 (USD) annually (salary, benefits, overhead)*

The one-time cost of $400,000 (USD) for the mining operation's share of the updates to the regulatory agreements plus the annual salaries for reporting, monitoring, fiscal arrangements, and contract

40 These costs are estimated because the PNG government is an equity partner in the mining operation and will also share a certain percentage of the costs. They are also key factors in the assessment of the economic feasibility of a DSM mining operation.

41 As noted in Section 3.2, at the time of writing this draft, PNG was in the process of developing and updating its existing Offshore Minerals Policy and the PNG Mining Act (1992) to better accommodate the unique aspects that differentiate DSM mining activities from terrestrial mining practices and strengthening monitoring and auditing requirements of cultural, environmental and fiscal management.

42 Assuming mining is a 24/300 operation and allowing for 30% of a monitors time to be spent on administrative duties and travel, six workers are required to ensure 100% at-sea coverage. This is semi-skilled work so employees are assigned a salary just above the median income for PNG.

43 Even without onshore processing, DSM mining would be a large part of the economy. This is a fairly skilled employee who makes sure payments are received in a timely manner and funds are dispersed in a manner consistent with laws and policies. It is envisioned as a full-time position with a salary bracket in the top 10% of income distributions.

44 This is a more junior position responsible for monitoring contractor performance for compliance with applicable laws, delivery schedules, payment provisions, inspections, contract and date reporting requirements. The reduced salary, relative to the position responsible for DSM related payments, is commensurate with this more junior position.

administration results in an amortised annual amount of $242,757 (USD).[45] Discounting at 7% administrative costs are calculated to be $438,909 (USD) over the course of the two-year operation.[46]

In PNG, administrative costs have been specifically recognised as a cost incurred by the government and the people of PNG. However, specific to PNG, mine operators are required to pay a production levy equal to 0.25% of revenue from the mining operation (which equates to approximately $1.9 million in this scenario). This is a tax specifically designed to offset government administrative cost which effectively transfers the burden to the mining company (i.e. Nautilus).

3.5.3.2 Costs Incurred by Foreign Owned Mining Companies

As previously described (see Figure 2.2), the mining value chain is divided into four main phases: exploration (including resource assessment), extraction, transportation and processing. Phase-specific costs for the Solwara 1 Project were based on the SRK Consulting (2010) cost assessment of SMS mining. This section provides estimates of the total amount of capital and operating expenses for the operation of an SMS mine site, the majority of which is incurred by the foreign owned mining company (i.e. Nautilus Minerals, Ltd).

3.5.3.2.1 Exploration Costs

The exploration costs associated with deep-sea minerals include the investment in capital equipment to locate and assess the characteristics of mineral deposits. Additionally, labour in the form of research and analysis is required to process the deposits collected and assess the feasibility of the mining operation. SMS exploration typically involves the following activities:

- Location of active and inactive vent sites,
- Direct detection of SMS mineralisation using:
  - water geochemistry and plume sensors,
  - side-scan sonar profiling and mapping using video cameras,
  - deep-tow magnetic, electromagnetic, and other geophysical methods, and
  - dredging and direct sampling with ROV,
- Core drilling to determine thickness and grade of massive sulphide mineralisation.

The 2010 cost assessment for the Solwara 1 project does not provide a cost estimate for capital and operating expenses related to exploration since exploration for the Solwara 1 site is complete. However, upon the issuance of the mining lease, it took approximately six years for Nautilus to complete its 5 stage exploration process. Prior to the issuance of the mining lease there was at least 5-10 years of additional exploration, therefore, for the purpose of the CBA, it is estimated that the exploration timeline for SMS mining is approximately five years, with an average cost of $7 million (USD) per year.

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[45] The ammortisation formula for calculating annual costs is: $C_t * \frac{r*(1+r)^n}{(1+r)^{n-1}} + OM_a$ where C_t is the fixed cost (400,000), *r* is the discount rate (7%), *n* is the number of years (2), and OM_a is the annual operating and maintenance cost ($120,000 + $50,0000 + $35,000).

[46] In developing this document some stakeholders have suggested that these costs are grossly underestimated while others have suggested they are grossly overestimated. While there is uncertainty around these estimates, it is noted that with the exception of regulation updates, activities are intended to represent an ongoing annual cost specific to a single mining operation, and these estimates continue to reflect reasonable assumptions made in the absence of specific data.

3.5.3.2.2 Capital Expenditures

The primary capital costs associated with SMS mining include investments in the capital equipment associated with the preferred engineering technology (i.e., mining equipment and support vessel), and the direct costs associated with the purchase of vessels to transfer the ore from the support vessels. As previously mentioned, the 2010 cost estimates for the Solwara 1 project are used and updated to reflect 2014 (USD). Table 3-6 shows the breakdown of initial capital expenditures for the Solwara 1 Project

Table 3-6 Summary of Capital Costs for Solwara 1 Project (indexed to 2014 PPI, in millions USD)

Mining Phase	Description	Cost
Excavation and Materials Handling	Seafloor Mining Tool	$90.9
	Riser and Lift System	$109.3
	Dewatering Plant	$25.9
	Production Support Vessel Mobilisation	$7.0
	Integration and Testing	$64.5
Transport	Barges	$11.7
Other	Project services, owner's costs and contingency (17.5%)	$103.8
Total Initial Capital Investment to Extract and Transfer Ore		**$413**[1]

Source: Table 20-3 from SRK Consulting (2010) indexed to 2014 PPI

Note 1: This amount reflects 100% of the capital expenditures required for the project. As noted in Section 3.2, the PNG government has exercised its right to be a 15% equity partner in the project, meaning that the amount of capital expenditures paid by Nautilus will decrease by 15% (approximately $61 million (USD)).

The analysis uses Monte Carlo methods to evaluate the risks associated with the uncertainties inherent in DSM mining (See Section 2.3.4). Rather than specifying single point estimates for inputs Monte Carlo allows inputs to be specified as a distribution. For capital costs, the distribution uses $413 million is the most likely value, with the maximum and minimum values set at plus or minus 20%.[47]

3.5.3.2.3 Operating Costs

Daily operating expenses include:

- Vessel charter costs (costs of the provision of a transport vessel and crew to operate the vessel),
- Labour (wages, food, flights, accommodation and transport),
- Fuel, and
- Spares, consumables and miscellaneous expenses.

Table 3-7 reports the daily cost in USD and the unit cost per mined tonne for each of the various operating expenses. This equates to an annual estimate of approximately $103 million (USD).

[47] In the cash flow analysis for PNG, capital expenditures are adjusted downward by 15% to account for the PNG governments role as an DSM mining partner. This amount is then treated as a "debit" when determining gross revenues from mining.

Table 3-7 Summary of Operating Costs for Solwara 1 Project (indexed to 2014 PPI, in millions USD)

Mining Phase	Description	Daily Cost (in USD)[1]	Unit Cost per Mined tonne (USD)[1]
Excavation and Materials Handling	Seafloor Mining Tool	$21,759	$5.9
	Riser and Lift System	$25,060	$6.8
	Dewatering Plant	$8,291	$2.2
	Production Support Vessel	$156,514	$42.3
	ROVs	$22,602	$6.1
Transport	Barges	$1,3721	3.7
Other	Project services, owner's costs and contingency (17.5%)	$42,080	$11.4
Total Operating Costs to Run Mine		**$290,030**	**$78.4**

Source: Table 20-10 and 20-12 from SRK Consulting, 2010.
Note 1: Total daily cost and unit cost per mined tonne are adjusted to include costs associated with dewatering.

As with the capital costs, uncertainty is incorporated by specifying operating costs as a distribution where $103 million is the most likely value and the minimum and maximum values are set to plus or minus 20%..

3.5.4 Environmental Costs

The CBA monetises environmental costs associated with DSM mining to the extent practical. The following text provides a detailed description.

3.5.4.1 Cost of Offsetting CO_2 Emissions

CO_2 emissions are monetised by estimating the total mine emissions (in tonnes) and then determining the cost of offsetting those emissions.[48] Assuming the DSM mining company will purchase these offsets in the open market, the burden of CO_2 emissions is shifted from the citizens of Papua New Guinea to the DSM mining company.

The operation of a DSM mine generates CO_2 during:

> The operation of vessels used in the transport of ore to a destination port,

> The transport of personnel and supplies via supply boats, and

> The process of generating power on the production support vessel.

48 As discussed in Section 2.3.2, a complete CO_2 valuation requires an understanding of the effect of DSM activity on global metals production. Because an analysis of the global metals markets and facility-specific carbon footprints is beyond the scope of this report, it is assumed that the host countries take a precautionary approach to CO_2 emissions and require the purchase of CO_2 offsets by the DSM mining company. This requirement assures DSM activity results in no net increase in CO_2 emissions. This effectively internalises the potential externality by requiring the DSM mining company to invest in operational technology that eliminates the source of the potential impact.

The external cost associated with increases in CO_2 emissions from vessel transport and mining operations are based on an estimate of the total annual fuel use (in tonnes) from the Solwara 1 EIS. Fuel usage includes the following activities:

> Powering of seafloor mining tools and production support vessel,
> Barging, and
> Crew boat.

As illustrated in Table 3.8, the total estimated annual cost to offset CO_2 emissions is $0.368 million (USD). This is entered as a "debit" in the calculation of profits to the mining company.

Table 3-8 Basic Inputs Required to Estimate the Annual Cost of Offsetting Carbon Emissions from Solwara 1 Project Operations

Input	Assumption
Fuel usage per year (tonnes)	20,255
Conversion to kilograms	18,371,285
CO_2 emission factor (g of CO_2/kg of fuel)	3,179
CO_2 emissions (tonnes/year)	64,390
Cost of Carbon Offset ($USD/tonne)	$5.8[1]
Estimate of annual cost to offset CO_2 emissions	$368,100 (USD)
Note 1: The probability distribution for this input is taken from a report on the State of the Voluntary Carbon Market (low of $3.7, most likely of $5.8, and maximum estimate of $7.4).	

3.5.4.2 Unplanned Release

In the day-to-day operation of the mine, there is the potential that hazardous materials, such as fuel, may leak or spill from their containment vessels; this risk is elevated during fuel transport and transfer. When spills occur, they impose costs that fall into three broad categories: clean-up costs, environmental costs, and social costs. To determine who would bear these costs (the mine operator or PNG) and how these costs might be quantified, it is necessary to understand PNG's legal framework as it relates to unplanned releases.

In PNG, spill-related regulations require the DSM mining company to carry insurance to insure post-spill clean-up. For example, the NMSA developed a Marine Pollution (Liability and Cost Recovery) Act that provides for the establishment of a National Maritime Pollution Fund and also provides a comprehensive regime for ships to carry compulsory insurance against marine pollution and for the payment of damages to PNG citizens in the event of marine spills. It also gives PNG access to major international funds (up to $1,105 million USD) for oil pollution compensation. The annual insurance premium paid by the DSM mining company (approximately $1 million annually) effectively internalises this external social cost.

Outside of the PNG domestic policy, PNG is also party to the following international conventions: the Civil Liability Convention (CLC), and the Fund Convention. Under the Fund Convention, compensation above the vessels liability limit may be available from the International Oil Pollution Compensation Funds (IOPC Funds) secretariat based in London. The basic premise of the international policies is to ensure that claimants who have experienced financial loss as a result of an unplanned spill are restored to the same economic condition they would have been in absent the spill. There is not any additional requirement to make the public and the environment “whole,” such that the emphasis is on compensating the people of society for the loss of goods and services provided by the environment. In other words, admissible claims must be economic in nature (i.e. indicative of a financial loss).

Given this legal context, the CBA assumes that the mining company would be liable for any spill-related clean-up costs and any spill-related financial losses. It is further assumed that these costs are appropriately reflected in the mining companies annual insurance cost of $1 million based on information associated with the Solwara 1 project.

To estimate costs associated with the potential loss of ecosystem services, an expected annual spillage (tonnes) is calculated using spill frequency data from the International Tanker Owners Pollution Federation Limited (ITOPF) and information describing the DSM-related vessel activity and fuel transfer. The expected annual spillage is multiplied by $24,000 per tonne which reflects the cost of compensating the public for ecosystem services lost following a spill as reported in Kontavas and Psaraftis (2010).

The estimate of annual spillage is based on vessel utilization:

- Three 25,000 dead weight tonne (DWT) handy-size vessels transporting ore from the mine site to the processor,
- One support vessel transferring crew and supplies, and
- One PSV located at the mine site.

To estimate the probability of a spill occurring, the CBA uses data from ITOPF, which reports the total number of small, medium and large spills by tankers, combined carriers and barges over time. According to their 2014 report, the 10-year average number of medium spills (7 to 700 tonnes) is approximately 7 per year. Given that there are approximately 16,000 vessels in the world merchant fleet, this equates to a 0.04% probability of a medium sized spill per vessel (7/16,000). For large spills (> 700 tonnes), the 10-year average is approximately 3 per year, or a 0.02% probability of a spill of this magnitude occurring per vessel (3/16,000).[49] Table 3-9 illustrates expected unplanned release costs assuming the maximum amount of fuel that could be released.[50]

Table 3-9 Estimated Environmental Cost of Unplanned Oil Spill for Solwara 1 Project Mine Operation

Vessel	Total fuel capacity[1] (in tonnes)	Probability of spill	Expected Present Value of Spill Volume (in tonnes)	Total estimated annual cost per vessel (in USD)
PSV	1,192	0.02%	0.23	$5,520

[49] http://www.itopf.com/fileadmin/data/Documents/Company_Lit/Oil_Spill_Stats_2014FINALlowres.pdf Accessed August 17, 2015. It is also noted that in each CBA respectively, the probability of a spill does not change based on site specific conditions. This is because spills are largely due to human error, and there is no evidence to support that the probability of a spill occurring would go up or down based on site specific characteristics.

[50] In a typical spill, not all of the fuel is lost, therefore this is likely to be an overstatement of the actual cost. In terms of the cost of clean-up and compensation, it is also recognized that due to the remote location, there would be fewer receptors (i.e. wouldn’t be a shoreline component), thus further reducing the cost of compensation. Conversely, the remote location would also serve to increase the cost of clean-up, therefore, the analysis used an average global cost of clean-up and compensation to better represent the true cost.

Vessel	Total fuel capacity[1] (in tonnes)	Probability of spill	Expected Present Value of Spill Volume (in tonnes)	Total estimated annual cost per vessel (in USD)
Transport	724 /vessel 2,172 total	0.02%	0.43	$10,320
Crew boat and supplies	351	0.04%	0.14	$3,360
Total	**3,715**		**0.78**	**$18,720**
Note 1: Source: http://www.seacormarine.com/cgi-bin/ourfleet.cgi?type=psv Accessed August 19, 2015				

3.5.4.2.1 Unplanned Release Summary

Costs associated with spill clean-up and financial compensation are reflected in the $1 million insurance premium paid by the DSM mining company.

The annual expected cost associated with lost ecological services would be borne by the host country citizens. Those costs calculated as the product of expected annual spillage (0.78 tonnes) by the per tonne cost of compensating the public for ecosystem services lost following a spill ($24,000) are estimated to be $18,720 annually. Discounted at 7% over the course of the two year mining operation, the PV of the total estimated cost is $0.034 million (USD).

3.5.4.3 Cost of Discharging Nutrient Rich Water

Once at the surface, the raw ore has to be separated from the seawater in a process known as dewatering. All recovered solids larger than 8 micrometers (μm) are transported to a shuttle barge for shipment to an overseas processing facility. The remaining seawater is mixed with suspended solids (less than 8 micrometeres) that were too small to be recovered. Often the solids will contain nutrients recovered from the sediment on the seabed. If large quantities of nutrients from the seabed were to be deposited at the surface or in the upper water column, it could trigger the growth of small organisms called phytoplankton in large numbers creating the development of algal blooms. Algal blooms can be harmful to marine life because they use up the oxygen in the water, thus causing other fish and smaller organisms to die. Therefore, there have been concerns over the appropriate discharge of the nutrient rich seawater mix from the dewatering process.

In the Solwara 1 project, Nautilus proposes to transport the seawater mix back via the riser and lift system (RALS) and deposit it between 25 and 50 m above the seabed. This will eliminate the potential for the nutrient rich water to cause harmful effects at the surface. Therefore, for the purposes of monetisation, a value of $0 is assigned to this category in terms of a cost to citizens of PNG.

3.5.4.4 Valuing the Change in Environmental Services Provided by the Seabed

As discussed in Section 3.3.1, the potentially impacted deep-sea vent community consists mostly of macrofauna living in and around the vent site like tube worms, gastropods, bivalves and crustaceans. High levels of genetic diversity amongst microorganisms have also been found at the Solwara 1 site, with few “dominant” species (Coffey Natural Systems, 2008). Relative to a deep seabed with little three dimensional structure or thermal/chemical loading, the site has high productivity and diversity. However, relative to other deep-sea vent systems around the world, species density and diversity at Solwara 1 site is low.

Table 3-10 identifies and discusses the services that may be provided by deep seabed communities of the Solwara 1 site. Following convention, services are divided into four broad categories:

1. Provisioning services (e.g., material goods such as food, feed, fuel, and fiber) are associated with goods provided directly to people,
2. Regulating services (e.g., climate regulation, flood control, and water purification) control ecosystem processes that influence the well-being of humans,
3. Cultural services generate human well-being outside any direct or indirect consumption of goods. Examples include recreational opportunity and well-being generated by the knowledge an ecosystems exists in a certain state (often called existence or spiritual value), and
4. Supporting services (e.g., nutrient cycling and primary production) generate human well-being by facilitating the production of future provisioning, regulating or cultural services.

For each specific service, the baseline level of ecological service provision is discussed and compared to the level of service provided by the more familiar forest and wetland habitats.

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

For each specific service, the sign and magnitude of project related changes are qualitatively evaluated.

- Changes may be positive (the value of service provided increases) or negative.
- A ranking of 1 implies that the change is unlikely to be perceptible by residents of the host country.
- A ranking of 2 implies that the change in the level of service may be perceived by residents of the host country.
- A ranking of 3 implies that the change would most likely by perceived by most host country residents.

Table 3-10 Ecosystem Services Provided by Deep Seabed Communities Relative to Solwara 1 Project Site

Service Category	Service Description	Baseline Level of Service Provisions	Sign and Magnitude of Expected Change
Provisioning	Some benthic organisms are directly consumed by people (e.g. clams and oysters)	Human consumption and utilisation of organisms deep-sea vent organism (0)	0
	Some benthic organisms are used as bait (e.g. worms, clams) or in other processes (e.g. shells may be crushed used in industrial processes)		0
	Genetic material may be extracted from sediment dwelling bacteria or benthic organism for research and pharmaceutical use	Utilisation of genetic resources from deep-sea vent areas (1)	-1 to +1
	Proteins or chemical compounds may be extracted from sediment dwelling bacteria or benthic organisms for pharmaceutical and industrial use	Utilisation of mineral resources is limited today but potential exists for future mineral development (1)	-1 to +1
Regulating	Benthic organisms and sediment dwelling bacteria influence climate processes; these organisms regulate some organic decomposition processes which influence CO_2 sequestration and the sediment itself may be a sink for organic (e.g. carbon-based) material	Deep-sea sediments act primarily as a carbon and nutrient sink. The vents represent sources of heat and chemicals which support local increases in productivity and diversity (1)	-1 to +1
	Benthic organisms and sediment dwelling bacteria influence pollution attenuation processes; burying by the sediment itself may reduce the bioavailability of pollutants; sediment and sediment dwelling organisms regulate water purification processes.		-1 to +1
	Sediment structure and the accumulation of sediment regulates accretion and erosion processes as well as storm surge and flood control	Sediments and sediment processes at the depths in question have almost no influence on erosion processes or storm surge protection (0)	0
Cultural	Well-being may be derived via shell fishing outside any consumptive use	Recreational collection of deep-sea vent organisms is very limited (0)	0
	Well-being may be derived by individuals simply because they know a healthy sediment community exists	Given the remoteness and limited development of PNG seabed resources, these values may be high relative to similar values held by individuals in more developed areas (3)	-2
	Well-being may be derived because the sediment system exists and can be used in the process of generating human well-being, education, or scientific understanding		+1

Service Category	Service Description	Baseline Level of Service Provisions	Sign and Magnitude of Expected Change
Supporting	Sediment dwelling organisms cycle energy, nutrients, and organic matter within and between ecosystems this energy cycling facilitates the production of future services across multiple ecosystems. Three dimensional vent structures represent a feature around which organisms may aggregate while feeding and/or reproducing.	The deep-sea acts primarily as a sink as energy and nutrient transport from deep-see back into resources that provided provisioning or regulating services is limited (1). Nursery utilisation, association with three dimensional structure, and association with thermal and chemical loading are all elevated relative to an undifferentiated deep seabed. However, few organisms that provide provisioning or regulating services benefit from these services (1)	-1

3.5.4.4.1 DSM Mining Related Impacts to the Deep Seabed

Nautilus is proposing the use of three different mining machines. The auxiliary miner levels the mine site. The bulk miner cuts, grinds and sizes deposits which contain the mineral and then the gathering machine removes the cut ore from the seafloor and transfers it to the riser and lift system (RALS). 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 (35 acre) mining site.

The project would result in the conversion of a relatively three-dimensional hard bottom seabed into a flatter seabed with some sediment overlay.

- The soft bottom seabed would initially be characterised by a community of benthic organisms tolerant of disturbance. Through time the soft bottom community would likely evolve to be more similar to that typical of an undisturbed, soft bottom deep seabed associated with a thermal or chemical seep.
- As previously discussed, active vent chimneys can grow very rapidly and it is not uncommon for an active vent site to experience two or more cycles of local extermination and re-colonisation by species due to volcanic and seismic activity. This suggests that, despite the inconsistent and relatively short life-span of hydrothermal venting sites, faunal species have high resilience through their dispersal and recruitment processes, allowing them to move and recolonise new sites relatively quickly (SPC, 2013a). Thus it is likely both the three dimensional structure and the associated community would recover through time.

3.5.4.4.2 DSM Mining Related Impacts to Deep Sea Vent Service Provision

Given the overall scale of the project (DSM mining activity is proposed in only a small proportion of Papua New Guinea’s deep-sea vent habitat), 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.

Mining activity would materially alter the localised communities that develop around vents and the conversion of a relatively three-dimensional hard bottom seabed into a relatively flat seabed with some sediment overburden would reduce the quantity and quality of nursery and other supporting services with recovery through time expected. It is unlikely the effects of altering these supporting services would be perceptible to PNG residents.

It is 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.

3.5.4.4.3 Valuing Changes in Environmental Service Provision

There are two approaches to valuing the DSM-mining related changes in ecosystem service provision:

1. Estimate willingness-to-pay for specific environmental services and multiply willingness-to-pay by the change in environmental service provision, or
2. Estimate of the cost of generating environmental services of similar type and quantity and use this “replacement-cost” as a substitute for willingness-to-pay.

Earth Economics (2015) reports the results of their willingness-to pay assessment. This effort is, perhaps, best described as a screening level analysis designed to place an upper bound on the value of lost ecosystem services for three reasons.

- Earth Economics reports an annual willingness-to-pay for ecosystem services of up to $1,766 per hectare of deep seabed. In doing so, they noted the figure was based on values associated with cloud forests; this choice was made given the absence of valuation studies related to the deep-sea vent services. This implies that the deep-sea vent habitat provides services as valuable as cloud forests. As cloud forests are some of the most productive and bio-diverse ecosystems on the planet, Earth Economics reports that the approach represents a highly cautious (tending to overestimate) approach to valuation.
- The Earth Economics report appears to describe a global willingness-to-pay whereas this cost benefit analysis is from the perspective of PNG residents only.
- The Earth Economics report implies that that all value will be lost if DSM mining occurs. In reality some of the services provided by deep-sea vent habitats under baseline would continue to be provided even if DSM mining occurred.

Using these three cautious assumptions, Earth Economics estimated the value of the lost ecological services would be no more than $605,871.

To complement the willingness-to-pay approach, Cardno employed a replacement cost approach that relies on a method referred to as HEA (See appendix A). This approach (a) relaxes the Earth Economics assumption that DSM mining will result in a complete loss of all service provision and (b) replaces the difficult to estimate “willingness-to-pay” with a “service replacement cost.”

The basic premise underlying HEA is that all of the services flowing from a habitat can be treated as a single composite ecological service. If an action results in a reduction in the quantity of the composite ecological service produced by the impacted habitat, the public can be compensated via a restoration project that creates composite ecological service at some other site. The cost of implementing the restoration project is the service replacement cost.

The HEA metric is generally the Discounted Service Acre Years (DSAYs) where one Service Acre Year (SAY) represents a composite measure of all of the services flowing over the course of one year from one acre of the habitat. That is, the SAY is a composite measure of the provisioning, regulating, supporting services provided by one acre of habitat over one year. Future services are discounted to reflect society's rate of time preference.

HEA is typically discussed in terms of debits and credits flowing from two discrete sites. Debits accrue when the level of composite service provided by the injured site is below baseline; credits accrue when the level of composite service provided by the restored site is above baseline (Figure 3-9). Compensation is achieved when the debit (present discounted value of the area represented in red in Figure 3-9) is equal to the credit (present discounted value of the green area in Figure 3-9). Note that this definition of compensation assumes that the value of any cultural services lost at the impacted site is equal to the value of the cultural services provided by the restored site.

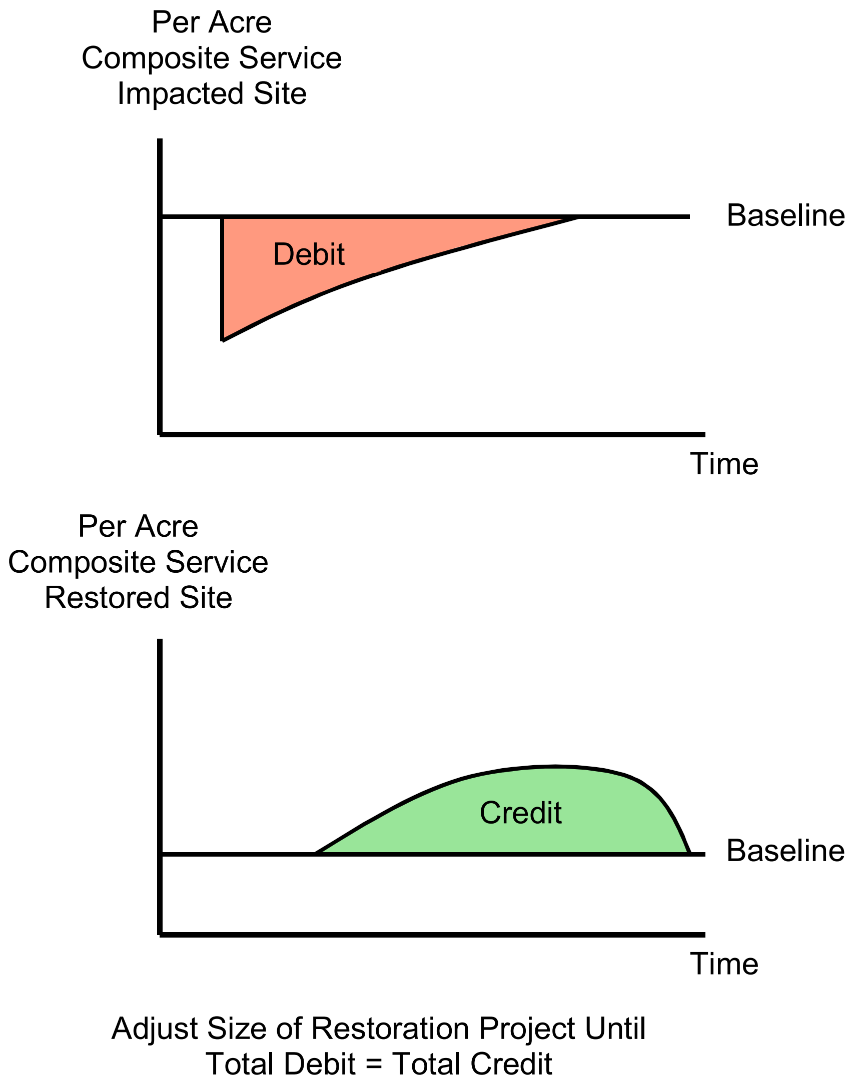


Figure 3-9 HEA Illustrated as Services Flowing from Two Discrete Sites

As is the case with the willingness-to-pay estimate, application to a deep-sea vent system is challenging given the state of our biological and economic understanding. This is true for two reasons:

1. Given the current level of biological and ecological understanding related to the production of composite service in deep-sea vent habitat, it is necessary to estimate service losses qualitatively.
2. Because it is not technically feasible to replace the services provided by the deep seabed ecosystem "in place" (that is, it is not technically feasible to create or restore deep seabed habitat), the deep seabed HEA relies on ratios that equate composite service provided by deep- sea vents with composite service provided by wetlands.

DSM mining activity is assumed to result in an initial service loss of 85% within the mining footprint.

> An initial service loss of this magnitude is consistent with a cautious assumption that the majority of the deep-sea vent composite service stems from the three dimensional nature of the habitat and or will be interrupted by mining activity. If a large proportion of the composite service flows from thermal loading, chemical loading, and/or organisms not reliant on topographic relief and robust to DSM mining related disturbance, then service loss as great as 85% would not occur.

> Given the reported ability of chimneys to recover and hydrothermal vent organisms to recolonise, the service level is assumed to linearly recover to baseline over 100 years.

Given these assumptions, the expected loss of services, using a 7% real rate of discount is 367 deep-sea vent DSAYs. To put this in context the assumptions embedded in the Earth Economics assessment would imply a loss of approximately 500 DSAYs.

Because it is not technically feasible to replace the services provided by deep seabed communities "in place" (that is, it is not technically feasible to create or restore deep-sea vent habitat), the deep-sea vent HEA relies on ratios that equate services provided by one habitat with services provided by another.

Peterson et al. (2007) established a series of equivalency ratios based on the relative productivity of any two habitats. Using the productivity logic, the equivalency ratio between a relatively flat and undifferentiated deep seabed (4.23 g C/m^2/y at 1500m depth (Rowe and Kennicutt 2009)) and salt marsh (860 g C/m^2/y reported for salt marsh (Feijtel et al 1985)) would be 1:203. Allowing for the fact that the seabed in this area is relatively three dimensional and includes thermal and chemical loading sources, the ratio is reduced by a factor of 22 (Peterson et al. 2007) to 1: 9.22.

This implies a loss of 367 deep-sea vent DSAYs would 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).

3.5.4.4.4 Valuing the Change in Environmental Services Provided by the Seabed: Summary

DSM mining related changes in ecosystem service provision were valued using willingness-to-pay and replacement-cost methods. 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.

In preparing these estimates, many helpful comments from SPC GSD staff and in-country stakeholders helped frame the discussion and have been incorporated into the text. There were also several comments that have not been incorporated. These include:

> Individuals expressed concern that impacts related to spills and air emissions were not considered. These impacts are omitted from this section because they are unlikely to affect

the deep-sea vent habitat. They are however considered when overall environmental costs are estimated.

> Individuals expressed concern that indirect impacts to fish and other mobile organism that depend on deep-sea vents were not considered; these impacts are included via the consideration of deep-sea vent supporting services.

> Commenters questioned the utility of compensating the public for the loss of deep-sea vent services via the creation of wetland services. While it is agreed that this is a sub-optimal approach, it is necessitated by the impracticality of restoring deep-sea vent habitat.

3.5.5 Total Monetised Social Costs

The following potential social costs were identified:

> Administrative costs to the government,

> Cost of offsetting CO_2 emissions,

> Cost of unplanned spill and/or vessel grounding, and

> Cost of replacing services that may be lost by DSM mining activities.

Where possible these costs are transferred to the DSM mining operation and are treated as “debits” in the calculation of the mining company’s profit. This includes PNG administrative costs, cost to offset CO_2 emissions, costs to avoid negative impacts of introducing nutrient rich waters to the sea surface, and clean-up costs associated with unplanned release. The remaining costs associated with lost ecosystem services following a spill and the loss of deep-sea vent ecosystem services are incurred by the citizens of the host country. Table 3-11 summarises each individual cost element, as well as how it was factored into the analysis.

Table 3-11 Summary of Monetised External Cost Estimates for the Solwara 1 Project Site (in USD)

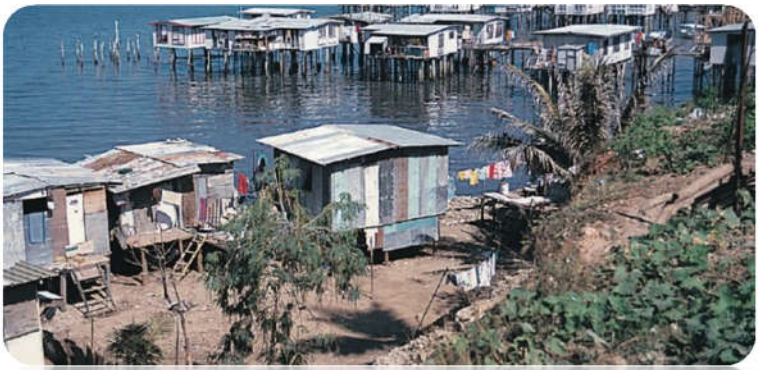
Cost Estimate	Mean Values based on Monte Carlo Simulation	
	Present Value Social Cost Incurred by Citizens of Papua New Guinea (in millions of USD)	*Annual Private Cost Incurred by DSM Mining Company (in millions of USD per year)*
Government administrative costs	$0	$1.9 [1]
CO_2 offset costs	$0	$0.37 [2]
Clean-up and restoration cost associated with unplanned spill	$0.03[4]	$1[3]
Lost deep-sea vent ecological services	$0.61[5]	$0
Present value of total cost	**$0.64**	**$3.3**

Note a: Total amount of production levy paid to the government
Note b: Present value of the cost of acquiring carbon dioxide offsets
Note c: Costs to acquire insurance to assure oil spill clean-up costs are covered
Note d: Expected cost to replace ecological services lost from an unplanned spill or release from the time the spill occurs to the time the baseline level of services are restored
Note e: Value of lost ecological services provided by the deep-sea vent community

3.5.6 Discussion of Non-Monetised Social Costs

The following section provides a detailed assessment of the external costs that were not monetised. These include cultural costs such as the concession of traditional ownership and community level impacts that may affect the well-being of various members of society.

3.5.6.1 Concession of Customary Land Ownership



Coastal village in Southern Papual New Guinea
Source: International Journalism

Customary land ownership is an important part of the cultural fabric of PNG. While it may be more applicable to activities that take place on land, concessions made by coastal communities and villages based on their traditional beliefs are also important to consider. It is common for indigenous populations to feel as though they are losing their rights when natural resources to which they claim ownership are being exploited. This has been the case in PNG where a stakeholder group called the West Coast Seabed Mining Land Owners Association (WCSMLOA) was formed to represent people in the villages along the coast of New Ireland who want to have a say in the decisions about DSM activities, including how the benefits are distributed. As previously noted, the State has ownership over the seabed and its resources after 3 nm offshore from the coastline, which has been a point of contention for the group that asserts its rights over the sea's resources in its region. They also have concerns over the potential environmental damage to the sea and artisanal fisheries, calling for another environmental impact study to be conducted and inclusion of feedback from the international community.

3.5.6.2 Community Level Impacts

There is some concern that mining-related changes in employment patterns could change social and cultural patterns. For the purpose of this analysis, community level impacts are:

- Changes in employment patterns, including impacts to existing industries and the potential impact of in-migration on local villages and communities due to DSM mining related activities,
- Changes in societal norms due to increased wealth from mining revenues,
- Disruptions to locals fishing in proximity of mine site, and
- Disruptions to local customs such as shark calling.

Nautilus would employ approximately 242 employees in offshore mining operations. They plan to give preference to qualified locals (i.e. residents of New Ireland) but realise that there may be some in-migration as a result of the presence of the mining operation. In-migration has the potential to increase the social tensions among locals and outsiders, reduce the opportunity for locals to gain employment and put pressure on existing infrastructure. To minimise the impact of in-migration, Nautilus has developed a recruitment policy that is designed to deter non-local citizens from seeking employment, thus reducing the impact on locals and the ability of locals to secure employment. Given this policy and the limited number of jobs directly associated with DSM mining, it is unlikely that the project will generate significant migration among PNG citizens.

Concerns related to the presence of non-native workers have also been expressed. Nautilus intends to use expatriates during the start-up phase and commissioning of the mine, but will eventually phase in PNG nationals as they are trained. Nautilus plans to have non-native workers on a four week rotation, where they fly in/fly out form local airports and be transferred directly two and from the crew boat or vessel to eliminate the need for more permanent lodging (Coffey Natural Systems, 2008). This will reduce the potential impact of an influx of non-native workers into the local and coastal communities.

A concern shared by all of the countries considered in this report related to cultural changes related to an influx of wealth. It is possible that windfall gains associated with a DSM mining operation may contribute to a culture of welfare dependence by increasing the available funding for welfare distribution, without addressing the base cause of dependency. There is a general concern that DSM mining activities may increase rather than decrease PNG citizen's dependence on these types of programs. To minimise the potential for welfare dependence, the PNG government has the ability to use policy mechanisms to ensure the wealth is managed in a manner that maximises the welfare of its people.

Concerns related to the disruptions to local customs were also expressed. Given the mine site's distance from the shore (30 to 40 km) and the low probability that offshore mining operations would be perceived either directly or indirectly by host country residents, impacts on subsistence fishing and/or cultural customs such as shark calling are not anticipated.

3.6 Benefits Methodology

Total private benefit is approximated as revenue received by the government.[51] Revenue estimates rely on total geological specifications and extraction timeframes, as laid out in Section 3.4, and metal prices. Metal prices are adjusted to reflect the fact that Nautilus will sell the raw ore to a processor, and the processor will pay Nautilus a price somewhat less than the market price in order to cover costs and make a profit.

Profit to Nautilus is estimated by subtracting capital and operating expenditures from the mining company's revenue which comes from the sale of the ore. If there is a positive profit in a given year, the following downward adjustments are made:

- Corporate income tax of 30%, and
- Production levy of 0.25%.

In addition to the tax revenue, the PNG government will receive royalties paid at 2% of the net smelter returns of mine products exported from PNG, and a 15% equity share of the net profits received by Nautilus from the sale of the ore.

3.6.1 Private Benefits

To estimate the gross revenues of the mining operation, the CBA uses metal grade estimates for copper, zinc, gold and silver from the SRK Consulting Cost Study (2010). In this scenario, both inputs (price and metal grade) are drawn from probability distributions. The probability distributions are based on estimates of "best-case", "most-likely" and "worst-case" values for each input. For prices, the most-likely value is the current market price of each metal reduced by 25% to reflect the price that would be offered to Nautilus by the processing company. Best and worst case values are plus or minus 50% of the most likely value (Table 3-12).

[51] External benefits associated with Solwara 1 mining activities were not monetised but are discussed in Section 3.6.3

Table 3-12 Distribution of Prices (in USD/lb) used in PNG Mining Scenario[52]

Metal	Minimum	Most Likely	Maximum
Zinc	$0.35	$0.69	$1.03
Copper	$1.00	$1.97	$3.00
Gold	$6,143	$12,285	$18,427
Silver	$75	$165	$250

Table 3-13 reports the range of potential metal grades in the SMS deposits at the Solwara 1 Project site; while Table 3-14 shows the resulting estimate of contained metal (in dry tonnes) at the mine site. The range of values used to inform the probability distribution (i.e., the minimum and maximum and minimum values reflect highs and lows reported for the area).

Table 3-13 Distribution of Estimated Metal Grades used in PNG Mining Scenario

Metal	Minimum	Most Likely[1]	Maximum
Zinc	0.36%	0.47%	0.58%
Copper	4.1%	5.9%	7.4%
Gold (grams per tonne)	3.7	5.3	7.2
Silver (grams per tonne)	15.9	25.2	34.4
Source: SRK Consulting Note 1: Most likely, min and max estimates come from Table 19-17 in SRK Consulting (2010).			

Table 3-14 Contained Metal (in dry tonnes) at Solwara 1 Project Mine Site

Metal	Minimum	Most Likely[1]	Maximum
Copper	66,735	120,945	147,560
Zinc	6,458	9,197	11,937
Gold	7.4	11	16.3
Silver	28.5	55	76.2
Note 1: The most likely value is based on the average grade across all zones within the Solwara 1 mine site (Table 19-17, SRK Consulting (2010)). The minimum and maximum values are based on the low and high ends of the range of grades across all zones.			

The total estimated dry tonnes of production in each year are approximately 1,398,029 in Year 1, and 559,001 in Year 2 (SRK Consulting, 2010). The expected price of each metal is multiplied by the amount extracted each year and aggregated across two years to estimate the total gross revenue from the mine site over the course of production.

A basic cash-flow analysis was used to estimate the profit to the mining company in each year that the mine is producing to determine the amount of tax revenue in addition to the royalty.[53] In the model Nautilus receives a price for the sale of the raw ore that is lower than the market price. The analysis assumes the processor receives the full market value for the processed metals, to which a 2% royalty rate

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52 All prices were based on http://www.infomine.com.

53 Detailed results of the cash flow analysis are in Appendix B.

is applied to determine the PNG government's share of revenue from royalties. The end result (gross revenues to the government in the form of royalties + taxes + 15% share of Nautilus' profits) is discounted to reflect the value of the cash flow in present value terms.

At the end of the two year mining operation, components of the offshore mining operation may be shipped to another site if mining has been approved (Coffey Natural Systems, 2008). However, for the purpose of this assessment it is assumed that all capital equipment is fully expended during the two-year mining operation. This may result in an underestimate of profits and the resulting social benefits.

3.6.2 Total Monetised Social Benefits

Figure 3-10 illustrates the range of private benefits to Nautilus, and the resulting revenues to the PNG government.

The median PV of profit to Nautilus is approximately $136 million (USD) (point C on red line); the median PV of government revenue is $83 million (USD) (point B on blue line).

- The PV of the profit to Nautilus reflects what they receive after selling the ore to a buyer and taking out capital and operating expenses. The PV of the social benefits is the sum of the 2% royalty paid on net smelter returns, the transfer of corporate tax payments from Nautilus, production levy and the PNG government's 15% share of Nautilus' profits (discounted at 7% to reflect people's time preference for money).

The position (primarily to the right of zero) and slope of the blue line suggests (1) there is less than a 5% probability of the government incurring a financial loss and (2) there is less than a 19% probability of government revenue exceeding $130 million (point A in the blue line).

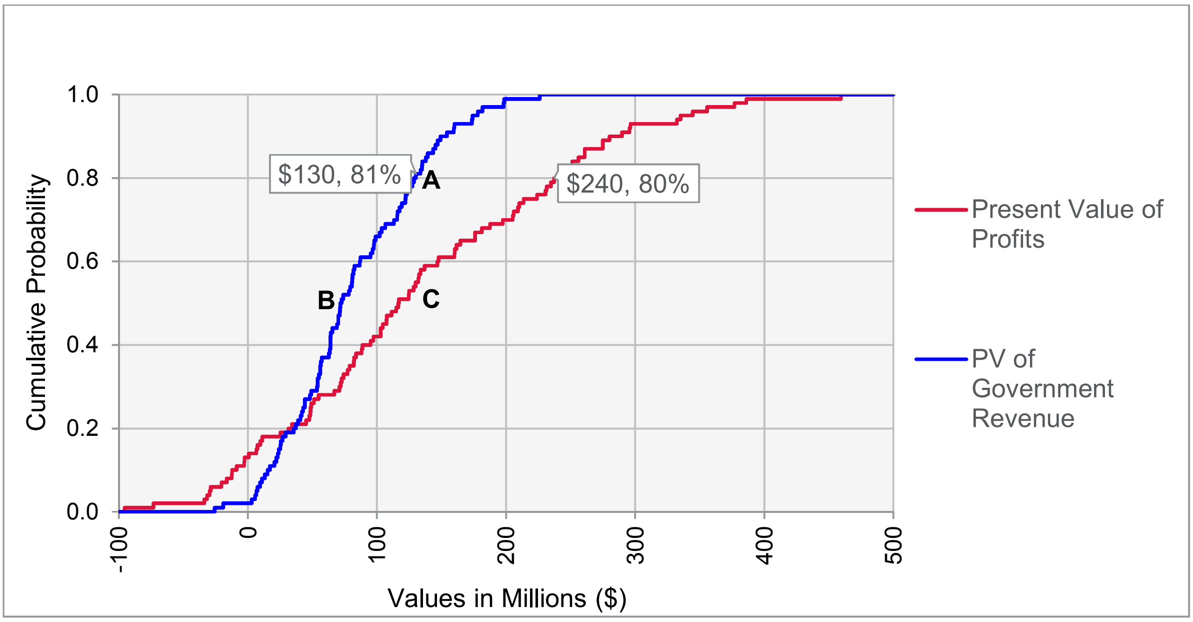


Figure 3-10 Comparison of Nautilus Profit and Government Revenue in Solwara 1 Project Scenario

3.6.3 Non-Monetised Social Benefits

DSM mining may facilitate PNG citizens' professional development and/or result in an increased understanding of the deep-sea environment. The value of these potential benefits has not been quantified.

3.7 Cost-Benefit Comparison

The net social benefit (NSB) of DSM mining is calculated as the present value of social benefits minus the present value of social costs.

NSB = PV of BENEFITS (**government **revenue) – PV of COSTS (**private government **costs +** external **costs)

A NSB greater than zero suggests the project has the potential to make citizens of PNG better off. A NSB less than zero suggests the project will leave PNG citizens worse off.

Table 3-15 presents the median net social benefits and benefit to cost ratio associated with the PNG mining scenario. These results suggest the DSM mining activity has the potential to increase the well-being of PNG residents.

Table 3-15 Expected Net Social Benefits in PNG Mining Scenario (in millions USD)

Category	Present Value
Government revenue	$83.3
Unplanned spills and grounding	(-$0.03)
Replacing lost environmental services	(-$0.61)
Mean Net Social Benefits	**$82.7**
Benefit-Cost Ratio	**124**

3.8 Sensitivity Analysis

Figure 3-11 is an NSB probability distribution. Each line illustrates the probability NSB will exceed a specific value given the range of inputs specified for the Monte Carlo analysis and assuming the specified discount rate.

The horizontal distance between each line reveals the effect of the discount rate. As expected with a project with a very short time horizon (two years), there is not a large gap between the NSB at the various discount rates.

Importantly:

> *The net social benefit is approximately $82.7 million,*

> *There is a very low probability (less than 15%) that NSB will be less than zero, and*

> *The slope up and to the right suggests there is a reasonable probability of NSB being positive and larger than $75 million (USD), regardless of the discount rate applied.*

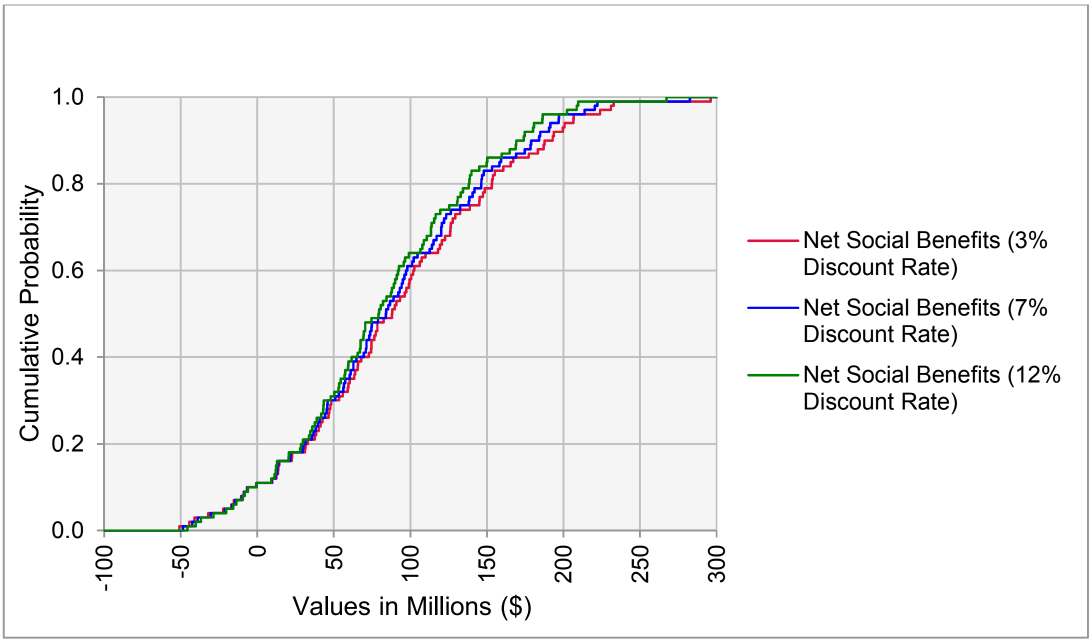


Figure 3-11 Sensitivity of PNG Mining Scenario Results to Changes in Discount Rate

3.9 Regional Economic Impact Analysis

To understand how a business activity such as DSM mining, affects a regional economy, it helps to understand how different sectors or industries are linked to each other within an economy. To do this, as described in Section 2.4, a regional impact analysis is performed to determine the indirect benefits associated with DSM mining. First, the analysis uses information on mining related expenditures to determine employment and income effects as a result of DSM mining in PNG. Then, the annual estimates of government royalties are used to evaluate the employment and income effects of government spending of a portion of the royalty payments.

The economic impact analysis for PNG relies on previous research for large scale resource development projects to approximate the direct, indirect and induced income and employment impacts of DSM mining. Specifically, the analysis relies on research previously completed for the ExxonMobil LNG project and other studies on hard rock mining in PNG. This approach was selected because IMPLAN data for PNG, or a reasonable proxy country, does not readily exist.

Based on previous research, the analysis assumes an indirect income multiplier of 0.79 and an induced multiplier of 0.31. That is, for every dollar increase in direct income within the local economy, there is an additional $0.79 of income within those industries supplying inputs to the mine (indirect effect). Furthermore, for that same $1 increase in direct local income there is an additional $0.31 of income in other industries providing goods and services to households as higher incomes lift consumer expenditures (induced effect). In total, for every dollar of direct local spending it is assumed that income will increase by an additional of $1.10.

Based upon information from the Solwara 1 project, it is estimated that direct local mining income would equal $6.6 million USD. In order to approximate the local income effects of DSM mining operation expenditures, it is also assumed that 20% of project expenditures for local goods and services (i.e. fuel, spares and consumables) in PNG would comprise payments to labour, which is consistent with previous research conducted as part of the ExxonMobil LNG Project.[54]

Table 3-16 Representative Input-Output Multipliers

Industry Bundle	Direct	Indirect	Induced	Total
Industries supplying inputs to the Project	1.00	0.79	0.31	2.10
Source: Adapted from ACIL Tasman and Economic Insights, November 2002, The PNG Gas Project: Implications for the Economy of Papua New Guinea				

To estimate the indirect employment effects for the proposed mining operation, the analysis relies on data reported for the three largest hard rock mines in PNG. As illustrated in Table 3-17 below, across all three mines there is on average one additional employee (0.98 employees) indirectly employed for every employee directly employed by the mines. The analysis assumes that for every employee directly employed by the mine, there are an additional 0.98 indirect employees supported by mining operations.

Table 3-17 Formal Employment by Three Largest Hard Rock Mines in PNG

	OK TEDI	Porgera	Lihir	All
Direct Employees	2,162	2,596	2,181	6,939
Indirect Employees	3,062	884	2,842	6,788
Total Direct and Indirect	5,224	3,480	5,023	13,727
Indirect employment multiplier	1.42	0.34	1.30	0.98
Source: Flier, Colin, Andrew, Marjorie, Carr, Phillipa, Imbun, Benedict Y and Bill F. Sagir, June 21, 2013, Papua New Guinea, Jobs, Website (http://www.inapng.com/pdf_files/Final%20report%20Jobs%20in%20extractive%20industries%20in%20PNG%20-%20June%202013.pdf) accessed August 14, 2015.				

3.9.1 Mining Expenditures

Estimated capital costs (Table 3-6) and operation expenditures (Table 3-7) were derived from the Solwara 1 SRK Consulting (2010) cost study with scenario-specific adjustments as appropriate. The estimated annual government royalty outlays rely upon the analysis provided in Section 3.6. The adjusted cost estimates form the basis of IMPLAN model inputs.

54 ExxonMobil, February 6, 2008, PNG LNG Economic Impact Study, Prepared by ACIL Tasman, Website (http://pnglng.com/downloads/acil_tasman_impact_study_revision_01.pdf) accessed August 14, 2015.

3.9.1.1 Capital Expenditures

As described in Section 2.4, capital expenditures have been excluded from the impact analysis given that most of these items are highly specialised and are not expected to be procured from study area countries.[55] The only local employment and income benefits associated with DSM mining are expected to be associated with project operations and are for procurement of project fuel, spares, consumables, and labour.

3.9.1.2 Operating Costs

The SRK Consulting Cost Study (2010) estimated a steady state employment of 121 during operations. Given that the 121-person crew is expected to work a four-week-on-four-week-off rotation, there would be a total of 242 local and non-local workers required for the DSM operation.[56] The percentage of local versus non-local labor in Papua New Guinea is based on research conducted for the Papua New Guinea mining industry.[57]

- Of the 7,791 workers employed in that industry, approximately 46.1% were PNG nationals from the province in which the mine was located, 45.7% were PNG nationals from outside of the local area and 8.2% were expatriates. It is anticipated that the same proportion of local and non-local employees could be reasonably expected to occur for DSM mining operations in PNG over the long run.
- Total wages paid to local mining employees are expected to average $29,000 (USD) per person annually. For spares, consumables, and fuel in PNG, it is assumed that 20% of operational expenditures for local goods and services (i.e. fuel, spares, consumables and miscellaneous) would comprise payments to labour, which is consistent with previous economic impact research in PNG.[58]
- Non-local consumer spending estimates assume each non-local worker would make 12 inbound trips and 12 outbound trips, and subsequently stopover for one night each time traveling through the city hub serving the DSM mining operation. Hotel costs are assumed to equal $50 per night; whereas, food expenditures are assumed to equal $50 each night.
- The allocation of operational costs to major cost categories relied on the allocation of operation costs as described for the Solwara 1 Project. These estimates are reported in Table 3-18.

[55] Various suppliers of the mining equipment are described in the Solwara Cost Study, none of which are located within PNG

[56] SRK 2010

[57] Callan, Margaret, June 2013, Economic Policy Challenges: The Contribution of Mining Companies to PNG Development.

[58] ExxonMobil, February 6, 2008, PNG LNG Economic Impact Study, Prepared by ACIL Tasman, Website (http://pnglng.com/downloads/acil_tasman_impact_study_revision_01.pdf) accessed August 14, 2015.

Table 3-18 Summary of Mining Operational Expenditure Estimates for PNG (in millions USD)

Category	Total	Local
Production Support Vessel (PSV) Charter	$29.6	$0.0
Remotely Operated Vehicle (ROV) Charter	$3.7	$0.0
Fuel (PSV/Barges)	$12.1	$12.1
Spares, Consumables and Miscellaneous	$8.6	$8.6
Labor (PSV/Barges)2	$39.6	$6.5
Contingency (10%)	$9.3	$0.0
Total Operating Costs	**$102.9**	**$27.2**
Other Operational Spending		
Non-local Consumer Spending	$0.3	$0.3

3.9.2 Government Expenditures

The analysis assumes two separate scenarios for estimating the employment and income effects of government spending of DSM mining royalties and revenue. Scenario 1 assumes the government of each case study country will adopt a revenue sharing plan similar to the Norwegian Petroleum Fund, which is often held as a 'best practice' approach in resource revenue management.[59] Under the program, the Norwegian government transfers all of the government revenues obtained from petroleum to the fund. In all, over the 2004-2006 period, 28% of annual resource revenue was consumed by the government, while 76% was saved in the fund. Scenario 1 of the analysis, assumes that 25% of total government revenue from DSM mining activities is used by the PNG government. Furthermore, it is assumed that resource revenue is spent equally by the PNG government in three industries; health, education and construction.

Scenario 2 of the analysis assumes that rather than the PNG government spending the same proportion of their DSM mining revenue in the health, education and infrastructure development, the government revenue is distributed to residents. Subsequently, it is assumed residents will spend this transfer of wealth on local goods and services. It should be noted, in both government spending scenarios it is assumed that each respective government will not incur any transaction costs for collections and distribution. It is also assumed DSM mining royalties will be used to fund government operations.

As an example, Table 3-19 below illustrates the average annual government revenues of $43.9 million for DSM mining in PNG, of which it is assumed 25% ($11.0 million) will be spent equally ($3.7 million) in the health, education and construction industries.

59 Website (http://www.environmentportal.in/files/RFF-Rpt-BenefitSharing.pdf) accessed August 5, 2015.

Table 3-19 Annual Expenditures of Government DSM Mining Revenue in PNG (in millions USD)

Industry	Amount
Total annual government revenue	$43.9
25% of total	$11.0
Scenario 1	
Health	$3.7
Education	$3.7
Construction	$3.7
Scenario 2	
Income Transfer	$11.0

3.9.3 Model Results

Table 3-20 provides the annual employment and income estimates for DSM mining operations in PNG. It is estimated that a total of 222 local jobs will be directly supported by DSM mining operations. DSM mining operations in PNG are anticipated to provide $6.6 million (2014 USD) of income directly to local workers. Operational expenditures for goods and services by the mine will support an additional $9.7 million of income throughout the country, while household spending resulting from mining operations will generate an additional $2.8 million of income throughout the country. In total, it is estimated that of $19.2 million of income will be generated by DSM mining operations in PNG annually.

It is estimated that operational expenditures for goods and services procured by the mine will support an additional 406 jobs throughout the country. Given the lack of information regarding the average wage income in PNG, the associated employment effects for the $2.8 million of induced income were not approximated. Therefore, it is conservatively estimated that DSM mining operations will support a total of 628 local jobs each year throughout PNG.

Table 3-20 Annual Mine Operating Impacts for PNG Mining Scenario (in millions USD)

Impact Type	Direct	Indirect	Induced	Total[1]
Employment	222	406	unknown	628
Income	$6.6	$9.7	$2.8	$19.2
Note 1: Totals may not sum due to rounding. Monetary values are in 2014 dollars				

Under Scenario 1 (Table 3-21), it is assumed the PNG government spends 25% of the government's total resource revenue in three industries; health, education and construction. For PNG, it is assumed that 20% of the total $11.0 million spent in these sectors is for labour. Therefore, it is expected that approximately $2.2 million of income will accrue to PNG workers directly employed in these the industries receiving government funding. Industries providing goods and services to the health, education and construction sectors are expected to experience increased income of $1.7 million, while firms providing goods and services to workers are expected to experience an increase of $0.7 million in income. In total, it is estimated that $4.6 million of income will be generated annually under Scenario 1 assumptions.

It is estimated that revenue sharing under Scenario 1 will support 91 jobs directly and 72 jobs indirectly throughout the country. Similar to the induced impacts for PNG mining operations, the unavailability of wage income data for PNG precludes us from estimating induced employment effects. Therefore, it is conservatively estimated that DSM mining revenue sharing under Scenario 1 will support a total of 163 local jobs in PNG each year.

Table 3-21 Scenario 1: Government DSM Mining Royalty Expenditure Impacts in PNG (in millions USD)

Impact Type	Direct	Indirect	Induced	Total
Employment	91	72	unknown	163
Income	$2.2	$1.7	$0.7	$4.6
Note 1: Totals may not sum due to rounding. Monetary values are in 2015 dollars				

Under Scenario 2 (Table 3-22), it is assumed the PNG government spends 25% of the government's total resource revenue by distributing it as income to residents. As provided below, this transfer of wealth does not directly support any employment; it is simply a payment to PNG residents. However, there is an estimated $3.4 million of income in industries providing goods and services due to increased resident spending. Again, the employment impacts associated with this induced income is unknown given the uncertainty surrounding average wage income within PNG.

Table 3-22 Scenario 2: Government DSM Mining Royalty Expenditure Impacts in PNG (in millions USD)

Impact Type	Direct	Indirect	Induced	Total
Employment	0	0	unknown	0
Income	$11.0	$0.0	$3.4	$14.4

3.10 Distribution of Costs and Benefits

From the perspective of PNG citizens, the primary benefit of DSM mining will be payments made to the PNG government. With the exception of a relatively modest expenditure on salaries associated with the regulation of DSM mining activity, the government itself would determine the distribution of these funds and/or the benefits derived from associated government expenditures. That is, the PNG government itself will largely determine who benefits from DSM mining activity.

Under the Mining Act (1992), which is the legislation that governs the mineral sector, securing a mining lease requires among other things, an agreement between the applicant and a set of Memorandums of Agreements (MoAs) between the developer, the PNG government and the affected landowners, providing for the distribution of benefits between the PNG government and the affected communities. For the purposes of DSM activities, the mining act is being revised to detail what community stakeholders would be considered to be beneficiaries for offshore resource revenues: the "Coastal Area of Benefit". This is likely to consist of the closest ward in a direct line to the mine site, and the three wards on either side. The benefit to be distributed to each ward within the Coastal Area of Benefit would be dependent upon the Memorandum of Agreement and any equity partnership option adopted for the specific project in question.

In addition, Nautilus has also established a Community Development Fund, where approximately $0.75 (USD) per tonne of ore mined will be placed into a fund used to support health and education projects in New Ireland and island provinces such as East New Britain.

The primary costs potentially incurred by PNG citizens would be associated with environmental and cultural externalities. Many of these costs can be transferred to the mining company and or minimized via regulatory or technological requirements.

- Existing spill-related clean up requirements transfers these cost to the DSM mining company,
- If the DSM mining company were required to purchase CO_2 offsets, costs associated with this potential source of impact would effectively be transferred to the DSM mining company, and
- Costs associated with a reduction in ecological services following an unplanned release and/or due to impacts on deep sea vent habitat while minor, would be borne relatively evenly among PNG citizens.

3.11 Discussion of Results

The CBA provides decision makers with a comprehensive overview of the potential costs and benefits of DSM mining from the perspective of PNG citizens. This includes, to the extent practical, quantification and monetisation of financial, environmental and social impacts.

- *The median benefit is approximately $82.7 million (USD).*
- *There is a very low probability (less than 15%) that NSB will be less than zero.*
- *The slope up and to the right suggests there is a reasonable probability of NSB* being *positive and larger than $75 million (USD), regardless of the discount rate applied.*

In general, the total monetised social costs represent a small portion of the monetised social benefits, ultimately having very little impact on the overall results. Some of the factors that contributed to this finding include:

- The assumption of regulatory mechanisms designed to transfer potential environmental externalities to the mining company,
- The remote location of the mine site (30-40 km offshore) when compared to land-based mining that often disrupts and/or displaces local communities,
- The small footprint of the mine site (0.11 km^2) as it relates to the potential for long-term environmental impacts and permanent loss of biodiversity, and
- Nautilus' commitment to discourage in-migration through its employment policy and its commitment to providing assistance to local communities in the form of social programs.

4 Cost-Benefit Analysis – Mining Manganese Nodules in the Cook Islands

The Cook Islands are located in the South Pacific Ocean, approximately half way between New Zealand and Hawaii. They include 15 islands separated into a northern group of seven low-lying sparsely populated coral atolls and a southern group of eight "high" islands mainly of volcanic origin although some are virtually atolls, including Rarotonga, the country's most densely populated island. The islands are spread out over approximately two million km^2 of open ocean that falls within the country's national jurisdiction.

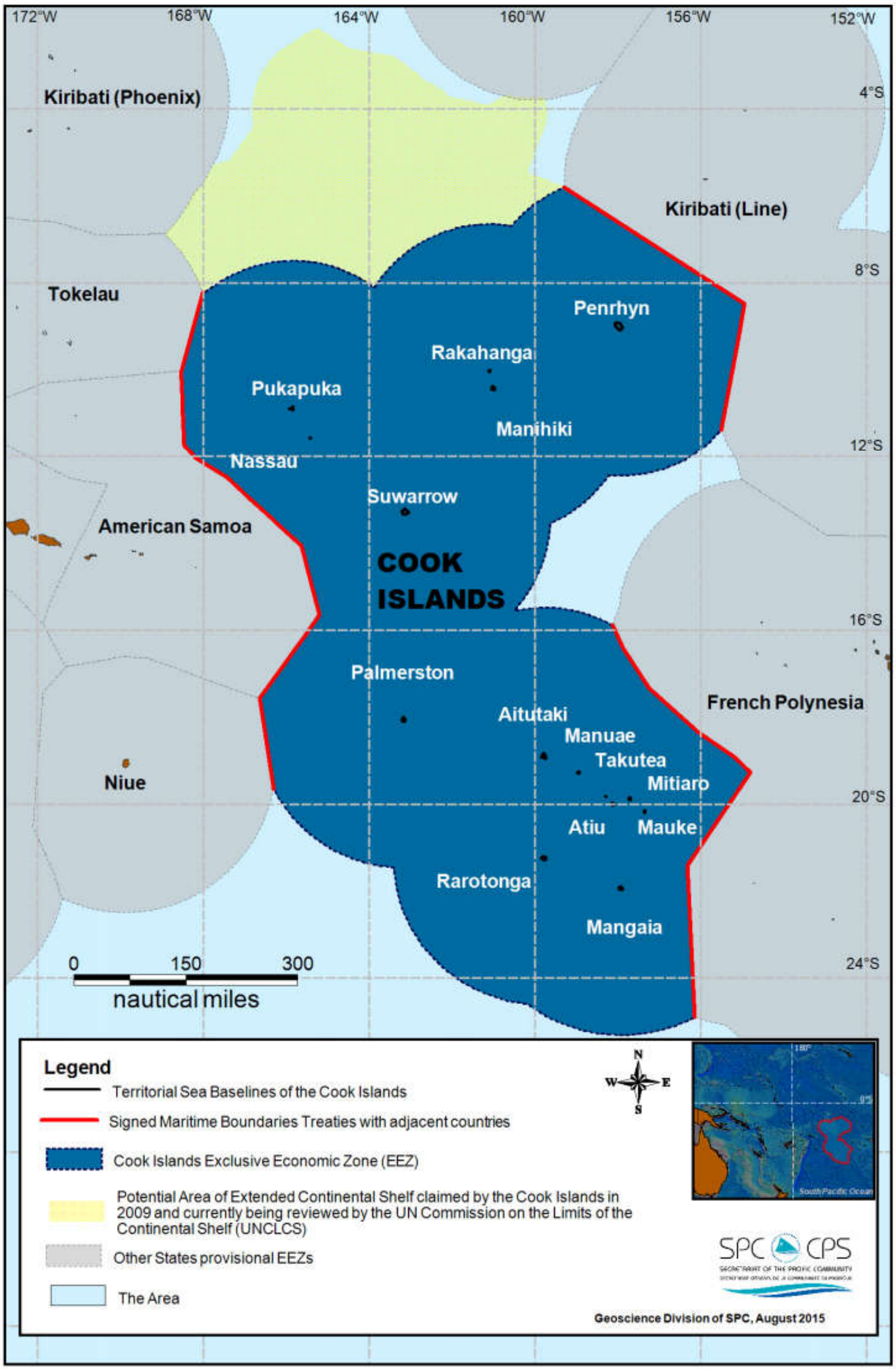
The country's ocean boundary, or exclusive economic zone (EEZ), currently extends 200 nautical miles from the seaward or coastal boundary of the islands. Within their EEZ, the Cook Islands has sovereign rights for exploring, exploiting, conserving, and managing natural resources, whether living or non-living, of the seabed and the subsoil and of the adjacent water with regard to other activities for the economic exploitation and exploration of the zone, such as the production of energy from the water, currents, and winds. Figure 4-1 shows the Cook Island's current EEZ, as well as the EEZs of neighbouring Pacific Island states.

The Cook Islands is actively pursuing an extension of their EEZ in the Manihiki Plateau region, which may allow for additional jurisdiction rights and privileges (Yellow shaded area in Figure 4-1).

As of 2013, the total gross domestic product (GDP) for the Cook Islands was $230.4 million (USD) (NZD $360 million). Tourism is by far the largest component of the Cook Islands' gross domestic product (GDP), which was $105 million (USD) (NZD $165 million) or 45% of GDP as of 2013.[60] Outside of tourism, GDP consists largely of revenues from Transport and Communication services (13%), Finance and Business services (10%) and agriculture and fisheries industry (10%). The growth rate of GDP per capita decreased by -0.5% from 2012, while the overall growth of GDP increased by 4.7% in the same year.

Based on data from the Cook Islands Ministry of Finance and Economic Management, the industries that employ the largest number of citizens include the retail trade, restaurant and hospitality industry at 36% and the community, personal and social services industry at 34%. The Cook Islands faces challenges similar to those facing the majority of small Pacific Island states, which includes its remote location, limited natural resources, and a diminishing labour force. Given these challenges, the Cook Islands depend heavily on foreign aid from New Zealand.

60 Source of data is from the Ministry of Finance and Economic Management. Estimate of GDP from tourism includes GDP from the Retail and Wholesale Trade industry and the Restaurant and Accommodation industry.



Source: Geoscience Division of SPC, August 2015

Figure 4-1 Map of the Cook Islands Exclusive Economic Zone (EEZ)

4.1 Description of the Seabed Mineral Resource

Manganese nodules are rock-like minerals that contain manganese and limited amounts of nickel, copper, titanium, cobalt, and rare earth elements. They range in size from as small as a golf ball to as large as a potato, and are found lying loosely on the sediment covered abyssal plains of the world's deep-sea basins at depths ranging from 3,500 to 6,000 metres. Nodules from when metal compounds dissolved in sea water precipitate around a nucleus (growth core) on the sea floor. The growth core can be, for example, a shark's tooth or a fragment of a clam shell, around which the nodule will grow. This process is very slow, and can take millions of years to form nodules that are large enough to mine.

Photo courtesy of Cook Islands Seabed Mineral Authority

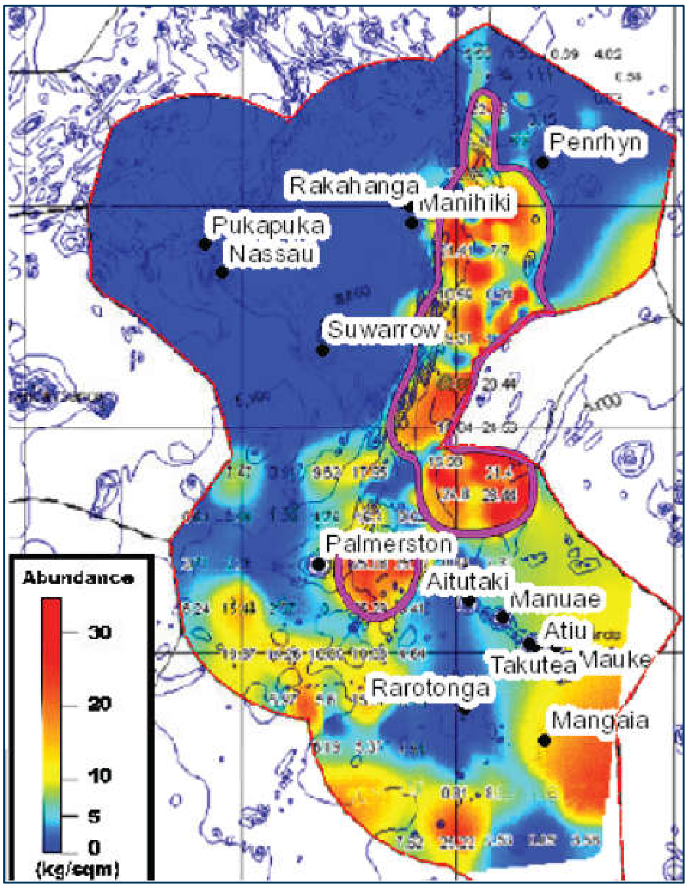
While the nodules can be found in many regions of the world's oceans, there are four primary locations with densities high enough for potential commercial extraction: (1) the Clarion Clipperton Zone, (2) the Peru basin, (3) the Penrhyn basin in the Cook Islands, and (4) the Indian Ocean. The primary reason these areas have the highest nodule densities is that they all share similar environmental conditions:

- Constant flow of Antarctic bottom water that (a) flushes away the sediment particles that would otherwise burry the nodules and/or prevent nodule formation and (b) provides oxygen-rich water that promotes the formation of the manganese oxide.
- Moderate productivity in the surface water to provide the organic material that serves as the basis of the growth process (SPC, 2013b).

4.1.1 Cook Islands Nodule Abundance

The Penrhyn Basin of the Cook Islands is known to have a high concentration of nodules over a very large area (Hein et al., 2015) A recent study reports that very high nodule abundance (>25 kg/m^2) covering approximately 124,000 km^2 and contains 3.6 billion tonnes in wet nodules (Hein et al., 2015).

With respect to density, the commonly accepted cut-off in nodule density for commercial mining is approximately 5 kg/m^2. While highly variable, nodule density within the Cook Islands EEZ ranges from 5 kg/m^2 to more than 50kg /m^2 (Cronan, 2013). Data collected from a series of cruises by the Japan International Cooperation Agency (JICA) funded cooperative study between the Metal Mining Agency of Japan (MMAJ) and the former Pacific Islands Applied Geoscience Commission (SOPAC) from 1985 to 2000 were used to map the distribution of nodule abundance throughout the Cook Islands EEZ (Hein et al., 2015). This survey indicates the highest average nodule densities occur in the east-central portion of the EEZ (outlined in pink in Figure 4-2), and decline to the southwest until reaching the outer limits of Palmerston Island (also outlined in pink in Figure 4-2). It is likely that the initial licenses to explore and ultimately mine will be located in the east-central portion where nodules occur in the greatest abundance.



Source: SPC Information Brochure 11

Figure 4-2 Map of Cook Islands Nodule Abundance

4.1.2 Composition of Cook Islands Nodules

The composition of Cook Islands nodules varies by location (Table 4-1).

- Nodules located in the northern part of the EEZ, where densities are not as high, tend to be higher in manganese content (e.g., 20%) whereas nodules in the South Penryhn Basin contain less manganese (15%) and more iron (18%).
- Copper concentration averages approximately 0.31%, and ranges from a high of 1.25% in the north to mostly below 0.25% in the south and central zones of the EEZ.
- Cobalt concentrations generally range between 0.25% and 0.50% with an average concentration of 0.27% in the north and an average of 0.48% in the south with pockets of high cobalt nodules (concentrations >0.50%) located in pockets within the South Penrhyn Basin.
- Nickel concentrations are uniformly <0.50%.

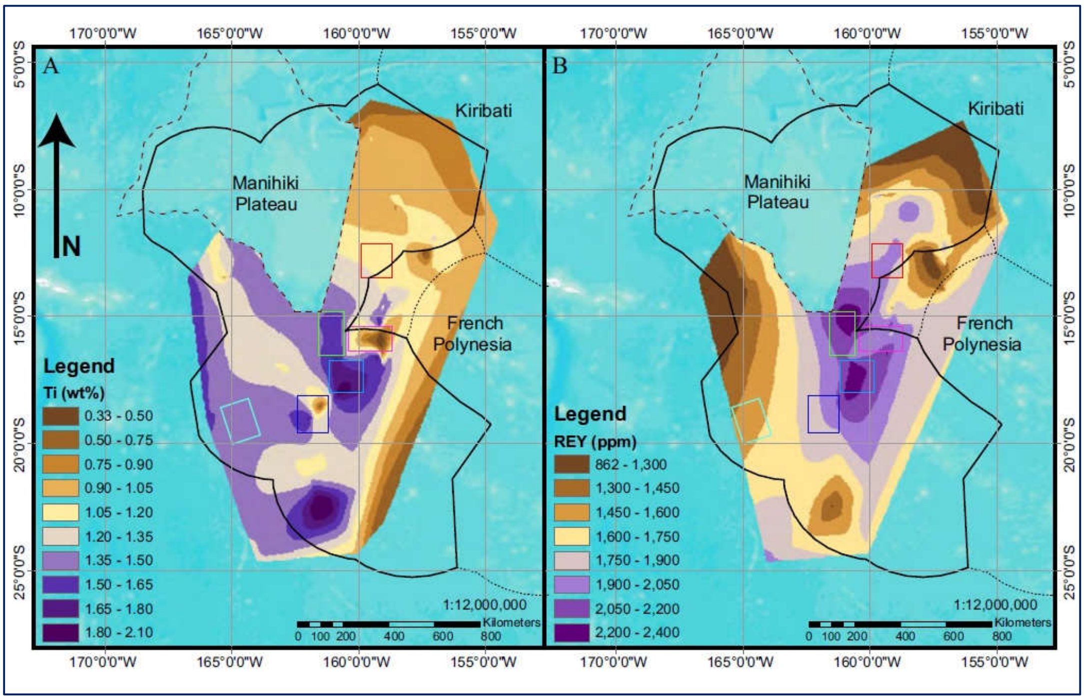
In addition to these more common metals, Hein indicates extracting less common metals including titanium (Ti), tellurium (Te), Niobium (Nb), Platinum (Pt) and Zirconium (Zr), as well as the 14 rare earth elements including Yttrium (collectively REYs) may be commercially viable.

- On average, the Cook Islands nodules contain titanium concentrations of 1.28%, and range as high as 2.10% in portions of the southern basin. This is much higher than concentrations found in other nodules around the world.
- REY concentrations average 0.16% in Cook Islands nodules, with highs of 0.321%.

Table 4-1 compares the metal content of Cook Islands nodules to those found in the Clarion Clipperton Zone, while Figure 4-3 shows the distribution of metal concentrations for titanium and REYs within the Cook Islands EEZ.

Table 4-1 Comparison of Metal Content in Cook Islands Nodules to Clarion Clipperton Zone Nodules

Component	Metal Grade in South Penryhn Basin	Metal Grade in Clarion Clipperton Zone
Iron (Fe)	18% (wet)	7% (wet)
Manganese (Mn)	16.9%	26%
Cobalt (Co)	0.38%	0.26%
Nickel (Ni)	0.38%	1.21%
Copper (Cu)	0.23%	1.00%
Copper + Nickel + Cobalt	0.90%	2.47%
Titanium (Ti)	1.28%	0.32 ppm
Tellurium (Te)	38 ppm	3.6 ppm
Rare earth elements + Yttrium (REY)	0.16%	0.08%
Source: Hein et al., 2015 and Darryl Thorburn at Seabed Mineral Authority		



Source: Hein et al., 2015

Figure 4-3 Distribution of Selected Metal Concentrations in Cook Islands EEZ –Ti (wt. %, left) and REY (ppm, right)

4.2 Current Status of DSM Policy and Legislation

The Cook Islands has developed a national policy for the sustainable management of its deep-sea minerals. The Cook Islands' DSM national policy is intended "to provide for the wise regulation and management of seabed mineral resources under the jurisdiction of the Cook Islands for the benefit of present and future generations."[61] This includes accomplishment of nine primary goals:

1. Administrating seabed mineral activities cooperatively with the community, within the government, and across the region.
2. Sustainable environmental management.
3. Minimisation of social impacts.
4. Offering a competitive environment for potential investors while safeguarding the nation's earnings.
5. Sound revenue management practices.
6. Maximising the benefits of Cook Island seabed mineral resources.
7. Establishment of sound regulatory framework for resources under national jurisdiction.
8. Establishment of sound regulatory framework in "The Area", outside of national jurisdiction.
9. Maximising the benefits of scientific research.

[61] Cook Islands National Seabed Minerals Policy, p 3

Prior to the adoption of their national policy, the Cook Islands established a legal framework through which the national policy could be implemented via the Seabed Minerals Act of 2009. As part of the Act, the Seabed Mineral Authority was established with the primary responsibility of developing the DSM sector to maximise the benefit of the Cook Islands mineral resources, while acknowledging important environmental and social considerations.

Some key components of the Cook Islands legal framework inform the CBA:

- The proposed fiscal regime that includes the application of a corporate income tax, a resource rent tax, and tax collection and enforcement mechanisms.
- Requirements for environmental impact assessments, environmental permits, monitoring and compliance throughout the duration of the DSM activity.
- A long-term management plan for DSM-related revenues.
- Building capacity and generating job opportunities associated with DSM activities.

These concepts are used to frame various aspects of the CBA and inform the evaluation of gaps and considerations to consider before DSM mining activities begin.

4.3 Description of the Baseline Scenario

This section describes the state of the Cook Islands in the absence of DSM mining. In other words, it describes the counterfactual (the “Do-Nothing” scenario) to which the proposed project will be compared. The CBA determines, quantifies and monetises, to the extent practical, changes to these baseline conditions that may result from DSM mining within the Cook Islands EEZ.

For the purposes of the CBA in the Cook Islands, the baseline discussion focuses on the deep-sea environment, fisheries, black pearls, environmentally-based tourism, income and employment statistics, and various cultural norms.

Figure 4-4 illustrates the primary locations of fishing (green circled area), pearl harvesting (purple circled area), and tourism-related activities (yellow circled areas) relative to the assumed location of the initial DSM activity (red rectangular area). For reference, the distance between Manihiki (purple circle) in the north and Rarotonga (bottom yellow circle) in the south is approximately 1,200 km. Given that the mine site is approximately half way in between, this puts it approximately 600 km from either location.

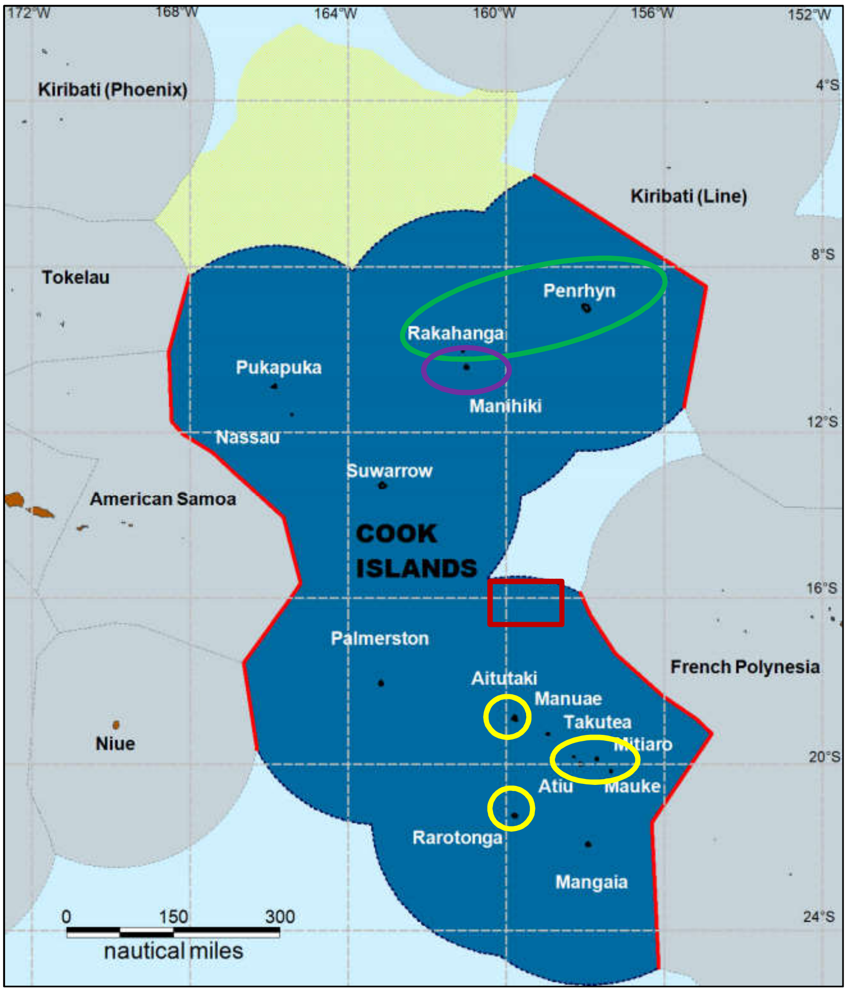


Figure 4-4 Location of Fishing, Pearl Harvesting and Tourist Areas in the Cook Islands

4.3.1 Deep-sea Environment

The deep-sea environment in the Cook Islands consists primarily of slow currents and low temperatures (around two degrees Celsius). According to a local biologist, these conditions lead to the lowest productivity, in terms of biological biomass, in the world.[62] The low productivity of the surface waters is caused by the low level of nutrients in the South Pacific gyre where there are no up-wellings of the deep nutrient-rich water, which is rich from 1000 metres below sea level to the abyssal seabed. For the South Penrhyn Basin, the very low surface productivity leads to a very low level of sinking organic matter which leads to a very low level of biomass on and near the seabed. The very few samples of megafauna and macrofauna indicate that species diversity is also likely to be limited compared to the CCZ.

The community at these depths consists mostly of macrofauna living in the sediment, such as polychaete worms, crustaceans, and bivalve molluscs. The abundance of these animals is relatively low in abyssal plains and most animals are fairly small (only a few millimetres to 1 centimetre). The community also consists of microfoauna (mainly bacteria) living on the nodules along with some sponges, molluscs, polychaetes, and encrusting bryozoans attached to the nodules (SPC, 2013b). Since there have been no

62 Personal communication with Gerald McCormack on March 23, 2015

site-specific studies undertaken to assess the environmental conditions in the deep-sea of the Cook Islands, the exact composition and environmental conditions are relatively unknown.

It is reported that the Cook Islands are commonly perceived as pristine and unique when compared to neighbouring Pacific Island states, and have been referred to as a jewel in an unspoiled paradise. Although the actual impact of DSM mining occurs thousands of metres beneath the surface, people may associate higher value with environmental changes occurring in this pristine environment relative to changes occurring in environments already influenced by human activity.

4.3.2 Fisheries and Black Pearls

Cook Islands commercial landings are dominated by tuna, with most of this activity taking place in the north, from Penrhyn to Pukapuka, and north of Suwarrow (Table 4-2). The tuna species found in the Cook Islands EEZ can typically be found in surface waters and at depths of down to 300 metres, well above any DSM mining activities.

Table 4-2 Total Catch in the Cook Islands EEZ by Species (tonnes)

Species	2012		2013			2014		
	Longline	Purse Seine	Longline	Purse Seine	Local	Longline	Purse Seine	Local
Albacore	8,800		6,500		1	4,691	-	3
Bigeye	2,800	100	500	60	<1	751	204	0
Yellowfin	1,800	800	900	300	180	2,114	823	113
Skipjack		11,000	900	3,400	10	228	11,874	14
Other	2,100				80	780	-	81
Total	15,500	11,900	8,800	3,760	270	8,566	12,901	212

Note: Source of data is from Ministry of Marine Resources in the Cook Islands

In addition to commercial fishing, there is also subsistence and artisanal fishing for inshore reef and lagoon fish. In the Northern Group and in the smaller islands of the Southern Group, fishing remains largely subsistence in nature and is mostly conducted from small outboard-powered craft and canoes in the lagoons and along the outer reef edge.[63] As of 2014, there are 302 licensed and active vessels that participate in the local artisanal and game fishery. This is up from 223 vessels in 2013.

Black pearls are also found in the north, located and harvested at Manihiki atoll. Based on an increase in farming materials and a grant from the Chinese government, pearl production is projected to increase over the next two to three years.

4.3.3 Tourism

Rarotonga and Aitutaki in the south are the primary tourist destinations for recreation-based activities such as scuba diving, snorkelling, and boating. While tourism in the South Pacific in general has been growing at about 5% per year, tourism in the Cook Islands has remained relatively flat, only growing at about 1% per year.[64] Tourism is likely to continue to play a large role in the Cook Islands' economy.

[63] http://www.fao.org/fi/oldsite/FCP/en/COK/profile.htm (Accessed May 26, 2015)

[64] Based on personal communication with members of the Cook Islands Chamber of Commerce

4.3.4 Distribution of Income and Employment

There are approximately 7,000 men and women employed in the Cook Islands' formal economy. Table 4-3 illustrates the current/baseline income distribution across Cook Islands residents. The average income across all residents is USD $10,733, with nearly 50% of the population earning less than USD $7,142 per year. Residents of the Northern Group of islands have the lowest average annual income of USD $5,669, with 54% of the population making less than USD $3,500. On average, income among women is less than among men and income among outer island residents is less than residents of Rarotonga.

Table 4-4 reports current employment numbers by industry in the Cook Islands. As indicated in the table, the retail trade and accommodation, as well as the community, social and personal services industries employ the majority of Cook Islands residents representing 71% of the total people employed.

4.3.5 Perspective of Traditional Leaders

During consultations with several of the traditional leaders on the Cook Islands, including a paramount chief, the traditional leaders explained that they view themselves as the original owners of all of the natural resources in the Cook Islands: the land, the water, the sea, and the seabed. In their eyes, the government is not respectful of this tradition, ultimately forcing them to give up their resources "for the benefit of the people of the Cook Islands," when it is they, not the government, who represent the people of the Cook Islands.

In their opinion, with the government "owning" the resources, the people do not benefit when those resources are used. They cited the upsurge in purse seine licenses as an example and stated that, in their view, the people have not seen any benefits from the related increase in revenue to the government.

Table 4-3 Distribution of Income in the Cook Islands in 2011 – Percent of Total

	Cook Islands			Rarotonga			Southern Group			Northern Group		
Income range[1]	Total	Male	Female	Total	Male	Female	Total	Male	Female	Total	Male	Female
No Income	13.7	12.3	15.1	12.2	10.9	13.6	18.1	16.8	19.4	15.9	13.7	18.4
Less than $3,500	19	16.2	21.8	14.2	12.3	16.1	29.6	24.6	34.3	38.4	31.8	45.9
$3,500 - $7,141	15.1	15.1	15	13	12.5	13.5	21.3	23	19.7	17.8	19.2	16.3
$7,142 - $10,712	16.1	17.2	15	16.6	16.8	16.4	15.4	18.6	12.3	12.6	17.3	7.2
$10,713 - $14,283	11.1	12.5	9.7	12.6	14.1	11.2	7.3	8.7	6	5.7	6.6	4.7
$14,282 - $17,854	7.5	7.2	7.8	9.2	8.9	9.5	3.3	2.8	3.7	2.2	2.7	1.6
$17,855 - $21,245	5.1	5	5.3	6.2	6	6.3	2.1	2.3	2	3.5	2.7	4.4
$21,426 - $24,996	3.6	3.5	3.7	4.6	4.4	4.7	0.9	0.8	1	1.9	2.5	1.3
$24,997 - $28,567	2.4	2.5	2.4	3.1	3.1	3.1	0.8	0.9	0.7	0.4	0.5	0.3
$28,568 - $35,709	2.6	3.3	2	3.3	4	2.5	0.8	1	0.6	1.3	2.5	0
$35,710 - $42,851	1.3	1.7	1	1.8	2.3	1.3	0.1	0.2	0.1	0	0	0
$42,852 - $49,993	0.6	0.8	0.3	0.8	1.1	0.4	0	0.1	0	0	0	0
$49,994 - $57,135	0.5	0.7	0.4	0.7	0.9	0.5	0.1	0.1	0.1	0	0	0
$57,136 - $64,277	0.4	0.6	0.2	0.5	0.7	0.3	0.1	0.1	0.1	0.3	0.5	0
$64,278 - $71,419	0.2	0.2	0.1	0.2	0.3	0.1	0	0	0	0	0	0
> $71,420	0.8	1.2	0.4	1.1	1.6	0.5	0	0	0	0	0	0
Average annual income ($USD)	10,733	12,033	9,458	12,638	14,190	11,121	5,764	6,299	5,254	5,669	6,780	4,402

Note 1. Income ranges adjusted to reflect $USD. Conversion to NZD is 1 USD = 1.40 NZD.
Source: 2011 Cook Islands Population Census Report

Table 4-4 Number of Cook Islanders Employed by Age Group and Industry (As of 2013)

Age Group	Agriculture, forestry, fishing	Mining, quarrying	Manufacturing	Electricity, gas, water	Construction	Retail Trade, Restaurant, Accommodation	Transport and Communication	Finance, Property Business Svcs	Community, Social, Personal Svcs
Total	**297**	**70**	**270**	**66**	**409**	**2,539**	**524**	**368**	**2,395**
15-19	7	8	12	2	28	208	32	11	68
20-24	26	5	26	11	62	358	69	51	200
25-29	24	4	36	4	58	341	50	39	231
30-34	23	9	24	6	48	266	51	58	225
35-39	25	14	30	8	40	283	80	42	284
40-44	33	11	47	10	47	289	71	54	325
45-49	41	8	40	11	41	274	61	32	367
50-54	40	5	26	8	39	194	45	38	273
55-59	32	4	13	4	20	145	36	17	213
60-64	16	1	6	2	18	93	19	12	126
65-69	13	1	4	0	6	50	7	11	58
70-74	14	0	5	0	1	28	2	3	20
75-79	3	0	1	0	1	10	1	0	4
> 79	0	0	0	0	0	0	0	0	1

Source: Statistics Office, Ministry of Finance and Economic Management for the Cook Islands

4.4 Cook Island Nodule Mining Scenario

This section defines the scope of the hypothetical DSM mining project for the Cook Islands. It includes a description of the size, duration, and approximate location of the mining operation as well as the total estimated resource potential and the expected metal content in the nodules. It also includes a description of the current capacity of the port system in the Cook Islands, and the anticipated utilisation of that system.

4.4.1 Description of Cook Island Mining Scenario

The CBA is based on operation of a single mine site within Area B of Figure 4-5. This area contains high nodule density and the nodules themselves are rich in the elements of economic interest including the REYs. The mining footprint within Area B, identified by the pink rectangle with arrow in Figure 4-5, covers 2,705 km^2.

It is assumed 135 km^2 of seafloor will be mined annually implying a 20 year mining operation that yields 2.5 million dry tonnes of nodules per year, for a total of 50 million tonnes over the course of the operation (Hein et al., 2015). The basic inputs are summarised in Table 4-5.

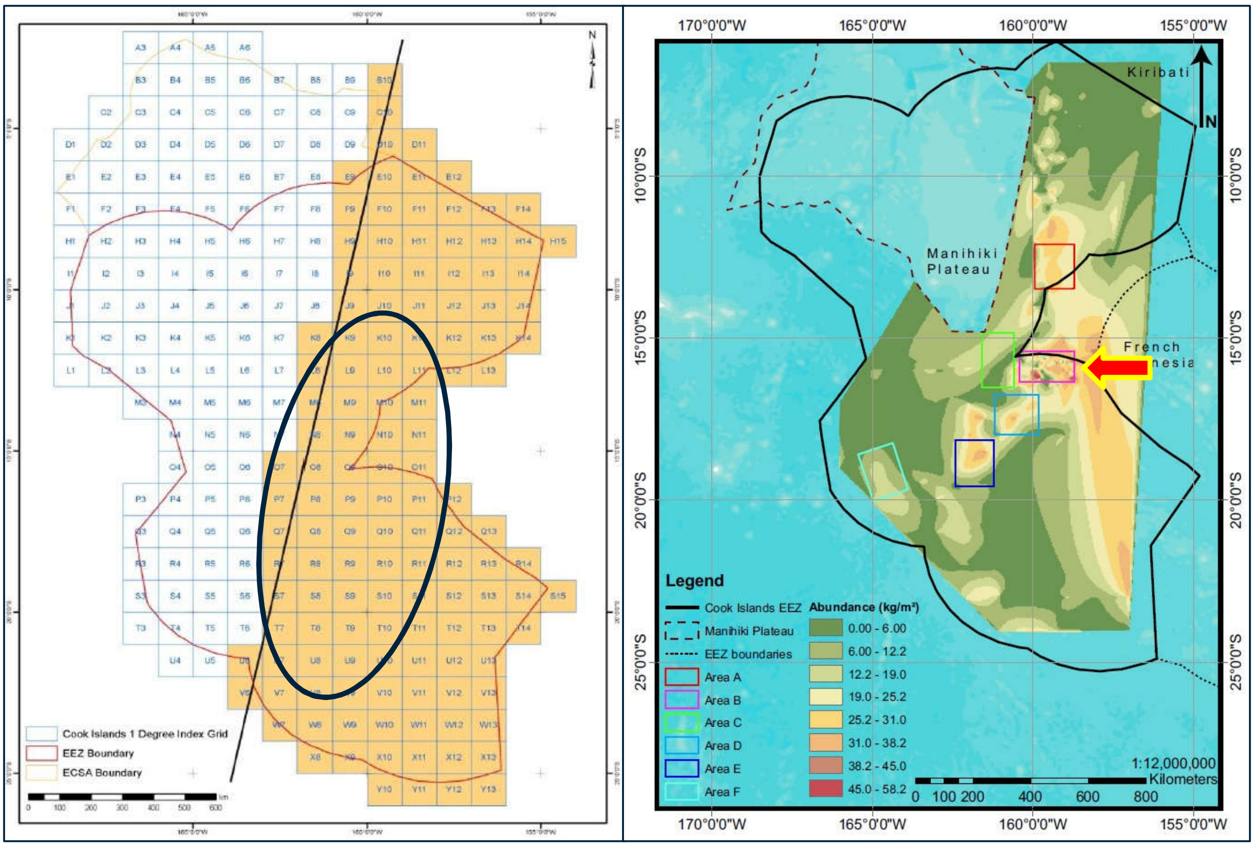
Dry tonnage by element is derived from Hein et al. (2015) and summarised in Table 4-6. Note that Hein et al. report tonnage based on the resource as it is on the seafloor. The potential yields, also reported in Table 4-6, assume variations in metal grades, collection efficiency ranging from 80% to 90%, and additional loss occurring during the metallurgy process.[65]

As discussed further in the section related to the proposed engineering system for extracting the nodules, the technology for extracting the metals from nodules has been proposed and tested on a small scale, but is yet to be proven on a commercial scale. As such, there is a great deal of uncertainty around potential yields.

It should also be noted that the basic mining scenario assumes that the processing of the nodules occurs overseas in Mexico. Section 4.6 evaluates an alternate scenario where a processing facility is built in the Cook Islands.[66]

65 Based on this, the scenario in this case study assumes that annual production will vary between 2 and 3 million dry tonnes per year (dtpy), with an average of 2.5 million tonnes going to the processing plant.

66 The basic parameters of the mine site remain the same, however, the alternate scenario includes the additional private cost associated with infrastructure upgrades necessary to support the day-to-day operation of a processing facility, the added premium on labour associated with hiring ex-patriots, as well as the associated external costs (i.e. environmental and cultural change).



Source: Image on the left is from a presentation authored by the SBMA, Image on the right is from Hein et al., 2015.

Figure 4-5 Area within Cook Islands EEZ with Greatest Potential for Initial Mine Site

Table 4-5 Basic Assumptions used in Cook Islands Mining Scenario

Category	Assumptions Used
Total mineable area	2,705 km^2
Distance from nearest island	>300 km
Nearest processing facility[1]	Mexico (8,000 km)
Total estimated resource potential (dry tonnes)	50,000,000
Annual estimated resource potential (dry tonnes)	2,500,000
Duration of mining operation	20 years
Area mined per year	135 km^2
Collection efficiency	80%
Metallurgic Processing	Assume both three-metal and four-metal extraction technologies available

Note 1: The CBA assumes the nearest existing processing facility is in Mexico based on conversations with Cook Islands Seabed Mineral Authority. It is possible that a suitable processing facility could also be located in China or Korea.

Table 4-6 Contained Metal (in dry tonnes per year) in Cook Islands Mine Site

Metal	Value from Hein et al. (2015)	Minimum	Most Likely	Maximum
Manganese	392,128	244,598	310,844	374,529
Titanium	25,804	13,168	21,021	32,117
Cobalt	13,323	7,645	10,209	12,912
Nickel	6,444	3,924	5,164	6,785
Copper	3,467	1,874	3,432	6,144
Sum of REEs and Yttrium	5,357	3,011	4,331	6,749

4.4.2 Ports and Logistics

The Cook Islands has only two ports large enough to support the types of vessels that would be involved in DSM mining: one is located in Rarotonga and the other is on the island of Aitutaki.

- Channel depth along the run into Aitutaki currently limits the port to small vessels. There are plans to deepen the channel in Aitutaki, which would provide access to local interisland ships and visiting yachts. There may also be plans to develop a marina.
- The port in Rarotonga recently underwent a $24 million (USD) expansion and upgrade, making it more accessible to larger vessels. It currently receives approximately two container vessels a month, and has limited storage availability on site.

According to the Cook Islands Port Authority, there are currently no plans to expand or upgrade the ports in the Cook Islands based on the recent expenditures on the port in Rarotonga. However, if a bigger wharf can be built on Aitutaki to cater to the needs of the mining operation, then it is likely that the Port of Aitutaki will be the main hub of activity for shuttling workers or supplies to and from the mining vessel.

Assuming the port at Aitutaki undergoes an upgrade, then the production support vessel, or mining vessel could get provisions and have personnel, fuel, and supplies transported via helicopter or supply boats that depart from Aitutaki. Aitutaki is geographically located closer to the mine site and has established infrastructure, such as sealed roads, an airport, and several options for accommodations. It is assumed that foreign workers will fly in and fly out (FIFO) of Rarotonga and take one of the domestic flights from Rarotonga to Aitutaki where they would then be transported via supply boat to the main mining vessel. As specified in Section 2.4, it is assumed that non-local workers would make 12 inbound trips and 12 outbound trips, and subsequently stopover for one night each time traveling through Aitutaki before transfer to the mining vessel.

4.5 Cost Methodology

As described in Section 2.3.2, the CBA quantifies and monetises both the private and environmental costs of a single DSM mining operation. This section begins with a brief discussion of the status of the current technology in each phase of the DSM mining process followed by a description of the proposed engineering system.

4.5.1 Status of Current Nodule Mining Technology

Two of the key factors determining DSM mining feasibility are the availability and cost of the technology needed to extract, transport, and process the raw ore at a commercial scale.

Since mining of DSM has yet to commence anywhere in the world, the technology required to extract and lift the raw ore has not been proven in a commercial operation. While some of the required module mining technology required can be adapted from technology used in the offshore oil and gas industry, there are inherent differences that make module mining more complex and costly. These differences are largely driven by the technology required for the vertical transport of raw material from the seabed to the surface.

Figure 4-6 identifies the technological readiness associated with each step in the mining value chain for nodules. Red indicates a low to very low level of readiness, yellow a moderate level of readiness, and green a high level of technological readiness.

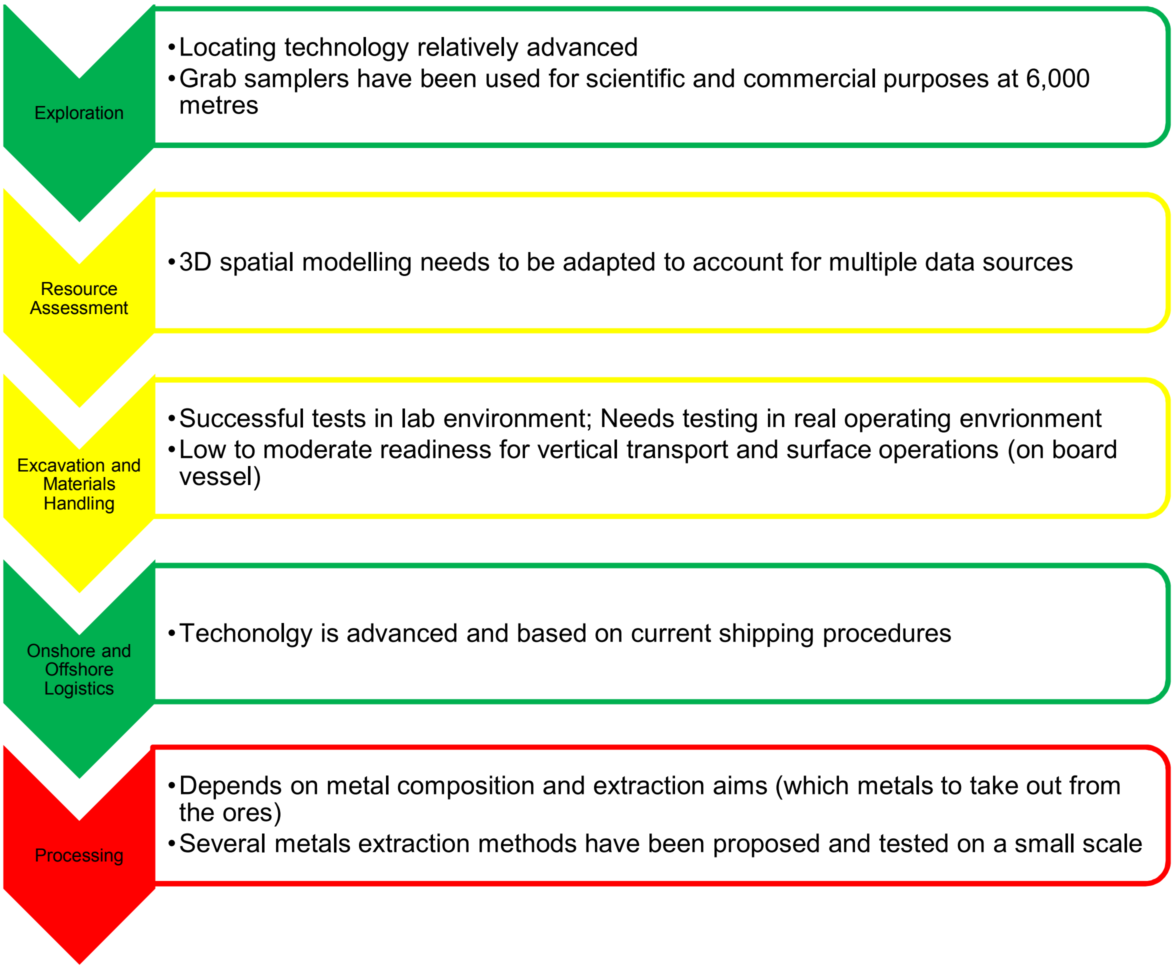


Figure 4-6 Assessment of Technology Readiness in Manganese Nodule Mining Value Chain

At this stage, the technology required for exploration including equipment used to locate and sample nodules is relatively advanced and has been in development since the 1970s (ECORYS, 2014). While most of the technology associated with each phase of the MN mining value chain is either at a moderate or high level of readiness, opportunities for technological improvements still exists. These include:

- Resource modelling and reserve estimation is relatively well-developed from a modelling perspective, but in many cases has yet to be confirmed in a laboratory setting.
- The technology required to extract, lift and pre-process the material has yet to be validated.

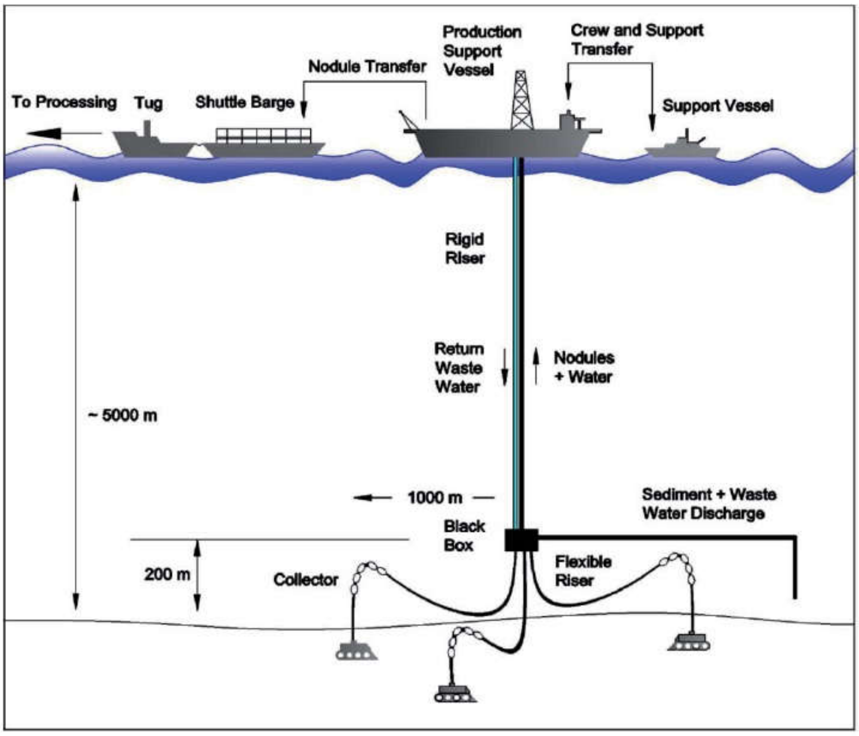
  - Most of the preferred technology for extraction has been tested in a laboratory setting or at depths of 400 to 500 metres, but has yet to be tested in real operating environments (>5,000 metres).
  - Vertical transport technology currently exists in the offshore oil and gas industry, but has yet to be tested in deep-sea environment and has not been tested with ore which may tend to clog and wear equipment more frequently than oil.
  - Surface operations such as dewatering require demonstration aboard the support vessel.
- The technology for offshore and onshore logistics of transporting and storing the raw materials is advanced.
- Nodule processing methods have been tested on a small scale, but are yet to be proven on a commercial level.

4.5.2 Proposed Engineering System for Nodule Mining

As recently as 2012, post-doctoral and doctoral students at the University of Southampton proposed an engineering system for the recovery of seabed nodules and assessed its feasibility based on conditions in the Clarion Clipperton Zone.

The integrated system they proposed is comprised of individual subsystems determined to be the most efficient and best performing. The system starts with a production support vessel (PSV), which is the source of the power supply for the entire mining operation, and serves as the platform by which the mining operations are controlled. The PSV is connected to one or more mining collection systems, which collects nodules from the sea bed. Nodules are transported up the riser to the PSV where they undergo several pre-processing steps. Water from the pre-processing steps is transported back down the riser to be discharged near the seafloor. The pre-processed nodules are transferred to a shuttle barge which takes them to a processing facility. Figure 4-7 shows the nodule harvesting system proposed in the University of Southampton study.[67]

[67] It should be noted that this system was based on an annual production rate of 0.5 million tonnes per year instead of the 2.5 million tonnes as described in this scenario.



Source: Agarwal et al., 2012

Figure 4-7 Proposed Nodule Mining System

4.5.2.1 Nodule Collecting System

The proposed nodule collecting system consists of multiple small self-propelled collector units (Figure 4-8). The primary task of the collector is to lift and collect the nodules from the seafloor and aid in their movement upward from the seafloor. Each collector unit has several components that determine its overall efficiency in collecting nodules from the seafloor. For the purposes of the proposed system, the study recommends the use of hybrid collector with a crawler propulsion system. The hybrid collector combines both mechanical and hydraulic components and has several advantages:

- A more effective technique for separating nodules from sediment.
- A hydraulic lift that involves zero contact with the seafloor while extracting nodules, thus minimising the amount of suspended sediment.
- A crawler subsystem that has a lower penetration depth into the soft sediment.

Source: SPC, 2013

Figure 4-8 Nodule Collector Unit

4.5.2.2 Vertical Transport of Nodules

Directly above the collector units is a “black-box” buffer system that pre-processes the nodules prior to transport up a vertical riser. The black box cleans sediments from the nodules using the wastewater from the pre-processing on-board the production support vessel. This reduces the mass concentration of sediments to less than 2% from the initial intake of 20% (Flentje et al., 2012). It also allows sediments and nutrient rich water to be discharged at depth, minimising the potential for adverse environmental impacts.

After cleaning, the nodules are transported to the PSV via a riser system. Nodules are dewatered and the wastewater from the PSV is transported back down the riser to the black box. The design of the riser system is based on technology currently employed in the oil and gas industry known as a fully enclosed riser and lifting system (RALS).

4.5.2.3 Surface Operations

Before transferring the nodules to the shuttle barge, they are dewatered and dried. This process allows for nodule sampling to test for metal concentrations, returns excess water, and reduces the total weight of the nodules. Once this process is complete the dry nodules would be transferred to the shuttle barge and transported to the closest coastal port with a processing facility. For the Cook Islands, this would most likely be Mexico or China.

4.5.2.4 Onshore Processing

The Cook Islands currently lack the infrastructure (power, water, roads, etc.) necessary to support an onshore processing facility. However, several stakeholders in the Cook Islands expressed interested in understanding the potential costs and benefits if a DSM mining company were to invest in a processing facility on the Island. Because these costs are dependent upon the chosen processing method, processing options are discussed in the following text.

Once nodules are on-site, processing generally includes:

1. Crushing and grinding of the raw ore to reduce the size of the ore particles and expose the mineral,
2. Separation of the mineral from the ore,
3. Recovery and purification of the metal,
4. Disposal of waste, tailings, etc.

In Step 2, it is common to implement either hydrometallurgy processes (leaching), which rely on the use of chemicals to extract the metals, pyrometallurgy processes (smelting) which use heat/roasting to extract metals or a combination of the two known as pryo-hydrometallurgical processes. Overall, research has determined that there are five promising process routes for manganese nodules which include either:

Three-metal processing routes (the first two have been adapted from nickel laterite processing)

- Reduction/ammonia leaching,
- High pressure/high temperature sulphuric acid leaching, or
- Cuprion ammonia leaching (i.e. Cuprion process).

Four-metal processing routes

- A combination of smelting and sulphuric acid leaching, and
- Reduction and hydrochloric acid leaching.

Table 4-7 compares and contrasts each of the five methods for the metallurgic processing of manganese nodules.

Table 4-7 Comparison of Metallurgy Methods for Processing Manganese Nodules

Metallurgy Method	Level of Readiness	Advantages	Disadvantages	% Recovery (Maximum)			
				Mn	Cu	Co	Ni
Reduction roast/ ammonia leaching[1]	Commercial scale for nickel laterites Pilot scale 100 kg/day for nodules	> Simple organisation > Moderate cost > Mn is recovered in residue /slag and must undergo additional processing	> High energy consumption	N/A	90%	60%	90%
High pressure/high temperature leaching[2] **(Using sulphuric acid)**	Commercial scale for nickel laterites Lab scale on nodules	> Lower energy consumption > Metals are extracted in concentrate form	> High acid consumption > High capital costs	N/A	95%	85%	95%
Cuprion ammonia leaching[3]	Commercial scale with nickel laterites Pilot scale on nodules	> Low energy consumption	> Mn cannot be recovered	N/A	92%	65%	92%
Smelting/ Sulphuric acid leaching[4]	Pilot scale for nodules	> Mn can be recovered as Fe-Mn or Fe-Si-Mn	> Energy intensive	85%	95%	90%	95%
Reduction hydrochloric acid leaching[5]	Pilot scale on nodules	> Low energy consumption > High metal recovery	> Requires very high concentration of HCL > High operating costs and corrosiveness	98%	98%	98%	98%

Note 1: Atmanand, 2011
Note 2: Premchan and Jana, 1999
Note 3: Yamazaki, 2006
Note 4: Sen, 2010
Note 5: Premchan and Jana, 1999

Each of these methods has inherent advantages and disadvantages, and the ultimate selection of a decision to choose the three-metal or four-metal process will depend on variety of factors such as the world demand for manganese, expected recovery of manganese after metallurgic processing, and the required capital and operating expenditures. Additional factors such as the dependability of a supply of inputs such as process chemicals and reagents, energy and water requirements, and the ability to dispose of process wastes will also need to be evaluated when determining a process route.

It has also been shown that three-metal plants only become attractive as long as the plants receive 2-3 million dry tonnes of nodule per year as inputs. This is based on the additional revenue required to offset the capital and operating expenditures. Four metal plants can sustain a much smaller operation at 1.5 million dry tonnes of nodules per year, as long as there is a high manganese recovery rate to make the operation competitive with respect to the additional capital and operating expenditures. This is because the manganese recovery step is extremely energy intensive and would require a significant offset through high recovery rates given it would be competing with the higher grade of manganese found in the world's terrestrial resources. A possible alternative with the three-metal path would be to select a process that creates Mn rich slag that could be stockpiled or stored on land for sale at a later date or sold to a facility for additional processing. Both the reduction roast/ammonia leaching and the high pressure/high temperature acid leaching methods create Mn rich slag that could be further refined to obtain ferromanganese.

Overall, the consensus in the literature is that the most promising methods are based on methods currently employed in the processing of terrestrial nickel laterites. These include: 1) reduction roasting and ammonia leaching, and 2) methods that use an acid leaching processes. These are both three-metal recovery processes in which a separate residue treatment is required for the recovery of manganese. As an alternative, Sen (2010) pointed out that the sulphuric acid leaching method when combined with a preheating stage and medium temperature leaching (180° C), as opposed to the high temperatures of the laterite pressure leaching produced a reasonable rate of return for a processing facility (IRR of 15.7%) when compared to other potential forms of nodule processing. French researchers have patented this procedure, but it has not been proven at the commercial scale as the reduction roast/ammonia leaching or high pressure/high temperature acid leaching process has been for nickel laterites.

Another example of a process that utilises an acid leaching process is known as the INCO (International Nickel Company) process in which the nodules are reduced in a kiln, followed by smelting. During smelting, the Mn is converted to a slag, which can be used to produce ferromanganese. This process also results in an alloy that contains almost all of the Ni, Co, and Cu (which is only about 6-8% of the original nodule feed); this is then further subject to leaching in sulphuric acid to separate the metal (Premchand and Jana, 1999). The extra step of smelting reduces the amount of sulphuric acid required for leaching and is much lower than the amount required for methods that use the direct leaching process.

Despite the advantages, both processes are extremely energy intensive and have not been proven at a commercial scale. In terms of energy consumption, it has been estimated that the reduction roasting/ammonia leaching method based on a 1.5 million dry tonne/year nodule operation would require approximately 2.7 million megawatts/year of energy consumption (Kotlinski, et al., 2008). This is 100 times the current energy production in the Cook Islands as of 2009 (27,000 megawatts/year) (SPC, 2012). The construction of a metallurgy plant that requires significant amounts of energy consumption would most likely also require the construction of a steam or coal powered turbine, capable of supplying energy directly to the plant. Therefore, a large portion of the operating expenses for the metallurgy plant would be associated with fuel and costs of energy use and consumption.

As for the alternate mining scenario which includes the construction of a processing facility on the Cook Islands, all of the four-metal recovery processes are ruled out based on the amount of energy generation required for the removal of the Mn from the slag. As a result, out of the three-metal processes, the high pressure/high temperature acid leaching method is selected based on its proven success at the commercial level for terrestrial nickel laterites, the lower energy consumption requirement compared to the reduction/ammonia leaching, and the higher expected recovery rates for each of the three metals (Co, Ni, and Cu). Despite these advantages, there are some drawbacks to using this process. These include high operating costs due to the corrosive nature of the reagents, and a larger amount of hazardous liquid waste to store and/or dispose. Many of these issues, including the additional environmental and social considerations of constructing a high pressure/high temperature acid leaching processing facility in the Cook Islands are discussed further in Section 4.6.2.3

4.5.3 Private Costs

This section describes the quantification and monetisation of private costs. These include:

- Costs incurred by the government (a willing participant in the mining operation), and
- An estimate of the capital and operating costs associated with each of the phases of a MN mining operation.[68]

4.5.3.1 Administrative Costs to the Government

As noted in Section 4.2, the Cook Islands government established the Seabed Minerals Authority (SBMA) in 2012 with the primary responsibility of developing the DSM sector to maximise the benefit of the Cook Islands mineral resources, while acknowledging important environmental and social considerations. The SBMA played a large role in the drafting of the 2014 Cook Island Seabed Policy with assistance from the DSM Project, and eventually will regulate the day-to-day seabed minerals activities.

These activities impose a cost on the Cook Islands government and ultimately the host country residents. For the purposes of the CBA, the following costing assumptions are made:

- The development of the initial laws governing seabed mining, as well as the relevant policies and amendments that followed and the day-to-day operation of the SBMA requires a onetime expenditure of $2,000,000[69] in the years prior to the onset of DSM activity. To estimate the share of the cost that is attributable to a single mining operation, the CBA assumes that in time, there will be approximately ten single mine sites that will eventually use this framework.[70] Therefore, the one-time cost of $2 million divided equally among ten mining operations equates to $200,000 USD ($2 million/10 single mining operations).
- Costs associated with monitoring and reporting of DSM activity associated with a single mining operation assumes the Cook Island government will employ six full-time equivalent workers to provide constant monitoring of DSM activities.[71]
  - *$120,000 annually (salaries, benefits, overhead)*
- Collection and distribution of DSM related payments requires one full time equivalent[72]
  - *$50,000 annually (salary, benefits, overhead)*

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68 These costs are estimated because they are key factors in the assessment of the economic feasibility of a DSM mining operation.

69 In the U.S., an Environmental Impact Statement (EIS) for a small project includes a review of engineering, impacts to all natural resources including socioeconomic resources, public meetings to discuss and solicit input, and review of applicable laws will cost 3 to 5 million. While the U.S. cost structure is much higher, the regulatory framework discussed here is applied to a new technology so the efficiencies associated with prior learning are very low. This figure is also supported by the estimated annual budget of the SBMA of NZDNZ$400,000/year based on personal communication with stakeholders in the Cook Island.

70 This figure is based on the total potential number of 20-year mine sites reported in Hein et al. (2015), (i.e., 30 sites) if all the resources were exploited, and is reduced by a third because in reality it is unlikely that all the potential areas will be mined in the future. Then the one time expenditure of $2 million (USD) is divided by 10, to get the average cost attributed to a single mining operation. ($200,000 USD).

71 Assuming mining is a 24/300 operation and allowing for 30% of a monitors time to be spent on administrative duties and travel, 6 workers are required to ensure 100% at-sea coverage. This is semi-skilled work so employees are assigned a salary just above the median income for the Cook Islands

72 Even without onshore processing, DSM mining would be a large part of the economy. This is a fairly skilled employee who makes sure payments are received in a timely manner and funds are dispersed to the 15,000 residents in a manner consistent with laws and policies. It is envisioned as a full-time position with a salary bracket in the top 10% of income distributions.

> Contract Administration requires one full time equivalent.[73]
  - *$35,000 annually (salary, benefits, overhead)*

The one-time cost of $200,000 (USD) for the mining operation's share of the cost to establish and develop the regulatory framework plus the annual salaries for reporting, monitoring, fiscal arrangements, and contract administration results in an amortised annual amount of $223,878 (USD).[74] Discounted at 7% to place future costs into today's dollars brings this amount to a total of $2.3 million (USD) over the course of the 20-year mining operation.

4.5.3.2 Costs Incurred by Foreign Owned Mining Companies

As described in Section 4.5.1, the mining value chain is divided into four main phases: exploration, extraction, transportation and processing. Phase-specific costs for the Cook Island mining scenario are based on conversations with various stakeholders in the Cook Islands and from various studies of nodule mining in the Clarion Clipperton Zone and in India.

4.5.3.2.1 Exploration Costs

The exploration costs associated with deep-sea minerals include the investment in capital equipment to locate and assess the mineral deposits' characteristics. Additionally, labour in the form of research and analysis is required to process the deposits collected and assess the feasibility of the mining operation. Manganese nodule exploration typically involves the following activities:

> Mapping the bathymetry and seafloor topography to determine areas that are suitable for nodule occurrence and future mining operations

> Determining nodule coverage using high-resolution imagery

> Nodule sampling to determine grade and confirm nodule abundance

> Bulk nodule sampling to obtain sufficient quantities for mineral processing studies

> Geotechnical studies to provide data for the engineering design of the mining technology

> Calculating the size and grade of the resource

> Carrying out environmental baseline studies and impact assessments (SPC, 2013b)

The CBA uses an estimate of annual exploration costs provided by the Cook Islands SBMA, of $10 million USD/year for approximately five years. There were only two other sources of estimated exploration costs for nodules that were based on studies over 10 years old; therefore, the estimate provided by the authority is deemed as the "most likely" value and assume a range around this estimate (plus or minus 20%) to incorporate uncertainty.

4.5.3.2.2 Capital Expenditures

The primary capital costs associated with the nodule mining operation includes investments in the equipment associated with the preferred engineering technology (i.e., mining equipment and support vessel), the direct costs associated with the purchase of vessels to transfer the ore from the support

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73 This is a junior position responsible for monitoring contractor performance for compliance with applicable laws, delivery schedules, payment provisions, inspections, contract and date reporting requirements. The reduced salary, relative to the position responsible for DSM related payments, is commensurate with this more junior position.

74 The ammortisation formula for calculating annual costs is: $C_t * \frac{r*(1+r)^n}{(1+r)^{n-1}} + OM_a$ where C_t is the fixed cost (200,000), *r* is the discount rate (7%), *n* is the number of years (20), and OM_a is the annual operating and maintenance cost ($120,000 + $50,0000 + $35,000).

vessels to processing facilities, and the investment in a processing facility. At this stage, there are no known cost estimates for the individual components of the sub-systems described in section 4.5.2. Therefore, the CBA uses a range of estimates from the literature based on similar engineering systems. Similarly, the transportation and costs are also based on ranges from the literature. Table 4-8 shows the range of values from the literature and the average estimate across all of the studies.

Table 4-8 Summary of Capital Costs for Nodule Mining Operation (indexed to 2014 PPI, in millions USD)

Study and Year	Mining equipment and support vessel	Transportation	Processing Facility[1]	Estimated Dry Tonnes/Year
SBMA, 2013	$1,547	Assumed lease	$629	2,500,0000
Agarwal et al., 2012	$200	$136	$333	500,000
Sharma, 2011	$472	$553	$758	1,500,000
ISA, 2008	$596	$525	$743	1,500,000
Yamazaki, 2006	$215	$151	$442	1,390,000
Soreide et al., 2001	$191	$407	$407	700,000
Ham, 1994	$543	$381	$2,039	3,000,000
Lenoble, 1990	$573	$439	$1,091	1,500,000
Charles et al., 1990	$497	$331	$828	1,500,000
Hilman and Gosling, 1985	$1,161	$610	$1,402	3,000,000
Andrews et al., 1983	$363	$355	$1,036	1,500,000
Average	**$579**	**$329**	**$874**	**-**

Note 1: The estimated capital cost for a processing facility varies depending on the type of processing route and the number of metals processed. In this table, studies that report an estimated 1.5 million dry tonnes per year in total operating capacity follow four-metal processing routes, while the increased capacity of 3 million dry tonnes per year is based on a three-metal processing route.

The average capital outlay for nodule mining is approximately $579 million (USD), while the estimated capital costs associated with investing in transport vessels is approximately $329 million (USD).

For the purposes of the CBA, the capital costs enter the analysis via a probability distribution, reflecting the fact that there is significant uncertainty surrounding any point estimate. The mean is based on the average of the studies listed in Table 4-8. The minimum and maximum values are based on the high and low values reported in Table 4.8.

- It is assumed that transport vessels will be leased and so enter the analysis as an operating cost (See Section 4.5.3.2.3).
- In scenarios where processing costs are considered (whether three-metal or four-metal), the CBA assumes an average capital expenditure based on three-metal and four-metal processing routes as described in the literature (See Section 4.6)).

4.5.3.2.3 Operating and Maintenance Costs

The primary operating costs are associated with supplying power to each system component (three collectors, riser system, and the support vessel), refuelling, and labour (Table 4-9). It is assumed that the majority of the operating costs will be associated with transporting fuel, ore, and supplies via barges and other vessels. While there may be additional repairs or upgrades over the 20-year operation, such costs are not currently considered.

Table 4-9 Summary of Operating and Maintenance Costs for Nodule Mining (indexed to 2014 PPI, in cost/tonne USD)

Study and Year	Mining equipment and support vessel	Transportation	Processing
SBMA, 2013	$40	$20	N/A
Agarwal et al., 2012	$109	$73	$111
Sharma, 2011	$56	$76	$168
ISA, 2008	$102	$34	$166
Yamazaki, 2008	$55	$44	$57
Soreide et al., 2001	$47	$29	$49
Charles et al., 1990	$56	$54	$183
Hilman and Gosling, 1985	$51	$24	$73
Andrews et al., 1983	$61	$34	$222
Average	**$36**	**$24**	**$150**

As previously discussed, the operating costs enter the analysis via a probability distribution, reflecting the fact that there could be a significant amount of deviation from a single discrete value. In the Cook Islands, it is assumed that operating expenditures on a mining system and transportation will be close to the average; therefore, the mean value that enters the distribution is the average value listed in Table 4-9. The minimum and maximum values are based on the high and low values reported in Table 4.9. In scenarios where processing costs are considered (whether three-metal or four-metal), the CBA assumes an average cost/tonne for operating expenditure based on three-metal and four-metal processing routes respectively (See Section 4.6).

4.5.4 Environmental Costs

As described in Section 2.3, the approach is to monetise the environmental costs associated with DSM mining activities in the Cook Islands. The following sections provide a detailed assessment of how these costs are estimated in the CBA. The external costs associated with cultural impacts are discussed in section 4.5.6.

4.5.4.1 Cost of Offsetting CO_2 Emissions

As described in Section 2.3.2, the approach to quantifying and monetising CO_2 emissions is to 1) estimate the total amount of carbon (in tonnes) that is emitted by the operation of a single mine, and 2) estimate the average cost to the DSM mining company to offset these emissions.[75] In this approach, the cost of the carbon offsets are treated as a private cost to the mining company, thus shifting the burden from Cook Island Citizens to the DSM mining company.

75 As discussed in Section 2.3.2, a complete CO_2 valuation requires an understanding of the effect of DSM activity on global metals production. Because an analysis of the global metals markets and facility-specific carbon footprints is beyond the scope of this report, it is assumed that the host countries take a precautionary approach to CO_2 emissions and require the purchase of CO_2 offsets by the DSM mining company. This requirement assures DSM activity results in no net increase in CO_2 emissions. This effectively internalizes the potential externality by requiring the DSM mining company to invest in operational technology that eliminates the source of the potential impact.

The operation of a DSM mine is likely to contribute to increases in CO_2 in the following ways:

> Through emissions associated with vessels transporting ore to a destination port,
> Through the transport of personnel and supplies via supply boats, and
> Through emissions associated with the power generation unit on board the production support vessel.

CO_2 emissions based on the transport of ore are calculated by:

> Estimating total distance travelled (in nautical miles) from the mine site to a processing facility in Mexico and the estimated tonnage per nautical mile based on the maximum capacity of a freight vessel per trip,
> Multiplying the tonnage transported per nautical mile for the entire year by the tonnes of CO_2 emitted per tonne, and
> Multiplying the total tonnes/year of CO_2 emissions by the per tonne CO_2 offset cost.

Table 4-10 reports the inputs used to calculate CO_2 offset costs related to transportation.

Table 4-10 Inputs Used to Calculate CO_2 Offset Costs Related to Transportation

Input	Assumption (processing occurs overseas)
Annual extraction (dry tonnes)	2,500,000
Freight vessel capacity (tonnes)	25,000
Trips per year (including return trip)	200
Estimated distance to nearest processing facility	8,000 km
Total distance travelled in nautical miles	863,930
CO_2 emissions (tonnes/year)	107,995
Cost of Carbon Offset ($USD/tonne)	$5.8[1]
Estimate of Annual Cost to Offset CO_2 emissions	$0.617 million (USD)

Note 1: The probability distribution for this input is taken from a report on the State of the Voluntary Carbon Market (low of $3.7, most likely of $5.8, and maximum estimate of $7.4).

For the transport of personnel and supplies via supply boats, the CBA makes the following assumptions:

> A supply boat will make a run from the mine site to the nearest island (approximately 300 km from mine site, 600km round trip) once per week. Assuming 300 operating days, this is equal to 42 trips or total distance of 25,200 km in a year.
> A typical supply boat uses approximately one gallon of fuel per half km travelled, therefore the annual trips made by the supply boats will equate to the use of 50,400 gallons.
> At 1 tonne of CO_2 per every 100 gallons of fuel, this equates to approximately 504 tonnes/year of CO_2 emissions. At a cost to offset of $5.8/tonne, this only adds an additional $3,024 to the total cost of the operation.

In addition to the emissions associated with the transportation of ore and personnel, there are also emissions associated with the burning of fuel to operate the support vessel and to generate the power for mining vessels and equipment. Based on the University of Southampton study referenced in Section

4.5.2, the estimated fuel needed to power the support vessel and auxiliary machinery is approximately 45 tonnes per day. However, this operation is based on an annual extraction of 0.5 million dry tonnes, therefore this would need to be multiplied by five to estimate the fuel usage associated with the hypothetical Cook Islands mining scenario. From here, the annual fuel usage is estimated and multiplied by the tonnes of CO_2 emitted per kg of fuel to get an estimate of the total amount of carbon emissions associated with fuelling the mining operation. Table 4-11 shows the basic assumptions used to calculate the cost of offsetting carbon emissions from powering the mining operation.

Table 4-11 Inputs Used to Estimate CO_2 Offset Costs from Powering the Cook Island Mining Operation

Input	Assumption
Fuel usage per operating day	225 tonnes
Fuel usage per year (assuming 300 operating days)	72,675 tonnes
CO_2 emissions (tonnes/year)	231,033
Cost of Carbon Offset ($USD/tonne)	$5.8[1]
Estimate of annual cost to offset CO_2 emissions	$1.3 million (USD)
Note 1: The probability distribution for this input is taken from a report on the State of the Voluntary Carbon Market (low of $3.7, most likely of $5.8, and maximum estimate of $7.4).	

Combining the two offset cost estimates, total CO_2 related costs are$1.9 million (USD). This figure is entered as a "debit" in the calculation of profits to the mining company.

4.5.4.2 Unplanned Release

In the day-to-day operation of the mine, there is the potential that hazardous materials, such as fuel, may leak or spill from their containment vessels; this risk is elevated during fuel transport and transfer. When spills occur, they impose costs that fall into three broad categories: clean-up costs, environmental costs, and social costs. To determine who would bear these costs (the mine operator or Cook Islands) and how these costs might be quantified, it is necessary to understand the Cook Island's legal framework as it relates to unplanned releases.

The Cook Islands' Prevention of Marine Pollution Act of 1998 states that vessel owners are liable for any pollution damage that occurs as a result of an unplanned spill or release. The act also provides limits on the liability associated with the damage and states that the entire amount in aggregate will be placed in a fund that is to be distributed among claimants.[76] The interpretation of this rule is that the polluter is paying for clean-up and immediate remediation associated with the incident, however, there does not appear to be a provision for compensation related to restoration of the damaged natural resources. In other words, while the polluter pays for the direct costs of clean up, it does not appear that the polluter is required to compensate the public for the loss of the marine resources until they are restored to the conditions that existed before the spill. Despite this omission, the Cook Islands Seabed Mineral Policy requires

[76] Cook Island Prevention of Marine Pollution Act. 1998. Section 24, paragraphs 1-4. Examples of claimants for a spill occurring several hundreds of miles from shore would be fisherman, tourists, recreational operators and those involved in the tourism industry.

companies engaging in DSM mining activities to pay a financial bond to cover the cost of clean-up or compensation for environmental damage.

Outside of the Cook Islands' domestic policy, the Cook Islands are also parties to the following international conventions: the Civil Liability Convention (CLC), the Fund Convention, and the Bunkers Convention. The CLC limits environmental damage compensation to costs incurred for reasonable measures to reinstate the contaminated environment. Under the Fund Convention, compensation above the vessels liability limit may be available from the International Oil Pollution Compensation Funds (IOPC Funds) secretariat based in London.[77] The basic premise of the international policies is to ensure that claimants who have experienced financial loss as a result of an unplanned spill are restored to the same economic condition they would have been in absent the spill. There is not any additional requirement to make the public and the environment "whole," such that the emphasis is on compensating the people of society for the loss of goods and services provided by the environment. In other words, admissible claims must be economic in nature (i.e. indicative of a financial loss).

Given this legal context, the CBA assumes that the mining company would be liable for any spill-related clean-up costs and any spill-related financial losses. It is further assumed that these costs are appropriately reflected in the mining companies annual insurance cost of $1 million based on information associated with the Solwara 1 project.

To estimate costs associated with the potential loss of ecosystem services, an expected annual spillage (tonnes) is calculated using spill frequency data from International Tanker Owners Pollution Federation Limited (ITOPF) and information describing the DSM-related vessel activity and fuel transfer. The expected annual spillage is multiplied by $24,000 per tonne which reflects the cost of compensating the public for ecosystem services lost following a spill as presented in Kontavas and Psaraftis (2010).

The estimate of annual spillage is based on vessel utilization:

- Three 25,000 dead weight tonne (DWT) handy-size vessels transporting ore from the mine site to the processor,
- One support vessel transferring crew and supplies, and
- One PSV located at the mine site.

To estimate the probability of a spill occurring, the CBA uses data from ITOPF, which reports the total number of small, medium and large spills by tankers, combined carriers and barges over time. According to their 2014 report, the 10-year average number of medium spills (7 to 700 tonnes) is approximately 7 per year. Given that there are approximately 16,000 vessels in the world merchant fleet, this equates to a 0.04% probability of a medium sized spill per vessel (7/16,000). For large spills (> 700 tonnes), the 10-year average is approximately three per year, or a 0.02% probability of a spill of this magnitude occurring per vessel (3/16,000).[78]

Table 4-12 illustrates expected unplanned release costs assuming the maximum amount of fuel that could be released.

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77 http://www.itopf.com/knowledge-resources/documents-guides/compensation/ Accessed June 1, 2015

78 http://www.itopf.com/fileadmin/data/Documents/Company_Lit/Oil_Spill_Stats_2014FINALlowres.pdf Accessed August 17, 2015. It is also noted that in each CBA respectively, the probability of a spill does not change based on site specific conditions. This is because spills are largely due to human error, and there is no evidence to support that the probability of a spill occurring would go up or down based on site specific characteristics.

Table 4-12 Estimated Environmental Cost of Unplanned Oil Spill for Cook Island Mine Site

Vessel	Total fuel capacity[1] (in tonnes)	Probability of spill	Expected Present Value of Spill Volume (in tonnes)	Total estimated annual cost per vessel (in USD)
PSV	1,192	0.02%	0.23	$5,520
Transport	724 /vessel 2,172 total	0.02%	0.43	$10,320
Crew boat and supplies	351	0.04%	0.14	$3,360
Total	**3,715**		**0.78**	**$18,720**
Note 1: Source: http://www.seacormarine.com/cgi-bin/ourfleet.cgi?type=psv Accessed August 19, 2015				

4.5.4.2.1 Unplanned Release Summary

Costs associated with spill clean-up and financial compensation are reflected in the $1 million insurance premium paid by the DSM mining company.

The annual expected cost associated with lost ecological services would be borne by the host country citizens. Those costs calculated as the product of expected annual spillage (0.78 tonnes) by the per tonne cost of compensating the public for ecosystem services lost following a spill ($24,000) are estimated to be $18,720 annually. Discounted at 7% over the course of the 20 year mining operation, the PV of the total estimated cost is $0.2 million (USD).

4.5.4.3 Cost of Discharging Nutrient Rich Water

Once at the surface, the nodules are dewatered and the excess seawater is returned to the ocean. Often the solids will contain nutrients recovered from the sediment on the seabed. If the water contains high nutrient levels and if that water were returned near the sea surface, it could trigger harmful algal blooms.

The proposed technology is designed to eliminate this risk by returning the water at depth. As such, a value of $0 is assigned to this category in terms of a cost to citizens of the Cook Islands.

4.5.4.4 Valuing the Change in Environmental Services Provided by the Seabed

As discussed in Section 4.3.1, the potentially impacted deep-sea environment is characterized by slow currents, low temperatures and the absence of light. These conditions are reported to lead to the lowest productivity, in terms of biological biomass, in the world. The community consists mostly of macrofauna living in the sediment, such as polychaete worms, crustaceans, and bivalve molluscs. The abundance of these animals is relatively low in abyssal plains and most animals are fairly small (only a few millimetres to 1 centimetre). The community also includes microfoauna (mainly bacteria) living on the nodules along with some sponges, molluscs, polychaetes, and encrusting bryozoans attached to the nodules.

Table 4-13 identifies and discusses the services that may be provided by deep seabed communities at the Cook Island mining site. Following convention, services are divided into four broad categories:

1. Provisioning services (e.g., material goods such as food, feed, fuel, and fiber) are associated with goods provided directly to people,

2. Regulating services (e.g., climate regulation, flood control, and water purification) control ecosystem processes that influence the well-being of humans,
3. Cultural services generate human well-being outside any direct or indirect consumption of goods. Examples include recreational opportunity and well-being generated by the knowledge an ecosystems exists in a certain state (often called existence or spiritual value), and
4. Supporting services (e.g., nutrient cycling and primary production) generate human well-being by facilitating the production of future provisioning, regulating or cultural services.

For each specific service, the baseline level of ecological service provision is discussed and compared to the level of service provided by more common environments such as forests and wetlands.

- A relative level of 0 implies the deep seabed habitat provides almost no service relative to a forest or wetland.
- A relative level of 1 implies the deep seabed habitat provides the service but at a level much less than a forest or wetland.
- A relative level of 2 implies the deep seabed habitat provides the service at a level somewhat less than a forest or wetland.
- A relative level of 3 implies the deep seabed habitat provides the service a t a level similar to or greater than a forest or wetland.

For each specific service, the sign and magnitude of project related changes are qualitatively evaluated.

- Changes may be positive (the value of service provided increases) or negative.
- A ranking of 1 implies that the change is unlikely to be perceptible by residents of the host country.
- A ranking of 2 implies that the change in the level of service may be perceived by residents of the host country.
- A ranking of 3 implies that the change would most likely by perceived by most host country residents.

Table 4-13 Ecosystem Services Provided by Deep Seabed Communities Relative to Cook Islands Project Site

Service Category	Service Description	Baseline Level of Service Provisions	Sign and Magnitude of Expected Change
Provisioning	Some benthic organisms are directly consumed by people (e.g. clams and oysters)	Human consumption and utilisation of deep seabed organism is limited (0)	0
	Some benthic organisms are used as bait (e.g. worms, clams) or in other processes (e.g. shells may be crushed used in industrial processes)		0
	Genetic material may be extracted from sediment dwelling bacteria or benthic organism for research and pharmaceutical use	Utilisation of genetic resources from deep-seabed areas is limited (0)	0
	Proteins or chemical compounds may be extracted from sediment dwelling bacteria or benthic organisms for pharmaceutical and industrial use	Utilisation of mineral resources is limited today but potential exists for future mineral development (1)	0
Regulating	Benthic organisms and sediment dwelling bacteria influence climate processes; these organisms regulate some organic decomposition processes which influence CO_2 sequestration and the sediment itself may be a sink for organic (e.g. carbon-based) material	Deep-sea sediments act primarily as a carbon and nutrient sink. (1)	-1 to +1
	Benthic organisms and sediment dwelling bacteria influence pollution attenuation processes; burying by the sediment itself may reduce the bioavailability of pollutants; sediment and sediment dwelling organisms regulate water purification processes.		-1 to +1
	Sediment structure and the accumulation of sediment regulates accretion and erosion processes as well as storm surge and flood control	Sediments and sediment processes at the depths in question have almost no influence on erosion processes or storm surge protection (0)	0
Cultural	Well-being may be derived via shell fishing outside any consumptive use	Recreational collection of deep seabed organisms is very limited (0)	0
	Well-being may be derived by individuals simply because they know a healthy sediment community exists	The remoteness and limited development of seabed resources tends to increase cultural value whereas the commonality of the habitat within the EEZ tends to decrease value (2)	-2
	Well-being may be derived because the sediment system exists and can be used in the process of generating human well-being, education, or scientific understanding		+1

Service Category	Service Description	Baseline Level of Service Provisions	Sign and Magnitude of Expected Change
Supporting	Sediment dwelling organisms cycle energy, nutrients, and organic matter within and between ecosystems this energy cycling facilitates the production of future services across multiple ecosystems. The structure added to the seabed by nodules represents a feature around which organisms may aggregate while feeding and/or reproducing.	The deep-sea acts primarily as a sink as energy and nutrient transport from deep-see back into resources that provided provisioning or regulating services is limited (1). Topographic relief associated with nodules may provide some nursery and feeding opportunities relative to an undifferentiated deep seabed. However, few organisms that provide provisioning or regulating services benefit from these services (1)	-1 to 0

4.5.4.4.1 DSM Mining Related Impacts to the Deep Seabed

The primary DSM mining related impacts are related to the proposed nodule collecting system as it lifts and collects nodules from the 2,705 square kilometres (668,420 acres) of seafloor.

> There would be temporary and localised increases in sedimentation rates and a transitive increase in turbidity. `

> While the proposed hybrid collector utilises a hydraulic lift that involves zero contact with the seafloor, the crawler subsystem will penetrate soft sediments and disturb the associated communities (crawler design specifications suggests approximately half of the sediment will be impacted by the crawler tracks themselves). This would result in some mortality among the sediment dwelling organism that are immobile, fragile, and in the direct path of the crawler tracks. Re-colonization of disturbed soft bottom seabed in shallower water would occur over the course of months or years (FERC 2008). It has been speculated that recovery in deeper water may take longer.

> The density of nodules in the proposed mining area is relatively high with over 80% of the seabed often being covered by nodules (Figure 4.9). Removing the nodules effectively converts a primarily hard substrate deep seafloor into a primarily soft bottom deep sea floor. This change would persist in the long term.

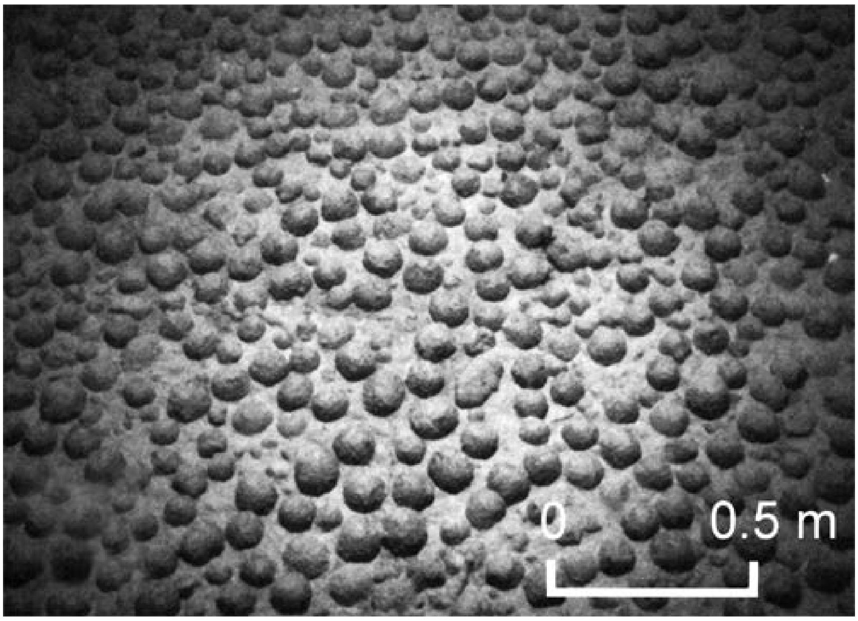

Figure 4-9 Example of Nodule Density on Seabed

4.5.4.4.2 DSM Mining Related Impacts to Deep Seabed Service Provision

While the conversion of primarily hard substrate deep seabed to primarily soft bottom deep seabed would result in long term changes to the resident community, the resulting change in the provision of services is expected to be minor and may, in some instances, be positive.

> Given the overall scale of the project (the site represents approximately 2% of the very high nodule acreage in the Cook Island EEZ), material changes in biodiversity and/or impacts to the limited provisioning services (other than mineral extraction) are not anticipated.

> Mining activity would result in acute mortality among the sediment dwelling organisms that dominate the system. However, in the long run, the increase in available soft substrate may result in a net increase in sediment dwelling macrofauna and a subsequent increase in the regulating services they provide. Regardless of whether the net effect is an increase or decrease in regulating service provision, the change is unlikely to be perceptible to host country citizens.

> Supporting services related primarily to feeding and nursery areas would be impacted by the conversion of primarily hard substrate deep seabed to primarily soft bottom deep seabed. Specifically intermediate services provided to fish and mobile fauna that associate with the nodules would be reduced whereas the level of intermediate service provided to fish and mobile fauna that associate with soft bottoms would increase. This may be perceived as a loss of supporting service that would persist in perpetuity.

> The primary component of any change in composite service provision would be associated with cultural values and these changes could persist in the longer term.

4.5.4.4.3 Valuing Changes in Environmental Service Provision

There are two approaches to valuing the DSM mining related changes in ecosystem service provision:

1. Estimate willingness-to-pay for specific environmental services and multiply willingness-to-pay by the change in environmental service provision, or

2. Estimate of the cost of generating environmental services of similar type and quantity and use this “replacement-cost” as a substitute for willingness-to-pay.

The following text applies each method to the Cook Island DSM mining scenario.

Willingness-to-pay

As discussed in Section 3.5.4.4, Earth Economics (2015) estimated an annual willingness-to-pay of $1,766 per hectare for ecological service provided by deep-sea habitat. This estimate was based on three sources of ecological service provision.

1. Biological control services were (referred to as regulating services herein) were valued at $26 per hectare per year.
2. Genetic material which provides stock form which areas may be colonized (a supporting service) and may provide provisioning services was valued at $277 per hectare per year.
3. The provision of nursery habitat (a supporting service) was valued at $1,464 per hectare per year.

Each value put forth by Earth Economics was adopted from a study that related to cloud forests (one of the most diverse and productive habitats on earth) and, where multiple studies existed, the highest available value was adopted. Noting that the area to be mined in the Cook Island EEZ is reported to be one of the least productive habitats on earth, these values would need to be adjusted downward if applied to the Cook Island scenario.

- The DSM mining operation is not expected to result in the loss of regulating services or materially alter the services derived from genetic diversity. As such, Cook Island-specific willingness-to-pay estimates for these services were not derived.
- Because the quantity and quality of nursery services would likely be reduced by the DSM mining operation, a nursery value more applicable to the Cook Island deep sea bed was identified. Absent a site specific study, 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).

If DSM mining reduced deep seabed nursery services by as much as 25%, and assuming this loss persists from the time an area is mined in perpetuity, the NPV of ecosystem service losses is calculated to be no more than $1,859,000.

Replacement Cost

To complement the willingness-to-pay approach, Cardno employed a replacement cost approach that relies on a method referred to as HEA (See appendix A). This approach replaces the difficult to estimate “willingness-to-pay” with a “service replacement cost.”

The basic premise underlying HEA is that all of the services flowing from a habitat can be treated as a single composite ecological service. If an action results in a reduction in the quantity of the composite ecological service produced by the impacted habitat, the public can be compensated via a restoration project that creates composite ecological service at some other site. The cost of implementing the restoration project is the service replacement cost.

The HEA metric is generally the Discounted Service Acre Years (DSAYs) where one Service Acre Year (SAY) represents a composite measure of all of the services flowing over the course of 1 year from one acre of the habitat. That is, the SAY is a composite measure of the provisioning, regulating, and supporting services provided by one acre of habitat over 1 year. Future services are discounted to reflect society’s rate of time preference.

HEA is typically discussed in terms of debits and credits flowing from two discrete sites. Debits accrue when the level of composite service provided by the injured site is below baseline; credits accrue when the level of composite service provided by the restored site is above baseline (Figure 4-10). Compensation is achieved when the debit (present discounted value of the area represented in red in Figure 4-10) is equal to the credit (present discounted value of the green area in Figure 4-10). Note that this definition of compensation assumes the value of any cultural services lost at the impacted site is equal to the value of the cultural services provided by the restored site.

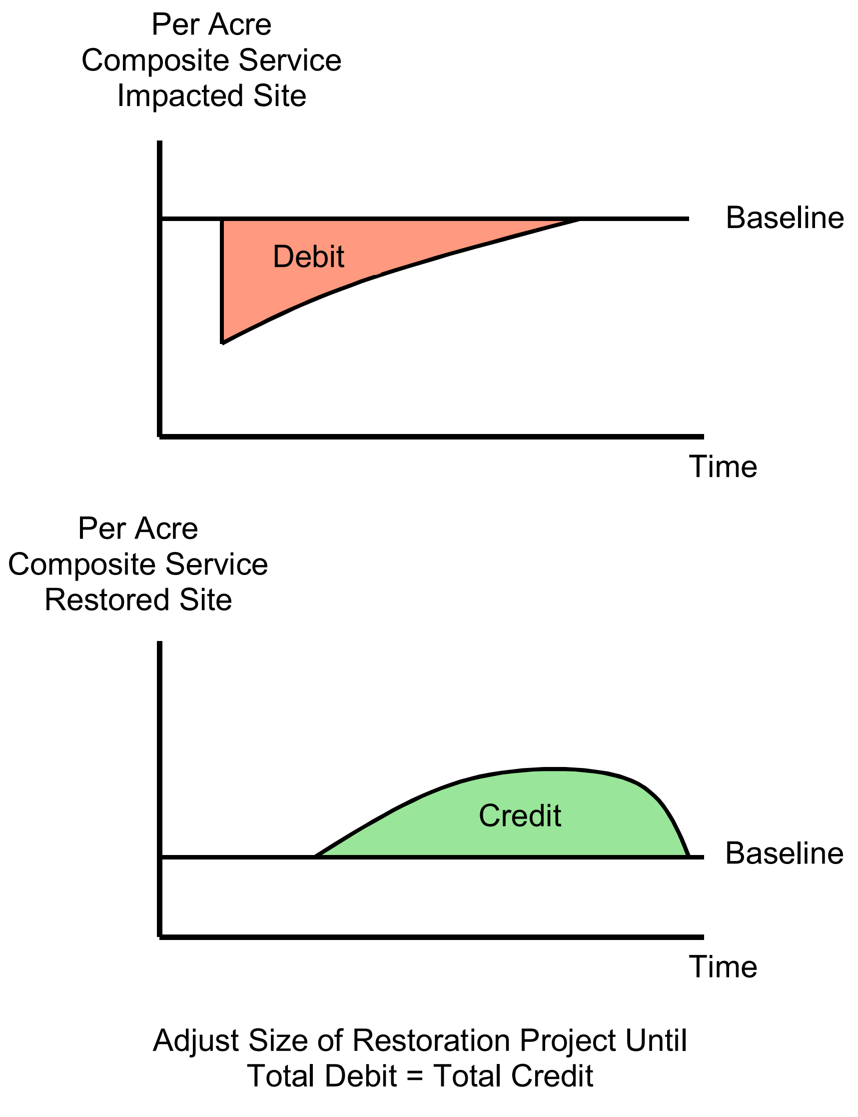

Figure 4-10 HEA Illustrated as Services Flowing from Two Discrete Sites

As is the case with the willingness-to-pay estimate, application to a deep seabed system is challenging given the state of the biological and economic understanding. This is true for two reasons.

1. Given the current level of biological and ecological understanding related to the production of composite service in deep seabed habitat it is necessary to estimate service loss qualitatively.
2. Because it is not technically feasible to replace the services provided by the deep seabed ecosystem "in place" (that is, it is not technically feasible to create or restore deep seabed habitat), the deep seabed HEA relies on ratios that equate composite service provided by deep seabeds with composite service provided by wetlands.

As previously noted, material impacts to provisioning or regulating services are not anticipated. The primary impact to service provision 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.

Because it is not technically feasible to replace the services provided by deep seabed communities "in place" (that is, it is not technically feasible to create or restore deep-sea habitat), the deep sea HEA relies on ratios that equate services provided by one habitat with services provided by another.

Peterson et al. (2007) established a series of equivalency ratios based on the relative productivity of any two habitats. Using the productivity logic, the equivalency ratio between a relatively flat and undifferentiated deep seabed (4.23 g C/m^2/y at 1500m depth (Rowe and Kennicutt 2009)) and salt marsh (860 g C/m^2/y reported for salt marsh (Feijtel et al 1985)) would be 1:203.

This implies a loss of 445,857 deep seabed DSAYs would be offset by the creation of 2,196 wetland DSAYs.

The cost of creating 2,196 wetland DSAYs is estimated to be $24,928,000 based on NOAA et al. (2002).

4.5.4.4.4 Valuing the Change in Environmental Services Provided by the Seabed: Summary

DSM mining related changes in ecosystem service provision were valued using willingness-to-pay and replacement-cost methods. While both valuations are challenging given the current level of biological and economic understanding, both methods suggest the present value of seabed-related changes would be less than $24.928 million.

In preparing these estimates, many helpful comments were received, most of which have been incorporated into the text. Several comments were also received that have not been incorporated. These include:

- Individuals expressed concern that impacts related to spills and air emissions were not considered. These impacts are omitted from this section because they are unlikely to affect the deep seabed habitat. They are however considered when overall environmental costs are estimated.
- Individuals expressed concern that indirect impacts to fish and other mobile organism that depend on the deep seabed were not considered; these impacts are included via the consideration of deep seabed supporting services.
- Commenters questioned the utility of compensating the public for the loss of deep seabed services via the creation of wetland services. While it is agreed that this is a sub-optimal approach, it is necessitated by the impracticality of restoring deep seabed habitat.

4.5.5 Total Monetised Social Costs

The following potential social costs were identified:

- Administrative costs to the government,
- Cost of offsetting CO_2 emissions,
- Cost of unplanned spill and/or vessel grounding, and
- Cost of replacing services that may be lost by DSM mining activities.

Where possible these costs are transferred to the DSM mining operation and are treated as "debits" in the calculation of the mining company's profit. This includes Cook Island administrative costs, cost to offset CO_2 emissions, costs to avoid negative impacts of introducing nutrient rich waters to the sea surface, and clean-up costs associated with unplanned release. The remaining costs (those associated with lost ecosystem services following a spill and the loss of deep-sea ecosystem services) are incurred by the citizens of the host country.

Table 4-14 summarises each individual cost element, as well as how it was factored into the analysis.

Table 4-14 Summary of Monetised Cost Estimates in the Cook Island Mining Scenario (in USD)

Cost Estimate	Mean Values based on Monte Carlo Simulation	
	Present Value Social Cost Incurred by Citizens of Cook Islands (in millions of USD)	*Annual Private Cost Incurred by DSM Mining Company (in millions of USD per year)*
Government administrative costs	$2.3	$0
CO_2 offset costs	$0	$1.9[a]
Clean-up and restoration cost associated with unplanned spill	$0.2[c]	$1.0[b]
Lost deep-seabed ecological services	$24.9[d]	$0
Present value of total cost	**$27.4**	**$2.9**

Note a: Present value of the cost of acquiring carbon dioxide offsets
Note b: Costs to acquire insurance to assure oil spill clean-up costs are covered
Note c: Expected cost to replace ecological services lost from an unplanned spill or release from the time the spill occurs to the time the baseline level of services are restored
Note d: Value of lost ecological services provided by the deep seabed community

4.5.6 Discussion of Non-Monetised Social Costs

The following section provides a detailed assessment of the external costs that were not monetised. These include the cultural costs such as the concession of tribal ownership and community level impacts that affect the well-being of various members of society. In addition, the CBA evaluates the potential that tourism and commercial fishing could be adversely impacted if the Cook Islands were perceived as industrializing its ocean resource.

4.5.6.1 Concession of Tribal Ownership

Perhaps one of the more overlooked and difficult to quantify impacts of an activity that involves natural resources with cultural significance is the potential negative impacts to indigenous populations. The on-site interviews suggest that, from the perspective of many indigenous people, there needs to be a balance between what is taken from the environment and what is given to the people. In other words, they do not want to see both the environment and the people of the Cook Islands diminished by DSM mining.

They are specifically concerned that corruption in the government may ultimately leave the people to bear the negative consequences of DSM and not reaping any of the benefits.

To mitigate these concerns, the traditional leaders indicated that they would like to play a larger role in the decision-making process, thus strengthening their leadership role within the government and giving their constituents a stronger voice. By becoming partners with the government, they might be able to regain some of their traditional roles, instead of feeling marginalised and that their rights are continually being diminished.

4.5.6.2 Community Level Impacts

For the purpose of this analysis, community level impacts are considered as:

- Changes in employment patterns that would negatively impact Cook Islanders, and
- Mismanagement of wealth from mining revenues.

There is some concern that DSM related changes in employment patterns could have a large effect on social and cultural patterns. One way this could happen would be if the islands were hosting large numbers of foreign workers over an extended period of time. Given the assumptions laid out in Section 4.4.2, it is assumed that the majority of direct DSM mining workers would be housed temporarily (1-2 nights) in Aitutaki on a FIFO system; therefore, a large influx of foreign miners over an extended period of time is not anticipated. Based on this assumption, it is unlikely that communities living in Aitutaki would experience any significant changes to their existing social and cultural patterns due to a large influx of workers.

Two additional ways that DSM mining related activities could cause negative changes in employment patterns would be 1) if the distribution of DSM mining related royalties in the form of income payments to Cook Islands citizens caused a large influx of emigrants who returned solely to cash in on the welfare, with little or no intentions of gaining employment, thus increasing the unemployment rate or 2) if DSM mining related royalty payments caused a general change in social patterns and behaviours of Cook Islands citizens toward becoming dependent on the welfare system, also increasing the unemployment rate. The potential for negative impacts associated with an influx of former emigrants would depend on the magnitude of DSM mining related payments made by the government to its citizens, and also the structure of those payments. For example, if payments were not limited to Cook Islanders living in the Cook Islands, there would be less motivation for emigrants who plan to return home for the sole purpose of exploiting the royalty payments. Additionally, the magnitude of government payments could also cause current residents to become dependent on the welfare payments, thus dropping out of the workforce and relying on government payments as a primary source of income. Again, it is noted that this will all depend on if and how the government decides to distribute mining royalties to the citizens of Cook Islands.

An additional potential impact that echoed among the various stakeholder groups was based on the concern over the mismanagement of the returns of DSM mining. This has serious implications for future generations of the Cook Islands. Improper long-term management could lead to wealth that is squandered, leaving little for future generations; a situation that could mirror what happened with phosphate mining in Nauru.

4.5.6.3 Perception of Environmental Degradation on Tourism and Commercial Fisheries

While it is unlikely that the natural resources upon which Cook Islands tourism is based would be adversely impacted by DSM mining, the mere perception of potential adverse impacts could reduce the number of tourists frequenting the Cook Islands.

To evaluate the potential magnitude of such an effect, the extensive literature on the effects of environmental disasters is reviewed. This literature provides insight because property values reflect the NPV of all services flowing from a property, which includes environmentally-based recreation. While an imperfect proxy, it is likely, that any potential cost associated with reduced tourism due to perception would be less, on a percentage basis, than property diminution.

- Several studies examining the effects of pipeline easements on sales and property values have found no effects (Diskin et al. in 2011, PGP 2008, Fruits 2008). Hansen (2006) analysed property sales near a pipeline accident location and noted a short-term decline in property values with values returning to baseline over the course of several years.
- Similarly, several studies have evaluated the effect of cell phone towers on property values. Dorin and Smith (1999), Bond and Wang (2005), Bond (2007) and Valentine (2014) compared sales among properties with varying proximity to cell phone towers, they found a minor (often zero, consistently less than 15% diminution) associate with extreme proximity to cell towers and that any potential effect diminished in the years following cell tower construction.
- These results are consistent with meta-analysis of wind farm (COE 2004) and landfill (FERC 2008) impacts.

There is also evidence from a study on the economic value of watershed pollution in Rarotonga, Cook Islands. The study found that on average there is a 3% reduction in tourism due to the presence of watershed pollution (Hajkowicz and Okotai, 2006) in Rarotonga. Given that watershed pollution is much more visible to prospective tourist than an offshore mining operation that takes place over 300 km from the nearest island, it would be reasonable to assume that negative perceptions related to DSM mining activities may have no adverse effect on tourism. If there would be an effect, it is unlikely to result in no more than a 10% reduction in tourism.[79]

As with tourism, there is a potential for people's perception of environmental degradation to affect revenue to the commercial fishing industry in the Cook Islands. Skewed perceptions or risk are common when it comes to damage associated with the environment. A recent example of this behaviour is associated with the British Petroleum (BP) oil spill in the Gulf of Mexico. Despite in-depth analyses by both federal and state scientists proclaiming that all seafood that entered the market during the time of the spill was safe, a survey conducted by the Gulf and South Atlantic Fisheries Association indicated that 30% of the respondents would not eat any seafood coming from the Gulf of Mexico. However, quantifying financial loss due to loss of consumer confidence is difficult to quantify, unless it can be reliably connected to falling sales and prices related to the environmental contamination. In the case of the Cook Islands, mining occurs at depths that are thousands of metres away from commercial species; therefore it is assumed that perceptions related to DSM mining activities may have no adverse effect on revenues to the commercial fishery.

[79] This assumption is based on the upper bound figure from the study in Rarotonga (Hajkowicz and Okotai, 2006) and is considered a "worst-case" scenario as the Rarotonga water pollution studied by Hajkowicz and Okotai is likely to be visible to tourists, whereas any potential environmental degradation due to deep-sea mining would occur and likely remain hundreds of kilometres off shore.

4.6 Benefits Methodology

The CBA begins by calculating the amount of revenue received by the government. The first step in this calculation is to estimate amount of revenue that the mining company receives based on the total geological specifications as laid out in Section 4.4. Next, a 3% royalty is applied to the gross revenue to estimate the amount the government receives in royalty payments. From here a cash flow model is used to determine in what year, if any, there is positive profit to the mining company (Profit is estimated by subtracting capital and operating expenditures and from the mining company's net revenue, before any taxes are applied).

If there is positive profit in a given year, the following assumptions based on the current fiscal regime in the Cook Islands is applied:

> Withholding tax of 15%

> Corporate income tax of 28%[80]

> Resource rent of 20% on "super profits" that is applied when the mining company has achieved an internal rate of return that is greater than 20%.

4.6.1 Private Benefits

Given nodule processing uncertainty the CBA estimates private benefits under three scenarios:

1. **Miner owns the mining operation and exits the value chain by selling the raw ore to a processor overseas.** Revenue to the miner is estimated based on the value of the raw ore before the metals are extracted and sold to the market.
2. **Miner owns both the mining operation and a processing operation located overseas.** Revenues to the miner are based on the sale of the final product to the market.
3. **Miner is required to invest in a processing facility in the Cook Islands**. Revenues are also based on the sale of the final product; however, cost to the private mining company now includes infrastructure upgrades and capital expenditures which are costed at a premium to reflect the need to import everything, as well as the addition of waste disposal expenditures.

With the exception of Scenario #3, all scenarios include an evaluation of benefits under a three-metal processing route (Co, Ni and Cu), a four-metal processing route (Mn, Co, Ni, and Cu) and a three-metal processing route with REYs. Under the three-metal processing route, metal recovery is based on methods that use sulphuric acid leaching, while metal recovery for the four-metal processing route is based on a combination of smelting/sulphuric acid leaching. This is due to the high recovery rates for Mn, Co, Ni, and Cu at 85%, 90%, 94%, and 95% respectively.

Under a four-metal processing route, the output for manganese is in the form of silico-manganese, therefore the price used in this alternate scenario is based on the price/lb of silico-manganese instead of pure manganese metal. Processing cost estimates are based on an average of the numbers provided in the 2008 ISA technical workshop proceedings for three-metal and four-metal processing routes that use sulphuric acid/smelting, as well as from eight other studies in the peer-reviewed literature. Scenario #3 is based on the preferred processing route as described in Section 4.5.2, based on the site specific conditions for the Cook Islands. Each scenario and the underlying assumptions are described in more detail in the next section, followed by a summary of the results for the basis of comparison.

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80 The assumptions used for the corporate income tax and the royalty percentage come from Section 5.5 (p. 10-11) of the Cook Islands National Seabed Mineral Policy. The assumptions for the withholding tax and the resource rent come from personal communication with the SBMA and the Ministry of Finance and Economic Management.

The following inputs enter the estimation of gross benefits as random draws from a probability distribution[81]:

> Price,
> Metal grade (assumed in the seabed),
> Mining efficiency (percent recovered from the seabed), and
> Metallurgic recovery (percent of metal recovered after processing).

Table 4-15 illustrates the inputs used in estimating the gross revenue from the mining operation. The estimates in the table represent the "most likely" or mean value by which the probability distribution was based.

Table 4-15 Description of Inputs used to Estimate Gross Revenue in Cook Islands Mining Operation

Metal	Metal Content	Dry tonnes in 1 year of production	Mining Efficiency	Metallurgic Recovery[1]	Market Price (USD/lb)	Revenue from Metal (per tonne of ore/USD)	Total expected revenue in 1 year (in USD/millions)
Manganese	15.6%	392,128	80%	85%	$0.63[2]	$216	$360
Cobalt	0.51%	13,323	80%	90%	$13.74	$154	$278
Nickel	0.26%	6,444	80%	94%	$6.50	$37	$70
Copper	0.17%	3,467	80%	95%	$2.91	$11	$21
Sum of REYs	0.21%	5,357	80%	60%	$54.50	$253	$420

Note 1: Recovery rates are based on processing route that involves smelting and/or sulphuric **acid leaching as** reported in the 2008 ISA Workshop proceedings. The estimate for REYs is hypothetical and could be much higher or lower since it has not been proven in a laboratory setting.
Note 2: As previously indicated, this represents the price/pound for silico-manganese.

Table 4-16 shows the additional inputs used to estimate profit to the miner, which ultimately determines whether the Cook Islands receives revenue in the form of royalties, taxes and resource rent. Profit is estimated as what is left over to the miner after subtracting royalty payments and operating and capital expenditures. As previously described, the values for capital and operating expenditures also enter the estimation of profit as random draws from a probability distribution, with the estimates in the table representing the "most likely" values. The minimum and maximum values are based on the high and low values reported earlier in Table 4.8.

Table 4-16 Description of Inputs used to Estimate Profit to the Miner in Cook Islands Mining Scenario (in USD)

Category	Three-Metal (cost/tonne)	Four-Metal (cost/tonne)	Three-Metal + REY (cost/tonne)
Capital expenditure – mining operation (one-time)	$500	$500	$500

[81] Ranges for all inputs can be found in Appendix B.

Category	Three-Metal (cost/tonne)	Four-Metal (cost/tonne)	Three-Metal + REY (cost/tonne)
Capital expenditure – processing facility (one-time)	$592	$592	$592
Operating expenditure – mining operation	$60	$60	$60
Operating expenditure – processing	$114	$179	$228

4.6.2 Total Monetised Benefits

The following section presents the results of each scenario followed by a summary and comparison across the various scenarios and processing routes.

4.6.2.1 Scenario #1 – Miner exits the value chain before processing

Under this scenario, the mining company exits the value chain after the ore is extracted by selling the raw ore to a processor. The processor will pay the mining company a price that is lower than the market value of the extracted metals, given that he has to cover his costs and make a profit.

- This scenario limits the number of uncertainties faced by the Cook Islands and ensures that no processing-related environmental impacts are borne by Cook Island Citizens. In trade, the Cook Island government would forfeit any royalties or rents that are based on profits accruing to the processor.

Three potential processing routes were evaluated under Scenario #1: three-metal, four-metal, and three-metal with REY processing. In all cases, it is assumed that the processor has the capacity to accept approximately 2.5 million dry tonnes of nodules per year (DTPY). It is also assumed that the processor will receive revenue equal to the full market value for the metals (after processing).

The amount the processor will pay the miner is equal to the gross revenue received from the sale of the processed metals minus (a) the amortised capital expenditure and operating costs associated with the processing facility, and (b) a reasonable profit which is calculated as 5% of total costs.

Table 4-17 illustrates processor profitability for each processing route. Note that the three-metal processing route does not generate enough revenue to cover processing costs (That is, the processer would not accept nodules even if they were provided for free). The four-metal and the three-metal + REY routes do generate sufficient revenue for the processer to operate at a 5 percent profit margin and pay the miner for nodules.[82] A four-metal processor would pay up to $160,690,259 for a year's supply of nodules whereas a three-metal + REY processor would pay $81,248,079.

Table 4-17 Evaluation of the Profitability of a Nodule Processor

Category	Three-Metal	Four-Metal	Three-Metal + REY
Annual gross revenue ($USD)	$368,867,725.48	$729,677,831	$684,467,725
Amortised capital expenditure[1] ($USD)	$ 94,392,925	$94,392,925	$94,392,925
Annual operating expenditure ($USD)	$ 285,000,000	$447,500,000.00	$570,000,000
Operating cost/tonne[2] ($USD)	$114	$179	$228

82 Typical profit margins for refineries are less than 7%, so this value is within the range of what is expected.

Category	Three-Metal	Four-Metal	Three-Metal + REY
Processor's profit (at 5% of total annual cost) ($USD)	$18,969,646	$27,094,646	$33,219,646
Gross revenue minus costs ($USD)	(-$29,494,847)	**$160,690,259**	**$81,248,079**
Note 1: Amortisation is a procedure by which the total capital outlay (in this case approximately $ 1 billion (USD) is distributed over time into multiple cash flow installments. It assumes that the processor does not pay the full amount upfront, rather pays the amount over time in monthly installments. Note 2: This evaluation uses an average cost/tonne based on individual values for each of the various processing routes detailed in Section 4.5.2.4. The averages are based on a compilation of nine cost estimates for each processing route (three-metal vs. four-metal) from a variety of sources in the literature and ISA workshop proceedings, which are updated to 2014 dollars using the producer price index. In each case, a separate average value is estimated for the number of metals extracted (three-metal vs. four-metal). In the case of REY, there are no known estimates of processing costs; therefore, the cost/tonne for a three-metal processing route is doubled.			

Even under the four-metal scenario, where the miner will receive approximately $160 million (USD) for the sale of the raw ore it is unlikely the DSM operation will commence. This is because the miner has to accept a price/tonne of metal that is approximately 80% below the market value in order for the refinery to operate.[83] Table 4-18 shows the comparison of the current market prices for the extracted metals, versus what the miner would have to accept under this scenario. As previously described, price enters the equation based on a random draw from a probability distribution. The probability distribution is based on a range around the most likely values (i.e., plus or minus 50%) for each of the prices. Table 4-18 shows the "most-likely" values used. All prices were obtained from infomine.com, unless otherwise noted.

Table 4-18 Distribution of Estimated Metal Prices in Four-Metal Scenario (in USD/lb)

Metal	Most Likely Value	
	Market Price	*80% Reduction*
Manganese (in the form of silico-manganese)	$0.63[1]	$0.14
Cobalt	$13.74	$3.01
Nickel	$6.00	$0.64
Cu	$1.56	$1.43
Note 1: The price of manganese is based on the price/pound for silico-manganese from the US Geological Survey's 2012 Minerals Yearbook for Manganese (indexed to 2014 dollars using the consumer price index (CPI)		

After applying the royalty, the amount the miner receives in payment from the processor is not enough to cover expenses throughout the duration of the mining operation. Based on the lower market value, the expected mean present value of profit (PV of net revenue minus expenses) to the miner at the reduced prices is $-136 million (USD), giving the miner a negative return on his investment.

Figure 4-11 is a probability distribution; lines represent the probability or likelihood that the PV of profit and/or government revenue will take on a particular value, based on changes in the input values. As illustrated by the red line, there is a 70% probability that, even under the four-metal scenario, PV of profit to the DSM mining operation would be less than $0. While the blue line illustrates government revenue should DSM mining occur, actual government revenues are assigned a zero value to reflect the probability that DSM mining would not be initiated under Scenario #1.

83 As previously explained, in this scenario, the miner has to accept a price for the raw ore that is lower than the market value of the metal contained within the ore, since it is being sold to an overseas processor before the metal is extracted. After processing, the processor sells the refined metals to the market at the prevailing market price for each extracted metal. He cannot then turnaround and pay the miner the same value, since he has to cover costs and recover a profit. Therefore, at the time the raw ore is sold, the processor will pay the miner a value that is less than the value of the extracted metals on the market. In this case, to cover cost and make still make a small profit, the miner has to accept a value that is 80% below market value.

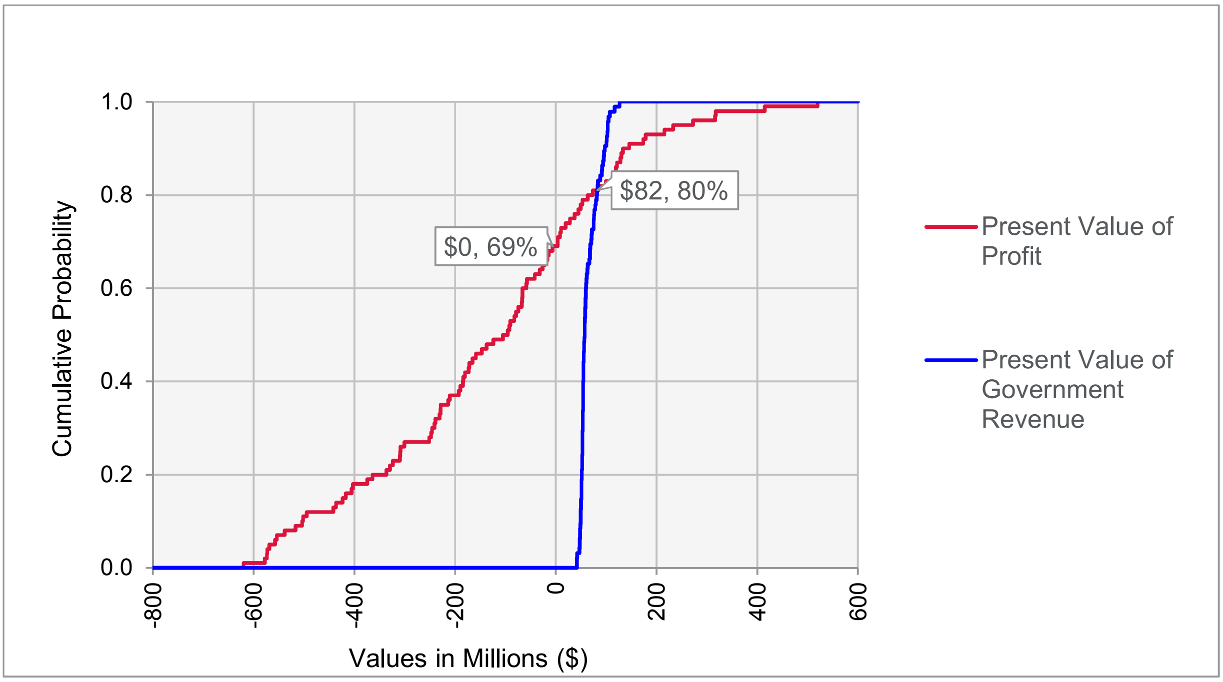

Figure 4-11 Distribution of Profit and Government Revenue in Four-Metal Scenario – Miner Exits the Value Chain before Processing

Figure 4-12 helps identify the key source of uncertainty in the four-metal scenario. The length of each horizontal bar reflects the effect variation in the specified variable has on profits. The price of silico-manganese had the largest impact on the output mean (PV of profit to miner), followed by the operating expenditures and the price of cobalt. These results suggest that decision makers may want to take into consideration these factors when evaluating future opportunities.

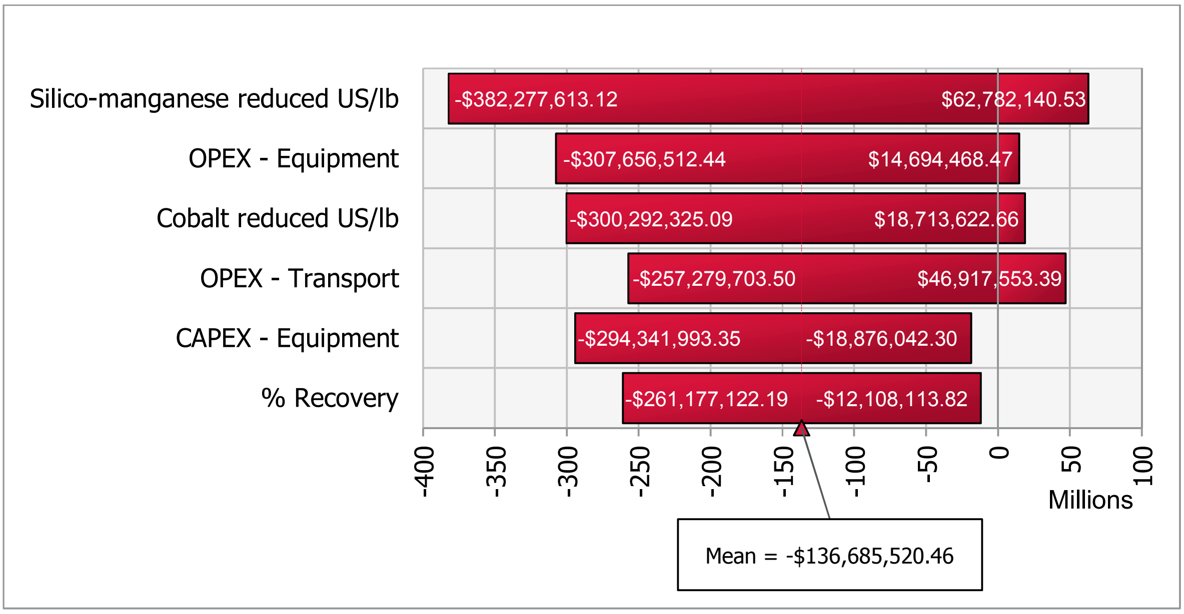

Figure 4-12 Sensitivity of Mean Output (PV of Profit to Miner) to Changes in the Input Values

Because the DSM mining company is unlikely to operate under Scenario #1, the CBA does not estimate expected revenues to the government for Scenario #1.

4.6.2.2 Scenario #2 – Miner owns both the mining and processing operation

Under this scenario, the mining company owns both the mining operation and the overseas processing facility. It is further assumed that the Cook Islands is able to negotiate royalty, tax and resource rent payments based on the full market value of the extracted metals and any associated profits.

- Relative to Scenario #1, this scenario increases the number of uncertainties faced by the Cook Islands. In trade, the Cook Island government may capture royalties, taxes and/or rents on profits accruing to the processor.
- As was the case with Scenario #1, no processing-related environmental impacts are borne by Cook Island Citizens.

Table 4-19 reports mean inputs for each of the alternate processing routes and the corresponding PV of profit to the mining operation and revenue to the government. As was the case under Scenario #1, neither the three-metal nor the three-metal with REY routes are profitable.[84] However, under the four-metal processing route and assuming mean input values, the operation is profitable.

[84] The reasons that the remaining scenarios are infeasible could be the loss in revenue from silico-manganese in the three-metal scenario, and the higher cost and loss of metallurgic efficiency of processing REYs in the three-metal + REY scenario. Because it is virtually unknown whether the processing of REYs alongside the three other metals is possible at a pilot scale, the analysis uses a conservative estimate of a 60% recovery after processing, which could be much lower or higher in reality.

Table 4-19 Present Value of Profit to Mine Operator by Process Route

Input	Three-Metal	Four-Metal	Three-Metal + REY
Gross revenue (in USD)	$368,867,725.48	$729,677,831	$684,467,725
Total capital expenditure (*mining equipment + processing, one-time USD)*	$2 billion	$2 billion	$2 billion
Operating expenditure (*mining, + transportation + processing, annual USD)*[1]	$441 million	$550 million	$756 million
PV of Profit to Miner	-$1 billion	**$402 million**	$-2 billion
PV of Revenue to Government	$123 million	**$494 million**	$200 million
Government share of revenue	N/A	**55%**	N/A
Note 1: This also includes insurance payments of $1 million USD/year and carbon offsets at $1.9 million USD			

Figure 4-13 is a probability distribution illustrating both profit to the mining operation and revenue to the government under the four-metal scenario. The median draw reveals a profitable mining operation and positive revenues to the government (Noted by the intersection of the blue, red and green lines). However, the analysis suggests nodule mining is risky proposition. As illustrated by point A, there is a 35% chance that the mining operation loses money under Scenario #2 and four-metal processing (i.e. 35% chance that the PV of profit to the miner is less than $0). A private mining operator may not find this risk profile economically viable.

It is unlikely that the total PV of revenue to the government over the course of the 20-year operation will exceed $770 million (USD) noted by the intersection of the yellow and blue lines.

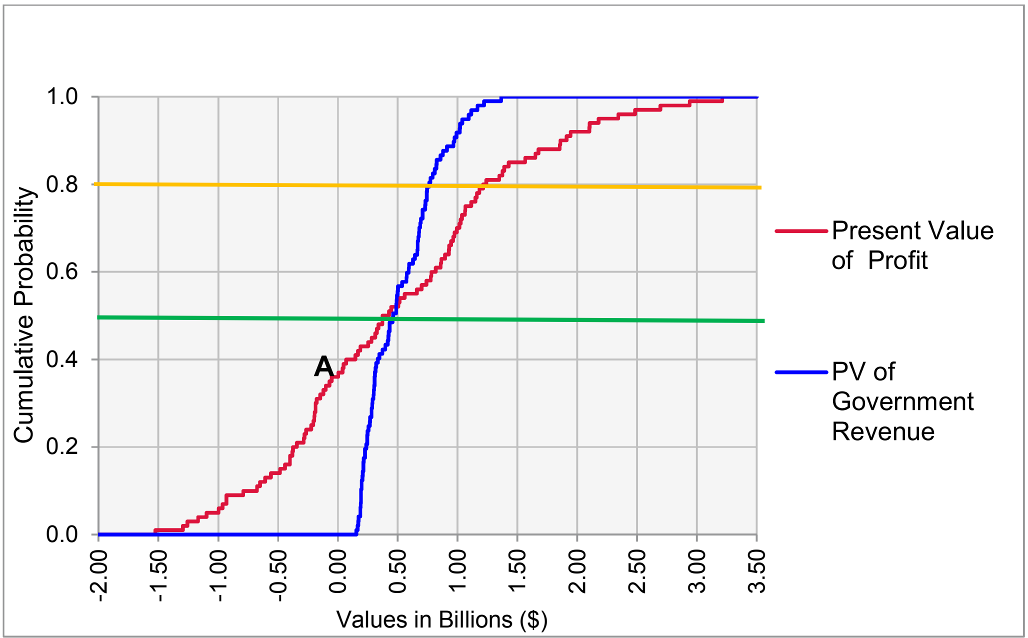

Figure 4-13 Distribution of Profit and Government Revenue in Four-Metal Scenario – Miner Owns Mining and Processing Operations

4.6.2.3 Scenario #3 – Miner invests in processing facility in the Cook Islands

The third and final scenario under consideration is one in which the mining company invests in a processing facility in the Cook Islands. In this scenario, it is assumed processing will rely on the high pressure/high temperature acid leaching method. This method was chosen primarily because this process has relatively low energy requirements and relatively high recovery potential for cobalt. A four-metal processing route was ruled out given the extreme amount of energy required and consumed during the additional step of roasting/smelting to recover the manganese (100 times the current energy output of the Cook Islands). It is also important to note that the high pressure/high temperature leaching method generates a manganese rich slag that could be stockpiled or stored on land and then sold to an off-island facility for additional processing.

The following text summarises processing requirements including major inputs, outputs and necessary infrastructure upgrades.

- The facility will be a pressure acid leaching (PAL) facility based on the high pressure/high temperature sulphuric acid leaching process route for the extraction of three metals (Co, Cu, and Ni).
- The facility will be located on Rarotonga in close proximity to the existing power station. Colocation with the power-generating facility provides direct access to power and port infrastructure, and reduces overall environmental costs. While construction of the facility at the existing port would reduce overall operating costs, this location would adversely alter the Port of Avatiu scenery and noise levels. This would most likely have a noticeable impact on tourism.
- The operator/owner will pay a premium of 25% on capital equipment since it will require assembly in a foreign country, disassembly for transport via vessel, then reassembly in the Cook Islands.
- Daily operation of the facility will require the following infrastructure upgrades:
  - Expansion of the Port of Avatiu to allow for the increased frequency in vessel traffic and vessel size for the unloading of raw ore and loading of manganese rich slag, finished product and additional processing inputs. The expanded port would also allow for the temporary warehousing/storage of equipment and materials,
  - Construction of a rail line that connects the port to the processing facility to facilitate the delivery of raw ore and other inputs to the processing facility as well as the return of finished product and manganese rich slag to the port,
  - Construction of on off-shore liquefied natural gas (LNG) import terminal and subsea pipeline to facilitate the delivery of LNG required to operate the facility, and
  - Construction of a cooling tower and associated intake infrastructure to draw the necessary quantity of process water to the facility.

Operation of an on island processing facility will also generate adverse environmental externalities (public costs) including visual degradation, noise, waste streams, and unplanned release risks.

4.6.2.3.1 Facility Description and Plant Operational Requirements

The construction of a high pressure/high temperature acid leaching facility would require approximately 180 acres of land, which includes processing and support facilities as well as long term waste containment areas (if wastes were not transported overseas) (Dames and Moore, 1977).

There would also be separate processing buildings for the copper and nickel electrowining, nodule grinding and leaching, pH adjustment and neutralization and ammonia recovery. There would be a boiler house/power house and several cooling towers located adjacent to the chemical process areas, and offices, laboratories, maintenance shops, warehouses, cafeteria and parking. These areas would take up approximately 20-40 acres, while an additional 20 acres would be needed for raw ore storage, settling ponds for treating wastewater, and storage for various other inputs that feed into the process (Dames and Moore Inc., and E.I.C. Corp., 1977).

Aerial image of Basamuk Refinery in Papua New Guinea – High Pressure Acid Leaching Plant for land-based nickel laterites

Source: http://www.ramunico.com/plus/list.php?tid=240 Accessed August 13, 2015.

In addition to the raw nodules and waste products, approximately 5,500 tonnes of fuels and process material would be brought in to the facility and approximately 240 tonnes per day would be moved out (Dames and Moore Inc., and E.I.C. Corp., 1977). Table 4-20 illustrates the major inputs, outputs and materials and supplies associated with the annual operation of a high pressure/high temperature acid leaching plant. It also includes the inputs required to treat the hazardous waste products.

Table 4-20 Summary of Major Inputs, Outputs and Materials for a High Pressure/High Temperature Acid Leaching Facility[1]

Material	Input	Output	Materials and Supplies
Raw nodules	2.5 million dry tonnes/year	-	-
Liquefied natural gas	16.7 million cubic feet/year	-	-
Limestone	163,000 tonnes/year	-	-
Lime	380,000 tonnes/year	-	-
Sulphuric acid	940,000 tonnes/year	-	-
Water	1.6 billion gallons/year	-	-
Purchased power	149 GW		
Solid waste (including manganese slag)	-	4.2 million tonnes/year	-
Liquid waste	-	1.1 billion gallons/year	-
Transport water	-	1.9 billion gallons/year	-
Gases	-	-	7,000 tonnes/year
Liquids (other than sulphuric acid)	-	-	800,000 gallons/year
Sulphuric acid	-	-	134 million gallons/year
Solids	-	-	1,358 tonnes/year
Finished Product			
Cobalt		9,180 tonnes/year	
Nickel		4,891 tonnes/year	
Copper		3,250 tonnes/year	
Note 1: Numbers are from Table 7.1 in Dames and Moore Inc., and E.I.C. Corp., 1977			

In terms of labour to support day to day operations, it is assumed that the facility would operate 365 days per year on a three-shift basis requiring approximately 500 full-time employees. Approximately one third of the employees would be skilled and/or management level, one third administrative and/or clerical, and one third unskilled labour (Dames and Moore Inc., and E.I.C. Corp., 1977).

4.6.2.3.2 Supporting Infrastructure Upgrades and Requirements

Based on the magnitude of the inputs/outputs and materials described in the previous section, there would need to be a significant amount of infrastructure upgrades, and the addition of several supporting industries to facilitate the delivery of supplies and movement of materials. These infrastructure upgrades include:

- **Expanding the Port of Avatiu.** The Port of Avatiu would need to be expanded significantly in order to accommodate the increased vessel size required to facilitate the arrival of raw ore and input materials, the transfer of waste material, and the export of the final products from the island to a destination overseas. It would also require the installation of the associated bulk material handling equipment required to offload the raw nodules and ore storage sheds to periodically stockpile the ore until it could be transported to the facility.
- **Constructing an offshore LNG import terminal.** As described in Table 4-20, processing requires a significant amount of fuel; annual requirements include approximately 16 million cubic feet of liquefied natural gas to power the operation and an additional 29 million cubic feet to treat the waste. To limit adverse impacts at the existing Port, it is assumed, an offshore LNG import terminal and regasification unit would be constructed several miles off shore to handle the incoming vessels and pipe the natural gas to the facility.
- **Building an industrial railway** from the port to the facility to accommodate the transfer of raw ore, product, material and supplies. The most practical transport method may be industrial rail system running on a continuous loop. Given the need to move a large supply of raw ore (approximately 25,000 tonnes every 3 days), the rail line would need to consist of approximately 80 cars each carrying up to 100 tonnes of freight.
- **Constructing water intake system to provide ample water supply.** Processing consumes 1.6 billion gallons of water annually to make up for cooling tower evaporative loss and other consumptive processes. This will require the construction of marine water intake system as well as a transport pipeline or canal to the processing facility.

Ports

As previously described, the Port of Avatiu would need to be expanded and the port access dredged to ensure the reliable transport of materials. Based on annual production at the mine site (2.5 million tonnes/year), it is estimated that freight vessels carrying raw nodules will make approximately 100 trips from the mine site to the port (This is based on a production rate of 2.5 million tonnes per year and an average freight capacity of 25,000 tonnes). For a 300 day/year operation, this will mean that a freight vessel would be coming into port every three days and unloading up to 25,000 tonnes of nodules. In addition, the operation of the facility requires over 300 million gallons of sulphuric acid per year.

Aerial image of Port of Avaitu in Rarotonga

Source: http://www.dredgingtoday.com/2013/04/16/new-zealand-adb-to-open-upgraded-avatiu-port/ Accessed August 13, 2015

Given that a large chemical transport vessel can carry approximately three million gallons of liquid, this would require an additional 100 trips into port from chemical transport vessels. Currently, the port is a day-time only port, and would also need to increase the labour force to be able to become a 24 hour/365 day per year operation.[85]

To support the increased vessel traffic, vessel size and unloading/loading of material, the following upgrades would need to be made:

- Expansion of existing jetty to increase berth size and the number of berths,
- Deepen the port to (currently 8 m) to accommodate larger vessels with up to 11 m draft,
- Construction of additional storage sheds and/or warehouse for the temporary stock piling of ore and/or materials,
- Installation of bulk material handling equipment,
- Train loading facility and rail loop for the transfer of raw ore and supplies to the processing facility and the transfer of product and waste material from the facility, and
- Installation of 1-2 fixed ship loaders.

The total estimated cost for an upgrade of this magnitude would be in the range of $150 to $200 million (USD).[86] It is also estimated that a project of this magnitude would create approximately 200 jobs during construction, with 50 additional ongoing jobs to support the 24/365 operation.

LNG Import Terminal

To ensure reliable access to fuel to power the processing facility and waste treatment, an LNG import terminal would need to be constructed at least five miles offshore. The structure, known as a Floating Storage and Regasification Unit (FSRU) would be attached to a mooring tower that connected to the seabed. The net storage capacity would be approximately 350,000 cubic metres. Given than an average LNG tanker can carry approximately 25,000 cubic metres of LNG, and that the operation requires 1.3 million cubic metres/year, the terminal would receive approximately 50-60 LNG carriers per year.

Image of FSRU designed for the Bridgewater Project in the U.S.

Source: http://www.lipower.org/pdfs/company/papers/broadwater/proddesc.pdf Accessed August 14, 2015

Power generation for the FSRU includes three 22-MW gas turbines, which would use vaporized LNG for fuel. The regasification plant includes a recondenser for boil-off gas, shell and tube vaporizers (STVs), super-heaters and metering and odorisation equipment, and is designed to vaporize LNG at a peak capacity of 2,500 m^3/hr. After regasification, the gas would be transported via a subsea lateral pipeline, for delivery to the facility. Based on a similar project recently proposed in the United States, it is estimated that the cost to build the import terminal would be approximately $600-$700 million (USD).[87] It is estimated that a project of this magnitude will

[85] http://www.thisisnoble.com/in-the-press/2488-port-kembla-upgrade-gets-started.html Accessed August 18, 2015.

[86] This is based on similar upgrades to a port in Australia: http://www.pirie.sa.gov.au/webdata/resources/files/Strategic%20Port%20Expansion.pdf Accessed August 13, 2015.

create 160 jobs during construction and 30 to 40 jobs ongoing.[88]

Industrial Rail Spur

A short industrial rail line would transport large quantities of raw ore, material and finished product to and from the port. The rail system would consist of a low-speed rail circuit approximately 2.5 km in length (assuming the processing facility is located near the existing power plant). Using rule of thumb costs for rail line construction costs would likely range between $1.5 and $4 million (USD).[89] The rail project would also include construction of an "unloading rack" to facilitate the movement of ore into the facilities storage area or stock piles. Based on the quantity of ore arriving at the port every three days (25,000 tonnes total or 8,333 per day), and assuming each rail car can carry up to 100 tonnes, up to 80 rails cars would be needed to deliver the raw ore to the refinery every day. In 2012, the average cost of a freight car was approximately $85,000. For 80 freight rail cars, this would cost approximately $7 million USD.[90]

Using information from a similar project at a refinery in the U.S., it is anticipated that this project will create 30-50 temporary jobs during construction and the addition of several full-time positions during operation.[91]

Cooling Water Intake and Transport System

Water is needed to make up for evaporative loss from the cooling tower and to facilitate other ongoing processes. Water would need to be drawn in from the ocean, separated from debris, and transported to the facility. To minimise costs and potential environmental externalities, it is assumed that the intake structure is integrated into port upgrades and that rail tanker cars can be added to the nodule train to haul the water to the processing facility. The cost to install a cooling tower is approximately $10-14 million (USD) (USEPA, 1999).

4.6.2.3.3 Environmental Costs of Processing on the Cook Islands

Nodule processing results in multiple adverse environmental externalities. These include:

- The combustion of 45 million cubic feet on LNG during the processing operation would result in the release of approximately 223,000 tonnes of CO_2 annually. As outlined in Section 4.5.4.1, the cost of offsetting these emissions would be $5.8 USD per tonne or $1,293,400 (USD) annually.
- The consumptive use of 1.6 billion gallons of water annually will result in the loss of marine organisms that get impinged on the water intake structure or entrained in the processing water itself. The U.S. EPA has done extensive analysis to predict the economic value of impingement and entrainment related economic losses. The economic losses per gallon of water are extremely variable dependant largely upon the type and density of aquatic organisms present near the intake. In some circumstances, losses associated with 1.6 billion gallons per year would be *de minimis*. If commercially or recreationally valuable species were impinged and entrained, and assuming those populations are characterised by limited resilience,

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87 https://www.downstreamtoday.com/(X(1)S(xdcrh355hq5mud55orhmcp55))/Projects/Project.aspx?project_id=75&AspxAutoDetectCookieSupport=1 Accessed August 14, 2015.

88 http://www.ncleg.net/documentsites/committees/BCCI-6576/2015-2016/Reports/LNG%20Export%20Terminal%20Report%20-Final.pdf Accessed August 14, 2015

89 http://www.acwr.com/economic-development/railroads-101/rail-siding-costs Accessed August 17, 2015.

90 https://www.aar.org/Documents/Railroad-Statistics.pdf Accessed August 17, 2015

91 http://www.phillips66.com/EN/about/our-businesses/refining-marketing/refining/santamaria/Pages/rail-project-information.aspx Accessed August 17, Accessed August 17, 2015.

impingement and entrainment related impacts may be as high as $200,000 (USD) annually based on loss rates observed in some U.S. facilities (Gentner, 2009).

- Each year, 1.1 billion gallons of liquid waste as well as the manganese rich slag would need to be managed. Given the high manganese content of slag, it is likely that arrangements could be made to transport this material to an off-island facility for further processing resulting in little cost to the processing facility.
- Drying and evaporation ponds would materially reduce liquid waste streams. However, some liquid waste (about 1,000,000 gallons annually) would need to be transported off island for additional treatment prior to disposal. While transport could likely be arranged with an outbound (empty) vessel that delivered sulphuric acid for a nominal fee, treatment cost would likely be $.01 to $0.05 per gallon (City of Portland, 2015) resulting in an annual cost of up to $50,000.
- Evaporative loss from the cooling tower would result in a cooling tower plume that would likely be visible from many locations on the island during daylight hours. In addition, operation of the processing facility would result in noise emissions beyond the border of the facility. The quantification and valuation of these adverse environmental externalities typically requires a site-specific engineering analysis to determine actual plume height and frequency and as well as noise levels at specific receptor points. The existing literature describing the effects of environmental externalities on property values is then used to estimate a value for the specified change (EPRI, 2011).
    - Absent an actual siting plan, these externalities are not monetised. However, in the case of Rarotonga it is likely that plumes or industrial noises that consistently degrade key sites and destinations could jeopardize the tourism industry.
- The introduction of heavy industrial processes to an island such as Rarotonga also introduces the potential for unplanned releases. The quantification and valuation of this risk requires a site-specific engineering analysis to determine the probability and nature of releases and an economic evaluation to determine their expected costs.
    - Absent such an analysis these externalities are not monetised. However, in the case of a small closed system such as Rarotonga, what would be considered a localised effect in mainland Asia or Australia, could affect the entire island ecosystem.

4.6.2.3.4 Summary of Total Monetised Costs of Processing in the Cook Islands

In summary, the costs of processing in the Cook Islands include the increased private cost to the foreign-owned mining company required to pay a premium on capital and labour; the facility's components need to be constructed, deconstructed, transported, and then re-constructed in the Cook Islands; and the required labourers' skills are highly specialised and would require ex-patriates to be hired at the onset of the operation. It also includes the cost of additional infrastructure that would be required to support the operation at the processing facility. In addition, nodule processing results in multiple adverse environmental externalities. Table 4-21 summarises the additional costs (private and external) associated with constructing a processing facility in the Cook Islands.

Table 4-21 Summary of Monetised Costs (Private + External) of Miner Owned Nodule Processing Operation in the Cook Islands

Category	One-time Cost (in millions of USD)	Amortised Annual Cost (in millions of USD)
Processing Facility	$1,900[1]	$179
Mining Operation	$500	$48
Ports	$200	$18
LNG terminal	$600	$56
Rail line	$12	$1.3
Cooling tower	$10	$1.0
Carbon dioxide offsets	-	$1.4
Waste disposal	-	$0.05
Loss of marine and aquatic species from cooling water intake	-	$0.200
Total	**$3,020**	**$305**

Note 1: Includes premium on materials. Original amortised amount was $1 billion, or $94 million/year, representing an increase of $85 million/year.

The costs in Table 4-21 make it clear that it also would not be economically viable for a mining company to invest in the construction of a processing facility in the Cook Islands. Even under the scenario in which the mining company owns an existing processing facility, the PV of profits is unlikely to exceed $1.3 billion. This is less than half of the money required to construct the facility and develop the infrastructure to support operation. In other words, even under the best case scenario when the miner owns the mining operation and the processing facility overseas, there is not a huge profit margin that would indicate that the construction of a processing facility on the Cook Islands would be worth the investment.

4.6.3 Discussion of Non-Monetised Social Benefits

DSM mining would likely result in an increased understanding of the deep-sea environment that has benefits that extend beyond the national boundaries of the Cook Islands. The value of these potential benefits has not been quantified.

Given that relatively little, if anything, is known about the deep-sea environment in the Cook Islands, there stands to be a great deal of scientific knowledge extracted alongside the manganese nodules. This is most likely to occur during the five year exploratory phase so that much can be learned about the specific conditions related to the mine site. Part of the reason why deep-sea mining has been slow to evolve is the limited knowledge of the ecology and the interaction of species at the depths where mining is being considered. Improving this knowledge, specific to the environment where mining is taking place, could also help shape the current Seabed Minerals policy. It is often argued that knowledge and research is needed before the adoption of policy, and the policy adopted to date is largely based on hypothetical impacts of commercial mining operations. Therefore, the exploration process presents a unique opportunity to enhance this knowledge to include site specific data and information based on larger scale commercial activity that will help to inform both domestic and international policy related to seabed minerals.

4.7 Cost-Benefit Comparison

The NSB of the DSM mining project is calculated as the present value of the social benefits that accrue over the 20 years of mining minus the present value of the social costs that accrue during and after mining.

The equation used to estimate net social benefits (NSB) is as follows:

> ***NSB = PV of TOTAL BENEFITS*** *(government* ***revenue****)* ***– PV of TOTAL COSTS*** *(private government* ***costs +*** *external* ***costs****)*

As previously discussed, a NSB greater than zero suggests the project has the potential to make citizens of the Cook Islands better off. A NSB less than zero suggests the project will leave Cook Island citizens worse off.

Critically, for NSB to exceed zero, government revenue from DSM mining must be positive. For government revenue from DSM mining to be positive, a DSM mining company must have a reasonable expectation of making a profit or they will not enter the market. The only scenario under which a DSM mining company has a reasonable expectation of profits is one in which the mining company owns an off-island four-metal processing facility.

Table 4-22 presents the expected NSB for all scenarios considered. Where there is not a reasonable expectation of profits for the DSM mining company, NSB is reported as zero.

Table 4-22 Expected Net Social Benefits by Cook Islands Mining Scenario (in millions USD)

Processing Route	Scenario #1[1]		Scenario #2[2]		Scenario #3[3]	
	Net Social Benefit to Cook Islands	Benefit-Cost Ratio	Net Social Benefit to Cook Islands	Benefit-Cost Ratio	Net Social Benefit to Cook Islands	Benefit-Cost Ratio
3-Metal	$0	-	$0	-	$0	-
4-Metal	$0	-	**$467**	**18**	Not considered	Not considered
3-Metal + REY	$0	-	$0	-	Not considered	Not considered

Note 1 – Scenario #1 is where the miner owns only the mining operation and has to sell raw ore to processor overseas
Note 2 – Scenario #2 is where the miner owns both the mining and the processing facility located overseas
Note 3 – Scenario #3 is where the miner owns both the mining and the processing facility located in the Cook Islands

4.8 Sensitivity Analysis

Figure 4-14 illustrates the NSB associated with miner owned, four-metal processing scenario. Each line illustrates the probability the NSB will exceed a specific value given the range of inputs specified for the Monte Carlo analysis and assuming the specified discount rate.

The horizontal distance between each line reveals the effect of the discount rate. As expected with a project that is expected to deliver relatively constant revenue over a relatively long timeframe, the more future benefits are discounted, the lower NSB.

Some other important findings include:

> *The fact that all curves are entirely to the right of NSB=0, implies that, so long as the Cook Islands can find a company willing to enter into DSM mining under terms similar to those outlined in this report, and provided the assumptions and uncertainties specified herein prove accurate, there is no probability of DSM mining posing a net cost on Cook Island Citizens.*

> *The relatively gentle slope up and to the right suggests there is a reasonable probability of NSB being quite large ($250 million or more) regardless of the assumed discount rate.*

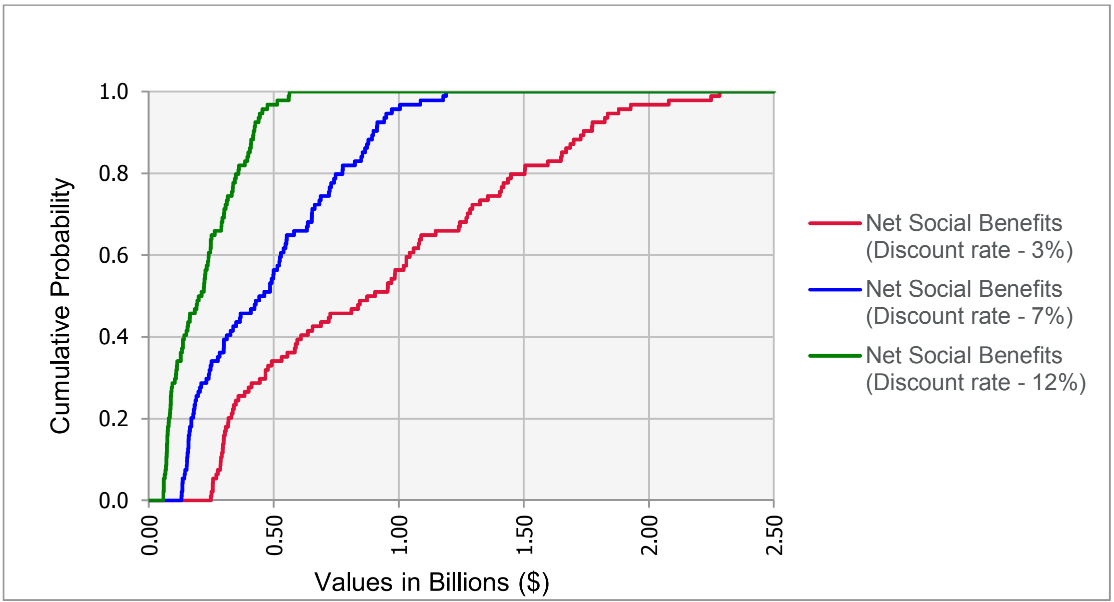


Figure 4-14 Sensitivity of Net Benefits and Profit in Cook Islands Mining Scenario to Changes in Discount Rate

Figure 4-15 helps identify the inputs which have the most effect on NSB. The length of each horizontal bar reflects the effect variation in the specified variable has on profits. In this case, the price per pound of silico-manganese, the cost effectiveness of processing and the efficiency with which nodules are recovered from the seafloor have the greatest impact.

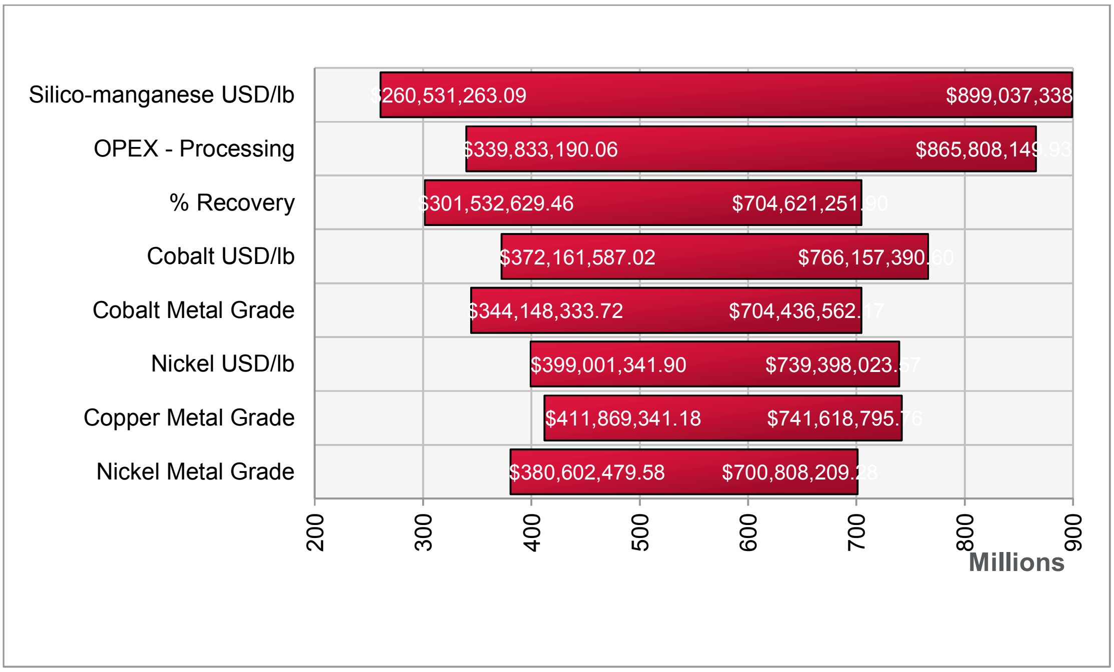


Figure 4-15 Sensitivity of NSB in Cook Islands Mining Scenario to Changes in Inputs

4.8.1 Comparison to Revenue from other Natural Resources

Stakeholders have requested the DSM mining-related revenues be compared to revenues generated by fishing, pearl harvest, and tourism.

Total net benefits over the duration of the mining operation are $467 million (USD). This represents the sum of all annual benefits minus the sum of all annual costs, discounted over 20 years. The average annual government revenue from the mining operation is equal to the undiscounted amount divided by the number of years the mine is in operation. This is equal to $47 million (USD) and will be used as the basis of comparison to other potential sources of revenue in the Cook Islands.

4.8.1.1 Revenue from Commercial Fishing and Black Pearls

The commercial fishery is mainly a longline fishery, but has recently expanded to include purse seine. In 2014, the total value of the Cook Islands commercial fishery was $9.1 million (USD), an increase of over 100% from 2013 which is largely attributed to the growth in the purse seine fishery.

The value of pearl exports has declined from $1.1 million (USD) in 2009/10 to $0.101 million (USD) in 2013 and improved slightly to $0.151 million (USD) in 2014.[92] As of 2013, both the pearl and fishing industries represented approximately 4% of the total gross domestic product (GDP) of the Cook Islands ($9 million USD, NZD$14 million).

[92] Personal correspondence with Ministry of Marine Resources

In comparison to the average annual mining royalties and taxes in Scenario #2 ($47 million USD), fishing and pearl revenues represents are one-fifth as large. In other words, the average annual revenue from nodule mining is approximately 5 times larger than the 2014 annual contribution of the fishing and pearl industries.

4.8.1.2 Revenue from Tourism

As of 2013, tourism-related industries represented nearly 45% of GDP and employed more than 40% of the currently employed individuals across all 15 islands. It was reported that income from tourism related industries such as food, retail, and lodging totals approximately $105 million/year (USD, NZ $165 million).

That figure ($105 million USD annually) is two times larger than the $47 million USD in annual government revenue projected to come from DSM mining. However, it is worth noting that this is a comparison between total tourism revenue and DSM mining tax and royalty payments. A more refined comparison, while not part of this scope, would be to compare tourism related profits and/or tourism-related tax revenue to DSM mining tax and royalty payments.

4.9 Regional Economic Impact Analysis

Regional impact analysis was performed to determine the indirect effects associated with DSM mining. The analysis first uses information on mining related expenditures to determine employment and income effects as a result of DSM mining in the Cook Islands. Then, the annual estimates of government royalties are used to evaluate the employment and income effects associated with government spending a portion of the DSM-related revenue.

4.9.1 Mining Expenditures

As described in Section 2.4, capital expenditures have been excluded from the impact analysis given that most of these items are highly specialised and are not expected to be procured from study area countries.[93] The only local employment and income benefits associated with DSM mining are expected to be associated with project operations and are for procurement of project fuel, spares, consumables, and labour.

4.9.1.1 Operating Costs

- The analysis assumes the number of local workers is equal to 20% at the onset of mining, given that the mining operator may be under contract to include a portion of locals in the mining labour force, but that the majority of labour would be provided by trained ex-pats. This obviously may vary over time as more locals are trained.
- Total wages paid to local mining employees are expected to average $29,000 (USD) per person annually.
- For spares, consumables, and fuel, the analysis relied on parameters generated using the IMPLAN system and knowledge of local infrastructure constraints to determine the proportion of expenditures that would be made locally.
- Non-local consumer spending estimates assume each non-local worker would make 12 inbound trips and 12 outbound trips, and subsequently stopover for one night each time traveling through the city hub serving the DSM operation. Hotel costs are assumed to equal $50 per night; whereas, food expenditures are assumed to equal $50 each night.

93 Various suppliers of the mining equipment are described in the Solwara Cost Study, none of which are located within PNG

> Operating costs are based on averages from the literature (see Sections 4.5). In the absence of specific information on the breakdown of operational costs, the detailed allocation of operational costs to major cost categories relied on the allocation provided for the Solwara 1 project and are reported Table 4-23 below.

Table 4-23 Summary of Mining Operational Expenditure Estimates for Cook Islands (in millions USD)

Category	Total	Local
Production Support Vessel (PSV) Charter	$48.8	$0.0
Remotely Operated Vehicle (ROV) Charter	$6.0	$0.0
Fuel (PSV/Barges)	$19.9	$17.5
Spares, Consumables and Miscellaneous	$14.2	$1.6
Labor (PSV/Barges)2	$65.3	$2.3
Contingency (10%)	$15.4	$0.0
Total Operating Costs	$169.8	$21.5
Other Operational Spending		
Non-local Consumer Spending	$0.8	$0.8

4.9.2 Government Expenditures

The analysis assumes two separate scenarios for estimating the employment and income effects of government spending of DSM mining royalties and revenue. Scenario 1 assumes the government adopts a revenue sharing plan similar to the Norwegian Petroleum Fund, which is often held as a ‘best practice’ approach in resource revenue management.[94] Under the program, the Norwegian government transfers all of the government revenues obtained from petroleum to the fund. In all, over the 2004-2006 period, 28% of annual resource revenue was consumed by the government, while 76% was saved in the fund. Scenario 1 of the analysis, assumes that 25% of total government revenue from DSM mining activities is used by the Cook Islands government. Furthermore, it is assumed that resource revenue is spent equally by the Cook Islands government in three industries: health, education and construction.

Scenario 2 of the analysis assumes that rather than the Cook Islands government spending the same proportion of their DSM revenue in the health, education and infrastructure development, the government revenue is distributed to residents. Subsequently, it is assumed residents will spend this transfer of wealth on local goods and services. It should be noted, in both government spending scenarios it is assumed that governments incur no transaction costs beyond those already noted for collections and distribution.

As an example, Table 4-24 below illustrates the average annual government revenues of $47 million for DSM mining in Cook Islands of which it is assumed 25% ($11.8 million) will be spent equally ($3.9 million) in the health, education and construction industries.

94 Website (http://www.environmentportal.in/files/RFF-Rpt-BenefitSharing.pdf) Accessed August 5, 2015.

Table 4-24 Annual Expenditures of Government DSM Mining Revenue in Cook Islands (in millions USD)

Industry	Amount
Total annual government revenue	$47.0
25% of total	$11.8
Scenario 1	
Health	$3.9
Education	$3.9
Construction	$3.9
Scenario 2	
Income Transfer	$11.8

4.9.3 Model Results

Table 4-25 provides the annual employment, income and value added (GDP) estimates for a DSM operation in the Cook Islands. It is estimated that a total of 80 local jobs will be directly supported by DSM operations. Operational expenditures for goods and services by the mining company will support an additional 65 jobs throughout the country, while household spending resulting from mining operations will support two additional jobs throughout the country. Overall, it is estimated that 147 jobs will be supported by DSM operations each year.

DSM in the Cook Islands is anticipated to provide $2.4 million of income directly to local workers. The mining company's operational expenditures for goods and services will support an additional $0.9 million of income throughout the country, while household spending resulting from mining operations will generate an additional $0.1 million of income throughout the country. In total, it is estimated that $3.4 million in local income will be supported by DSM operations annually.

As previously noted, value added is a measure of the contribution to gross domestic product (GDP) of a proposed enterprise. It is anticipated that DSM operation within the Cook Islands would directly generate $39.3 million in value added and indirectly support $3.7 million of value added each year. Induced value added impacts of the DSM operation would total $0.2 million each year. In all, it is expected that DSM operations would support $43.2 million of GDP each year of operation.

Table 4-25 Annual Mine Operating Impacts for Cook Island DSM Mining (in millions USD)

Impact Type	Direct	Indirect	Induced	Total
Employment	80	65	2	147
Income	$2.4	$0.9	$0.1	$3.4
Value Added (GDP)	$39.3	$3.7	$0.2	$43.2

Totals may not sum due to rounding
Monetary values are in 2015 dollars
Note 1: Based on the average value added per US 'other metal ore' mining employee from IMPLAN model

Under Scenario 1 (Table 4-26), it is assumed the Cook Islands government spends 25% of the government's total resource revenue in three industries; health, education and construction. It is estimated that approximately $1.8 million of income will accrue to Cook Islands' workers directly employed in these the industries receiving government funding. Industries providing goods and services to the health, education and construction sectors are expected to experience increased income of $0.3 million. In total, it is estimated that $2.1 million of income will be generated in the Cook Islands annually using the assumptions in Scenario 1.

This increased income is estimated to support 91 jobs directly and 72 jobs indirectly throughout the country. Increased household spending resulting from government spending will support one additional job throughout the country. Therefore, it is estimated that DSM revenue sharing under Scenario 1 will support a total of 109 local jobs in the Cook Islands each year.

It is anticipated that revenue sharing under Scenario 1 would directly generate $3.4 million in value added and indirectly support $1.0 million of value added each year. Induced value added impacts of Scenario 1 would total $0.1 million each year. In all, it is expected that Scenario 1 revenue sharing would support $4.5 million of GDP in the Cook Islands during each year of operation.

Table 4-26 Scenario 1: Annual Government DSM Royalty Impacts (in millions USD)

Impact Type	Direct	Indirect	Induced	Total
Employment	91	18	1	109
Income	$1.8	$0.3	$0.0	$2.1
Value Added (GDP)	$3.4	$1.0	$0.1	$4.5

Under Scenario 2 (Table 4-27), it is assumed the Cook Island government spends 25% of the government's total resource revenue by distributing it as income to residents. As provided below, this transfer of wealth does not directly support any employment; it is simply a payment to Cook Island residents. However, there is an estimated $0.2 million of income in industries due to increased resident spending. There are an estimated 9 jobs supported due to this increased spending.

Table 4-27 Scenario 2: Annual Government DSM Royalty Impacts (in millions USD)

Impact Type	Direct	Indirect	Induced	Total
Employment	0	0	9	9
Income	$11.8	$0.0	$0.2	$11.9
Value Added (GDP)	$11.8	$0.0	$0.6	$12.3

4.10 Distribution of Costs and Benefits

A CBA is designed to determine whether a project or policy has the potential to make a society better off. A positive net benefit means that the benefits of the project are sufficiently large to allow those who derive a net benefit from the project to compensate all those who experience a net cost; compensation does not actually have to occur, it only has to be possible. In other words, in CBA a positive net benefit does not imply society will be made better off, instead it implies society could be made better off.

In this context policy makers often find it helpful to consider the way in which costs and benefits are distributed among various segments of the population. For instance, policy makers may favour projects or policies that reduce the disparity between the wealthiest and poorest in a society.

In the case of DSM mining the primary benefit to the Cook Islands will be taxes and royalty payments made to the Cook Islands government. With the exception of a relatively modest expenditure on salaries associated with the regulation of DSM mining activity, the government itself would determine the distribution of these funds and/or the benefits derived from associated government expenditures. That is, the Cook Islands government itself will largely determine who benefits from DSM mining activity.

To evaluate the potential effect of distributing government royalties, the regional economic impact analysis considered two scenarios as described in the Section 4.9. Both scenarios assume the government invests the majority of the revenue in a sovereign wealth fund (75%). In the first scenario, the remaining 25% is spent via expansion of government programs. In this scenario, people of Cook Islands benefit through improvements to social programs and the support 91 jobs directly and 72 jobs indirectly throughout the country. In the second scenario, instead of increasing government spending by 25%, the remaining 25% is dispersed to households via direct payments. This reduces the number of jobs supported, but increases the disposable income of the people in the Cook Islands.

The primary costs incurred by Cook Islands citizens would be associated with environmental and cultural externalities.

- Requirements that the DSM mining company clean-up and also compensate for the interim loss of environmental services associated with unplanned releases or grounding would effectively transfer this cost entirely to the DSM mining company.
- A reduction in services provided by the deep-sea sediment habitat, while minor, would be borne relatively evenly among Cook Island citizens.

4.11 Discussion of Results

The CBA provides decision makers with a comprehensive overview of the costs, benefits and risks of DSM mining.

This analysis considered three scenarios: a mining company that sells ore to a processor, a mining company that owns the processing facility, and construction of an on-island processing facility. For each scenario, three processing routes were considered: three-metal, four-metal, and three-metal plus REY.

- Under no set of circumstances considered would the sale of unprocessed ore be sufficiently profitable to attract commercial interest.
- Under no set of circumstances considered would the on-island processing be sufficiently profitable to attract commercial interest.

In a scenario where the miner owns both the mining operation and a four-metal processing facility that recovered Mn, Co, Cu and Ni, there was a reasonable expectation of profits for the mine owner and net social benefit were consistently positive.

- Monte Carlo analysis suggests that, provided the Cook Islands can find a company willing to enter into DSM mining under terms associated with the miner owned four-metal processing scenario, and provided the assumptions and uncertainties specified herein prove accurate, there is a zero probability of DSM mining posing a net cost on Cook Island Citizens based on the assumptions used in this analysis.
- Monte Carlo analysis also suggested that the most important sources of uncertainty relate to (1) the market price of processed metals and (2) the cost effectiveness of ore processing.
- Almost all benefit accruing to the Cook Islands would come in the form of taxes and royalties paid to the government. As such, the government would have the responsibility of determining the distribution of those benefits.
- The costs borne by the citizens of the Cook Islands are small relative to the expected government revenues. Further, these costs would be distributed in a relatively uniform manner across the populace.

5 Cost-Benefit Analysis – Mining Cobalt Rich Crusts in the Republic of Marshall Islands

The Republic of Marshall Islands is located north of Nauru and Kiribati, and south of the U.S. territory of the Wake Islands. The country's population of 52,630 inhabits approximately 24 coral atolls in an area made up of 1,156 islands and inlets.[95] The islands are spread over approximately 2 million km^2 of open ocean that falls within the country's national jurisdiction. The country's ocean boundary, or exclusive economic zone (EEZ), extends 200 nautical miles from the seaward or coastal boundary of the islands. Approximately 50% of the RMI's EEZ borders international waters, while the remaining 50% borders the Pacific Island states of Micronesia, Wake Islands, Nauru and Kiribati (Figure 5-1). Within the EEZ, the RMI has the sovereign rights for exploring, exploiting, conserving, and managing natural resources, whether living or non-living, of the seabed and the subsoil and of the adjacent water with regard to other activities for the economic exploitation and exploration of the zone, such as the production of energy from the water, currents, and winds.[96]

In terms of their economy, RMI is in a free association with the United States, which means that the U.S. supports RMI through subsidies, by providing defence and access to various U.S. Federal agencies. Aid from the U.S. is approximately $70 million annually, and is a large component of RMI's gross domestic product (GDP), which was $190.9 million as of 2013.[97] Outside of foreign aid, GDP consists largely of revenues from the services (87%), industry (10%) and agriculture (4%) sectors.[98] Based on 2011 census data, the industries that employ the largest amount of citizens include the service industry at 73% and the industry and agriculture sectors at 16% and 11% respectively.[99]

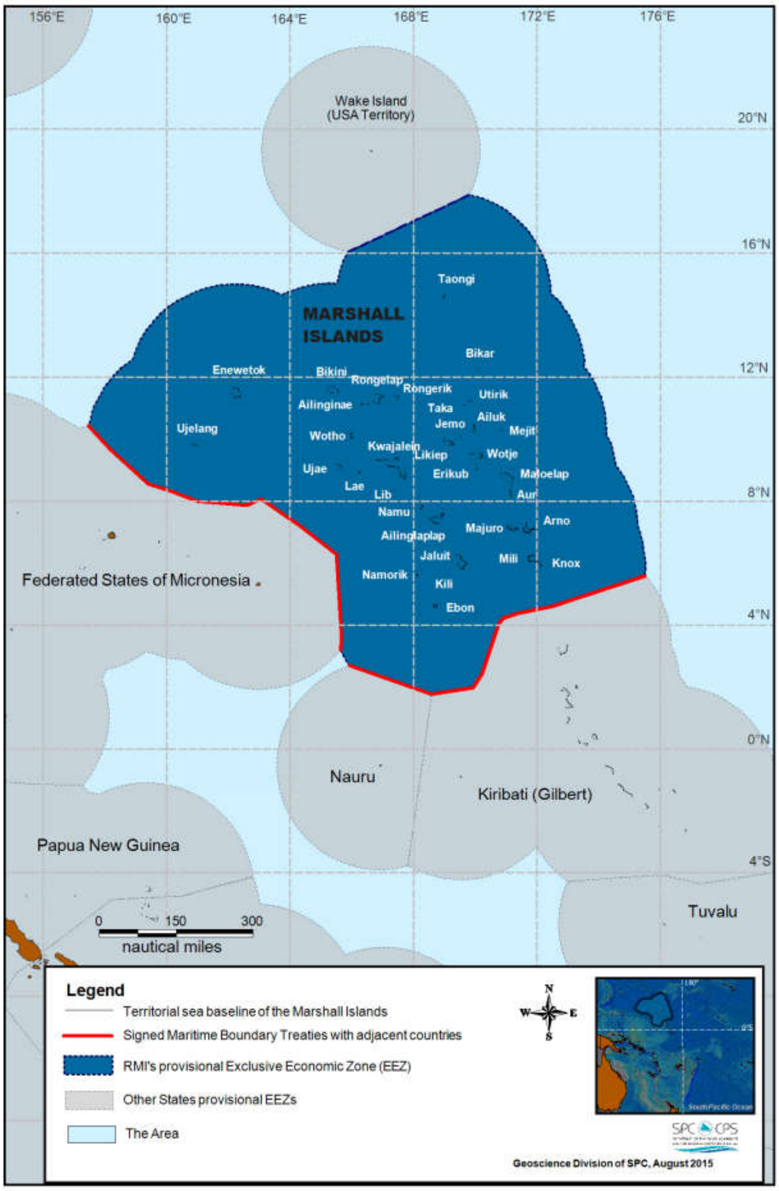
95 http://data.worldbank.org/country/marshall-islands Accessed June 10, 2015

96 http://oceanservice.noaa.gov/facts/eez.html Accessed on May 20, 2015

97 http://data.worldbank.org/indicator/NY.GDP.MKTP.CD Accessed June 10, 2015

98 https://www.cia.gov/library/publications/the-world-factbook/geos/rm.html Accessed October 6, 2015

99 Ibid Accessed June 10, 2015



Source: SPC Geoscience Division, August 2015

Figure 5-1 Map of RMI Exclusive Economic Zone (EEZ)

5.1 Description of the Seabed Mineral Resource

Cobalt-rich ferromanganese crusts occur on nearly all rock surfaces in the world's oceans that have been swept free of sediment by swift currents (Hein et al., 2009). They range in thickness from less than 1 millimetre to over 20 centimetres, forming at depths from 800 to 2,500 metres on the edges of seamounts, knolls, ridges and plateaus (SPC, 2013c). Cobalt-rich crusts are formed when dissolved metal compounds adhere to manganese and iron oxides present in the crusts (SPC, 2013c). This process is very slow, perhaps one of the slowest natural processes on earth, taking tens of millions of years to form crusts thick enough for commercial extraction.

Crusts contain concentrations of common trace metals of economic interest such as cobalt, nickel, manganese and copper. They also include the occurrence of rare metals and rare earth elements such as platinum, tellurium and yttrium. In particular, the grades of metals found in crusts is often orders of magnitudes greater than land based grades and, for rare metals and rare-earth elements, may significantly exceed the entire volume of land based reserves (Hein et al., 2013).

Cobalt-rich crust from the flank of a seamount in the Central Pacific;
Source: http://www.bgr.bund.de/EN/Themen/MarineRohstoffforschung/Tiefseebergbau/tiefseebergbau_inhalt_en.html (Accessed June 10, 2015)

While the crusts cover approximately 2% of the ocean floor, the Central Pacific region, particularly the EEZs around Johnston Island, Hawaii, RMI, the Federated States of Micronesia, and international waters in the mid-Pacific offer the greatest potential for crust mining.[100] The primary reason these areas have the highest potential for crust mining is that they all share similar environmental conditions:

> Constant and swift flow of Antarctic bottom water that flushes away the sediment particles that would otherwise prevent the formation of the manganese and iron oxides,

> Low rates of sedimentation that also keep the crusts from getting covered too quickly, and

> Moderate productivity in the surface water to provide the organic material that serves as the basis of the growth process.[101]

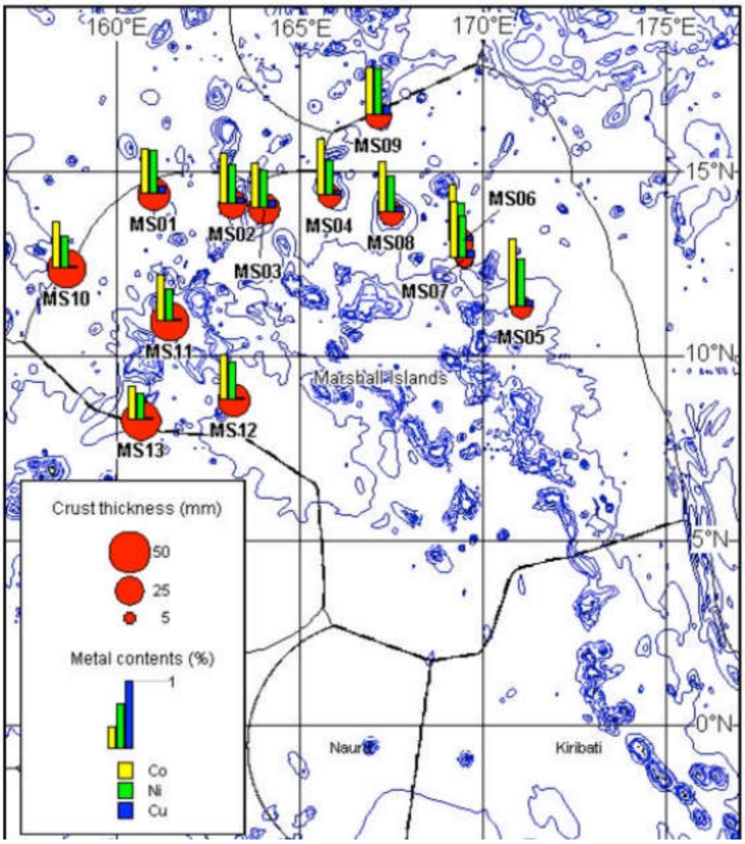
5.1.1 Republic of Marshall Island Crust Abundance

Within the RMI EEZ, there are two distinct seamount chains: the Ralik Seamount chain in the west, and the Ratak Seamount chain in the east. The only known resource assessments of the seamount chains in RMI are from the Korea Ocean Research and Development Institute (KORDI) and United States Geological Survey (USGS) investigation in 1989, and three joint Japan-SPC cooperative surveys in 1996,1998 and 2002. These surveys produced estimates of the crust resource for a total of 13 different seamounts (MS01 through MS13) as shown in Figure 5.2. In general, the results indicated that seamounts in the western side had the thickest crusts (MS10 through MS13), while seamounts in the east have higher metal grades (MS01 through MS09). The results of the 1996 and 1998 surveys revealed a total estimated inferred resource potential is approximately 186 million tonnes of crust for all 13 seamounts (SPC, 2013). The 2002 survey produced a revised estimate based on advances in surveying techniques, revealing that the actual inferred resource potential for seamounts MS01, MS11 and MS12

[100] https://www.isa.org.jm/files/documents/EN/Brochures/ENG9.pdf Accessed June 10, 2015

[101] Ibid

alone was approximately 261 million tonnes (SPC, 2013). Based on these assessments, it is likely that the initial location for commercial exploration and mining will occur in the north/northwest corridor, within the Ralik seamount chain.



Source: SPC, Information Brochure 12, Republic of the Marshall Islands Deep-Sea Minerals Potential

Figure 5-2 Location, Thickness and Metal Contents of Seamounts within RMI Exclusive Economic Zone

5.1.2 Composition of Republic of Marshall Island Crusts

The composition of RMI crusts varies by seamount location (Table 5-1). The CBA uses the metal grades in the seamounts that represent the greatest potential for commercial interest (MS01, MS11 and MS12).

- Based on the 2002 Japan-SPC survey, MS01 has the highest average metal grade in all metal of interest, except Cobalt (0.44%).
- Copper concentration ranges from a high of 0.12% in MS01 and MS11 to a low of 0.05% MS12.
- Cobalt concentrations generally range between 0.34% and 0.46%.
- Nickel concentrations are range between a high of 0.65% in the MS01 to a low of 0.39% in MS11.

In addition to these more common metals, the 2002 survey produced an estimate of the average concentration of platinum in parts per million (ppm).

> On average, the RMI crusts contain platinum concentrations as high as 0.87 ppm and as low as 0.38. This is still significant compared to land-based deposits.

Table 5-1 Average Metal Grade in RMI Crusts by Seamount

Seamount	Average Grade[1]			
	Cobalt	Nickel	Copper	Platinum (ppm)
MS01	0.44%	0.65%	0.12%	0.87
MS11	0.34%	0.39%	0.12%	0.38
MS12	0.46%	0.57%	0.05%	0.40

Note 1: Values reported are the most recent estimates from the 2002 surveys. Further exploration and survey may identify additional seamounts that are suitable for DSM activities.

5.2 Current Status of DSM Policy and Legislation

The RMI government is currently in the process of drafting and approving a national deep-sea minerals policy and seabed management bill that will form the regulatory and legislative framework that will shape the future of DSM activities. The formation of the policy and legislation has been driven by the National Seabed Minerals Management Board, a multi-agency board of stakeholders, and supported by the SPC-European Union Deep-sea Minerals (DSM) Project. It is likely that both the legislation and policy will be established in early 2016. Subsequent to this, any applications for exploration or extraction of DSM would be assessed and approved in accordance with these structures.

RMI has not issued any commercial exploration licenses (the scientific exploration undertaken as detailed in Section 5.1.2 was approved by the government) or extraction permits to date. Similarly, it is understood that RMI does not currently intend to issue any such licenses until the appropriate regulatory and legal frameworks are established. Due to the unique nature of land resources (i.e. an atoll with constrained developable land areas), no large-scale resource extraction projects have been undertaken in country and current legislation does not consider the regulation of such activities in detail. The RMI Environmental Protection Authority (EPA) would be responsible to the issue of environmental approvals and ensuring on-going environmental performance of any DSM activities. However, it is likely that the EPA would need to seek external advice to aid in the identification and assessment of the unique impacts associated with DSM activities.

The RMI government is working with the SPC-EU DSM Project to establish an adequate regulatory framework that aims to:

> Permit and encourage DSM exploration within the RMI EEZ,

> Provide confidence to potential investors as to associated processes and requirements,

> Facilitate assessment of impacts and issue of approvals, where appropriate, for exploration and extraction activities,

> Provide legal and financial assurance that unplanned environmental or social costs are recoverable,

> Seek to avoid, minimise and mitigate potential adverse impacts to the environment and society, and

> Ensure all project stakeholders receive a transparent and appropriate distribution of project benefits.

There are a myriad of ways, structures, policies and agreements that a government may adopt to achieve these purposes. For the purposes of this economic analysis, it has been assumed that adequate regulation and policy structures (in some form) are in place within the RMI. Consistent with best practice recommendations of SPC, this assumption includes, amongst others:

> A requirement for operators to hold sufficient insurance or funds to cover the costs of unplanned environmental or social damages that may arise during activities – for the purpose of the economic assessment, the risk of such damages were costed through insurance operating costs,

> A fiscal policy in which the national government receives and co-ordinates all monetary and non-monetary benefits (e.g. a DSM activity proponent may agree to assist in construction of roads, bridges, water supply programs) and the basis and magnitude of all such benefits, and

> A fiscal policy under which the national government transparently distributes appropriate financial benefits to project stakeholders.

Full details of the associated assumptions for the CBA (e.g. royalty structure, stakeholder distribution, etc.) are provided in Section 5.6. Where possible, assumptions made have been consistent with those adopted for the Cook Islands and Papua New Guinea to facilitate comparison between the three scenarios.

5.3 Description of the Baseline Scenario

This section describes the state of the RMI in the absence of DSM mining. In other words, it describes the counterfactual (the “Do-Nothing” scenario) to which the proposed project will be compared. The CBA determines, quantifies and monetises, to the extent practical, any changes to these baseline conditions that may result from the practice of DSM mining within the RMI EEZ.

For the purposes of the CBA in RMI, the baseline discussion focuses on the deep-sea environment, fisheries, and environmentally based tourism, income and employment statistics, and various cultural norms.

5.3.1 Deep-sea Environment

Sea-mounts are highly variable environments, with CRCs occurring at depths from 800 metres to 2,500 metres. The varying physical conditions at each sea-mount affect the biological distribution of sessile, benthic, demersal, reef or pelagic species. In general, CRCs tend to occur on sea-mounts with little sediment, and the habitat and fauna tend to be typical of rock-substrate environments. Studies to date have shown high similarity in faunal assemblages between CRC substrate sea-mounts and other non-CRC rock substrate locations (SPC, 2013c). This may suggest that the crusts themselves do not develop unique biotas.

Seamount biological communities are characterised by relatively low density and low diversity where the crusts are thickest and cobalt-rich. This occurs because the low oxygen contents in the oxygen minimum zone (OMZ) decrease the abundance of consumer populations, excludes most tolerant species from seafloor habitats, and can produce steep gradients in seafloor communities (Hein, 2004).

5.3.2 Fisheries

RMI has a commercial fishery that is dominated by a purse seine fishery for skipjack, yellow-fin and big-eye tuna. It also has a small long-line fishery for yellow-fin and big-eye tuna. Table 5-2 shows the historical catch (in metric tonnes) for each of the fisheries. These numbers are for catch totals within the he Western and Central Pacific Fisheries Commission Convention Area (WCPFC-CA), which includes the RMI EEZ, as well as vessels flagged by RMI, fishing in waters outside of the RMI EEZ. In 2013, the total domestic catch (by domestic and international vessels) within the RMI EEZ was approximately 33,637 metric tons. The annual contribution of the fishery in RMI to GDP is approximately $24 million (USD) per year.

Table 5-2 Annual Catch by RMI Vessels (in metric tonnes) from 2011-2013

Species	2011		2012		2013
	Purse Seine	Long-line	Purse Seine	Long-line	Purse Seine and Long-line Combined
Skipjack	73,054	0	63,277	0	70,688
Yellow-fin	6,214	99	7,904	113	5,478
Big-eye	1,827	259	776	335	1,595
Total	81,095	358	71,957	448	77,761

In general, commercial fishing is of high importance within Majuro, where it is estimated that that approximately 10% of the working population are involved within the fishing industry in some manner. This is equivalent to one individual in every two household involved in the fishing industry. It is noted that the importance of commercial fishing varies between atolls within RMI, where the outer atolls have a greater reliance upon other industries such as copra and handicraft production, and undertake more active artisanal fishing activities. Further, the fishing industry employs a proportionately high number of women workers (particularly within tuna canning and loining operations) than other industries.

5.3.3 Tourism

Tourism represents a small portion of the economic activity within RMI (the accommodation industry represents 1.7% of GDP). On average, RMI receives approximately 4,500 visitors per year, of which 37% are for business. Recreation tourism comprises approximately 15% of tourist activity (EPPSO, 2013). Most tourists arrive by air into Majuro (one or two cruise vessel make port at Majuro each year). Recreational tourism is generally based on the natural coastal resources of RMI (beaches, diving, surfing etc.). Consultation with the RMI Office of Commerce and Investment indicates that tourism growth is a priority for RMI and several tourism enhancement projects are in place. It is considered likely that tourism will play a significant role in the RMI economy into the future.

5.3.4 Distribution of Income and Employment

The 2011 census revealed that the median annual household income in RMI is $6,476 USD, down from the $6,840 (USD) reported in the 1999 census. The median annual household income varies widely by atoll/island. In Ebon, Jabat, Lae and Mili it is almost nil, and Aur, Likiep, Mejit and Namdrik reported a median annual household income of less than $1,000 (USD). Kwajalein reported the highest median annual household income ($11,640 USD), followed by Majuro ($9,400 USD). Two other atolls/ islands with a median annual household income higher than the national figure are Enewetak ($6,857 USD) and Kili ($6,727 USD) (SPC, 2012).

As shown in Table 5-3, the private sector and the RMI government are the two sectors employing the largest number of full-time and part-time workers in RMI, representing 63% of the total number of workers in 2013.

Table 5-3 Employment by Institutional Sector in RMI – Number of workers (full-time and part-time)[1]

Sector	2011	2012	2013
Private Sector	4,317	4,276	4,238
Public Enterprise	846	824	820
Banks	202	214	208
RMI Government	2,420	2,440	2,482
Government Agencies	599	639	616
Local Government	938	1000	997
NGO's and Non-Profits	376	384	360
Households	~	~	~
Foreign Embassies	39	40	41
Kwajalein US Base	933	890	904
Total	10,670	10,707	10,666
Note 1: Source: FY2013 Statistical Compendium, RMI			

5.3.5 Perspective of Traditional Leaders

Consultation with stakeholders identified that there are significant complexities in the traditional and governmental land ownership and authority responsibilities. Traditional ownership is taken to extend beyond the shoreline and includes seabed and sub-sea ownership. Traditional boundaries are generally determined on the visual extent of land/sea to the community in question, often exceeding the legislated boundary of local governments. In general, land within RMI is not sold in perpetuity to new owners, but rather leased for extended periods (e.g. 99 years).

5.4 Republic of Marshall Islands Mining Scenario

This section defines the scope of the hypothetical DSM mining project for RMI. It includes a description of the size, duration, and approximate location of the mining operation as well as the total estimated resource potential and the expected metal content in the nodules. This section also includes a description of the current capacity of the port system in RMI, and the anticipated utilisation of that system.

5.4.1 Description of RMI Mining Scenario

Hein et al., 2009, developed a “mine-site” model that identifies sub-blocks or mine-sites on a single seamount. In the RMI scenario, a private DSM mining company moves from mine site to mine site on a single seamount (RMI MS01) over the duration of 20-year commercial mining operation. As previously described, this sea-mount, whose location is depicted in Figure 5-3, has the highest average grade of the elements of economic interest including platinum. .

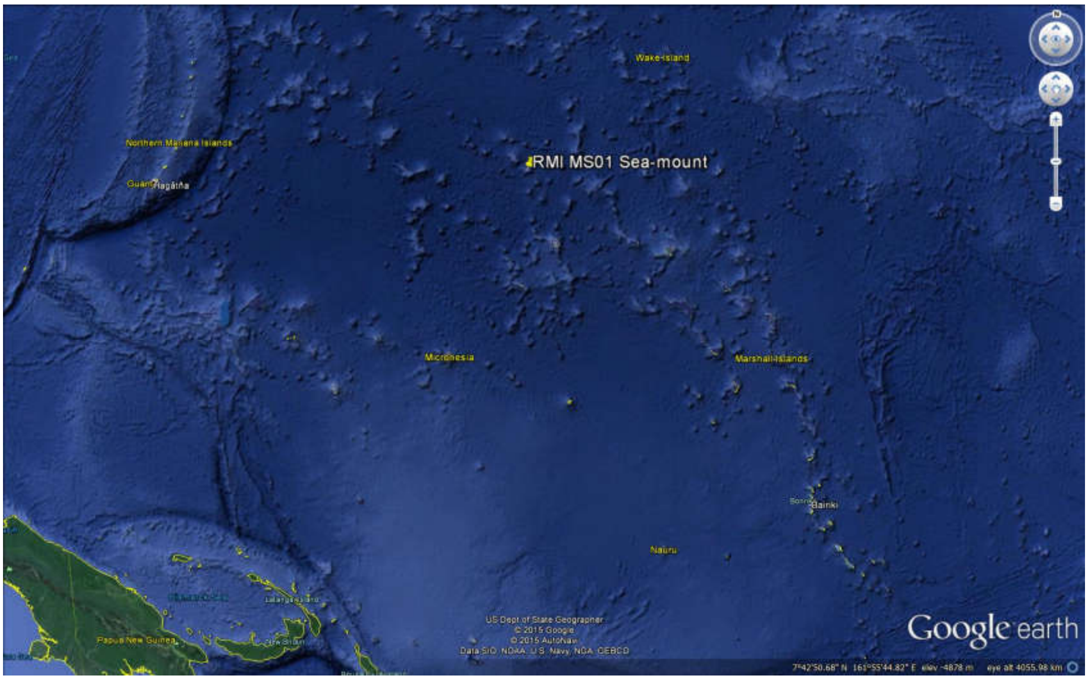


Figure 5-3 Location of RMI Mine Site

The 20 year mining footprint covers 470 km^2. Only a fraction of the total footprint will be mined each year yielding 670 thousand dry tonnes of crusts annually, or 12 million tonnes over the course of the 20 year commercial operation.[102] These basic inputs are summarised in Table 5-4.

[102] http://www.isa.org.jm/files/documents/EN/Workshops/Jul06/WSsum-ae.pdf (Accessed June 10, 2015)

Table 5-4 Assumptions Used in RMI Mining Scenario

Characteristics	Assumptions Used
Total minable area	470 km^2
Distance to nearest land	320 km
Depth	1,040 m (top of seamount) 1,600 m (lowest extent of resource)
Average crust thickness	59 mm
Total estimated resource in tonnes (wet)	55,000,000
Annual estimated resource potential in tonnes (wet)	1,000,000
Annual estimated resource potential in tonnes (dry)	670,000
Duration of commercial mining operation	20 years
Excavation efficiency	70%
Nearest processing facility	Shanghai (6000 km)
Metallurgic processing	> Assume three-metal processing using smelting and chloride leach

Dry tonnage by element is derived from the SPC Information Brochure 12 on the deep-sea minerals potential of RMI and summarised in Table 5-5. Note that the tonnage from the SPC factsheet is based on the resource as it is on the seafloor. The potential yields, also reported in Table 5-5, assume variations in metal grades, collection efficiency ranges from 70% to 90%, and additional loss occurring during the metallurgy process.[103]

Table 5-5 Total Estimated Dry Tonnage by Element for Duration (20 years) of RMI Mining Scenario (in tonnes)

Mineral Element	Value from SPC (2013)[1]	Minimum	Most Likely	Maximum
Cobalt	37,713	24,669	37,713	51,301
Copper	10,876	6,885	10,876	18,464
Nickel	53,675	33,281	53,675	78,599
Platinum	7	5	7	9
Note 1: The CBA uses the average metal grade from the 2013 SPC brochure and apply them to the total annual estimated dry tonnage of 670,000 from the ISA report.				

[103] The technology for extracting metals from crusts has been proposed and tested on a small scale, but is yet to be proven on a commercial scale. (See Section 5-5). As such, there is a great deal of uncertainty around potential yields..

5.4.2 Ports and Logistics

The Port of Majuro is RMI's only port large enough to support the types of vessels that would be involved in DSM mining. It is the primary gateway for incoming cargo that supports the people of RMI through the delivery of food and supplies via international cargo vessels. It currently receives one freight ship twice a month, and has limited storage availability on site. The port facilities are being upgraded and would be large enough to handle mining vessels

The CBA assumes that foreign workers will fly in and fly out (FIFO) of Majuro where they would then be transported via supply boat to the main mining vessel. This may require a 1-2 night stay in Majuro before transfer to the mining vessel. Unless a processing facility was located on-island, mining and ore transport vessels are not assumed to use the port.

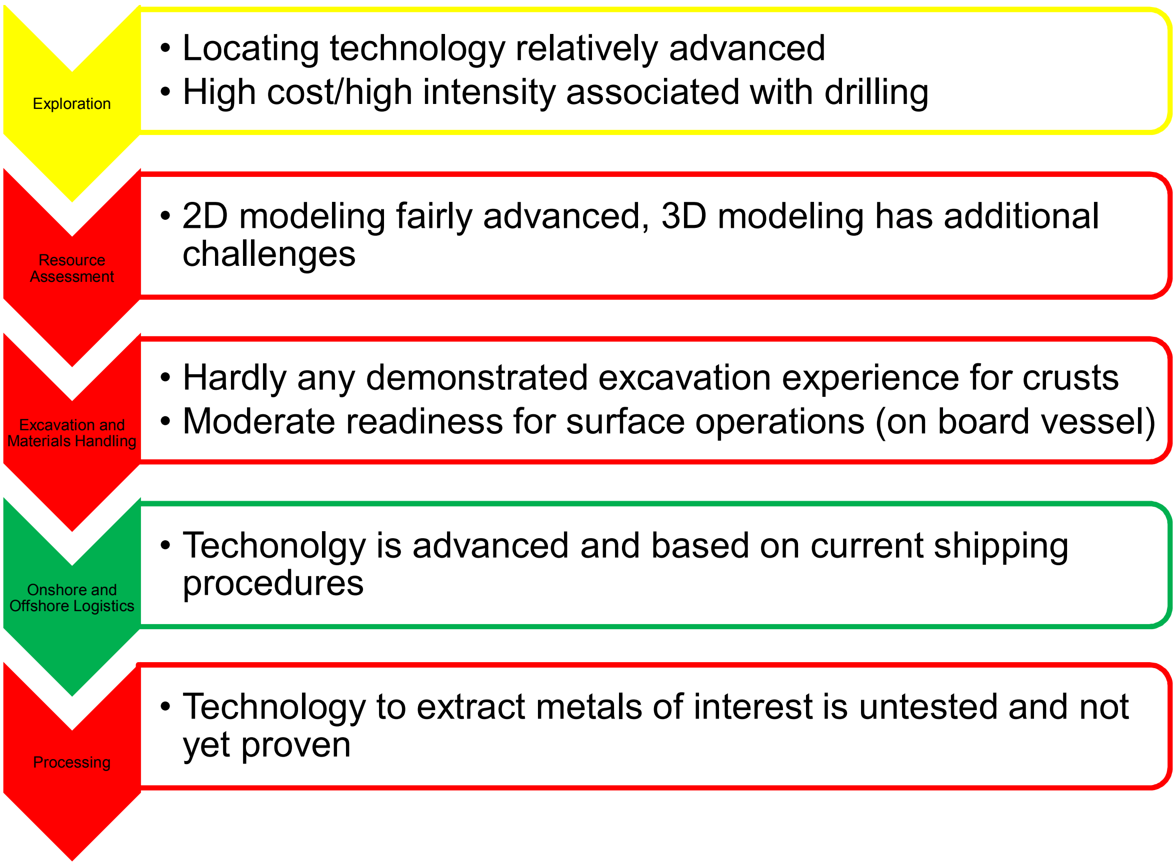
5.5 Cost Methodology

As described in Section 2.3.2, the CBA quantifies and monetises both the private and environmental costs of a single DSM mining operation. This section begins with a brief discussion of the status of the current technology in each phase of the DSM mining process followed by a description of the proposed engineering system.

5.5.1 Status of Current Crust Mining Technology

Two of the key factors determining crust mining feasibility are the availability and cost of the technology needed to extract, transport, and process the raw ore at a commercial scale.

Since mining of DSM has yet to commence anywhere in the world, the technology required to extract and lift the raw ore has not been proven in a commercial operation. Figure 5-4 identifies each step in the mining value chain for cobalt-rich crusts and describes the readiness of the associated technology. Red indicates a low to very low level of readiness, yellow a moderate level of readiness, and green a high level of technological readiness.



Source: ECORYS, 2014

Figure 5-4 Assessment of Technology Readiness in Cobalt-Rich Crust Mining Value Chain

As shown in Figure 5-4, the majority of the technology required in each phase of the crust mining value chain is at a moderate to low level of technological advancement. The largest technological uncertainties relate to the development of the technology required to excavate the raw ore. As discussed in the following section, the excavation of crusts requires the use of a cutter similar to what is used in the extraction of seafloor massive sulphides; however, the technology has yet to be applied to crusts.

While vertical transport technology currently exists in the offshore oil and gas industry, it has yet to be tested with ore, so there could be potential issues with clogging and wear on the system that is not accounted for in traditional oil and gas applications.

Surface operations like dewatering are relatively straightforward and would only require demonstration aboard the support vessel. Similarly, the technology for offshore and onshore logistics of transporting and storing the raw materials is advanced.

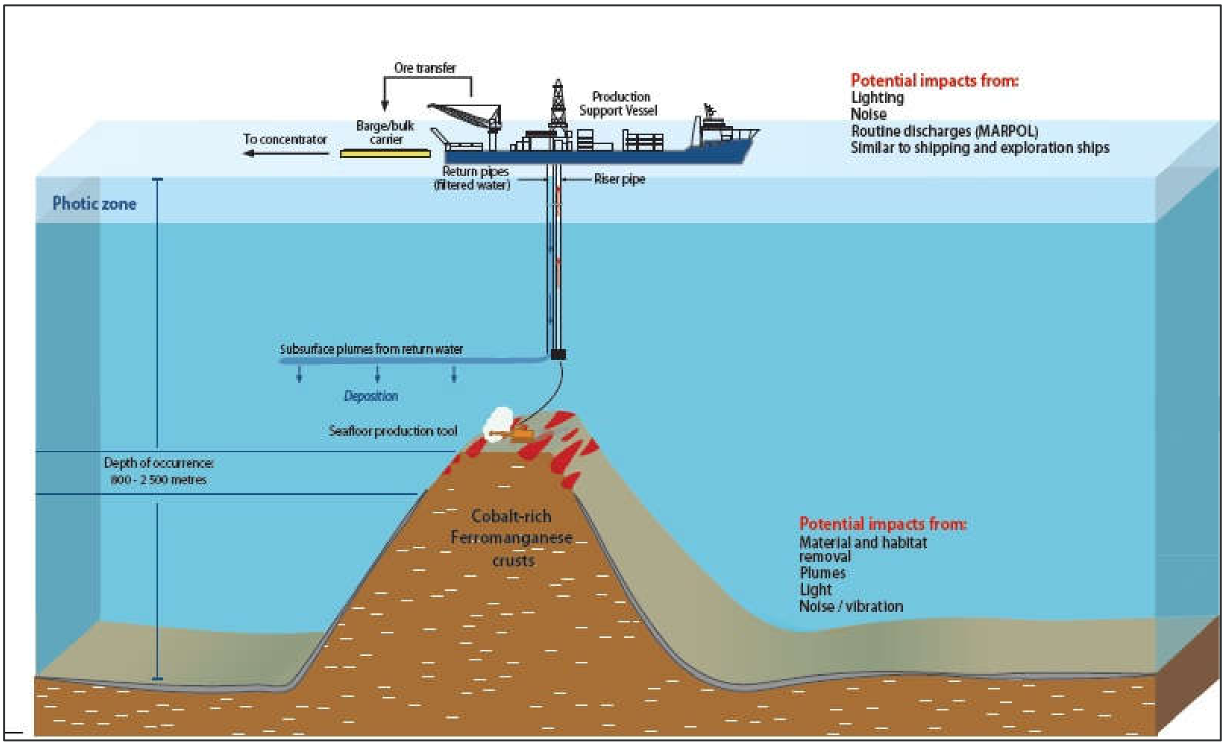
Crust processing is still in its infancy. Methods have been tested on a small scale but are yet to be proven on a larger scale.

5.5.2 Proposed Crust Mining System

The components of a crust mining system are similar to the components of a seafloor massive sulphide mining system. However, the variable crust thickness and seamount complicate remote operation of collection tools and poses significant engineering challenges.

At this time, the majority of crust mining technology is being developed in China, Russia and Japan and is proprietary. As such, the CBA uses literature-based information that is approximately 8-10 years old and ground truths that data against the equipment and technology used in the mining of seafloor massive sulphides.

Outside the crust excavation technology, the components of the mining system correspond to those identified for seafloor massive sulphides and nodules. At the centre of the operation is a production support vessel (PSV) that supports the surface and sub-surface seafloor operations. The PSV is connected to the seafloor production tools, which in the case of crusts, uses cutters to excavate the hard seabed rock in which the metal ores are found. The extracted ore is transported up the riser to the PSV where they undergo several pre-processing steps. Water from the pre-processing steps is transported back down the riser to be discharged near the top of the sea-mount. The pre-processed ore is transferred to a shuttle barge which takes them to a processing facility. Figure 5-5 illustrates the crust mining system envisioned in this CBA.

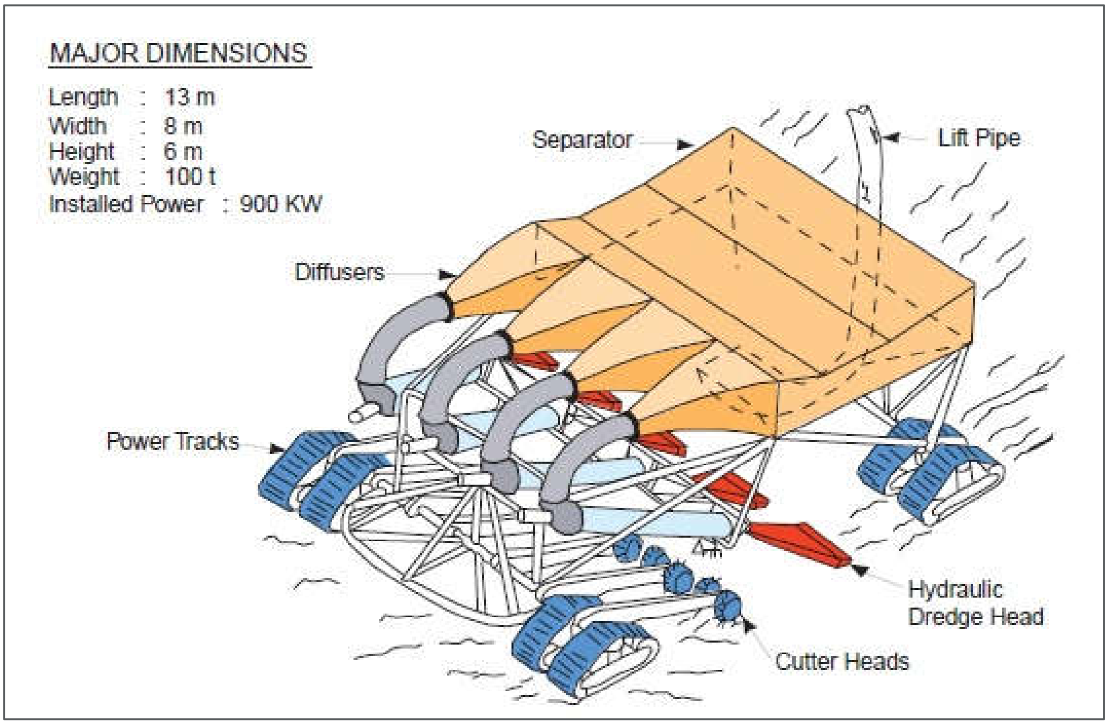


Source: SPC, 2013c

Figure 5-5 Proposed Mining System for Cobalt-Rich Crusts

5.5.2.1 Cutter System

In contrast to nodules which sit on soft-sediment substrate, crusts adhere to the underlying rocky substrate. This adherence necessitates the use of a self-propelled bottom-crawling vehicle (See Figure 5-6) that has pronounced cutters to fragment and loosen the crust while minimising the amount of substrate rock collected (Hein, 2004). The cutting system would likely employ a hydraulic lift system that uses a ramp-like device to transport and clean the ore before introducing it into the riser system. The cutting system would likely employ a hydraulic lift system that uses a ramp-like device to transport and clean the ore before introducing it into the riser system.



Source: Hein, 2004

Figure 5-6 Proposed Cutting Tool for Crust Mining

5.5.2.2 Riser System

The riser system transports the mined slurry to the PSV and return water (after the ore has been removed) back near the seafloor. The design of the riser system is based off of technology currently employed in the oil and gas industry known as a fully enclosed riser and lifting system (RALS).

5.5.2.3 Surface Operations

Ore is dewatered and dried before being transferred to a transport vessel[104]. After dewatering, the dry ore is transferred to the shuttle barge and transported to the closest coastal port with a processing facility. For RMI, this will most likely be China.

5.5.2.4 Onshore Processing

Once raw ore has been transported to an onshore facility, processing generally includes:

- Grinding raw ore to reduce the size of the ore particles and expose the mineral,
- Separating of the mineral from the ore,
- Recovering and purifying the metal, and
- Disposing of waste.

[104] It is possible that the crusts would be separated from any waste rock prior to transfer. During this process, referred to as ore dressing, the mined product is crushed and mineral particles are floated away. If ore dressing did occur at-sea, tailings or waste rock may be deposited into the water column at the surface. On-board ore-dressing is not considered in this CBA.

The literature describing the specific metallurgic processing of cobalt rich crusts is sparse. Yamazaki (2006), noted that crusts and nodules share the same mineral properties (both are ferromanganese oxides) and therefore would likely undergo similar processing routes (Section 4.5.2.4 provides a detailed overview of these routes). Yamazaki (2006) went on to identify smelting and chlorine leaching as a potentially preferred method for the metallurgic processing of crusts. Much like the three-metal recovery process for nodules, this would recover cobalt, nickel and copper only, leaving out platinum.

5.5.3 Private Costs

This section describes the quantification and monetisation of private costs. These include:

- Costs incurred by the government (a willing participant in the mining operation), and
- Capital and operating costs associated with each phase of the crust mining operation.[105]

5.5.3.1 Administrative Costs to the Government

As noted in Section 5.2, the RMI government is currently in the process of drafting and approving a national deep-sea minerals policy and seabed management bill that will form the regulatory and legislative framework guiding DSM activities. These activities come at a cost to the government and ultimately the people of RMI.

For the purposes of the CBA, the following costing assumptions are made:

1. The development of the initial laws and policies governing seabed mining require a onetime expenditure of $2,000,000[106] in the years prior to the onset of DSM activity. It is assumed that, in time, there will be three single mine sites that use the framework.[107] As such, the onetime cost of legal framework development associated with this project $667,000 USD).
2. Costs associated with monitoring and reporting of DSM activity associated with a single mining operation assumes the Cook Island government will employ six full-time equivalent workers to provide constant monitoring of DSM activities.[108]
   - *$120,000 annually (salaries, benefits, overhead)*
3. Collection and distribution of DSM related payments requires one full time equivalent[109]
   - *$50,000 annually (salary, benefits, overhead)*

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105 While the DSM mining company does not have standing, capital and operating costs are estimated because they are key factors determining the economic feasibility of DSM mining

106 In the U.S., an Environmental Impact Statement (EIS) for a small project includes a review of engineering, impacts to all natural resources including socioeconomic resources, public meetings to discuss and solicit input, and review of applicable laws will cost 3 to 5 million. While the U.S. cost structure is much higher, the regulatory framework discussed here is applied to a new technology so the efficiencies associated with prior learning are very low. This figure is also supported by the estimated annual budget of the SBMA of NZ$400,000/year based on personal communication with stakeholders in the Cook Island. Since the analysis did not have data specific to RMI, the study assumes the data obtained in the Cook Islands is a reasonable substitute.

107 This figured is derived by assuming the three seamounts with the greatest potential for mining will be mined in the 20 year timeframe).

108 Assuming mining is a 24/300 operation and allowing for 30% of a monitors time to be spent on administrative duties and travel, 6 workers are required to ensure 100% at-sea coverage.

109 Even without onshore processing, DSM mining would be a large part of the economy. This is a fairly skilled employee who makes sure payments are received in a timely manner and funds are dispersed to residents in a manner consistent with laws and policies. It is envisioned as a full-time position with a salary bracket in the top 10% of income distributions.

4. Contract Administration requires one full time equivalents.[110]
   - *$35,000 annually (salary, benefits, overhead)*

The one-time cost of $667,000 (USD) for the mining operation's share of the cost to establish and develop the regulatory framework plus the annual salaries for reporting, monitoring, fiscal arrangements, and contract administration results in an amortised annual amount of $267,960 (USD).[111] Discounted at 7% to place future costs into today's dollars brings this amount to a total of $2.8 million (USD) over the course of the 20-year mining operation.

5.5.3.2 Costs Incurred by Foreign Owned Mining Companies

Phase-specific costs for the RMI mining scenario are based on crust mining feasibility studies developed for coastal Japan, and the SRK Consulting (2010) cost assessment of seafloor massive sulphide mining.

5.5.3.2.1 Exploration Costs

The exploration costs associated with deep-sea minerals include the investment in capital equipment to locate and assess the characteristics of mineral deposits. Additionally, labour in the form of research and analysis is required to process the deposits collected and assess the feasibility of the mining operation. Crust exploration typically involves the following activities:

- Continuous mapping of sea-mounts using echo sounders, sonar, and seismic systems,
- Systematic sampling using dredging and corers,
- Bottom video and topography assessments,
- Water column sampling,
- Geotechnical studies to feed into engineering design for mining technology,
- Calculating the size and grade of the resource, and
- Carrying out environmental baseline studies and impact assessments (Hein, 2004).

Given the limited exploration that has occurred within RMI, a relatively long exploration period of 10 years is assumed. Exploration processes and costs (exploration leases, charter hire, feasibility studies, bathymetry, sampling, and environmental impact assessment) were adapted from the Nautilus Solwara 1 exploration phase[112] and estimated to be $10 million (USD) over 10 years. This is deemed as the "most likely" value with an assumed range around this estimate (plus or minus 20%) in order to incorporate uncertainty.

5.5.3.2.2 Capital Expenditures

The primary capital expenditures are associated with mining equipment, support vessel, and transport vessels. If a processing plant were constructed, this would also represent a sizable capital expenditure.

110 This is a junior responsible for monitoring contractor performance for compliance with applicable laws, delivery schedules, payment provisions, inspections, contract and date reporting requirements. The reduced salary, relative to the position responsible for DSM related payments, is commensurate with this more junior position..

111 The ammortisation formula for calculating annual costs is: $C_t * \frac{r*(1+r)^n}{(1+r)^{n-1}} + OM_a$ where C_t is the fixed cost (667,000), *r* is the discount rate (7%), *n* is the number of years (20), and OM_a is the annual operating and maintenance cost ($120,000 + $50,0000 + $35,000).

112 Given the logistical challenges associated with the RMI location exploration costs may exceed those incurred by Nautilus.

Table 5-6 provides capital cost estimates form the two existing crust mining studies as well as capital costs from the somewhat similar Solwara 1 operation in PNG.

Table 5-6 Summary of Capital Costs for Crust Mining (indexed to 2014 PPI, in millions USD)

Study and Year	Mining equipment and support vessel	Transportation (purchase of ore transfer vessels)	Processing facility	Estimated dry tonnes/year
Nautilus, 2009	$413	$12[1]	N/A	N/A
Goto et al., 2009	$462	$57	$516 million	500,000
Yamazaki, 2006	$115	$51	$242 million	500,000
Average	**$330**	**$54[2]**	**$379 million**	-

Note 1: Assumes that export vessels are bought used rather than brand new.
Note 2: Excludes Nautilus cost since it does not include purchase of barges

The CBA uses average costs from Table 5-6 to generate point estimates and establishes a distribution around the average costs to evaluate the effects of uncertainty using Monte Carlo methods. In this case, distributions are defined by the minimum, maximum and most likely, which is based on the average values reported in Table 5-6. The minimum and maximum values come from the low and high values reported in Table 5-6.

5.5.3.2.3 Operating and Maintenance Costs

The primary operating and maintenance costs are associated with fuelling the mining operation and providing the labour necessary to conduct maintenance and operations.

Table 5-7 provides operating and maintenance cost estimates form the two existing crust mining studies as well as capital costs from the somewhat similar Solwara 1 operation in PNG.

Table 5-7 Summary of Operating and Maintenance Costs for Crust Mining (indexed to 2014 PPI, in millions USD)

Study and Year	Mining equipment and support vessel	Transportation	Processing facility
Nautilus, 2009	$61.2	$41.8	N/A
Goto et al., 2009	$64	$22	$62
Yamazaki, 2006	$33	$18	$32
Average	**$53**	**$27**	**$47**

The CBA uses average costs from Table 5-7 to generate point estimates and establishes a distribution around the average costs to evaluate the effects of uncertainty using Monte Carlo methods. As was the case with capital costs, distributions are defined by the minimum, maximum, and average values reported in Table 5-7. The minimum and maximum values come from the low and high values reported in Table 5-7.

5.5.4 Environmental Costs

As described in Section 2.3, the goal is to monetise environmental costs associated with DSM mining activities in RMI. The following text describes how this was done.

5.5.4.1 Cost of Offsetting CO_2 Emissions

As described in Section 2.3.2, the approach to quantifying and monetising CO_2 emissions is to 1) estimate the total amount of carbon (in tonnes) that is emitted by the operation of a single mine, and 2) estimate the average cost to the DSM mining company to offset these emissions.[113] In this approach, the cost of the carbon offsets are treated as a private cost to the mining company, thus shifting the burden from host country residents to the DSM mining company. The operation of a DSM mine is likely to contribute to increases in CO_2 in the following ways:

- Through emissions associated with vessels transporting ore to a destination port,
- Through the transport of personnel and supplies via supply boats, and
- Through emissions associated with the power generation unit on board the production support vessel.

CO_2 emissions based on the transport of ore are calculated by:

- Estimating total distance travelled (in nautical miles) from the mine site to a processing facility in Mexico (if processing overseas) or to the closest island (if processing onshore) and the estimated tonnage per nautical mile based on the maximum capacity of a freight vessel per trip,
- Multiplying the tonnage transported per nautical mile for the entire year by the tonnes of CO_2 emitted per tonne, and
- Multiplying the total tonnes/year of CO_2 emissions by the per tonne CO_2 offset.

Table 5-8 reports the inputs used to calculate CO_2 offset costs related to transportation.

Table 5-8 Inputs Used to Calculate CO_2 Offset Costs Related to Transportation

Input	Assumption
Annual extraction (dry tonnes)	670,000
Freight vessel capacity (tonnes)	25,000
Trips per year (including return trip)	53
Estimated distance to nearest processing facility	5,000 km
Total distance travelled in nautical miles	144,708
CO_2 emissions (tonnes/year)	18,089
Cost of Carbon Offset (USD/tonne)	$5.8[1]

[113] As discussed in Section 2.3.2, a complete CO_2 valuation requires an understanding of the effect of DSM activity on global metals production. Because an analysis of the global metals markets and facility-specific carbon footprints is beyond the scope of this report, it is assumed that the host countries take a precautionary approach to CO_2 emissions and require the purchase of CO_2 offsets by the DSM mining company . This requirement assures DSM activity results in no net increase in CO_2 emissions. This effectively internalizes the potential externality by requiring the DSM mining company to invest in operational technology that eliminates the source of the potential impact.

Input	Assumption
Estimate of Annual Cost to Offset CO_2 emissions	$103,410 (USD)
Note 1: The probability distribution for this input is taken from a report on the State of the Voluntary Carbon Market (low of $3.7, most likely of $5.8, and maximum estimate of $7.4)	

For the transport of personnel and supplies via supply boats, the CBA makes the following assumptions:

> A supply boat will make a run from the mine site to the nearest island (approximately 300 km from mine site, 600 km round trip) once per week. Assuming 300 operating days, this implies 42 trips or total distance of 25,200 km in a year.

> A typical supply boat uses approximately one gallon of fuel per half km travelled, therefore the annual trips made by the supply boats will equate to the use of 50,400 gallons.

> At one tonne of CO_2 per every 100 gallons of fuel, this equates to approximately 504 tonnes/year of CO_2 emissions. At a cost to offset of $5.8/tonne, this adds an additional $3,024 to the total cost of the operation.

In addition to the emissions associated with the transportation of ore, personnel and supplies, emissions are associated with the burning of fuel to operate the support vessel and to generate the power needed to operate the mining equipment. Table 5-9 describes the methods and assumptions used to estimate the cost of offsetting carbon emissions related to the generation of power to operate the mine.

Table 5-9 Inputs Used to Calculate CO_2 Offset Costs Related to Power Generation

Input	Assumption
Fuel usage per operating day	135 tonnes
Fuel usage per year (assuming 250 operating days)	21,840 tonnes
CO_2 emissions (tonnes/year)	69,429
Cost of Carbon Offset (USD/tonne)	$5.81
Estimate of annual cost to offset CO_2 emissions	$369,905 (USD)
Note 1: The probability distribution for this input is taken from a report on the State of the Voluntary Carbon Market (low of $3.7, most likely of $5.8, and maximum estimate of $7.4)	

In total, $0.5 million (USD) would be required annually to offset CO_2 emissions. This figure is entered as a "debit" in the calculation of profits to the mining company.

5.5.4.2 Unplanned Release

In the day-to-day operation of the mine, there is the potential that hazardous materials, such as fuel, may leak or spill from their containment vessels; this risk is elevated during fuel transport and transfer. When spills occur, they impose costs that fall into three broad categories: clean-up costs, environmental costs, and social costs. To determine who would bear these costs (the mine operator or RMI) and how these costs might be quantified, it is necessary to understand RMI's legal framework as it relates to unplanned releases.

The RMI's Civil Liability for Oil Pollution Damage Act 1993 enforces the law of the International Convention on Oil Pollution and Damage within its territorial boundaries. The law ensures that any vessel carrying as cargo more than 2,000 tonnes of oil in bulk will have a valid insurance certificate or other means of financial security prior to entering or departing RMI's EEZ. The act also appears to call for compensation of any clean-up related costs but it is not clear whether the polluter is also liable for the interim loss of ecosystem services from the time of the spill until conditions return to baseline (i.e. environmental costs).

Outside of RMI domestic policy, RMI is also party to the following international conventions: the Civil Liability Convention (CLC), the Fund Convention, and the Bunkers Convention. Under the Fund Convention, compensation above the vessels liability limit may be available from the International Oil Pollution Compensation Funds (IOPC Funds) secretariat based in London. The basic premise of the international policies is to ensure that claimants who have experienced financial loss as a result of an unplanned spill are restored to the same economic condition they would have been in absent the spill. There is not any requirement to compensate the public for any interim loss of ecosystem services nor is there a requirement to compensate individuals for non-economic losses.

Outside of RMI domestic policy, RMI is also party to the following international conventions: the Civil Liability Convention (CLC), the Fund Convention, and the Bunkers Convention. Under the Fund Convention, compensation above the vessels liability limit may be available from the International Oil Pollution Compensation Funds (IOPC Funds) secretariat based in London. The basic premise of the international policies is to ensure that claimants who have experienced financial loss as a result of an unplanned spill are restored to the same economic condition they would have been in absent the spill. There is not any additional requirement to make the public and the environment "whole," such that the emphasis is on compensating the people of society for the loss of goods and services provided by the environment. In other words, admissible claims must be economic in nature (i.e. indicative of a financial loss).

Given this legal context, the CBA assumes that the mining company would be liable for any spill-related clean-up costs and any spill-related financial losses. It is further assumed that these costs are appropriately reflected in the mining companies annual insurance cost of $1 million based on information associated with the Solwara 1 project.

To estimate costs associated with the potential loss of ecosystem services, an expected annual spillage (tonnes) is calculated using spill frequency data from the International Tanker Owners Pollution Federation Limited (ITOPF) and information describing the DSM-related vessel activity and fuel transfer. The expected annual spillage is multiplied by $24,000 per tonne which reflects the cost of compensating the public for ecosystem services lost following a spill as estimated by Kontavas and Psaraftis (2010).

The estimate of annual spillage is based on vessel utilization:

- Three 25,000 dead weight tonne (DWT) handy-size vessels transporting ore from the mine site to the processor,
- One support vessel transferring crew and supplies, and
- One PSV located at the mine site.

To estimate the probability of a spill occurring, the CBA uses data from ITOPF, which reports the total number of small, medium and large spills by tankers, combined carriers and barges over time. According to their 2014 report, the 10-year average number of medium spills (7 to 700 tonnes) is approximately 7 per year. Given that there are approximately 16,000 vessels in the world merchant fleet, this equates to a 0.04% probability of a medium sized spill per vessel (7/16,000). For large spills (> 700 tonnes), the 10-

year average is approximately 3 per year, or a 0.02% probability of a spill of this magnitude occurring per vessel (3/16,000).[114]

Table 5-10 illustrates the expected spillage assuming the maximum amount of fuel that could be spilled per vessel.

Table 5-10 Estimated Environmental Cost of Unplanned Oil Spill for RMI Mine Operation

Vessel	Total fuel capacity[1] (in tonnes)	Probability of spill	Expected Present Value of Spill Volume (in tonnes)	Total estimated annual cost per vessel (in USD)
PSV	1,192	0.02%	0.23	$5,520
Transport	724 / vessel 2,172 total	0.02%	0.43	$10,320
Crew boat and supplies	351	0.04%	0.14	$3,360
Total	3,715		0.78	$18,720

Note 1: Source: http://www.seacormarine.com/cgi-bin/ourfleet.cgi?type=psv Accessed August 19, 2015

5.5.4.2.1 Unplanned Release Summary

Costs associated with spill clean-up and financial compensation are reflected in the $1 million insurance premium paid by the DSM mining company.

The annual expected cost associated with lost ecological services would be borne by the host country citizens. Those costs calculated as the product of expected annual spillage (0.78 tonnes) by the per tonne cost of compensating the public for ecosystem services lost following a spill ($24,000) are estimated to be $18,720 annually. Discounted at 7% over the course of the 20 year mining operation, the PV of the total estimated cost is $0.2 million (USD).

5.5.4.3 Cost of Discharging Nutrient Rich Water

It is assumed that technological solutions will allow the discharge of the seawater mix to occur in deeper waters, well below the mixed layer and the reach of sunlight in the water column (the so-called 'euphotic zone'), settling below a depth of 1,000 metres or more. Therefore, for the purposes of monetisation, a value of $0 is assigned to this category in terms of a cost to citizens of the citizens of RMI.

5.5.4.4 Valuing the Change in Environmental Services Provided by the Sea-mount

While sea-mounts are highly variable environments, in areas where the crusts are cobalt-rich and thickest biological communities are characterised by a relatively low density of organisms. Species that are observed include sea pens, soft corals, sponges and shrimps. The biological characteristics of many of these species suggest the recovery of sea-mount benthic communities following physical disturbance may be slow. (Hein, 2004; Schlacher et al. 2013).

Table 5-11 identifies and discusses the services provided by sea-mount communities at the RMI mining site. Following convention, services are divided into four broad categories:

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[114] http://www.itopf.com/fileadmin/data/Documents/Company_Lit/Oil_Spill_Stats_2014FINALlowres.pdf Accessed August 17, 2015. It is also noted that in each CBA respectively, the probability of a spill does not change based on site specific conditions. This is because spills are largely due to human error, and there is no evidence to support that the probability of a spill occurring would go up or down based on site specific characteristics.

1. Provisioning services (e.g., material goods such as food, feed, fuel, and fiber) are associated with goods provided directly to people,
2. Regulating services (e.g., climate regulation, flood control, and water purification) control ecosystem processes that influence the well-being of humans,
3. Cultural services generate human well-being outside any direct or indirect consumption of goods. Examples include recreational opportunity and well-being generated by the knowledge an ecosystems exists in a certain state (often called existence or spiritual value), and
4. Supporting services (e.g., nutrient cycling and primary production) generate human well-being by facilitating the production of future provisioning, regulating or cultural services.

For each specific service, the baseline level of ecological service provision is discussed and compared to the level of service provided by more common environments such as forests and wetlands.

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

For each specific service, the sign and magnitude of project related changes are qualitatively evaluated.

- Changes may be positive (the value of service provided increases) or negative.
- A ranking of 1 implies that the change is unlikely to be perceptible by residents of the host country.
- A ranking of 2 implies that the change in the level of service may be perceived by residents of the host country.
- A ranking of 3 implies that the change would most likely by perceived by most host country residents.

Table 5-11 Ecosystem Services Provided by Deep Sea-mount Communities Relative to RMI Project Site

Service Category	Service Description	Baseline Level of Service Provisions	Sign and Magnitude of Expected Change
Provisioning	Some benthic organisms are directly consumed by people (e.g. clams and oysters)	Human consumption and utilisation of deep sea-mount organism is limited (1)	0
	Some benthic organisms are used as bait (e.g. worms, clams) or in other processes (e.g. shells may be crushed used in industrial processes)		0
	Genetic material may be extracted from sediment dwelling bacteria or benthic organism for research and pharmaceutical use	Utilisation of genetic resources from deep sea-mount areas is limited (1)	0
	Proteins or chemical compounds may be extracted from sediment dwelling bacteria or benthic organisms for pharmaceutical and industrial use	Utilisation of mineral resources is limited today but potential exists for future mineral development (1)	0
Regulating	Benthic organisms and bacteria influence climate processes; these organisms regulate some organic decomposition processes which influence CO_2 sequestration and the sea-mounts themselves may be a sink for organic (e.g. carbon-based) material	Deep sea-mount communities may play a limited role in carbon and nutrient cycling and pollution sequestration (1)	-1
	Benthic organisms and sediment dwelling bacteria influence pollution attenuation processes; burying by the sediment itself may reduce the bioavailability of pollutants; sediment and sediment dwelling organisms regulate water purification processes.		-1
	Sediment structure and the accumulation of sediment regulates accretion and erosion processes as well as storm surge and flood control	Sediments and sediment processes at the depths in question have almost no influence on erosion processes or storm surge protection (0)	0
Cultural	Well-being may be derived via shell fishing outside any consumptive use	Recreational collection of deep sea-mount organisms is very limited (0)	0
	Well-being may be derived by individuals simply because they know a healthy sediment community exists	The remoteness and limited development of deep sea-mount resources tends to increase cultural value whereas the commonality of the habitat within the EEZ tends to decrease value (2)	-2
	Well-being may be derived because the seamount system exists and can be used in the process of generating human well-being, education, or scientific understanding		+1

Service Category	Service Description	Baseline Level of Service Provisions	Sign and Magnitude of Expected Change
Supporting	Benthic organisms cycle energy, nutrients, and organic matter within and between ecosystems this energy cycling facilitates the production of future services across multiple ecosystems. The topography of a sea-mount represents a feature around which organisms may aggregate while feeding and/or reproducing. While an individual sea-mount may act as a source of material to colonize another sea-mount, dissimilarity between sea-mount communities reported by Schlacher et al. (2013) suggest the magnitude of this service may be limited	Topographic relief associated with sea-mounts provide nursery and feeding opportunities relative to an undifferentiated deep seabed. Communities on one seamount may act as sources supporting eh colonization of other seamount communities (2)	-1

5.5.4.4.1 DSM Mining Related Impacts to the Deep Sea-mounts

The primary DSM mining impacts are related to the proposed crust collecting system as it cuts and collects crust from 23.5 km^2 of sea-mount annually (470 km^2 over the 20 year operation)..

1. There would be temporary and localised increases in sedimentation rates and noise as well as transitive increase in turbidity.
2. The cutting tool would first break up and then remove crusts to the surface. Along with the crust, sessile organism such as corals and sponges would be removed.
3. Because the substrate underlying the crusts is also rocky, the nature of the seamount substrate and the general topography would not be materially altered. However, the attributes of deep sea-mount biological community along with observations made during previous studies investigating the effect of trawling on deep sea-mount benthic communities ((Williams et al. 2010) suggest the recovery of the benthic community following crust mining would be slow.

5.5.4.4.2 DSM Mining Related Impacts to Deep Sea-mount Service Provision

While the 20 year mining footprint covers 470 km^2 on a single sea-mount, mining would occur at a number of small sites and, for purposes of this assessment, it is assumed that individual mining sites are widely distributed across the individual sea-mount. This “patchwork approach” maximizes the probability of recolonization and recovery.

- Mining activity would result in acute mortality among the sessile organisms (sponges and corals) that may be attached to crusts; recovery of these communities to baseline conditions may take decades. However, because mining would occur in a patchwork at only one of many sea-mounts in the RMI EEZ, material changes in biodiversity are not anticipated and noting that these organisms provide few direct provisioning, material reductions in the level of provisioning services are not anticipated.
- The benthic organisms removed during crust mining do provide regulating services which would be reduced and this reduction would persist in the long run.
- Supporting services related primarily to feeding and nursery areas would be adversely impacted by the removal of the benthic community. Specifically intermediate services provided to mobile fauna (fish and shrimp) that associate with the benthic invertebrate community would be reduced. To the extent populations of these fish and shrimp are limited by the absence of a

sea-mount benthic community, the level of future service provided by fish and shrimp populations would be reduced and tis reduction would persist in the long run.

- The primary component of any change in composite service provision would be associated with cultural values and these changes could persist in the longer term.

5.5.4.4.3 Valuing Changes in Environmental Service Provision

There are two approaches to valuing the DSM-mining related changes in ecosystem service provision:

1. Estimate willingness-to-pay for specific environmental services and multiply willingness-to-pay by the change in environmental service provision, or
2. Estimate of the cost of generating environmental services of similar type and quantity and use this "replacement-cost" as a substitute for willingness-to-pay.

The following text applies each method to the DSM mining scenario for the RMI.

Willingness-to-pay

As discussed in Section 3.5.4.4, Earth Economics (2015) estimated an annual willingness-to-pay of $1,766 per hectare for ecological service provided by deep sea vent habitat. This estimate was based on three sources of ecological service provision.

1. Biological control services were (referred to as regulating services herein) were valued at $26 per hectare per year.
2. Genetic material which provides stock from which areas may be colonized (a supporting service) and may provide provisioning services was valued at $277 per hectare per year.
3. The provision of nursery habitat (a supporting service) was valued at $1,464 per hectare per year.

Each value put forth by Earth Economics was adopted from a study that related to cloud forests (one of the most diverse and productive habitats on earth) and, where multiple studies existed, the highest available value was adopted. Noting that 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, these values would need to be adjusted downward if applied to the RMI scenario.

- The DSM mining operation is not expected to materially alter the services derived from genetic diversity. As such, RMI-specific willingness-to-pay estimates for diversity-related services are not estimated.
- Because the level of regulating services would be reduced, an RMI-specific willingness-to-pay estimate of $6.19 per hectare per year is adopted for this service. Absent a site -estimate and noting that this is Earth Economics (2015) lower end estimate for the value of regulating services provided by a cloud forest, the use of this value represents a highly cautious (likely to overestimate actual willingness-to-pay) approach to valuation.
- Because the quantity and quality of nursery services would also be reduced an RMI-specific willingness-to-pay estimate of $8.03 per hectare per year is adopted for this service. Absent a site-specific estimate and noting that this is within the range of values Earth Economics (2015) associated with nursery services provided by a cloud forest, the use of this value represents a highly cautious (likely to overestimate actual willingness-to-pay) approach to valuation.

If DSM mining completely eliminated deep sea-mount regulating and supporting service provision and assuming this loss persists from the time an area is mined in perpetuity, the NPV of ecosystem service losses is calculated to be no more than $5,411,000.

Replacement Cost

To complement the willingness-to-pay approach, Cardno employed a replacement cost approach that relies on a method referred to as HEA (See appendix A). This approach replaces the difficult to estimate "willingness-to-pay" with a "service replacement cost."

The basic premise underlying HEA is that all of the services flowing from a habitat can be treated as a single composite ecological service. If an action results in a reduction in the quantity of the composite ecological service produced by the impacted habitat, the public can be compensated via a restoration project that creates composite ecological service at some other site. The cost of implementing the restoration project is the service replacement cost.

The HEA metric is generally the Discounted Service Acre Years (DSAYs) where one Service Acre Year (SAY) represents a composite measure of all of the services flowing over the course of 1 year from one acre of the habitat. That is, the SAY is a composite measure of the provisioning, regulating, and supporting services provided by one acre of habitat over 1 year. Future services are discounted to reflect society's rate of time preference.

HEA is typically discussed in terms of debits and credits flowing from two discrete sites. Debits accrue when the level of composite service provided by the injured site is below baseline; credits accrue when the level of composite service provided by the restored site is above baseline (Figure 5-7). Compensation is achieved when the debit (present discounted value of the area represented in red in Figure 5-7) is equal to the credit (present discounted value of the green area in Figure 5-7). Note that this definition of compensation assumes the value of any cultural services lost at the impacted site is equal to the value of the cultural services provided by the restored site.

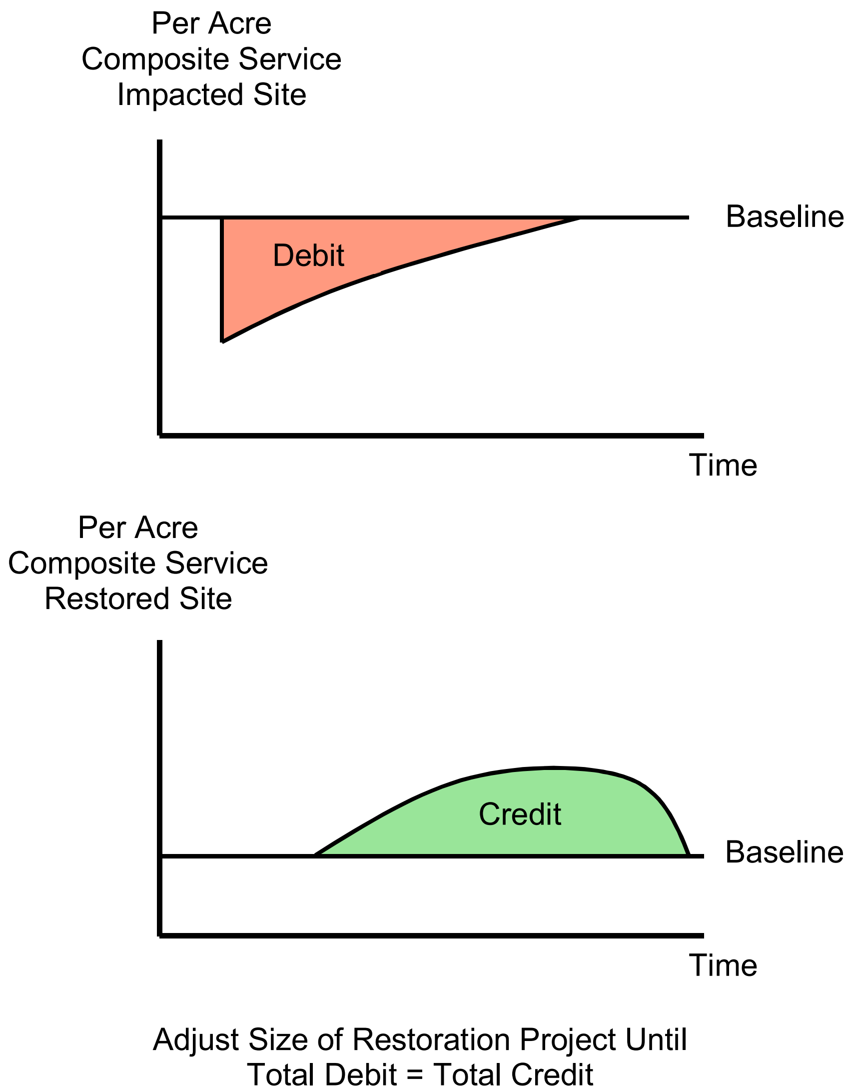

Figure 5-7 HEA Illustrated as Services Flowing from Two Discrete Sites

As is the case with the willingness-to-pay estimate, application to a deep sea-mount system is challenging given the state of the biological and economic understanding. This is true for two reasons.

1. Given the current level of biological and ecological understanding related to the production of composite service in deep sea-mount habitat, it is necessary to estimate service loss qualitatively.
2. Because it is not technically feasible to replace the services provided by the deep sea-mount ecosystem "in place" (that is, it is not technically feasible to create or restore deep sea-mount habitat), the deep sea-mount HEA relies on ratios that equate composite service provided by deep seabeds with composite service provided by wetlands.

As previously noted, material impacts to provisioning services (which are very limited even under baseline conditions) are not anticipated. The primary impact to service provision would be associated with the removal of the benthic community and the subsequent reduction in the provision of regulating and supporting services. Assuming supporting services represent the entire composite service and allowing for as much as a 50% reduction in the provision of these services from the time of impact in perpetuity,[115] the total loss is calculated to be 470,000 deep sea-mount DSAYs (assuming a 7 percent discount rate).

Because it is not technically feasible to replace the services provided by deep seabed communities "in place" (that is, it is not technically feasible to create or restore deep-sea habitat), the deep sea-mount HEA relies on ratios that equate services provided by one habitat with services provided by another.

Peterson et al. (2007) established a series of equivalency ratios based on the relative productivity of any two habitats. Using the productivity logic, the equivalency ratio between a relatively flat and undifferentiated deep seabed (4.23 g C/m2/y at 1500m depth (Rowe and Kennicutt 2009)) and salt marsh (860 g C/m2/y reported for salt marsh (Feijtel et al 1985)) would be 1:203.

This implies a loss of 470,000 deep sea-mount DSAYs would be offset by the creation of 2,315 wetland DSAYs. The cost of creating 2,315 wetland DSAYs is estimated to be $26,277,000 based on NOAA et al. (2013).

5.5.4.4.4 Valuing the Change in Environmental Services Provided by the Deep Sea Mount: Summary

DSM mining related changes in ecosystem service provision were valued using willingness-to-pay and replacement-cost methods. While both valuations are challenging given the current level of biological and economic understanding, both methods suggest the present value of seabed-related changes would be less than $26.3 million.

In preparing these estimates, many helpful comments were received, many of which have been incorporated into the text. Several comments were also received that have not been incorporated. These include:

- Individuals expressed concern that impacts related to spills and air emissions were not considered. These impacts are omitted from this section because they are unlikely to affect the deep seabed habitat. They are however considered when overall environmental costs are estimated.
- Individuals expressed concern that indirect impacts to fish and other mobile organism that depend on the deep seabed were not considered; these impacts are included via the consideration of deep seabed supporting services.

Commenters questioned the utility of compensating the public for the loss of deep seabed services via the creation of wetland services. While it is agreed that this is a sub-optimal approach, it is necessitated by the impracticality of restoring deep seabed habitat.

[115] Stakeholders have suggested this loss could be as high as 100 percent. Noting that (1) the topographic relief of the sea-mount itself, which would not be materially changed by DSM mining, provides both nursery and feeding services and (2) that a large portion of regulating services are provided by bacteria which would likely recover in a matter of days, the assumption of 100% service loss is inconsistent with the available facts.

5.5.5 Total Monetised Social Costs

The following potential social costs were identified:

- Administrative costs to the government,
- Cost of offsetting CO_2 emissions,
- Cost of unplanned release and/or vessel grounding, and
- Cost of replacing services that may be lost by DSM mining activities.

Where possible these costs are transferred to the DSM mining operation and are treated as “debits” in the calculation of the mining company’s profit. This includes RMI administrative costs, cost to offset CO_2 emissions, costs to avoid negative impacts of introducing nutrient rich waters to the sea surface, and clean-up costs associated with unplanned release. The remaining costs (those associated with lost ecosystem services following a spill and the loss of deep-sea ecosystem services) are incurred by the citizens of the host country.

Table 5-12 summarises each individual cost element, as well as how it was factored into the analysis.

Table 5-12 Summary of Monetised Cost Estimates in the RMI Mining Scenario (in USD)

Cost Estimate	Mean Values based on Monte Carlo Simulation	
	Present Value Social Cost Incurred by Citizens of RMI (in millions of USD)	*Annual Private Cost Incurred by DSM Mining Company (in millions of USD per year)*
Government administrative costs	$2.8	-
CO_2 offset costs	$0	$0.5 [1]
Clean-up and restoration cost associated with unplanned spill	$0.2 [3]	$1[2]
Lost deep sea-mount ecological services	$26.3 [4]	-
Present value of total cost	$29.3	$1.5-

Note 1: Present value of the cost of acquiring carbon dioxide offsets
Note 2: Costs to acquire insurance to assure oil spill clean-up costs are covered
Note 3: Expected cost to replace ecological services lost from an unplanned spill or release from the time the spill occurs to the time the baseline level of services are restored
Note 4: Value of lost ecological services provided by the deep sea-mount community

5.5.6 Discussion of Non-Monetised Social Costs

The following section identifies and discusses the external costs that were not monetised. These include potential cultural costs such as the concession of traditional ownership and community level impacts that affect the well-being of various member of society. In addition, this section discusses how the perception of potential adverse impacts could impact fisheries and tourism in the short-run.

5.5.6.1 Concession of Traditional Ownership

Engagement activities suggest that traditional authorities are generally supportive of DSM activities as long as:

> Compensation is provided for any impacts to affected stakeholders,

> Revenues are paid to relevant communities and governments (typically those geographically closest to the resource expect to receive a greater portion), and

> The environment and fisheries are protected.

In response to the first two concerns it is noted that the primary potential benefit of DSM mining in the RMI EEZ would be revenues to the government. As such, the government would have the opportunity to determine if, when and how revenues were used to compensate and benefit stakeholders.

With respect to the environmental and fisheries, DSM mining under the current scenario would occur well beyond any traditional or local use areas. As such it is unlikely that RMI citizens would be able to detect any impacts of DSM mining on the environment. .

5.5.6.2 Community Level Impacts

Stakeholders expressed a general concern that DSM mining related changes in employment patterns could fundamentally change social and cultural patterns.

One of the key concerns expressed by various stakeholders was related to the potential negative impacts to the commercial fishing industry in Majuro.

> Figure 5-8 shows the location of MS01 in relation to fishing activity by RMI vessels in 2013. Given the remote location of the proposed mine site and the limited potential for ecological impacts, the potential for direct or indirect impacts to artisanal or traditional fisheries appear minimal.

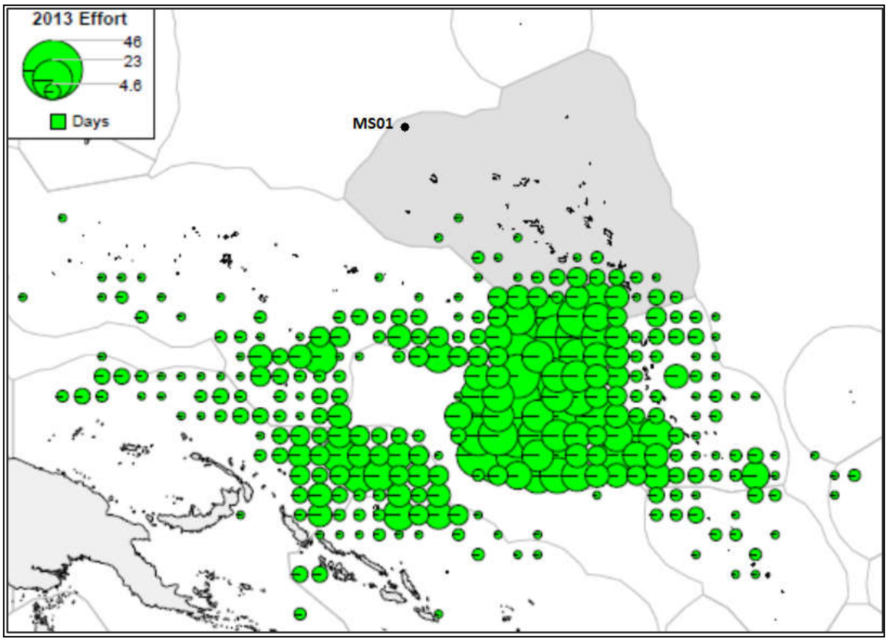

Figure 5-8 2013 Purse-Seiner Activity by RMI Vessels in Comparison to Location of Mine Site

A second frequently encountered concern is related to the potential for DSM-related employment to fundamentally change community structure.

> The on-board workforce associated with an MS01 mining operation is likely to be between 150 and 200 individuals at any one time. Given the highly technical nature of the mining work it is unlikely that the majority of workers would be local. Since the MS01 program maybe in operation for over 15 years, there may be training and education opportunity to increase the number of locals utilised on the PSV over the life of the project. However, much like in the Cook Islands, the demand for RMI labour would likely phase in slowly and is unlikely to reach magnitudes that would alter the islands social fabric.

Finally, stakeholders expressed concerns that windfall gains associated with a DSM mining may contribute to a culture of welfare dependence by increasing the available funding for welfare distribution, without addressing the base cause of dependency.

> The RMI government would have the responsibility of determining if, when and how any DSM related revenue were spent or distributed. With proper wealth management, the RMI government can seek to maximise the benefits of DSM mining-related revenue without imposing increased dependency on government programs by its citizens.

5.5.6.3 Perception of Environmental Degradation on Tourism and Commercial Fisheries

While it is unlikely that the natural resources upon which RMI tourism is based would be adversely impacted by DSM mining, stakeholders expressed a concern that the mere perception of potential adverse impacts could reduce the number of tourists frequenting RMI.

To evaluate the potential magnitude of such an effect, the extensive literature on the effects of environmental disasters is reviewed. This literature provides insight because property values reflect the net present value of all services flowing from a property, which includes environmentally-based recreation. While an imperfect proxy, it is likely, that any potential cost associated with reduced tourism due to perception would be less, on a percentage basis, than property diminution.

> Several studies examining the effects of pipeline easements on sales and property values have found no effects (Diskin et al. in 2011, PGP 2008, Fruits 2008). Hansen (2006) analysed property sales near a pipeline accident location and noted a short-term decline in property values with values returning to baseline over the course of several years.

> Similarly, several studies have evaluated the effect of cell phone towers on property values. Dorin and Smith (1999), Bond and Wang (2005), Bond (2007) and Valentine (2014) compared sales among properties with varying proximity to cell phone towers, they found a minor (often zero, consistently less than 15% diminution) associate with extreme proximity to cell towers and that any potential effect diminished in the years following cell tower construction.

> These results are consistent with meta-analysis of wind farm (COE 2004) and landfill (FERC 2008) impacts.

In the absence of any site specific information in RMI, there is evidence from a study on the economic value of watershed pollution in Rarotonga, Cook Islands that is applicable. The study found that on average there is a 3% reduction in tourism due to the presence of watershed pollution (Hajkowicz and Okotai, 2006) in Rarotonga. Given that watershed pollution is much more visible to prospective tourist than an offshore mining operation that takes place out of site form land, it would be reasonable to assume that negative perceptions related to DSM mining activities may have no adverse effect on tourism. If there would be an effect, it is unlikely to result in no more than a 10% reduction in tourism.[116]

As with tourism, there is a potential for people's perception of environmental degradation to affect revenue to the commercial fishing industry. Skewed perceptions or risk are common when it comes to damage associated with the environment. A recent example of this behaviour is associated with the British Petroleum (BP) oil spill in the Gulf of Mexico. Despite in-depth analyses by both federal and state scientists proclaiming that all seafood that entered the market during the time of the spill was safe, a survey conducted by the Gulf and South Atlantic Fisheries Association indicated that 30% of the respondents would not eat any seafood coming from the Gulf of Mexico. However, quantifying financial loss due to loss of consumer confidence is difficult. In the case of RMI, mining occurs hundreds of kilometres away from commercial fishing sites. It is therefore unlikely that perceptions related to DSM mining activities would adversely affect the commercial fishery.

5.6 Benefits Methodology

To quantify and monetise the benefits of DSM mining in RMI, the CBA calculates the amount of revenue received by the government. The first step in this calculation is to estimate amount of revenue that the mining company receives based on the total geological specifications as laid out in Section 5.4.

In the absence of a specific fiscal regime in RMI, the following assumptions are applied based on the current fiscal regime in the Cook Islands:

> Royalty payment of 3%

> Withholding tax of 15%

> Corporate income tax of 28%

> Resource rent of 20% on "super profits" that is applied when the mining company has achieved an internal rate of return that is greater than 20%.

116 This assumption is based on the upper bound figure from the study in Rarotonga (Hajkowicz and Okotai, 2006) and is considered a "worst-case" scenario as the Rarotonga water pollution studied by Hajkowicz and Okotai is likely to be visible to tourists, whereas any potential environmental degradation due to deep-sea mining would occur and likely remain hundreds of kilometres off shore.

A cash flow analysis is used to determine in what year, if any, there is positive profit to the mining company, in which case the government receives additional revenue from the withholding tax and the corporate income tax. Additionally, in years where the mining company achieves an internal rate of return of more than 20%, the government receives an additional source of revenue in the form of a "resource rent."

5.6.1 Private Benefits

Given the uncertainty related to processing, the CBA estimates private benefits under two scenarios:[117]

1. **Miner owns the mining operation and exits the value chain by selling the raw ore to a processor overseas**. Revenue to the miner is estimated based on the value of the raw ore before the metals are extracted and sold to the market.
2. **Miner owns both the mining operation and a processing operation located overseas**. Revenues to the miner are based on the sale of the final product to the market.

Both scenarios include an evaluation of benefits under a three-metal processing route (Co, Ni and Cu) where assumed metal recovery is based on methods that use smelting and chlorine leaching, as recommended by Yamazaki (2006).

The following inputs enter the estimation of gross benefits of the overall mining operation as random draws from a probability distribution[118]:

- Price,
- Metal grade (assumed in the seabed),
- Mining efficiency (percent recovered from the seabed), and
- Metallurgic recovery (percent of metal recovered after processing).

Table 5-13 reports the most likely value used in estimating the gross revenue from the mining operation.

Table 5-13 Description of Inputs used to Estimate Gross Revenue in RMI Mining Operation

Metal	Metal Content	Dry tonnes in 1 year of production	Mining Efficiency	Metallurgic Recovery[1]	Market Price (USD/lb)	Revenue from Metal (per tonne of ore/USD)	Total expected revenue in 1 year (in USD/millions)
Cobalt	0.44%	2,683	80%	90%	$13.74	$133	$82
Nickel	0.65%	774	80%	95%	$6.50	$93	$48
Copper	0.12%	3,819	80%	95%	$2.91	$8	$4

Note 1: Recovery rates are based on processing route that involves smelting and/or sulphuric acid leaching as reported in the 2008 ISA Workshop proceedings. Percentages for smelting and chlorine leaching could not be located.

117 A third scenario where the miner is required to invest in a processing facility (similar to the scenario in the Cook Islands) was also considered but ruled out based on the preliminary findings from Scenarios 1 and 2; therefore, the reader is directed to Section 4.6.2.3 for a detailed description of what investing in a processing facility in RMI would require.

118 Ranges of all inputs are reported in Appendix B.

Table 5-14 shows the additional inputs used to estimate profit to the miner where profit is calculated as gross revenue minus royalty payments, operating costs and capital expenditures. As with the inputs described in Table 5-13, the values for capital and operating expenditures also enter the estimation of profit as random draws from a probability distribution, with the estimates in the table representing the most likely values.

Table 5-14 Description of Inputs used to Estimate Profit to the Miner in RMI Mining Scenario (in millions USD)

Category	Cost
Capital expenditure – mining operation (one-time)	$396
Capital expenditure – processing facility (one-time)	$362
Operating expenditure – mining operation	$84
Operating expenditure – processing	$114

Metal grades are multiplied by the total estimated dry tonnes of production in each year to calculate the dry tonnes of metal produced each year. The expected price of each metal is multiplied by the amount extracted each year and aggregated across 20 years to estimate the total gross revenue from the mine site.

From here, the royalties are applied (i.e., 3% of total gross revenues) to determine the government's share of revenue from royalties. Additionally, under each scenario, a cash-flow analysis is used to estimate the profit to the mining company in each year that the mine is producing to determine whether the government would receive tax revenue in addition to the royalty.[119] The end result (gross revenues to the government in the form of royalties + taxes + resource rents) represents the aggregated amount of total social benefits over the 20 year period, adjusted for inflation and discounted to reflect what the amount is worth in today's dollars.

Figure 5-9 is a probability distribution for profits under the two scenarios evaluated. In both cases, there is a high probability of negative profits, indicating that the mining operation is not economically feasible under the assumptions identified in this analysis.

- The blue line corresponds to Scenario #1 (early exit from the value chain). Its position, entirely to the left of the point where profits become positive, indicates that even under very favourable assumptions, the miner is unlikely to make profits.
- The red line corresponds to Scenario #2 (miner owned processing facility). The position and shape of the red line suggest that 70% of the draws made during the Monte Carlo analysis resulted in negative profits.

[119] Detailed results of the cash flow analysis are in Appendix B.

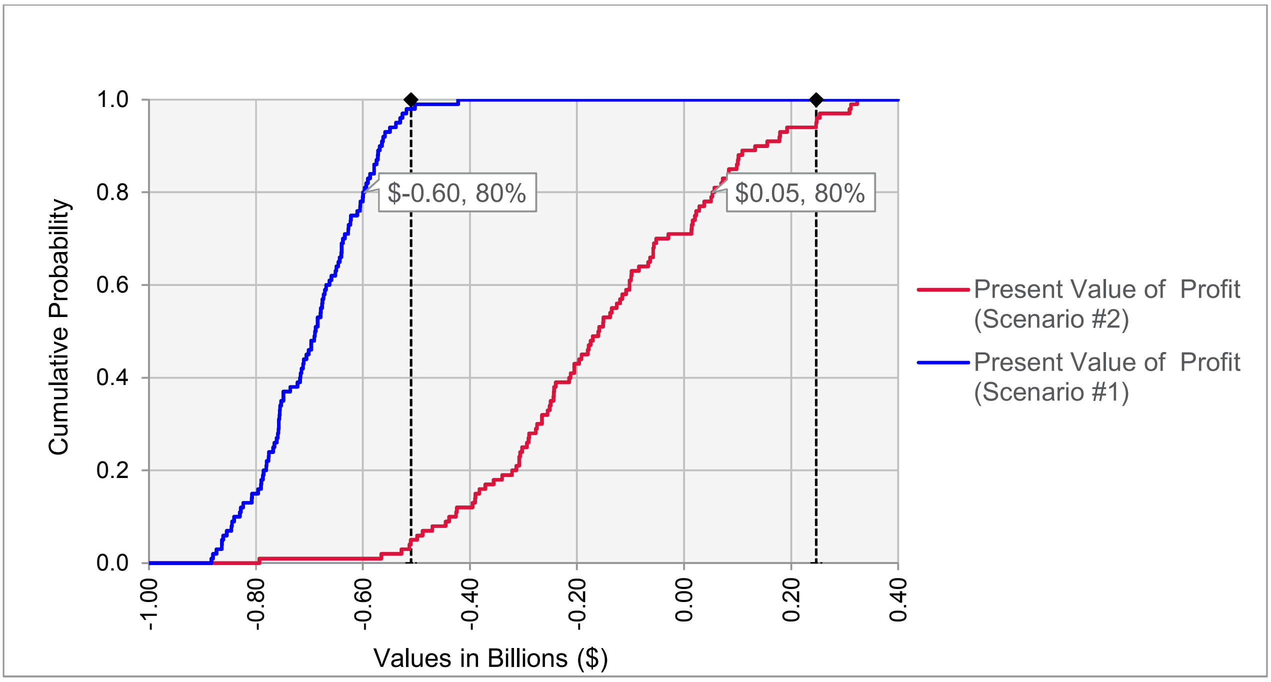

Figure 5-9 Probability Distribution for Present Value Profits: RMI Mining Scenarios

The results are consistent with a 2012 paper by Martino and Parson in which it is concluded that the price of cobalt would have to be over $40/kg (USD) for crust mining to be economically feasible.

To evaluate the assertion that $40/kg (USD) is a point at which crust mining might be profitable, the Monte Carlo analysis was performed a second time this time with cobalt prices restricted to $40 or more (Figure 5-10). Consistent with the Martino and Parson analysis, when cobalt prices exceed $40/kg crust mining can be profitable provided the miner also owns the processing facility. This is indicated by the position of the red line relative to zero.

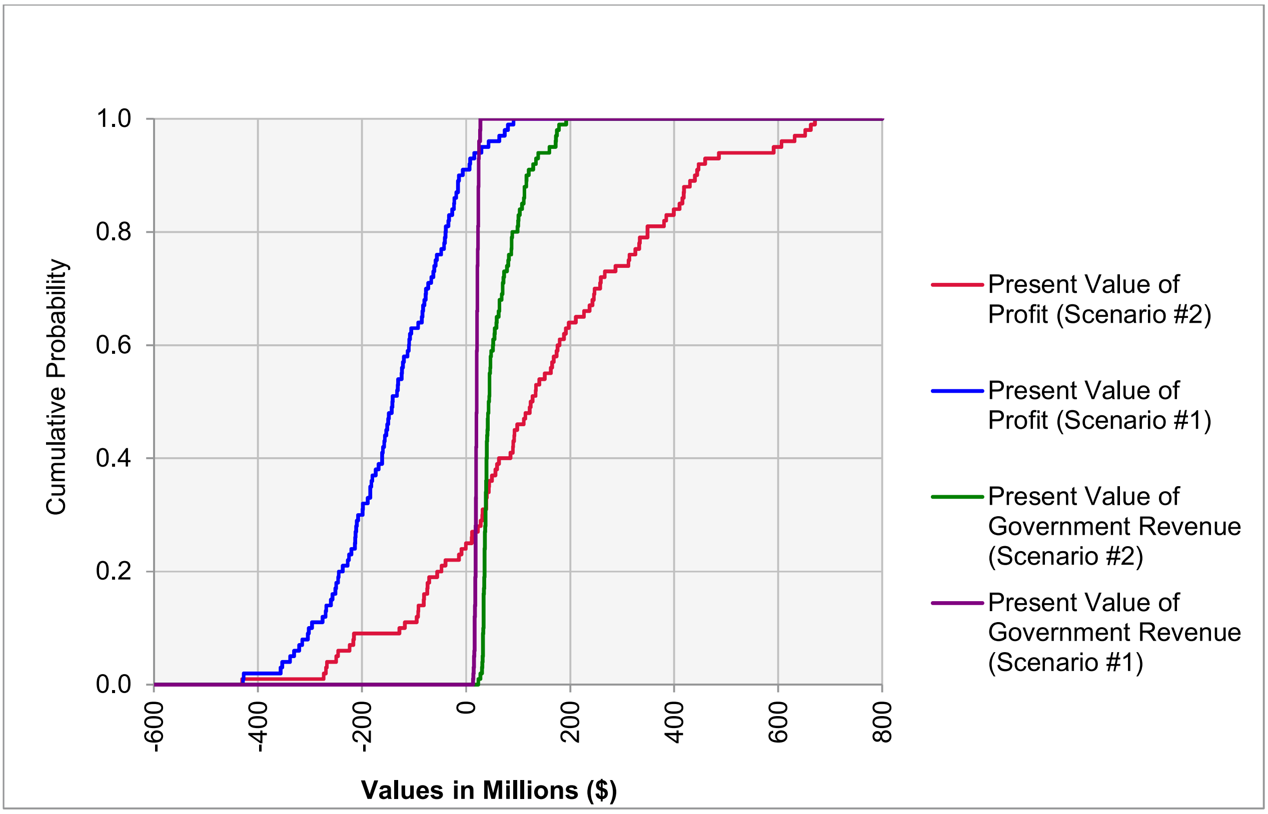

Figure 5-10 Present Value of Profit vs. Government Revenue in RMI Mining Scenarios with Increase in Cobalt Price above $40/kg (USD)

5.6.2 Non-Monetised Social Benefits

DSM mining may facilitate RMI citizens' professional development and/or result in an increased understanding of the deep-sea environment. The value of these potential benefits has not been quantified.

5.7 Discussion of Results

The intent of the CBA was to provide decision makers with a comprehensive overview of the potential impacts of DSM mining to the citizens of RMI. As previously discussed, at the current price of cobalt ($30/kg USD), the CRC mining scenario in RMI is not economically viable. Figure 5-11 helps identify those uncertainties that most effect profits; the longer the horizontal bar, the greater its influence. As expected, the primary drivers are metal prices and the cost of operating the mining equipment.

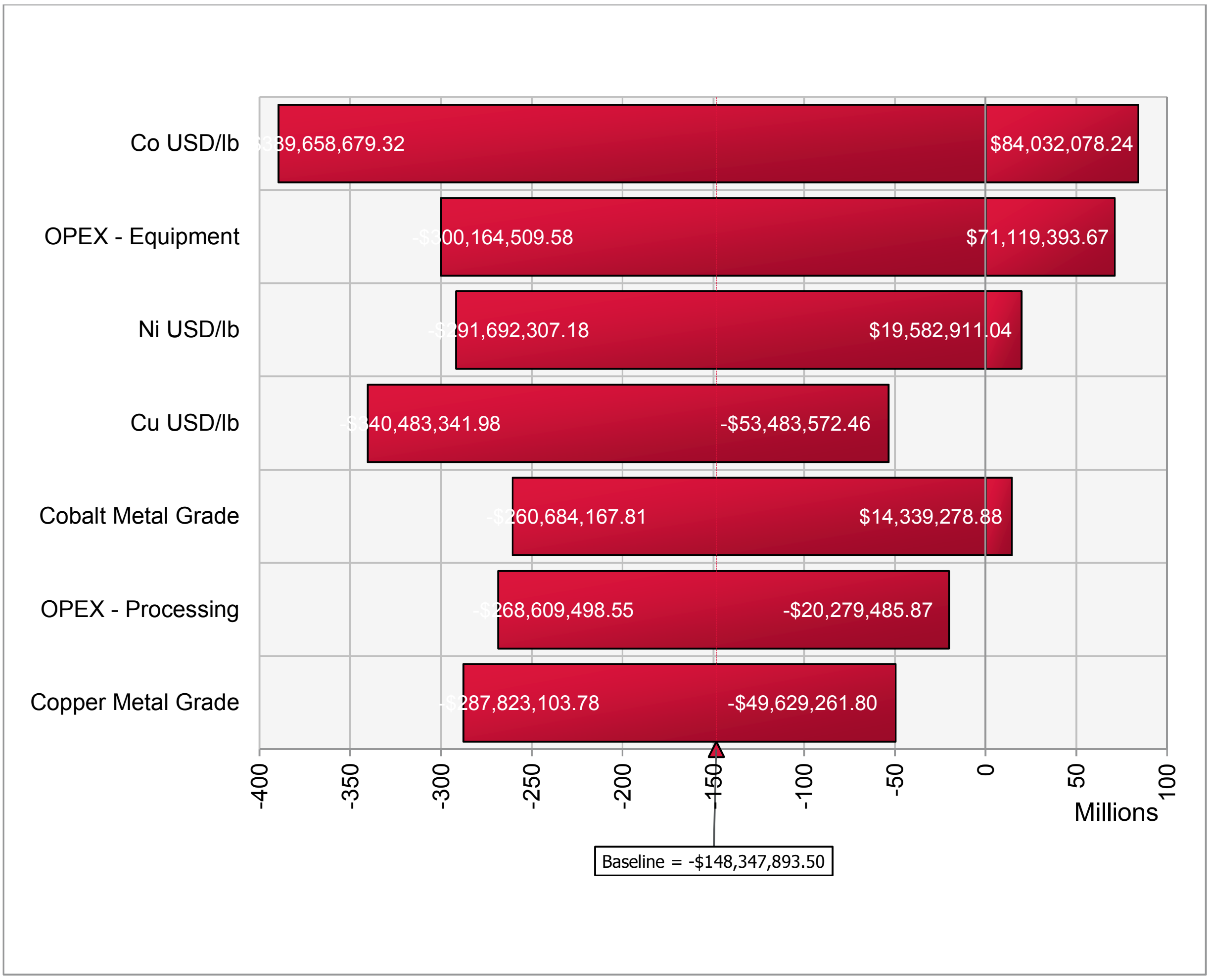

Figure 5-11 Sensitivity of Mean Output (PV of Profit to Miner in Scenario #2) to Changes in the Input Values

5.8 Regional Economic Impact Analysis

To understand how a business activity such as DSM mining, affects a regional economy, it helps to understand how different sectors or industries are linked to each other within an economy. To do this, as described in Section 2.4, a regional impact analysis is performed to determine the indirect benefits associated with DSM mining. First, the analysis uses information on mining related expenditures to determine employment and income effects as a result of DSM mining in RMI. Then, the annual estimates of government royalties are used to evaluate the employment and income effects of government spending of a portion of the royalty payments.

5.8.1 Mining Expenditures

As described in Section 2.4, capital expenditures have been excluded from the impact analysis given that most of these items are highly specialised and are not expected to be procured from study area countries.[120] The only local employment and income benefits associated with DSM mining are expected to be associated with project operations and are for procurement of project fuel, spares, consumables, and labour.

5.8.1.1 Operating Costs

The analysis assumes the number of local workers is equal to 20% at the onset of mining, given that the mining operator would be under contract to include a portion of locals in the mining labour force, but that the majority of labor would be provided by trained ex-pats. This obviously may vary over time as more local hires are trained.

- Total wages paid to local mining employees are expected to average $29,000 (USD) per person annually.
- For spares, consumables, and fuel the analysis relied on parameters generated using the IMPLAN system and knowledge of local infrastructure constraints to determine the proportion of expenditures that would be made locally.
- Non-local consumer spending estimates assume each non-local worker would make 12 inbound trips and 12 outbound trips, and subsequently stopover for one night each time traveling through the city hub serving the DSM operation. Hotel costs are assumed to equal $50 per night; whereas, food expenditures are assumed to equal $50 each night.
- Operating costs for were based on averages from the literature (see Section 5.5) to estimate the average operational cost. In the absence of specific information on the breakdown of operational costs, the detailed allocation of operational costs to major cost categories relied on the allocation provided for the Solwara 1 project and are reported Table 5-15 below.

[120] Various suppliers of the mining equipment are described in the Solwara Cost Study, none of which are located within PNG

Table 5-15 Summary of Mining Operational Expenditure Estimates for RMI (in millions USD)

Category	Total	Local
Production Support Vessel (PSV) Charter	$24.1	$0.0
Remotely Operated Vehicle (ROV) Charter	$3.0	$0.0
Fuel (PSV/Barges)	$9.8	$5.5
Spares, Consumables and Miscellaneous	$7.0	$0.9
Labor (PSV/Barges)2	$32.2	$1.2
Contingency (10%)	$7.6	$0.0
Total Operating Costs	$83.7	$7.6
Other Operational Spending	-	-
Non-local Consumer Spending	$0.4	$0.4

5.8.2 Model Results

Table 5-16 provides the annual employment, income and value added (GDP) estimates for DSM operations in the RMI. It is estimated that a total of 39 local jobs will be directly supported by DSM operation. Operational expenditures for goods and services by the mine will support an additional 57 jobs throughout the country, while household spending resulting from mining operations will support one additional job throughout the country. Overall, it is estimated that 97 local jobs will be supported by DSM operations each year.

Furthermore, DSM in the RMI will directly provide $1.2 million of income to local workers. Operational expenditures for goods and services by the mine will support an additional $0.4 million in income throughout the country. Overall, it is estimated that $1.5 million of income will be generated within the RMI by DSM operations.

It is anticipated that a RMI based DSM operation would directly generate $19.4 million in value added and indirectly support $0.9 million of value added each year. In all, it is expected that a DSM operation would increase RMI GDP by an estimated $20.3 million annually.

Table 5-16 Annual Mine Operating Impacts for RMI DSM Mining (in millions USD)

Impact Type	Direct	Indirect	Induced	Total
Employment	39	57	1	97
Income	$1.2	$0.4	$0.0	$1.5
Value Added (GDP)	$19.41	$0.9	$0.0	$20.3

Totals may not sum due to rounding
Monetary values are in 2015 dollars
Note 1: Based on the average value added per US ‘other metal ore’ mining employee from IMPLAN model

5.9 Potential Distribution of Costs and Benefits

Despite the finding of no net benefits to the citizens of RMI from the CBA, it is still important to discuss some of the potential distributional effects in the event that there are positive net benefits in the future.

A CBA is designed to determine whether a project or policy has the potential to make a society better off. A positive net benefit means that the benefits of the project are sufficiently large to allow those who derive a net benefit from the project to compensate all those who experience a net cost; compensation does not actually have to occur, it only has to be possible. In other words, in CBA a positive net benefit does not imply society will be made better off, instead it implies society could be made better off.

In this context policy makers often find it helpful to consider the way in which costs and benefits are distributed among various segments of the population. For instance, policy makers may favour projects or policies that reduce the disparity between the wealthiest and poorest in a society.

In the case of DSM mining the primary benefit to RMI citizens will be royalty payments made to the government. With the exception of a relatively modest expenditure on salaries associated with the regulation of DSM mining activity, the government itself would determine the distribution of these funds and/or the benefits derived from associated government expenditures. That is, the RMI government itself will largely determine who benefits from DSM mining activity.

6 Summary and Key Considerations

This analysis describes the costs and benefits of three potential DSM mining operations: extraction of seafloor-massive sulphide deposits in PNG, extraction of polymetallic manganese nodules in the Cook Islands, and extraction of ferromanganese cobalt-rich crusts in RMI. The following text summarises results and identifies key considerations related to those results.

6.1 Results Summary

In all cases costs and benefits are characterised from the perspective of host country citizens using a multi-step process.

- First, the economic viability of the operation is determined. If the operation is not economically viable it is assumed no action would be taken and costs and net social benefits are assigned a zero value.
- If the operation is expected to be economically viable:
  - Benefits to the host country, primarily in the form of tax and royalty revenue, are calculated for all viable operations,
  - Costs associated with both government administration and unavoidable environmental impacts are calculated, and
  - Net social benefits are estimated.

Results are prefaced by noting that DSM mining on a commercial scale has yet to take place anywhere in the world. While much of the necessary mining technology has been developed for other deep-sea applications and/or tested for DSM mining on a small scale, there exists considerable uncertainty as to its cost effectiveness and reliability. The same is true of processes necessary to extract and refine metals from the mined material. While the analysis attempts to capture these and other uncertainties through the use of Monte Carlo methods, the analyses are only as reliable as the underlying data.

- The operation in which seafloor-massive sulphide deposits are extracted from the seafloor in PNG is the most operationally advanced; mining is set to begin in the near term. The analysis indicates that, as envisioned by the current mining proponents, the operation has a high probability of economic viability. Further, the benefits accruing to the citizens of PNG are very likely to exceed the costs they incur.
- The operation in which polymetallic manganese nodules are collected from the Cook Islands seafloor is at an intermediate stage of development; most of the regulatory and investigative work is complete but no detailed operational plan exists. The analysis indicates that nodule collection is likely to be economically viable provided a single entity mines the nodules and processes them using a method that recovers manganese, cobalt, nickel and copper. Further, the benefits accruing to the citizens of the Cook Islands are very likely to exceed the costs they incur.
- The extraction of ferromanganese cobalt-rich crusts in RMI is the least operationally advanced DSM mining scenario. Previous work by Martino and Parson (2012) suggested that, for crust mining to be economically viable, cobalt prices would need to exceed $40/kg (USD) which is well above the current price of about $30/kg (USD). The results of the analysis are consistent with the conclusions of Martino and Parson; economic viability of crust mining is highly unlikely given the current price range for metals. However, if cobalt prices were around $40/kg (USD)

an integrated mining and processing operation would likely be economically viable and net social benefits would likely be positive.

6.2 Key Considerations

In addition to providing insight into the likely net social benefit of DSM mining, the analysis identified multiple factors that may warrant further consideration.

6.2.1 Cumulative Effects

Costs and benefits have been quantified for a single mining operation in each of three countries. Relative to each country's' EEZ, the mine sites are very small and pose little risk of material and adverse ecological changes at a national level. This conclusion, which tends to reduce costs related to environmental impacts, may not stand if DSM mining were significantly scaled up in each country.

If approval of a single DSM operation has the potential to set a precedence that makes it difficult to restrict future DSM mining activity, an assessment of potential cumulative effects and regulatory strategies to manage and mitigate them may be valuable.

6.2.2 Standing

The cost benefit analyses were conducted from the perspective of host country citizens. So long as the DSM mining operation was economically viable, the costs and benefits accruing outside the country were not considered.

From a more global perspective it appears likely that DSM mining would represent a significant reduction in global environmental costs associated with obtaining metals. This benefit was not considered because it generally would not accrue to host country residents. It may none-the-less be important.

6.2.3 Benefits Distribution

The analyses suggest that DSM mining in PNG and the Cook Islands has the potential to make the citizenry as a whole better off. Whether or not that actually occurred would depend largely upon the government's ability to manage DSM mining revenue to the benefit of their citizens.

During the in-country interviews and after reviewing several case studies, the following concerns and considerations were identified.

- There is a general preference for transparent wealth management.
- Any distribution of benefits among citizens creates tension. If the distribution among citizens is not perceived as fair, confidence in government may be lost.
- There is a tension between spending or distributing DSM related revenue to generate benefits in the short run and investing revenue to provide benefits in the future. If the distribution of benefits through time is not perceived as fair, confidence in government may be lost.
- If the government provided sufficiently large payments they may create a culture of welfare dependence or reliance on government support. This could alter community structures and lead to adverse societal changes in the longer term.
- If government investment in DSM mining activity displaced funding for other social programs in the short term, this could result in adverse social impacts even if benefits exceeded costs in the long run.
- Government spending and/or payments could have an effect on both migration and immigration. If specific regions receive a larger share of the benefits, citizens may migrate to

those areas. Depending on any residency requirements linked to payments, a system of direct payments could encourage or discourage immigration.

Each country would need to determine how it would manage and distribute their DSM related revenue. Lessons may be learned by reviewing existing wealth management strategies and the manner in which they manage risk, provide transparency, and balance the tension between short term spending and investment. Two examples considered in the regional economics modelling, Alaska and Norway, provide a starting point for such an evaluation.

> Alaska uses 75% of royalties and 100% of oil-related tax revenues to cover its operating budget (Fischer, 2007). This affords the citizens of Alaska the benefit of having no income tax or sales tax on the purchase of goods. The remaining royalties are placed into a fund and cannot be removed except by state-wide voter approval. Dividends from the fund are distributed equally among state households.

> In Norway, the central government transfers all revenues from petroleum activities into the Petroleum Fund after covering any non-oil budget deficit (Fischer, 2007). Assets are invested exclusively in foreign bonds, offering transparent reporting that is made available to the public. The fund reserves at least 75% of revenues to benefit future citizens by saving and investing in high yield opportunities. Through the years this has allowed Norwegian residents to benefit from a variety of public services that could not have been provided absent the minerals-related funding.

6.2.3.1 Social Costs Relative to the Overall DSM Operation

The total monetised social costs (i.e. cost incurred by the host country) associated with a single mining operation are generally small relative to the private costs and benefits associated with DSM mining (Table 6-1). That is, administrative and environmental costs incurred by the host country, which total tens of millions over the life of a mine, generally have little impact on the estimation of net social benefits when mining revenues and operating costs are measured in the billions.

This observation is driven by several factors. Key among them is that, with careful pre-planning, the host country government can transfer many of the costs they might incur to the mine operator. For example, the analysis assume miners will be required to adopt technology that reduces environmental impacts and/or fund environmental impact mitigation efforts that effectively transfer costs from the host country to the mine operator.

> The finding of limited environmental costs is predicated on the assumption that each country will develop regulations to insulate themselves against environmental risk. Absent such arrangements, the social costs incurred by host country citizens will be larger.

The other factors that tend to reduce social costs are inherent in DSM mining and so tend to impart this advantage regardless of the DSM regulatory framework.

> The remote location of the mine sites relative to land-based mining tends to reduce the potential for environmental impacts to adversely impact host country citizens.

> The limited ecological flow from deep-sea environments into habitats and populations that provide host country citizens with food, fuel, and recreational opportunity tends to reduce the potential for adverse impacts to host country citizens.

> Because the entire mining operation is run from a small number of vessels, tasks related to government monitoring and oversight are simplified relative to many land based operations.

Table 6-1 Summary of Social Costs

Category	Type	Monetised (Y/N)	Dollar Amount (PV, in millions USD)			Potential Magnitude of Impact
			PNG	Cook Islands	RMI	
Social Costs	Loss of environmental services from deep seabed communities	Y	$0.61	$24.9	$26.3	Minor
	Administrative costs to the government	Y	$0	$2.3	$2.8	Minor
	Cost of clean-up and compensation for unplanned spills and grounding	Y	$0.034	$0.2	$0.2	Minor
	Concession of traditional ownership	N	N/A	N/A	N/A	Could potentially be significant depending on how benefits are distributed
	Cultural Shifts	N	N/A	N/A	N/A	Could potentially be significant depending on how benefits are distributed
	Perception of environmental degradation on tourism and fisheries	N	N/A	N/A	N/A	Minor

6.2.4 Stakeholder Involvement

Table 6-1 identifies two potential social costs that were not monetised: costs associated with concession of tribal ownership and costs associated with cultural shifts. Each of these costs would ultimately be dependent upon the manner in which the government integrates its citizens into the DSM decision making process. While government decisions are important in determining the actual benefits of DSM mining, so too are the methods used to reach those decisions. Traditional leaders and other community leaders have expressed a desire to be involved in the decision making process.

6.2.5 Rare Earth Elements

The analyses identified value in the extraction of traditional metals. As technology facilitating the extraction of rare earth elements is refined, and assuming demand for rare earth elements remains strong, it is possible the focus of DSM mining may shift toward these elements.

6.2.6 On-Island Processing

The processing of ore is an energy intensive industrial activity. Given the current level of infrastructure in RMI and the Cook Islands as well as potential conflicts with tourism and other environmentally based activities, it is highly unlikely that on-island processing would be economically viable and even less likely that it would provide a net social benefit.

7 Conclusion and Policy Recommendations

As the global demand for metals continues to rise, nations with deep-sea mineral deposits face many important decisions related to the exploitation of these resources. The preceding analyses identify the costs and benefits of three potential DSM mining operations giving consideration to financial, environmental, and cultural issues. Results indicate that under specific circumstances, it is likely that DSM mining has the potential to improve the well-being of host country citizens.

While many of the PICs faced with these resource decisions are at different stages of development related to DSM mining, and noting that the potential for net social benefits is highly site specific, some general conclusions are applicable.

The following attributes were common among scenarios with positive net social benefits:

- A large supply of minerals that contain high grades of metals with economic value,
- Somewhat advanced mining and processing technology, allowing for gains in efficiency and reduced costs,
- Regulatory frameworks and domestic policy (either existing or in development) to protect against direct environmental damage, and
- Ongoing efforts to facilitate long-term wealth management and prosperity for future generations.

When DSM mining appears “on average” to be a viable source of revenue to governments, risks exist.

- DSM mining has not occurred anywhere in the world and so assumptions related to collection costs and efficiencies are somewhat speculative.
- Metal prices are volatile and returns on investment are not guaranteed.

Development initiatives often require trade-offs between financial gains and environmental degradation.

- In some circumstances, it appears the environmental impacts associated with DSM mining are outweighed by the financial gains to the host country.
- Ore processing is energy and infrastructure intensive, generates a significant liquid and solid waste, and may conflict with tourism and other environmentally based activities. Except in unusual circumstances, it appears unlikely the benefits of on-island processing would outweigh the costs.

Many of the environmental risks associated with DSM can be transferred to the DSM mining company. These include risks:

- Posed by carbon dioxide emissions that can be managed by requiring DSM mine operators to purchase carbon offsets.
- Related to unplanned releases that can be managed by requiring DSM mine operators to both clean-up spills and compensate the public for any financial or ecological injury.
- Related to the introduction of nutrient rich waters that can be managed by requiring DSM mine operators to return waters to depth.

The distribution and management of DSM related revenue is a responsibility of the host country government that promotes transparency, accountability, and can be viewed as an overall attempt to proceed in a manner that is fair. Wealth management activities in the U.S., Norway, and other countries provide useful case studies.

Crafting responsible DSM policy and regulatory frameworks may reduce risk in the following ways:

- The DSM decision process can be made transparent and predictable,
- Environmental costs can be transferred to mine operators,
- Regulatory compliance can be ensured,
- Wealth management and distribution can be made transparent and predictable, and
- Concerns related to corruption can be mitigated.

Finally, in some countries, DSM mining is transitioning from a possibility to a reality. Those countries not yet considering DSM mining may gain from the experience of those currently entering the market as technologies are improved and uncertainties are addressed.

APPENDIX A

HABITAT EQUIVALENCY ANALYSIS

Appendix A Habitat Equivalency Analysis

When economists value changes in the environment, they often rely on the concept of “ecosystem services” which are defined as the benefits people obtain from the environment. For example, ecosystem services can be divided into 4 broad categories:

- Provisioning services (e.g., material goods such as food, feed, fuel, and fibre) are associated with goods provided directly to people,
- Regulating services (e.g., climate regulation, flood control, and water purification) control ecosystem processes that influence the well-being of humans,
- Cultural services generate human well-being outside any direct or indirect consumption of goods. Examples include recreational opportunity, aesthetic opportunity, and well-being generated by the knowledge an ecosystems exists in a certain state (often called existence or spiritual value), and
- Supporting services (e.g., nutrient cycling and primary production) generate human well-being by facilitating the production of future ecosystem services.

Thus, when answering the question, what is the value of avoiding the environmental impacts associated with DSM, an economist might first attempt to quantify the DSM related change in the quantity and quality of ecological services provided. The economist would then attempt to answer the question, what value is associated with each of those changes.

Earth Economics (2015) is an example of an effort to first quantify change sin ecosystem service provision and then value those changes. After describing type and magnitude of services provided by the deep seabed, the authors report that, if DSM resulted in the loss of all ecosystem services provided by the deep seabed, the value of that loss might be as high as $1,766 per hectare. Of note, the authors report the $1,766 is “based on values used for cloud forests, due to the lack of available valuation studies conducted on the deep seabed.”

Unfortunately, such a course valuation approach provides very limited insight into the values that might be associated with subtle changes. Simply put, the science of bio-economics has not advanced far enough to confidently determine ***if*** society places different values on nodule covered and soft bottom deep seabeds. Estimating the precise magnitude of any potential difference is, in the current opinion, beyond reach.

As an alternative and/or supplement to the direct valuation approach, it is possible estimate the cost of creating ecological services to replace those that might be lost to DSM. This “replacement cost” can be used as a proxy for value.

The method used to estimate replacement costs for ecological services is Habitat Equivalency Analysis (HEA). The basic premise underlying HEA is that all of the services flowing from a habitat can be treated as a single composite service. If an injury to a habitat reduces the amount of composite service produced by an impacted habitat, those losses can be offset through a restoration project that creates composite service that otherwise would not exist (Dunford et al. 2004).

The metric used in a HEA is Discounted Service Acre Year (DSAY) where a service acre year is defined as all of the services provided by one acre of habitat over the course of a year. Service acre years are discounted to reflect society’s preference to have goods sooner than later all else equal.

HEA is typically discussed in terms of debits and credits flowing from two discrete sites (Figure A1).

> Debits accrue when the level of composite service provided by the injured site is below baseline.

> Credits accrue when the level of composite service provided by the restored site is above baseline.

> Compensation for lost ecological services is achieved when the debit (present discounted value of the area represented in red in Figure A1) is equal to the credit (present discounted value of the green area in Figure A1).

> Replacement cost is equal to the cost of implementing restoration at the restored site.

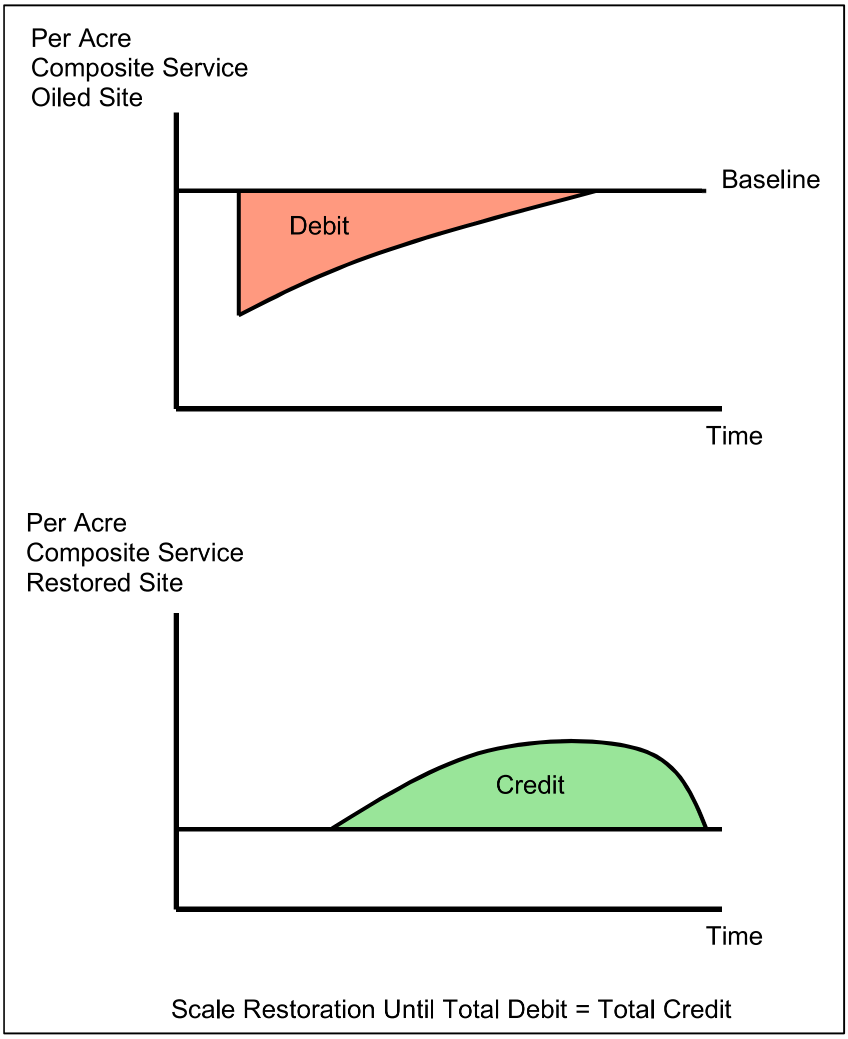

Figure A1 Graphical Representation of HEA

APPENDIX B

CASH FLOW ANALYSIS

Appendix B Cash Flow Analysis

In each case study country, a cash flow analysis is performed on the mining operation to determine whether or not the mine will be economically feasible for the foreign owned mining company. A cash flow analysis is simply the flow of cash throughout the project over time. It determines the mining projects projected results by measuring revenues against expenditures. This is a necessary step in the CBA since it determines whether the mine will be profitable, and how much, if any, revenue the government will receive in taxes in royalties. In each country, the cash-flow analysis is based on a set of inputs that determine the revenue potential and the anticipated costs to the foreign owned mining company.

The inputs used to determine revenue potential to the foreign owned company include:

- Total inferred resource (in dry tonnes),
- Estimated annual production (in dry tonnes),
- Efficiency of the mining operation (percent of metals recovered),
- Metal content of ore in the seabed (as a percentage),
- Prices of metals to be extracted ($/lb USD).

The inputs used to determine potential costs to the foreign owned company are:

- Capital and operating expenses associated with the operation of the mine, and
- Fiscal regime of host-country (taxes and royalties).

As described in Section 2.3 for the inputs that are uncertain, a range of estimates (minimum, most likely, maximum) is fitted to probability distributions to indicate the probability that the input parameter will take on a certain real world value at the time the project commences. After estimating revenue and cost streams in each year that the mine is in operation based on the input parameters, the pre-tax and after-tax cash flow to the mining company is estimated and adjusted for inflation by assuming a 2% increase each year. Also, in each case study country, with the exception of Papua New Guinea, the cash flow analysis is evaluated with and without the inclusion of processing costs. The following sections provide the detailed results of the cash-flow analyses in each of the case study countries.

B.1 Papua New Guinea – Cash Flow Analysis

Table B1 displays the values for the inputs that enter the cash-flow analysis as random draws from a probability distribution in the PNG mining scenario. These include the efficiency of mining operation (metal grade percentage), expected metal grade of ore in the seabed, metal prices, and capital and operating expenses.

Table B1 Model Inputs in PNG Cash Flow Analysis

Input[1]	Minimum	Most Likely	Maximum
% Efficiency	65.5%	75.8%	88.4%
Zinc Production (%)	0.33%	0.47%	0.61%
Copper Production (%)	3.4%	6.2%	7.5%
Gold Production (g/t)	3.41	5.26	7.54
Silver Production (g/t)	13.2	25.6	35.2
Zinc ($/lb) USD	$0.35	$0.69	$1.03
Copper ($/lb) USD	$1.00	$1.97	$3.00
Gold ($/lb) USD	$6,143	$12,285	$18,427
Silver ($/lb) USD	$75	$165	$250
CAPEX – mining equipment (millions of USD)[1]	$287	$342	$397
CAPEX – transportation (millions of USD)[2]	$7.7	$9.2	$10.7
OPEX – mining equipment and transport (millions of USD)[1]	$71.9	$86.5	$103

Note 1: Inputs are based on simulated inputs from Monte Carlo Analysis, not the initial range of inputs used to inform the distribution.

Note 2: Costs reduced by 15% to represent PNG governments share of the costs

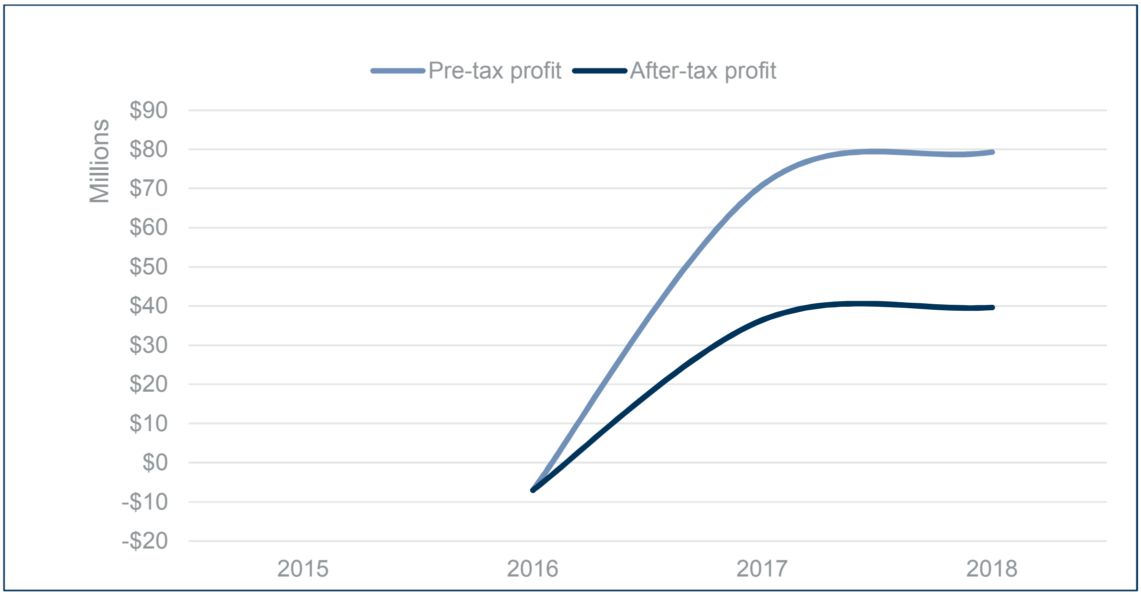

Figure B1 Comparison of Solwara 1 Project Pre-Tax Profit to After-Tax Profit

B.2 Cook Islands – Cash Flow Analysis

Table B2 displays the values for the inputs that enter the cash-flow analysis as probability distributions in each scenario (with and without processing costs). These include the efficiency of mining operation (metal grade percentage), expected metal grade of ore in the seabed, metal prices, and capital and operating expenses.

Table B2 Model Inputs in Cook Islands Cash Flow Analysis by Scenario

Input[1]	Scenarios 2 & 3			Scenario 1		
	Minimum	Most Likely	Maximum	Minimum	Most Likely	Maximum
% Mining efficiency	70%	80%	90%	No change	No change	No change
Manganese Production (%)	13.9%	15.5%	17.1%	No change	No change	No change
Cobalt Production (%)	0.37%	0.51%	0.59%	No change	No change	No change
Copper Production (%)	0.09%	0.17%	0.34%	No change	No change	No change
Nickel Production (%)	0.21%	0.26%	0.33%	No change	No change	No change
REY Production (%)	0.14%	0.22%	0.29%	No change	No change	No change
Silico-manganese ($/lb) USD	$0.32	$0.63	$0.95	$0.07	$0.14	$0.21
Cobalt ($/lb) USD	$6.87	$13.74	$20.6	$1.5	$3	$4.5
Copper ($/lb) USD	$1.5	$2.90	$4.4	$0.32	$0.64	$0.96
Nickel ($/lb) USD	$3	$6.5	$12	$0.67	$1.43	$2.14
REYs ($/lb) USD	$30	$54.5	$81	No change	No change	No change
CAPEX – processing facility (USD per tonne)	$500	$579	$700	N/A	N/A	N/A
CAPEX –equipment (USD per tonne)	$350	$500	$650	No change	No change	No change
CAPEX – transportation (USD per tonne)	Lease	Lease	Lease	No change	No change	No change
OPEX – processing 4-metal (USD per tonne)	$66.6	$179	$125.1	No change	No change	No change

Input[1]	Scenarios 2 & 3			Scenario 1		
	Minimum	Most Likely	Maximum	Minimum	Most Likely	Maximum
OPEX – processing 3-metal (USD per tonne)	$95	$114	$158	N/A	N/A	N/A
OPEX – processing 3-metal + REY (USD per tonne)	$180	$228	$400	No change	No change	No change
OPEX –equipment (USD per tonne)	$20	$36	$109	No change	No change	No change
OPEX – transportation (millions of USD)	$20	$24	$76	No change	No change	No change

Note 1: Inputs are based on simulated results from the Monte Carlo analysis

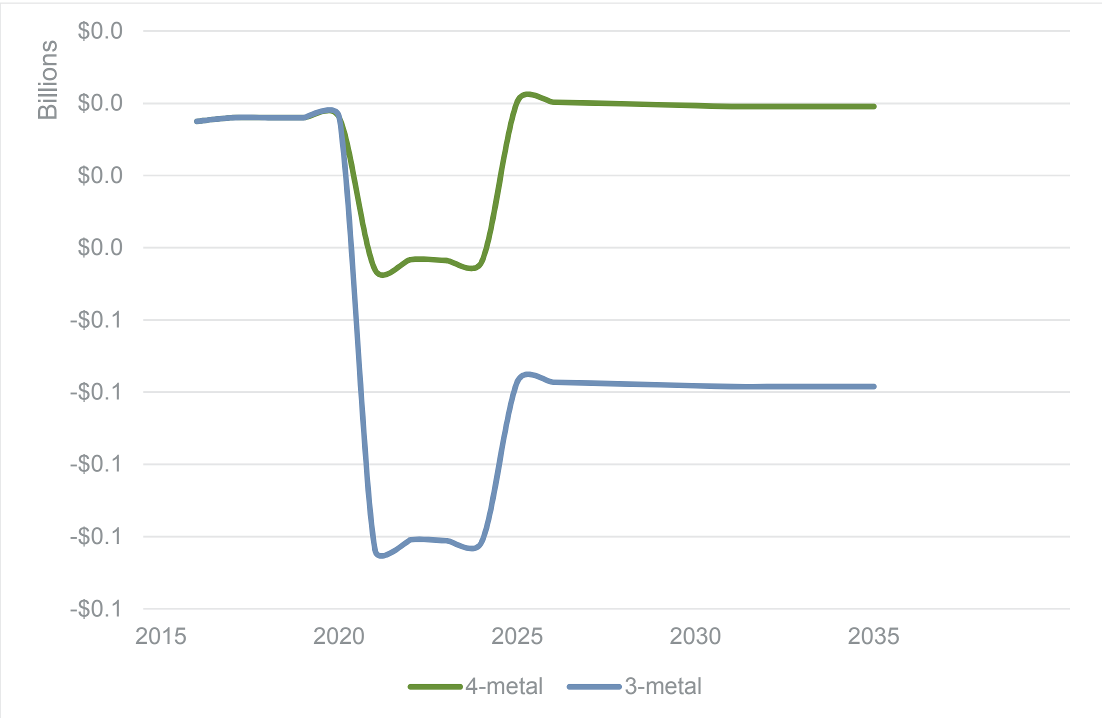

Figure B2 Cook Islands Pre-Tax Profit – Scenario #1

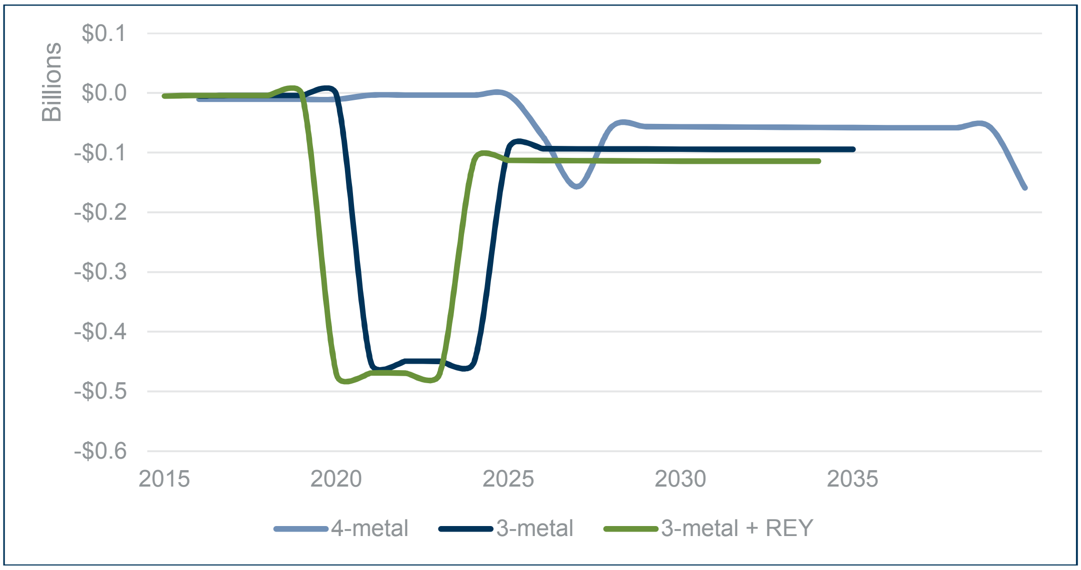

Figure B3 Cook Islands Pre-Tax Profit – Scenario #2

B.3 Republic of Marshall Islands – Cash Flow Analysis

Table B3 displays the values for the inputs that enter the cash-flow analysis as probability distributions in each scenario (with and without processing costs).

Table B3 Model Inputs in RMI Cash Flow Analysis by Scenario

Input[1]	Scenario 2			Scenario 1		
	Minimum	*Most Likely*	*Maximum*	*Minimum*	*Most Likely*	*Maximum*
% Efficiency	85.6%	89.9%	94.3%	No change	No change	No change
Cobalt Production (%)	0.31%	0.44%	0.56%	No change	No change	No change
Copper Production (%)	0.09%	0.13%	0.17%	No change	No change	No change
Nickel Production (%)	0.44%	0.63%	0.78%	No change	No change	No change
Cobalt ($/lb) USD	$6.87	$13.74	$20.6	$0.9	$1.6	$2.2
Copper ($/lb) USD	$1.5	$2.90	$4.4	$0.17	$0.29	$0.41
Nickel ($/lb) USD	$3	$6.5	$12	$0.33	$0.64	$0.89
CAPEX – processing facility (millions of USD)	$300.2	$379	$454.9	N/A	N/A	N/A
CAPEX –equipment and transport (millions of USD)	$150	$396	$470	No change	No change	No change
OPEX – processing (millions of USD)	$66.6	$114	$125.1	No change	No change	No change
OPEX –equipment (millions of USD)	$31	$57.8	$84	No change	No change	No change
OPEX – transportation (millions of USD)	$6.4	$13.3	$19.4	N/A	N/A	N/A

Note 1: Inputs are based on simulated results from the Monte Carlo analysis

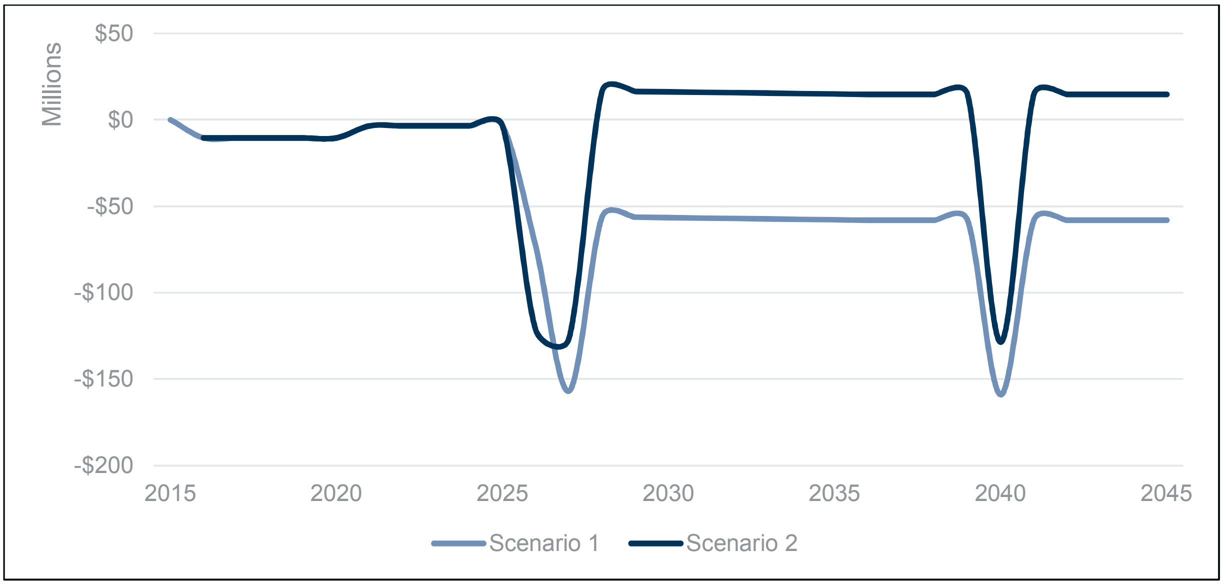

Figure B4 RMI Pre-Tax Profit – Scenarios #1 and #2

APPENDIX C

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APPENDIX D

UNDERLYING IMPLAN MODEL DATA: COOK ISLANDS

Appendix D Underlying IMPLAN Model Data Modification for the Cook Islands

Table D1 Baseline IMPLAN Industry Data for Commonwealth of Northern Mariana Islands (in millions USD)

Description	Employment	Employee Compensation	Value Added (GDP)
Agriculture	186	$0.7	$8.0
Fishing	4	$0.0	$0.1
Mining	36	$0.3	$0.4
Utilities	904	$18.0	$47.3
Construction	759	$7.2	$9.8
Manufacturing	925	$4.1	$3.5
Wholesale and retail	5,507	$40.9	$58.2
Transportation and communication	2,323	$59.0	$159.3
Finance	581	$15.7	$38.5
Real estate	4,806	$71.3	$221.5
Education	627	$8.2	$10.4
Health and social work	1,194	$31.0	$42.5
Hotels and restaurants	7,535	$88.9	$206.0
Community, social and personal services	1,296	$17.0	$32.6
Pubic administration	4,142	$155.7	$155.7
Total	30,826	$518.3	$993.7
Source: IMPLAN 2013, Commonwealth of Northern Mariana Islands			

Table D2 Underlying IMPLAN Industry Data for Cook Islands (in millions USD)

Description	Employment	Employee Compensation	Value Added (GDP)
Agriculture	168	$0.7	$6.3
Fishing	135	$0.6	$8.1
Mining and Manufacturing	317	$3.0	$8.8
Utilities	70	$1.4	$6.2
Construction	413	$3.9	$54.4
Trade	1,205	$9.0	$81.7
Transport and communication	377	$9.6	$34.7
Finance	712	$11.5	$37.0
Owner-occupied dwellings	0	$0.0	$22.3
Education and health	426	$9.2	$15.4
Restaurants	1,369	$16.2	$55.0
Community and personal services	484	$6.4	$6.5
Pubic administration	1,262	$47.4	$47.4
Total	6,938	$118.7	$383.9

Source: Cook Islands Government, February 2015, Economic Activity and Labour Force of the Cook Islands, Website (http://www.agriculture.gov.ck/contents/pdf-download/national-docs&acts/Economic%20activitiy%20and%20labour%20force%20of%20the%20Cook%20Islands.pdf) Accessed March 3, 2015.

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Note: IMPLAN software allows for the analyst to customize study area data. Industries within the underlying CNMI IMPLAN model (Table D1) were replaced with the employment, income and value added data illustrated in Table D2 to better reflect the economy of the Cook Islands.

Table D3 Underlying IMPLAN Industry Data for the Republic of Marshall Islands (in millions USD)

Description	Employment	Employee Compensation	Value Added (GDP)
Agriculture	10	$0.0	$8.5
Fishing	1,119	$3.9	$32.0
Mining	0	$0.0	$0.0
Utilities	326	$4.5	$7.4
Construction	425	$3.4	$10.3
Manufacturing	100	$0.8	$1.2
Wholesale and retail	1,802	$9.2	$24.1
Transportation and communication	638	$6.1	$14.6
Finance	235	$3.8	$7.2
Real estate	235	$1.8	$14.7
Education	481	$6.1	$22.2
Health and social work	223	$2.2	$12.5
Hotels and restaurants	243	$1.4	$3.2
Community, social and personal services	267	$1.8	$2.2
Pubic administration	3,617	$42.8	$23.7
Total	9,721	$87.8	$183.8

Source: Pacific Island Training Initiative, August 2014, Fiscal Year 2013, Statistical Appendices, Website (http://www.pitiviti.org/news/wp-content/uploads/downloads/2014/11/RMI_EconStat_tabs_FY13_publish.pdf) Accessed March 3, 2015.

Note: IMPLAN software allows for the analyst to customize study area data. Industries within the underlying CNMI IMPLAN model (Table D1) were replaced with the employment, income and value added data illustrated in Table D3 to better reflect the economy of the RMI.