Institut européen
European Institute

LUISS
School of Government

Joint Master in EU Trade and Climate Diplomacy

A State of Urgency: Evaluating the Utilitarian Potential of Deep-Sea Mining on the Brink of Net-Zero

Supervised by Sami Zeidan

Jeanelle Carty

2024

A State of Urgency: Evaluating the Utilitarian Potential of Deep-Sea Mining on the Brink of Net-Zero

Jeanelle Carty

July 2024

Plagiarism Statement

I certify that this thesis is my own work, based on my personal study and/or research and that I have acknowledged all material and sources as well as AI tools used in its preparation. I further certify that I have not copied or used any ideas or formulations from any book, article, or thesis, in printed or electronic form, or from AI tools without specifically mentioning their origin, and that complete citations are indicated in quotation marks.

I also certify that this assignment/report has not previously been submitted for assessment in any other unit, except where specific permission has been granted from all unit coordinators involved, and that I have not copied in part or in full or otherwise plagiarised the work of other students and/or persons.

In accordance with the law, failure to comply with these regulations makes me liable to prosecution by the disciplinary commission and the courts of the Republic of France for university plagiarism.

16.07.2024. *Jeanelle Carty*

Acknowledgements

I have wanted to study abroad since my first year of undergrad, to work on environmental problems at an international scale. Little did I know several years later, I would be writing my thesis while living in three different countries. Completing this master's is to me, a profound personal achievement. I have proven to my younger self that *I can*. For being able to say this, I am first thankful to my parents who have not only funded my studies, but who have been there for me every time I have had to make a call home, happy or sad, they were always there. I will forever be indebted to them for affording me this experience.

Before I started this thesis, I had never heard of deep-sea mining. I had extensive knowledge on global environmental problems, and their politics, but it was my now supervisor who revealed to me this contentious industry, and it is now my deepest passion to do something about such contention. I owe my gratitude to him for that brief mention of the industry in one of our seminars, for had it not been for his comment, I would perhaps not be writing this now. Sami, you have been a great help to me throughout this process, and I hope to build something that not only I, but you can be proud of.

I would also like to thank those industry professionals who generously shared their time and expertise to help guide my research. To Kaja Lønne Fjærtoft, Global Deep-Sea Mining Policy Lead at WWF, who articulated a compelling stance on the industry regarding the importance of moving forward in an environmentally sensitive manner. To Udo Barckhausen, Marine Resources Researcher for the German Federal Institute for Geosciences, who was willing to inform me on the nuances of exploration licenses and offered a realistic perspective about regulating such a unique cross-national resource. And finally, Dr. Lars Kristian Trellevik, Chief Sustainability and Operations Officer at Adepth Minerals, who's prompt response to my inquiry initially fueled my enthusiasm for my research. I am indebted to his honest and I'd say invaluable insights into the reality of those researching deep-sea mining, a reality which helped to inform the diplomatic stance I have taken in this thesis.

Last, I would like to offer my deepest gratitude to my good friend Saba, who despite being an entire ocean away, walked with me through every step of my time abroad. I probably would not have succeeded this difficult and transformative experience had it not been for her never-ending, intelligent, and gentle support.

In closing, I offer thanks to myself, for getting this far, for showing myself that *I can*. This paper is my opus, a culmination of everything that is me—all of my skills, up until this point.

I hope that it contributes something helpful to our Earth.

And I thank anyone who reads this. For your attention is also a form of support.

I hope you leave knowing a little more about this

climate conundrum we find ourselves in.

And I hope someday we no longer exist within it.

To find such a future is my life goal. And will be my life's work.

Acronyms

CCZ	Clarrion-Clipperton Zone
CFC	Cobalt Rich Ferromanganese Crusts
CHM	Common Heritage of [Hu]mankind
CRMA	Critical Raw Materials Act
CRMs	Critical Raw Materials
DSM	Deep-Sea Mining
EEZ	Exclusive Economic Zone
EV	Electric Vehicle
GHG	Greenhouse Gas Emissions
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
IRENA	International Renewable Energy Agency
ISA	International Seabed Authority
LFP	Lithium-Iron-Phosphate Batteries
LTC	Legal and Technical Commission
NDAA	National Defence Authorization Act
NDCs	Nationally Determined Contributions
NMC	Lithium Nickel Manganese Cobalt Oxide
NORI	Nauru Ocean Resources Inc
PMN	Polymetallic Nodules
PMS	Polymetallic Sulphides
TMC	The Metals Company
UNCLOS	United Nation Convention on the Law of the Sea
UNEP	UN Environment Programme

Abstract

This thesis evaluates whether deep-sea mining (DSM) has any value in the context of urgency to meet net-zero targets by mid-century. Specifically, this is examined through a structured, qualitative literature review and thematic analysis looking at Imperative and Utilitarian Values of DSM. The Imperative Value examines the imminence of a DSM industry, considering a potential “race to the bottom” scenario, and the regulatory capacity of the ISA to enact and maintain a permanent halt against DSM-related activity. The Utilitarian Value of DSM is then assessed by looking at three different facets: the influence of climate change in potentially necessitating DSM as a means for providing CRMs for renewable energy technologies. The effectiveness of DSM-relevant battery chemistries, in comparison with popular alternatives. And finally, the scalability of DSM technology, emphasizing dual requirements of technical capability and environmental sensitivity.

The results call for an approach to DSM that acknowledges its potential contributions to the global energy transition while also recognizing its inherent environmental risks as an exploitive industry. The conclusion urges for the development DSM exploitation regulations in a way that might bridge the discourse between its opposition and support.

Keywords: deep-sea, exploitation, mining, net-zero, energy transition, climate change, urgency

Table of Contents

1 Introduction

The 2015 Paris Agreement set an ambitious goal to limit climate warming to no more than 1.5°C above pre-industrial levels (United Nations, 2015; Climate Action Tracker, 2023). In response, many nations established net-zero emission targets for mid-century, a time constraint that puts immense pressure on one of the main paths to transition—electrifying the global transport fleet. To achieve a net-zero scenario, projections indicate that we will need around 1 billion electric vehicles (EVs) on the road by 2047 (Paulikas et al., 2020). This shift will ultimately increase demand for batteries, batteries that use critical raw materials (CRMs). Such a massive transition will subsequently require an estimated 3 billion tons of metals and minerals by 2050, according to the World Bank (IEA, 2023c). Despite ongoing innovations in alternative technologies and materials, it is crucial to acknowledge that meeting the demands for this transition will present formidable challenges to the CRM supply chain. This thesis aims to confront the stark reality of this fact.

Given escalating demand for CRMs and their role in the transition to net-zero, attention has been shifting to the deep-sea floor. Her vast mineral deposits present a tantalizing opportunity, reminiscent of historical gold rushes. However, this seemingly promising frontier comes with significant caveats and while the resource potential is great, there are major bottlenecks that prevent deep-sea mining (DSM) from being realized. The industry is inherently exploitative, and its environmental risks are amplified in a scenario where operations occur without proper intent or foresight. In a proactive response to this hypothetical, industry opposition often takes a degrowth stance, suggesting a total move away from mining. However, the fact withstands that with only a quarter-century remaining to achieve net-zero, we have entered a period of urgency in which [hu]mankind will be tasked to make huge leaps in innovation, with little room for failure. We must get this right, with what we have, and this necessitates the consideration of all potential solutions to achieve our ambitious environmental goals. The potential realization of DSM thus marks a critical juncture on humanity's path to a more sustainable future as it can either exacerbate our climate risks or solve them.

The conundrum of DSM will be parsed apart in this thesis through an examination of its value in the context of climate urgency. The research question seeks to answer whether DSM has a role to play on the path to net-zero, considering our narrowing window of time. This question will be examined through a structured, qualitative literature review and subsequent thematic analysis, that will look at factors of urgency through Imperative and Utilitarian Values. Urgency refers broadly to the time constraints of our climate goals and the pressure this creates to consider realizing DSM. Imperative Value therein examines the imminence of a DSM industry, while the Utilitarian Value assesses its potential to aid in the transition to net-zero. This structure aims to address two critical facts in response to the main research question. First, if DSM is indeed imminent and resistant to full cessation, then a structured regulatory framework to govern exploitation in an environmentally sensitive manner might be preferable. Second, if DSM demonstrates utility to acheive our climate goals, then regulations should be designed to maximize that.

The purpose of answering this research question is to chart a path forward for DSM that bridges divisive opinions about its development. How to go forward in a manner that is as diplomatic, as it is environmentally sensitive. Conversely, this thesis does not seek to refute the extractive nature of DSM but rather, explore its feasibility only as a transitionary aid to net-zero. The main goal is to foster constructive dialogue among stakeholders, through recognizing the conundrum we find ourselves in; pressed with intense resource needs to mitigate to our climate challenges. The goal therein is to provide insights that can inform policy decisions that ensure any potential implementation of DSM aligns with both environmental preservation and global decarbonization objectives.

2 Background

2.1 *Urgency of the energy crisis*

Human progress has largely been built on the perverse exploitation of finite resources. We have throughout history, often seen resources as more abundant than they really are due to a pattern of near-sightedness. A pattern which has set humanity on a challenging path, one that has become increasingly difficult to alter. The consequences of this trajectory have now culminated in a global effort to reverse course. In 2015, 196 countries agreed within the Paris Agreement to limit climate warming to no more than 2^{o}C above pre-industrial levels, with a preference to keep it below 1.5^{o}C (IISD, 2015). Despite efforts in response to the Agreement, global temperatures have continued to rise, ushering in a new era of human history. This era was defined in a report published by the UN Environment Programme (UNEP) in 2023 that projected a 2.5^{o}C-2.9^{o}C rise in temperature by the end of the century (United Nations Environment Programme, 2023). In other words, if participating countries fail to meet their Nationally Determined Contributions (NDCs) to the Paris Agreement, then we set ourselves on track for 3^{o}C warming by 2100 with a chance of 66% (United Nations Environment Programme, 2023). Within this predication, we have a remaining carbon budget of 235 metric gigatons, which would only allow for another 7 years of current emissions if we are to maintain temperatures within the 1.5^{o}C of pre-industrial levels (Friedlingstein et al., 2023). This is the period of urgency

2.2 *Demand for critical raw materials*

Despite this period, participating countries in the Paris Agreement still exert great efforts to keep temperatures within the 1.5^{o}C limit. A large part of this effort is facilitated by the transition to battery power—that which will require an immense supply of critical raw materials (CRMs). Currently, the World Bank estimates that 3 billion tons of metals and minerals will be needed by 2050 to usher the planet into a net-zero scenario (World Bank Group, 2020). For reference, this is equivalent to all the minerals that have been extracted since the beginning of civilisation. One of the greatest tasks of this transition therein, is figuring out how to sustainably meet such high demand. On the one hand, there is a push for degrowth strategies which mean to limit demand through technological innovation, encouraging behavioural changes to reduce consumption, and adopting business models that foster a circular economy (Pelaudeix, 2018). This call for degrowth is objectively sound in theory and can be unanimously agreed upon. However, it is also symptomatic of best-case scenario projections, in which mining for CRMs is limited all together, and alternative solutions for the green transition are ready and abundant. The current difficulty is in the fact that we simply do not have the CRM supply to directly transition to a best-case scenario model, and alternatives to CRM and DSM-relevant battery chemistries are themselves under immense pressure to keep up with urgent demand. The fact is, supply gaps exist, and the question remains on how to close them in a way that will bring the least environmental and social harm.

Deep-sea mining (DSM) has been proposed as contentious answer to this question. The case for this is often illustrated by examining the current state of the electric vehicle (EV) industry, which epitomizes the transition due to its heavy reliance on battery technology. To reach net-zero, it is currently projected that we will need a fleet of 1 billion EVs by 2047 (Paulikas et al., 2020). If a single Tesla Model 3's 75KWh NMC 811 lithium-ion battery needs 7kg of cobalt, 85kg of copper, 56kg of nickel, and 6.6kg of manganese, then in this crude hypothetical, we would require around 155 metric megatons (Mt) of these four base metals for 1 billion EVs (Paulikas et al., 2020). As of 2022, the global EV fleet surpassed 26 million units, representing the culmination of a trend of exponential growth since 2012 (IEA, 2023c). However, the material needs for an EV fleet of 1 billion still present significant challenges to the CRM supply chain. Even under best-case scenario projections in which 100% of current EV batteries are recycled, the supply of secondary materials will still fall short of meeting growing demands for battery production (Paulikas et al., 2020; Trellevik, 2023).

2.3 *The need to mine*

While recycling and innovation are crucial, the sheer demand for metals to reach net-zero will necessitate additional mining to bridge the supply gap. In response to this necessity, the EU has placed significant emphasis on securing sustainable access to CRMs through their recently enacted Critical Raw Materials Act (CRMA). The main goal of this Act is to reduce the EU's dependence on third countries for 34 different types of vital CRMs (European Commission, 2023). For these minerals, the EU has set targets so that no third country provide more than 65% of the EU's CRM imports by 2030 (European Commission, 2023). This is specifically to support a process of decoupling from China, which leaves the EU in need of new sources for its CRMs

(European Commission, 2023). To successfully decouple, the EU must now source its CRMs from other countries or places, stimulating a ‘sine qua non' condition—an obligatory search for new deposits (Trocan 2023). To fulfil this condition, theoretical and explorative attention has shifted to the deep-sea and her resources (Pelaudeix, 2018).

Deep-sea mining presents itself as a potential source of supply to the CRMA, and further, the global transition to net-zero. Herein, the CRMA specifically identifies underwater mineral occurrences as potential targets for extraction (Pelaudeix, 2018). This would mean that DSM projects could be realized as EU Strategic Projects for mining, permitting both their funding and initiation (Pelaudeix, 2018). However, even with the deep-sea’s resource potential, its mining has stimulated intense, divisive debate. This debate illustrates the current conundrum of the ‘green transition’—the fact that some degree of mining will be needed, even though the climate crisis dictates carbon consciousness in the very construction of the transition. Herein, the struggle to achieve a fully conscious transition reveals humanity's long-standing pattern of environmental exploitation. The challenges we face in decarbonizing our societies stem directly from our historical reliance on unsustainable resource consumption. This reality is brought to the fore with the prospect of DSM.

2.4 *The deep-sea*

The Clarrion-Clipperton Zone (CCZ), a vast region in the Pacific Ocean, situated between Hawaii and Mexico comprises about 1.5% of the world’s total abyssal plains (Paulikas et al., 2020). It is one of the most prominent focus regions for DSM, with a prospective 34 billion wet metric tons of nodules—small potato shaped rocks that contain minerals relevant to the green transition (Paulikas et al., 2020). Hein et al. (2020) assert that the identified marine deposits of CRMs contain greater quantities of nickel, manganese, and cobalt than all known terrestrial resources combined. This has drawn valid attention to explore the deep-sea’s potential to meet the needs of the green transition.

There are three main types of mineral deposits of interest for DSM.

Criteria	Polymetallic Nodules (PMN)	Polymetallic Massive Sulphides (PMS)	Cobalt Rich Ferromanganese Crusts (CFC)
Depth	Between 3500 and 6500 m (Pelaudeix, 2018)	Between 1500 and 3500 m (Pelaudeix, 2018)	Between 400 to 4000 m (Peterson et al., 2016; Toro et al., 2020)
Region	Mining locations particularly focused in the CCZ of the Pacific Ocean, the Peru Basin near the Cook Islands, and the Central Indian Ocean Basin (Pelaudeix, 2018)	No comprehensive global distribution of known seafloor massive sulphide sites, but research indicates concentrations in the Manus Basin in Papua New Guinea (MIDAS, n.d.)	Most known potential in the Pacific Ocean at 66%, 23% in the Indian Ocean, and 11% in the Atlantic Ocean (Lusty & Murton, 2018).
Location	Sediment-covered abyssal plains of the Indian, Pacific, and Atlantic Oceans (Trellevik, 2023)	Volcanic and tectonic settings such as in mid-ocean ridges, back arc basins, and island arc rifts (Trellevik, 2023)	Hard layers of metallic deposition on rockfaces such as ridges, seamounts, and plateaus where currents or slope angles have prohibited deposition of loose sediment (Hein et al., 2013; Toro et al., 2020)
Mineral Potential	Deposits contain elements aligned with the metal needs of EV	Deposits contain elements such as copper, zinc, gold,	Deposits contain elements such as cobalt, vanadium,

	battery and assembly manufacturers—nickel, cobalt, manganese, copper, and other rare-earth metals (Paulikas et al., 2020)	silver, gallium, cobalt, barium, rare earth elements and more, depending on the location (Pedersen et al., 2021)	cadmium, tellurium, barium, nickel, rare earth metals, yttrium, and all elements of the platinum group (Haugan & Leven; Toro et al., 2020)

Table 1. Overview of the three main targets for DSM.

The realization of any DSM operations remain in limbo due to two critical reasons. First, the regulatory framework for DSM is incomplete, leaving crucial legal and environmental questions unanswered. Second, the unique challenges posed by regulating a resource in international waters, otherwise known as “the Area”, have proven exceptionally complex (Pelaudeix, 2018). Since ownership over resources in the Area befall unto no one nation, they fall under the jurisdiction of the United Nations Convention on the Law of the Sea (UNCLOS) (Pelaudeix, 2018). The core principle of this convention is to regulate resources extracted from the Area for the "common heritage of [hu]mankind" (CHM) (Pelaudeix, 2018). This mandate is to ensure that the spoils of any exploitation benefit all of humanity, present and future, not just select nations or corporations.

Operating under UNCLOS and established in 1994, the International Seabed Authority (ISA) organizes and controls activities in the Area on behalf of its Member States, ensuring the responsible management and equitable sharing of deep-sea resources (United Nations, 1982). As the governing organization for the Area, the ISA is tasked with developing and implementing a comprehensive legal framework for deep-sea activities, particularly mineral exploration, and exploitation. Herein, The ISA issues exploration licenses, oversees mining operations, and generally governs resource-related activities in the Area according to the CHM principle. Currently, the ISA consists of 168 Member States and the EU (Blanchard et al., 2023).

2.5 *Exploration*

The ISA actively regulates exploration activity for polymetallic nodules (PMNs), Polymetallic Massive Sulphides (PMS), and Cobalt-Rich Ferromanganese Crusts (CFCs) (Pelaudeix, 2018; Hauner, 2024). Approved contractors, sponsored by UNCLOS State Parties conduct 15-year exploration contracts in assigned areas, gradually relinquishing portions over time (Hauner, 2024). The purpose of such activity is to survey for resources and evaluate the potential impacts of their mining (Hauner, 2024). Additionally, data collected from exploration has the secondary purpose of informing yet-to-be-established regulations for exploitation.

Since 2001, the ISA has granted 30 explorations licenses to 22 respective contractors (ISA, 2024a).

Country	Contractor	Polymetallic Nodules (PMN)	Polymetallic Massive Sulphides (PMS)	Cobalt Rich Ferromanganese Crusts (CFC)	Total
China	Beijing Pioneer Hi-Tech Dev. Corp	1			5
	China Minmetals Corp	1			
	China Ocean Mineral Resources Research and Development Assoc	1	1	1	
Singapore	Ocean Mineral Singapore Pte Ltd	1			1
Japan	Deep Ocean Resources Dev. Co Ltd	1			1

Korea	Government of the Republic of Kora	1	1	1	3
Germany	Federal Institute for Geosciences and Natural Resources	1	1		2
France	Institute français de recherche pour l'exploitation de la mer	1	1		2
Belgium	Global Sea Mineral Resources NV	1			1
UK	Loke CCZ (formerly UK Seabed Resources Ltd	2			2
Poland	Government of Poland		1		2
	Interoceanmetal Joint Organization	1			
Czcech Republic	Interoceanmetal Joint Organization	1			1
Slovakia	Interoceanmetal Joint Organization	1			1
Bulgaria	Interoceanmetal Joint Organization	1			1
Russian Federation	Ministry of Natural Resources and Environment		1	1	4

	of the Russian Federation				
	JSC Yuzhmorgeologiya	1			
	Interoceanmetal Joint Organization	1			
India	Government of India	1	1		2
Brazil	Companhia de Pesquisa e Recursos Minerais SA			1	1
Jamaica	Blue Minerals Jamaica	1			1
Cuba	Interoceanmetal Joint Organization	1			1
Nauru	Nauru Ocean Resources Inc	1			1
Tonga	Tonga Offshore Mining Ltd	1			1
Cook Islands	Cook Islands Investment Corp	1			1
Kiribati	Marawa Research and Exploration	1			1

Table 2. ISA mining exploration licenses as of 2024 (ISA, 2024b).

2.6 *Exploitation*

The ISA initially projected that it would finalize the regulations for deep-sea mineral exploitation, otherwise known as the Mining Code, by 2020 (Pelaudeix, 2018). However, this timeline has proven overly optimistic. As of now, negotiations on the regulations are ongoing, mired in controversy and conflicting perspectives. That said, Nauru, a small Pacific Island state, caused a major stirrup in the timeline by triggering what is popularly known as the “Two-Year Rule” in June 2021 (Pelaudeix, 2018). This Rule is an official provision in the UNCLOS, specifically under Section 1(15) of the relevant Implementation Agreement and it empowers a Member State to compel the ISA to finalize the Mining Code within a specified timeframe (UNCLOS Part XI, 1994; Neno, 2021). On part of this request, the ISA was effectively tasked to complete the Mining Code by July 2023. In the event the regulations were not finalized by this deadline, then Section 1(15) of Implementation Agreement would dictate that the ISA consider and potentially approve mining contracts based on whatever transitional, interim rules were in place at that time (UNCLOS Part XI, 1994).

The July 2023 meeting which aimed to finalize the Mining Code concluded without reaching this objective. Instead of adopting comprehensive regulations, the ISA merely set a new target date for 2025 to establish the Code. Notably though, this revised timeline is not legally binding and rather serves as an 'aspirational goal' (Alberts, 2023).

2.7 *Literature gaps*

Despite there being no definitive conclusion, negotiations on the development of the Mining Code remain ongoing largely due to the pressing reality of net-zero targets. To realize a net-zero scenario, humanity is faced with an unprecedented challenge to make monumental strides in emission reductions, with little to no room for failure. In this vein, DSM offers a contentious solution to our resource challenges. However, to act as a solution, the industry must navigate a landscape fraught with unknowns, balancing the urgent need for resources against the potential long-term consequences of their extraction. This delicate equilibrium between opportunity and risk continues to impede the industry's progress, highlighting a need to carefully re-evaluate DSM’s role on the path to net-zero. While its environmental impacts are undeniable, we have yet to fully explore the utilitarian value of DSM in this context of urgency.

Wilkerson & Trellevik (2021) advocate for a comprehensive systems-perspective approach to evaluate DSM’s role in the global transition. Their research encourages a holistic analysis, encompassing the geopolitical landscape surrounding DSM, the impact of climate change on the industry, the significance of innovation in green-tech, as well as broader trends in global mineral and mining markets. This multifaceted approach should provide a more nuanced understanding of DSM's potential contributions within the complex ecosystem of sustainable resource management and climate change mitigation. Therein, this thesis will attempt to extend their framework through a multi-faceted assessment of the imminence of DSM as an industry, and whether if in this period of urgency, it has any value.

3 Methodology

3.1 *Research Question*

The research question is based on the premise of urgency, broadly referring to the 1.5^{o}C target set in the Paris Agreement, and the trend to reach net-zero by mid-century (IPCC, 2015; Climate Action Tracker, 2023). Such ambitious targets ultimately put pressure on the global CRM supply, thus demanding a more systemic, utilitarian look at the potential role of DSM on the road to net-zero. The consideration of DSM herein, is not to refute its extractive or exploitive nature, but rather, to answer whether if in this context specifically, it has any value.

In light of these considerations, this thesis will address the following research question:

Does deep-sea mining have a role on the path to net-zero, considering factors of urgency?

3.2 *Theory*

Despite pressure to decarbonize, DSM remains heavily contested due to uncertainty over whether such an industry is either feasible, or necessary. This uncertainty is largely a result of the industry's relative infancy, and the fact that it is difficult to measure its real impacts since it is not commercially active at scale. This creates a paradox in which policymakers are pressed to make decisions with only limited data about the real-world implications of DSM. To address this paradoxical environment of uncertainty, utilitarian theory is essential. Developed in the 18th century, utilitarian theory, a moral philosophy, sought to judge an action based on its consequences, rather than on the degree of its adherence to a set of rules (Tardi, 2024). The purpose of such judgement was to evaluate if an action produced consequences of maximum utility—the greatest benefit to the greatest number of affected individuals at minimal cost (Tardi, 2024).

The utilitarian evaluation of DSM in this thesis is informed by Espen Dyrnes Stabell's (2019) conclusion that any decision to proceed with the industry should be based on the moral identity humanity wishes to achieve. This perspective addresses the need to consider the broader implications of DSM within the context of humanity's attempt to decarbonize, despite limited data regarding its commercial impacts. Stabell (2019) outlines that we should aspire to create a society grounded in principles of degrowth—one that exercises prudence to safeguard the Earth's health for future generations. However, it should be noted that how environmental health is defined, attained, and maintained, might vary. The journey to degrowth may not always follow a linear or straightforward path to simply "using less," especially given the complex structure of developed societies and the time it takes to make systemic changes. Hence, degrowth might take on a progressive definition towards its essential meaning to "use less", depending on DSM's potential role within the context of our current societal structures and the limited time we have to enact significant environmental changes.

In the context of shaping the society we aspire to become, Stabell (2019) concludes that the value of DSM should be assessed based on its potential to meet critical net-zero targets in an environmentally sensitive manner. It is important to note that this evaluation does not position DSM as a replacement for existing alternatives, but rather as a complementary solution to address critical gaps in the resource supply. This approach recognizes that while DSM is unlikely to entirely supplant current methods, it may still have a role to play given the urgency of our climate challenges.

3.3 *Orientation*

The approach to the research question is inductive. The research begins by establishing the urgent context for achieving net-zero emissions by mid-century, which frames the subsequent evaluation of DSM. Therein, DSM is analysed based on whether the industry has Imperative Value—whether it is imminent and there is a subsequent need for more concrete exploitation regulations and further, whether the industry has Utilitarian Value, whether it can aid the transition to net-zero.

If the analysis suggests that the industry has both a high Imperative Value (necessitating the completion of exploitation regulations) and high Utilitarian Value (can aid the transition to net-zero), it will suggest a need for progression in the industry to facilitate the degree of Utilitarian Value present in the results. Such a progression should prevent any 'worse-off scenario' where DSM either fails to materialize due to excessive restrictions, thereby not contributing to urgent resource needs, or without regulations at all, the industry proceeds in an uncontrolled manner that undermines its potential utility.

3.4 *Sampling Procedure*

To ensure a comprehensive and up-to-date literature sample, this research employed a snowballing technique, allowing access to the most relevant and current materials on DSM. To further enhance the breadth and depth of the analysis, industry professionals representing both supportive and opposing viewpoints were consulted, providing insights and literature suggestions reflective of the industry's current state. This approach facilitated an incorporation of the most recent industry developments, enabling a thorough consideration of DSM within its contemporary context.

3.5 *Research Design*

The research question is explored through a structured, qualitative literature review. First, relevant factors of urgency in relation to DSM are defined:

Imperative Value	This factor analyses the imminence of DSM and whether DSM would benefit from having a structured regulatory framework in place for exploitation
Utilitarian Value	This factor analyses whether DSM can aid the transition to net-zero

Table 3. Relevant factors of urgency in relation to DSM.

The purpose of examining these two factors is to assess whether any Utilitarian Value could be maximized if structured regulations were in place, thereby minimizing the potential of a 'worse-off scenario'. A comprehensive literature review is then conducted to analyse each factor in depth.

3.6 *Operationalization*

The factors are operationalized through the following facets:

Facets of Imperative Value	*These facets analyse the imminence of DSM and whether DSM would benefit from having a structured regulatory framework in place for exploitation*	
	Race to the Bottom	Presence of pressure to initiate DSM based on considerations of intent from different countries ('pressure of intent')
	Regulatory Capacity	Capacity of the regulatory body on DSM (ISA) to halt DSM mining operations

Facets of Utilitarian Value	*These facets analyse whether DSM can aid the transition to net-zero*	
	Climate Change	Influence of pressure from climate change on stimulating a need to consider DSM
	Alternatives	Competitiveness of alternative battery chemistries to those chemistries relevant to DSM
	Scalability	Technical feasibility and environmental sensitivity of DSM technology

Table 4. Facets of Imperative and Utilitarian Values.

Limits of this operationalization

This research structure notably lacks a comparative analysis with terrestrial mining and a comprehensive evaluation of environmental impacts beyond a broad recognition of their existence. These omissions are intentional, reflecting the study's focus on providing a broad overview of the complex situation surrounding DSM, rather than looking at its more direct and immediate effects, which the thesis acknowledges by default due to the industry's exploitive nature.

The well-documented environmental impacts of DSM are not the focus of this study, nor is the aim to challenge existing conclusions on this front. Instead, the research adopts a pragmatic approach, examining DSM through a lens of climate urgency and its impending reality, creating a situational context that might necessitate the consideration DSM. This approach is particularly valuable given the current opacity of DSM to the public, which has contributed to divisive opinions about whether or how the industry should proceed. Through providing a comprehensive yet accessible overview, the analysis aims to reduce disparities in public opinion.

3.7 *Thematic Analysis*

The literature review for each facet of each respective Value is then subjected to a thematic analysis using a coding scheme. This scheme employs a hierarchal rating from 1 to 3, with each number (code) representing the following:

Imperative Value	1	DSM presents no significant concern, having a structured regulatory framework for exploitation is negligible
	2	DSM presents some concern, a structured regulatory framework for exploitation should be considered
	3	DSM presents significant concern and a structured regulatory framework for exploitation is necessary

Utilitarian Value	1	DSM has no use on the path to net-zero
	2	DSM has considerable use on the path to net-zero
	3	DSM has definitive use on the path to net-zero

Table 5. Hierarchal rating scheme for thematic analysis of facets and Values.

This approach allows for a systematic evaluation of the literature across each facet of each Value.

3.8 *Data Collection and Analysis*

Each facet is evaluated using a unique set of qualitative factors, tailored to its specific context. Despite the diversity of these facets across the two Values, their analysis all adheres to the same three-point scale (Table 5) for consistency. The scale is applied uniformly, with the rating progression generally following this same order for each respective facet, despite the unique qualities that are being examined. This ensures a standardized evaluation method while allowing for the nuanced assessment of each distinct facet. The following graphic depicts the analysis of each facet for each respective Value in accordance with this hierarchal analysis (Table 5):

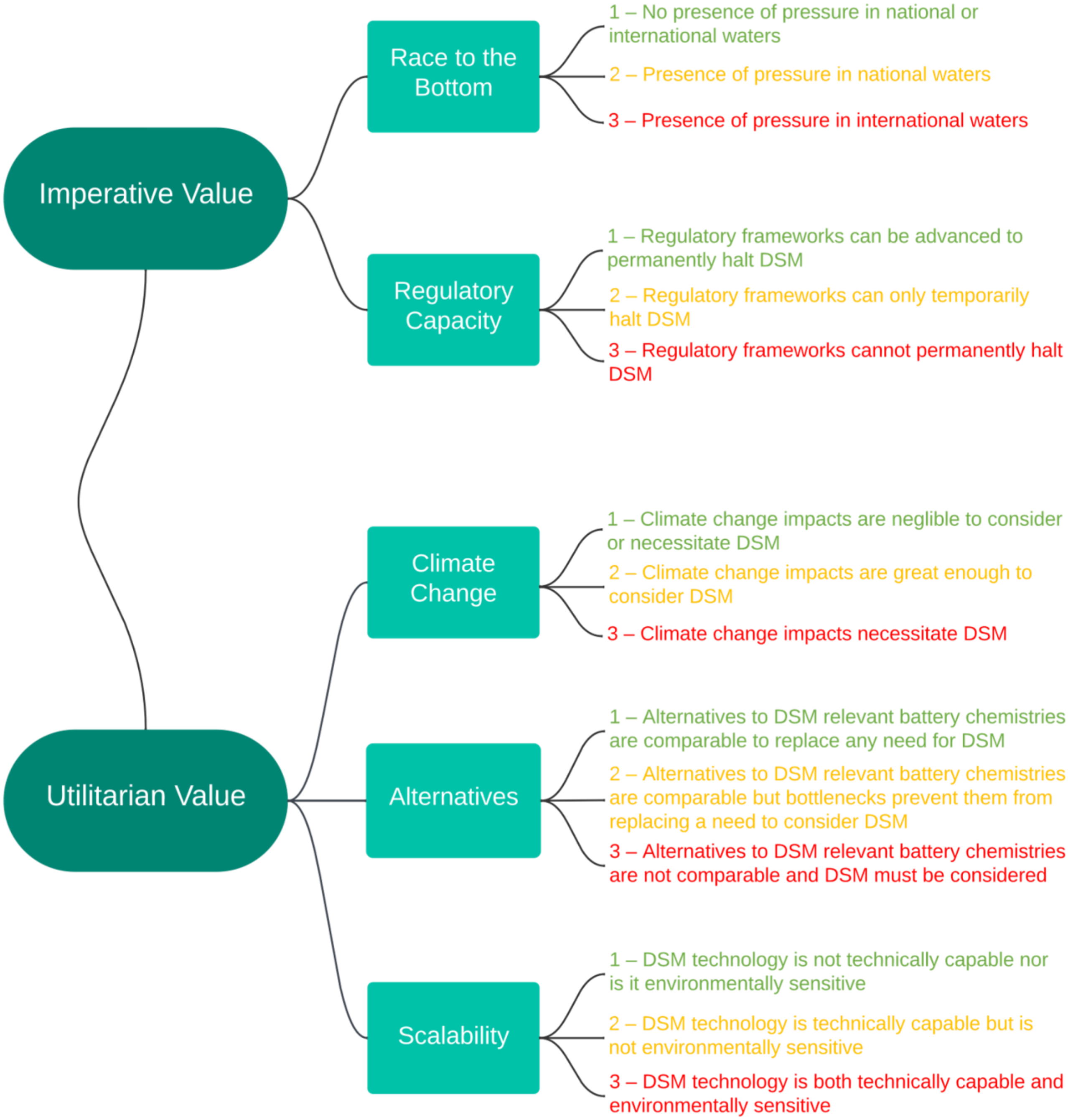

Figure 1. Analysis key for each facet of each respective Value.

For the thematic analysis, the literature review for each individual facet is analysed based on the analysis key (Figure 1) to identify points which adhere to the relevant codes. The frequency of each code is tallied within its respective facet, providing a quantitative measure of its occurrence.

The total is then converted into a percentage, representing the significance of that code and consequently the strength of the facet's Imperative or Utilitarian Value.

After analysing each facet individually, the codes are aggregated across all facets for each respective Value. The summation of each code for its respective Value is expressed as a percentage of the total (occurrences per Value). The resulting percentages represent a comprehensive measure of the overall strength of each Value.

4 Imperative Value

4.1 Race to the Bottom

4.1.1 *For exploitation*

Nauru

Nauru's decision to invoke the Two-Year Rule stems from its long history of exploitation by colonial powers. The Government of Nauru—sponsoring state of NORI (Nauru Ocean Resources Inc.), and a subsidiary of The Metals Company (TMC), stated that they would “proudly [be] taking a lead role” in developing the legal framework to govern exploitation in the Area (Government of Nauru, 2021). This trigger was meant to help establish a clear regulatory framework for DSM exploitation, which Nauru argued it could use to revitalize its struggling economy (Government of Nauru, 2021). To fully grasp this motive however, it is essential to understand the nation's complex history with phosphate mining.

Phosphate, once an abundant and highly lucrative resource on the Island, was unsustainably exploited for decades, destroying over 80% of its ecosystems. (Government of Nauru, 2021). The Pacific Phosphate Company of Australia and later the British Phosphate Commission of Great Britain were predominantly responsible for this exploitation throughout the 20th century (Roberts, 2008). Both countries took part in the exploitation of Nauru’s phosphate reserves for the benefit of the British Empire and its dominions (Australia and New Zealand at the time) (Roberts, 2008; Teaiwa, 2015). Nauru eventually gained its independence in 1968, however, this hardly put a stop to phosphate mining on the Island. Many were led to believe that the Nauruan government struggled to manage mining revenues or shift away from exploitive activity by its own faults. However, post-independence, Nauru’s continued exploitation of its phosphate reserves was largely driven by persistant external demand from Australia and New Zealand (Teaiwa, 2015; Gale, 2019). This pattern of external exploitation led to the near depletion of Nauru’s phosphate reserves by the year 2000 (Teaiwa, 2015; Gale, 2019). Now, the Island State heavily depends on financial aid from its former beneficiaries, Australia, and New Zealand, to compensate for its losses (Roberts, 2008; Teaiwa, 2015). Here, it becomes clear that Nauru’s reason for invoking the Two-Year Rule was not so simple as a means to boost its economy, but rather a symptom of its colonial history. It is a vulnerable country that has been driven to its last resort by centuries of exploitation, leaving the Island State at a crossroads between climate change, and economic downfall.

Nonetheless, the Government of Nauru maintains that invoking the Two-Year Rule was motivated by their desire to eventually apply for an exploitation license (Government of Nauru, 2021). While this move may potentially perpetuate a cycle of resource exploitation, Nauru's efforts to generate revenue from the Area's resources are, in light of its historical context, at least theoretically comprehensible. This is especially true given the importance of these resources for the green transition and the Island's vulnerability to climate change. Understanding this motive is crucial to grasp the nuanced reality of the Island State's intent to mine in international waters. Although invoking the Two-Year Rule has not yet resulted in any actualized Mining Code, their efforts have exerted legitimate pressure on the ISA to intensify negotiations on the matter.

Norway

In December 2023, the Norwegian Labour Party and the Centre Party achieved a majority vote in the Norwegian Parliament (Storting) to advance DSM in the country's Exclusive Economic Zone (EEZ) (Bessol, 2024). This would make Norway the first country to accept extraction applications in their national waters, demonstrating pressure of intent (Bessol, 2024). However, some of this pressure is nulled by the content of the decision itself. Within the agreement to open Norway's EEZ for DSM exploitation, it mandates that applications will only be accepted if the rules for future activity are first strengthened (Bessol, 2024). This development was recommended by the Norwegian Ministry of Petroleum and Energy—the Ministry that is intended to eventually oversee the assessment and approval of extraction licenses (Bessol, 2024). To strengthen the rules and increase the scrutiny of assessment for applications, it was proposed in January 2024 that in addition to assessment by the Ministry, potential applications must also be assessed and approved by the Norwegian Parliament (Storting) (Stortinget, 2024). This process would subject exploitation applications to two distinct levels of scrutiny, creating a more rigorous evaluation framework. In effect, the first licences will only be granted for exploration until the knowledge gaps required to justify a mining operation are fulfilled. This heightened scrutiny alleviates some pressure of intent in Norway's national waters by reducing the likelihood of application approval, which aims to ensure that only the most meritorious and environmentally sound projects advance.

Beyond Norway's self-imposed regulatory stringency, mounting public criticism and activism against DSM further mitigates their pressure of intent to exploit national waters. In response to the country's decision to open their EEZ for exploitation, WWF-Norway released a statement criticizing the environmental impact assessment conducted by the Ministry of Energy in Norway. According to WWF-Norway, the assessment, which forms the basis for the government's decision, fails to meet the minimum standards set by the Subsea Minerals Act 2-2 (WWF, 2024; Subsea Minerals Act 2-2, 2024). WWF-Norway, backed by the Norwegian Environment Agency (a division of the Ministry of Climate and Environment), contends that the Norwegian government's decision to open its EEZ for DSM exploitation lacks any legal foundation (Bessol, 2024). Specifically, their statement is based on the assertion that the impact assessment revealed "notable knowledge gaps regarding the nature of the marine environment, technologies for exploitation, and their associated environmental impacts" (Bessol, 2024). This internal and immediate response from national entities in Norway demonstrates that despite the government's move to pave the way for DSM exploitation in national waters, the country is by no means relieved of its responsibility to sustainably manage its own resources.

In response to WWF-Norway's legal challenge, the Norwegian government defended its position on DSM. Herein, Energy Minister Terje Aasland emphasized their commitment to understanding the environmental conditions of potential mining areas through a "step-by-step approach" (Bessol, 2024). A process that is meant to ensure extraction activities have acceptably minimal impacts before committing to any application for exploitation (Bessol, 2024). Herein, companies must first conduct obligatory exploration of the areas they wish to exploit (Bessol, 2024). Exploitation licenses would only be granted if approved by both the Ministry of Energy and Petroleum and the Norwegian Parliament, based on the Ministry's recommendations to tighten the rules for application (Bessol, 2024). This approach serves as a rebuttal to the criticism from WWF-Norway and the Norwegian Environment Agency regarding the government's failure to meet the standards of the Subsea Minerals Act 2-2. By opening the EEZ to exploration with the potential for future exploitation, the government asserts it is not embarking on a reckless or haphazard course (Bessol, 2024). Instead, it argues for a methodical, evidence-based approach characterized by incremental steps to thoroughly assess and validate the feasibility and environmental impacts of extraction activities before proceeding with any full-scale exploitation (Bessol, 2024). Whether this is a legitimate or solid enough argument, however, remains an ongoing debate, as WWF-Norway presses forward in taking the Norwegian government to court over the matter. As of now, pressure of intent is present in Norway's national jurisdiction, however, this pressure exists in limbo until further action is taken on the case between the Norwegian government and WWF-Norway (Solberg, 2024).

4.1.2 *For power*

China

China began its journey into DSM at the behest of President Xi Jinping's order for the country to 'master the key technologies for entering the deep-sea' back in 2016 (Kuo, 2023). Since the implementation of his directive, the nation has established at least 12 operational institutions for deep-sea research (Kuo, 2023). Among these, the largest facility located in Wuxi, Jiangsu Province, has ambitious plans to employ a workforce of 4,000 by 2025 (Kuo, 2023). This strategic initiative illustrates the country's commitment to advance its capacity for exploration, and potential exploitation of the deep-sea. A commitment which is supported by their holding the right to the most exploration licenses of any country at the ISA, accounting for up to 92 000 square miles of the Area (17% of the total area under the ISA's jurisdiction) (Kuo, 2023). This activity has sparked global concern, particularly among nations who also find themselves at the forefront of efforts to decarbonize by mid-century. As Carla Freeman, a senior expert on China at the United States Institute of Peace put, "If China can take the lead in seabed mining, [they] really [have] the lock on access to all the key minerals for the 21st century green economy." (Kuo, 2023). For China, the deep-sea is not just about resources, but security. To assert themselves as a global power underlies their very seat at the ISA (Silva, 2024).

When researchers first discovered the resource potential of the international seabed, it created ideological concern and global debate over the equitable distribution of the potential profits from exploitation (Silva, 2024). The U.S., a developed country, sought to operate on a first-come-first-serve basis, which was subsequently challenged by China, which, identifying as a developing country at the time, aligned itself with the interests of the Global South and argued that the benefits from these resources should be shared with all of [hu]mankind. (Silva, 2024). China's ideological approach received majority favour, and in 1982, their ideology formed the basis of the United Nations Convention on the Law of the Sea (Silva, 2024). In response, the U.S. maintained a non-participatory stance on UNCLOS and later in 1994, when the ISA was formed, they furthered this position, arguing that becoming a member would impede on U.S. sovereignty of the high seas (Silva, 2024). China took this response as a great victory against the 'maritime hegemony' by the West—indicative of 'a new international maritime order', in which China would play a pivotal role (Silva, 2024).

In this regard, China has actively asserted its position at the ISA to maintain its role in shaping the emergent maritime order. It remains the single most active country at the ISA, with a transparent, long-term, and strategic agenda set towards exploitation (Silva, 2024). As the world's largest processor of lithium, cobalt, copper and graphite, the country's current five-year economic and social development plan is to progress its DSM capabilities, an initiative which has already garnered national scientific interest (Silva, 2024). This plan is reflected in China's strategic agenda at the ISA's meeting as of July 2023, in which they blocked any debate on maritime protection or the moratorium on DSM activities (Silva, 2024). Furthermore, the Chinese representatives cautioned the ISA against imposing financial sanctions on contractors who might violate established rules (Silva, 2024). This was supported by Gou Haibou, a Chinese delegate to the ISA who openly criticized the outcome of the meeting, which sought to extend the soft deadline for the Mining Code to 2025 (Silva, 2024). Haibou argued that the Chinese delegation preferred more definitive language and a fixed timeline for completing the regulations, stating that it "otherwise…seems a little unclear what we are going to do in the coming months or in the coming years" (Silva, 2024). This behaviour at the meeting, and conclusion on its results demonstrate a clear and proactive approach to DSM. Rather than merely expressing interest, China is actively pushing for concrete steps to open the international seabed for exploitation. Through taking a lead role in ISA discussions, making large financial contributions to the organization, and being transparent about its goals, China is preparing for potential future mining operations, and exerting pressure of intent in international waters.

All said, their vocal advocacy and aggressive strategy will not be enough to realize their vision of the DSM industry. One of the strongest mandates in the UNCLOS prevents any haphazard progression, regardless of motive or intent. As Gina Guillen-Grillo, head of the Costa Rican delegation at the ISA, emphasized, there will be no mining without compliance to Article 145, which ultimately requires the protection of the marine environment from the harmful impacts of mining (Silva, 2024). Regardless of China's influence, any advancements will be contingent on adhering to these stringent environmental standards, which are collectively upheld by the ISA's other Member States. As China formulates its strategy for seabed exploitation thus, it must carefully consider these international environmental requirements, otherwise they will ultimately make little progress.

4.1.3 *For security*

The U.S.

Even if China's strategy to mine the Area will require more fine-tuning if it is to go forward, the U.S. has become increasingly aware of their objectives at the ISA. In response, the U.S. is showing interest to mitigate Chinese dominance through ISA membership. This move would theoretically allow the U.S. to exert influence on tentative DSM policies, and thus contribute to the global pressure of intent to pursue DSM in international waters. In June 2023, the U.S. Congress responded to China's activities by sending letters to the Pentagon requesting a new analysis of the U.S.'s role in DSM (Silva, 2024). Specifically, the House of Armed Services Committee requested that the Pentagon deliver in their 2024 National Defence Authorization Act (NDAA) an assessment on the U.S.'s capacity for domestic processing of PMN found at sea (House Armed Services Committee, 2023). In line with this, Jocelyn Trainer, a research assistant for the Energy, Economics, and Security Program at the Center for a New American Security, emphasized that China's preparedness for exploration and potential exploitation is increasingly becoming a U.S. national security concern (Silva, 2024). Despite the U.S. Senate's continued reluctance to ratify the UNCLOS, these developments demonstrate the tangible impact of China's stance on DSM. Although to date, the NDAA 2024 contains no significant analysis of the U.S.'s domestic processing capacity for PMN derived from the Area (National Defence Authorization Act for Fiscal Year 2024, 2023).

In light of U.S. attention on China, in November 2023, a direct urge to ratify the UNCLOS was initiated by a bipartisan coalition led by Senator Lisa Murkowski (R-Alaska) (Silva, 2024). This initiative urged the U.S. Senate to approve the long-pending treaty, in consideration of its strategic importance to counter China's maritime ambitions (Silva, 2024). This resolution was further supported by US Senators Mazie K. Hirono (D-HI), Tim Kaine (D-VA), and composed by Senators Angus King (I-ME), Jacky Rosen (D-NV), Bill Cassidy (R-LA), Chris Van Hollen (D-MD) and Sheldon Whitehouse (D-RI) (Mazie Hirono, 2023; Hirono et al., 2023). In December of the same year, a group of 31 Republican members of Congress requested that Secretary of Defence Lloyd Austin consider strengthening the supply chain for CRMs in the U.S., with the deep-sea emphasized as a “new vector of competition” out of direct concern for China’s advancements in the Area (Silva, 2024). Although these recent developments for UNCLOS ratification have yet to receive any formal response, the urge to ratify demonstrates the significant impact of China's maritime agenda on American interests. This renewed interest reflects an increasing awareness in the U.S. that they risk being side-lined from crucial decision-making processes regarding activities in the Area and their subsequent intent to partake in exploitation to maintain control over the CRM supply chain if it is to be supplemented by DSM.

4.2 Regulatory Capacity

4.2.1 *Democratic representation at the ISA*

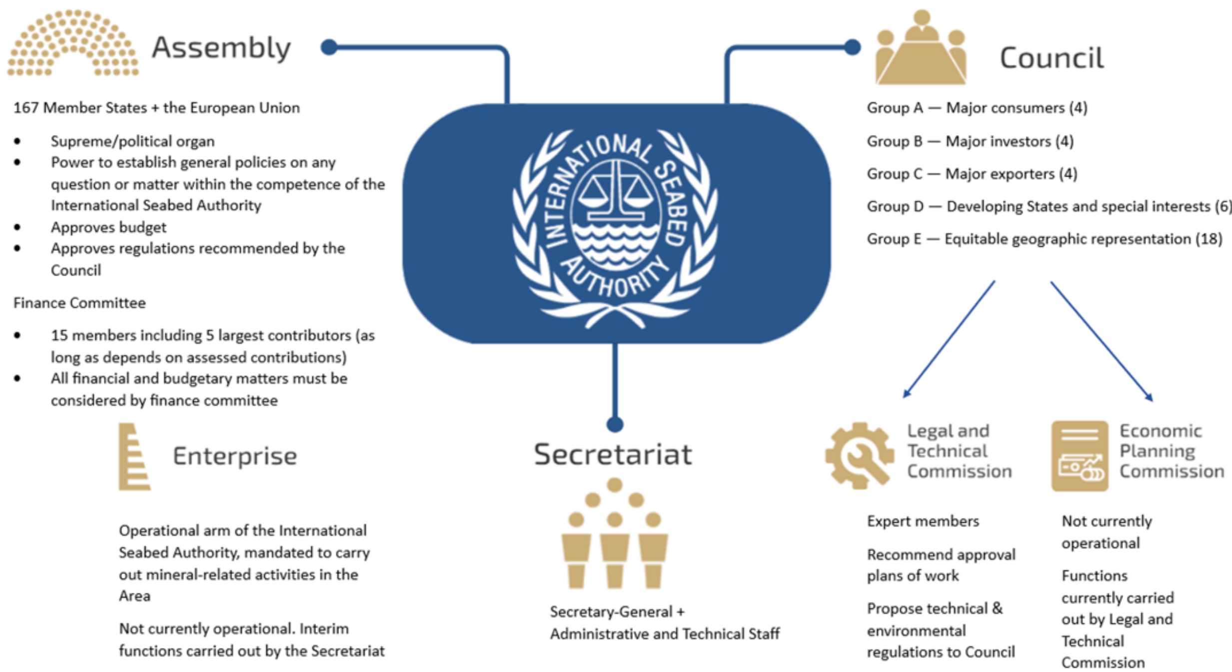

Figure 2. General structure of the International Seabed Authority (Blanchard et al., 2023; ISA, 2022b).

The ISA's regulatory capacity refers to its effectiveness and suitability in fulfilling its intended role. In this context, it is a measure of whether the ISA operates on sound democratic principles, ensuring that the opinions of all Member States carry equal weight in consultations regarding DSM in the Area.

The ISA has three main organs to facilitate regulation of the Area—the Assembly, the Secretariat, and the Council (Environmental Justice Foundation, 2023).

4.2.2 *The Assembly*

The Assembly is made up of 168 Member States plus the EU and acts as the supreme decision-making body of the ISA (Blanchard et al., 2023). Within this, each Member State has equal voting power as it functions on a 1 state, 1 vote structure (Blanchard et al., 2023). The purpose of this structure is to ensure that final decisions made by the ISA are made democratically. The Assembly is also responsible for electing the Finance Committee, which in turn oversees the ISA's finances (Environmental Justice Foundation, 2023). In this regard, financial matters within the ISA are handled 'democratically' as they are managed by proxy of the Assembly's elections, and the Assembly itself is democratic in structure. With that being said, the 15 elected members of the Financial Committee to the ISA include its 5 largest financial contributors (Environmental Justice Foundation, 2023). One such contributor, China, therefore wields considerable influence over the allocation of ISA funds (Environmental Justice Foundation, 2023). A leverage that aligns with China's progress-oriented agenda in DSM, potentially hindering efforts to impose any permanent halt against operations (Environmental Justice Foundation, 2023).

Importantly, the Assembly works in collaboration with the Council. Despite the Assembly's primary policy-making role, its practical function is to approve regulations recommended to it by the Council (Blanchard et al., 2023). This effectively undermines the democratic legitimacy of the Assembly because it is technically subordinate to Council recommendations (and the Council is not entirely democratic, as explored in section 4.2.4). Such an arrangement could significantly impact the ISA's ability to implement a permanent moratorium on DSM. The Assembly's limited autonomy in policy initiation means that any move to indefinitely halt DSM operations would likely need to originate from or gain support within the Council before reaching the Assembly for final approval.

4.2.3 *The Secretariat*

The Secretariat serves as the administrative backbone of the ISA. It assists the ISA through managing the organization's legal affairs and providing general operational support to its governing bodies (ISA, 2022a). The Secretariat is led by the Secretary-General who functions as the Chief Administrative Officer of the ISA (ISA, 2022a). The Secretary-General is democratically legitimized by proxy of their election by the Assembly, thus in theory, they should be able to represent and shift opinions at the ISA in reflection of its Member States and the EU (ISA, 2022a).

The Secretary-General is assisted by the Executive Office to coordinate the Secretariat (ISA, 2022a). However, the Executive Office functions under relevant directives made by the Council and further approved by the Assembly (ISA, 2022a). In practice this means that the Executive Office supports the Secretary-General based on recommendations made to it by the Council which are then ratified by the Assembly, and not based on independent recommendations from the democratically legitimized Assembly itself. This could implicate the democratic impartiality of the Executive-Office as it must function on Council recommendations (and the Council is not entirely democratic, as explored in section 4.2.4).

Functioning within the Secretariat is the Enterprise—the operational arm of the ISA, responsible for ensuring that activities in the Area are carried out in respect of the CHM principle (Blanchard et al., 2023). If it were independently operational, it would be represented by a democratically elected individual. However, due to funding constraints, it does not function independently from the Secretariat and from 2018 to 2023, was led by a special representative of the Secretary-General (ISA, 2022c). Since 2024 it has been staffed by an interim director, who functions in tandem with (and not independently of) the Secretariat (ISA, 2022c). This individual is therein subject to the powers of the Assembly and the Council, and due to the Council's own lack of democratic representation (refer to section 4.2.4), this could implicate the ISA's capacity to enforce a permanent ban on DSM.

The Office of Legal Affairs, the Office of Environmental Management and Mineral Resources, and the Office for Administrative Services were omitted from this review since they did not pose any significant contentions relevant to the analysis of the ISA's democratic representation.

4.2.4 *The Council*

The Council is the executive organ of the ISA (Blanchard et al., 2023). Its role is to recommend rules, regulations, and procedures to the Assembly, and so its power is in its capacity to initiate change (Blanchard et al., 2023). Its 36 members are elected by the ISA's democratically legitimized body—the Assembly, which in theory would mean that it itself is democratically legitimized. However, the structure of its member representation implicates this legitimization (Blanchard et al., 2023). The 36 members are elected based on their representation of the following interest groups (Blanchard et al., 2023):

- Group A – Major Consumers (4)
- Group B – Major Investors (4)

- Group C – Major Exporters (4)
- Group D – Developing States and Special Interests (6)
- Group E – Equitable Geographic Representation (18)

Major Consumers (Group A – 4 members) are those State Parties which consume or import more than 2% of the world's total imports of the same commodities which would be theoretically derived from the Area (ISA, 2022e). Further, Major Investors (Group B – 4 members) are members belonging to the 8 Member States that have made the largest investments in the ISA's preparation for work in the Area (ISA, 2022e). So forth, the Council's composition includes a subset of 8 members selected through criteria that prioritize mining interests. This is to ensure there is fair representation of entities which could eventually benefit from exploitation; however, it also means that a valid 22% of the Council's composition is representative of interests tilted in favour of DSM (Blanchard et al., 2023). To add, the criteria for electing representatives of Developing States and Special Interests (Group D – 6 members) also includes among 'States with large populations, that are landlocked, or geographically disadvantaged Island States', States which are major importers of the same minerals which would be derived from the Area, and States that are potential producers of such minerals (Blanchard et al., 2023; ISA, 2022e). This is not to say that all members belonging to Group D would have pro-mining interests but considering these criteria to include members from States that do, the composition of Group D has at least the potential to tilt in favour of pro-mining interests. In summary, the election criteria for Groups A, B, and partially D of the ISA Council favour pro-mining interests, potentially compromising the impartiality of its decisions on eventual DSM exploitation applications. This situation ultimately casts doubt on the ISA's capacity to impose a permanent halt on DSM in the event it were necessary.

4.2.5 *The Legal and Technical Commission*

The Legal and Technical Commission (LTC) is an advisory subsidiary organ formed by the Council. In practice, the Council is the main decision-making organ that initiates recommendations to the Assembly, but before then, the LTC makes its recommendations to the Council (Blanchard et al., 2023). The role of the LTC is to carry out the technical work of the ISA through reviewing plans of work for activities in the Area, form the ISA's rules, regulations, and procedures, and from a legal perspective, consider the protection of the deep-sea (ISA, 2022d). In summary, the power of the Assembly to vote and decide on rules, regulations and procedures is based on work conducted by the LTC, which then makes recommendations to the Council, and finally, the Council to the Assembly.

The LTC is made up of 41 members who are elected by the Council for a standing period of 5 years (Blanchard et al, 2023; ISA, 2022d). In theory, the Council is obligated to appoint members to the LTC based on their individual qualifications relevant to exploration and exploitation activities in the Area (ISA, 2022d). This measure is to ensure that the LTC's recommendations are informed by a multidisciplinary team with diverse expertise, in vain of upholding rigorous standards for the legal and environmental protection of the deep-sea and its resources (ISA, 2022d). However, since the Council nominates members of the LTC and the Council itself is structured with some level of bias towards pro-mining interests, the LTC is at some mercy of non-democratic representation which could hinder its capacity to initiate or maintain a permanent halt against DSM.

As of Article 165 of the UNCLOS, the LTC is responsible for the first drafts of the Mining Code, and as an important addition to their current responsibility to assess applications for exploration activities, they will eventually be responsible for assessing applications for exploitation in the Area (Blanchard et al., 2023). It is thus the most fundamental organ of the ISA given its purpose to advise the Council on whether to approve or deny mining contracts. This however has a caveat, such that if and when the LTC makes a recommendation for the Council to approve an application, it is effectively approved (after a certain duration) *unless* a majority (two thirds) of the Council decide to reject it (Blanchard et al., 2023). Simply put, 24 of the 36 members of the Council need to reject the application for it to be denied and since the Council's composition is, to some extent, tilted towards DSM interests, it raises doubts about whether the required majority to reject an application could ever be reached. This structural imbalance potentially compromises the ISA's capacity to prioritize environmental protection over mining interests when necessary. In this regard, the Council has yet to reject a plan of work for exploration that the LTC has recommended for approval (Blanchard et al., 2023).

4.2.6 *Prerogatives of the ISA*

Currently, the ISA is financed through contributions from its Member States, however, the long-term plan is for the organization to be self-sustaining, deriving its revenue from the contracts it issues (Blanchard et al., 2023). In response, the UK Parliament's House of Commons Environmental Audit Committee reflected that, "The fact the ISA, the licensing body for seabed exploration, also stands to benefit from revenues…is a clear conflict of interest" (Environmental Justice Foundation, 2023). Put plainly, the ISA's long-term financial viability is inextricably linked to the initiation of commercial DSM operations. Without exploitation contracts, the ISA remains reliant on Member State funding, which places the institution in limbo since its institutional survival would otherwise depend on the advancement of DSM activities. Herein, the ISA's funding structure, reliant on contributions from Member States and future revenues from exploitation, undermines its capacity to permanently halt DSM. The lack of interest in ceasing exploration or establishing a permanent ban is evident in the design of its exploration contracts. The contracts are initially awarded for 15 years, and it is mandated in the Implementation Agreement that the contracting party must apply for an exploitation license once this period ends (Environmental Justice Foundation, 2023). The only exceptions to this obligation would be within circumstances beyond the contractor's control or situations in which it is not economically viable to move forward with exploitation (the current situation). That said, 7 contracts have already been extended for an additional 5-year period and 6 of these have been extended for a second time (Environmental Justice Foundation, 2023).

Finally, the ISA is required to conduct an institutional review every five years (Environmental Justice Foundation, 2023). This periodic assessment is meant to evaluate the organization's effectiveness in fulfilling its mission and to identify and implement necessary changes in the event of subpar performance. In spite of this, the most recent review was completed in 2017, and as of 2022, a subsequent evaluation has not yet been conducted. This delay suggests a stagnation in the ISA's efforts to address critical aspects of its regulatory framework. Such inertia in institutional self-assessment and reform could potentially limit the ISA's capacity to effectively manage DSM activities, particularly in scenarios where a complete halt may be necessary.

4.2.7 *On drafting regulations for exploitation*

In June 2021, Nauru, the sponsoring state for the exploration contract held by NORI, and subsidiary of The Metals Company (TMC) triggered the Two-Year Rule (Blanchard et al., 2023). As a reminder, according to the Implementation Agreement, triggering this rule mandates that the Council "shall" finalize the relevant rules, regulations, and procedures of the Mining Code by July 2023. In theory, if the ISA failed to meet its deadline, it would mean that any Member State or the EU could apply for the approval of a 'plan of work' for exploitation, regardless of the incomplete regulations (Blanchard et al., 2023). Specifically, the Implementation Agreement dictates that the Council must "nonetheless *consider* and *provisionally approve* such plans of work based on the provisions of the Convention, and any rules, regulations and procedures that the Council may have adopted provisionally, or on the basis of the norms contained in the Convention and the terms and principles contained in this Annex as well as the principle of non-discrimination among contractors (Section 1(15)(c) of the Annex to the Implementation Agreement)" (Blanchard et al., 2023). However, to interpret this provision as a green light for unregulated mining would be a gross misunderstanding, as concluded by Pradeep Singh, a prominent consultant to the ISA specializing in ocean governance, and the law of the sea.

He asserts that Section 1(15)(c) refers to the "elaboration [on]" as opposed to the "adoption [of]" the rules, regulations, and procedures of the Mining Code (Singh, 2022). In this context, the Two-Year Rule should be understood to mean that the rules of the Mining Code need only be 'elaborated' within the two-year deadline, rather than be fully finalized and/or adopted. (Singh, 2022). This interpretation demonstrates the ISA's control over the pace and implementation of mining activities, even in the face of seemingly aggressive legal provisions. Further, 'consider and provisionally approve' within this excerpt of the Implementation Agreement implies that even in the absence of a finalized Mining Code, the ISA would still be responsible for assessing any plan of work for its adherence to the UNCLOS, the Implementation Agreement and any other applicable rules, regulations and procedures that exist (Singh, 2022). Moreover, it would have to be assessed by the relevant ISA organ—the LTC (Singh, 2022; ISA 2022d). It is important to remember however, that if the LTC were to receive a plan of work for exploitation, deem it adequate, and recommend its approval to the Council, it would effectively be approved (after a certain duration) unless rejected by 24 of the 36 Council members. This does not confer unilateral authority to the LTC over such decisions, but again, does raise some reasonable concerns. It should be further reminded that that LTC members are elected by the Council, which itself has a discernible pro-mining bias. This structural arrangement could hinder the objectivity of the decision-making process regarding DSM exploitation applications. While temporary halts have been implemented and are feasible, the ISA may not be capable of enacting a permanent ban against exploitive activity in the future due to this framework.

Despite these difficulties, there is still another layer of escalation that could prevent a default approval. If a plan of work were approved by the LTC, recommended to the Council, and approved either by default or legitimately in the absence of the Mining Code, the ISA could face a compulsory dispute resolution from any one of its Member States. This could be initiated due to concerns regarding the adequate protection of the marine environment from exploitation activities, insufficient environmental information or impact assessments, or a failure to apply the precautionary principle to planned activities (Singh, 2022). Ultimately, this measure illustrates the ISA's ability to enforce, at minimum, a temporary extended halt on DSM pending resolution of these critical issues.

5 Utilitarian Value

5.1 Climate Change

5.1.1 *DSM in the context of climate change*

DSM presents a complex duality in the context of climate change. Illustrating this duality requires a comprehensive analysis of the multifaceted impacts of climate change, encompassing both its global ramifications and specific consequences for marine ecosystems. Through an understanding of the severity of climate change in this vein, it can be better understood why DSM might at all be considered. Broadly, the anthropogenic impacts of climate change on the deep-sea are categorized into three main groups: disposal, exploitation, and ocean acidification & warming. Disposal refers to the historical dumping of various wastes into the deep-sea, while exploitation includes immediately impactful, extractive activities, of which DSM would fall under (Ramirez-Llodra et al., 2011). Ocean acidification & warming on the other hand, encompass the more general effects of increasing atmospheric CO_2, changing temperatures, and their impacts on the ocean's oxygen capacity (Ramirez-Llodra et al., 2011; Rabalais et al., 2010). The importance of outlining these categories lay within their 'synergistic impacts'. With respect to the deep-sea, Ramirez-Llodra et al. (2011) assert that the compounded impacts of climate change will considerably weaken already fragile deep-sea ecosystems (Ramirez-Llodra et al., 2011). Deep-sea mining could thus have a further weakening effect if conducted haphazardly, but with correct innovation and intent, it also holds the potential to reverse impacts elsewhere (Ramirez-Llodra et al., 2011). The significance of DSM herein, is in the fact that it can both exacerbate and potentially relieve anthropogenic stressors.

5.1.2 *In a race against time*

The 1.5^{o}C limit set in the Paris Agreement has thrust us into a race against time despite being based on what the IPCC believed would be technically achievable to avoid reaching any tipping points—a state of no return (United Nations, 2015). To maintain global temperatures below this limit, they asserted that greenhouse gas emissions (GHGs) must peak *before* 2024, and decline by 43% by 2030 (United Nations, 2015). However, as of February 2024, the EU's Copernicus Climate Change Service confirmed that the threshold for global warming had been breached for a full 12 month period for the first time (Poynting, 2024). This warming translates directly to the ocean with its respective temperatures recorded at their highest in history, culminating a pattern of steady and consistent increase (Poynting, 2024).

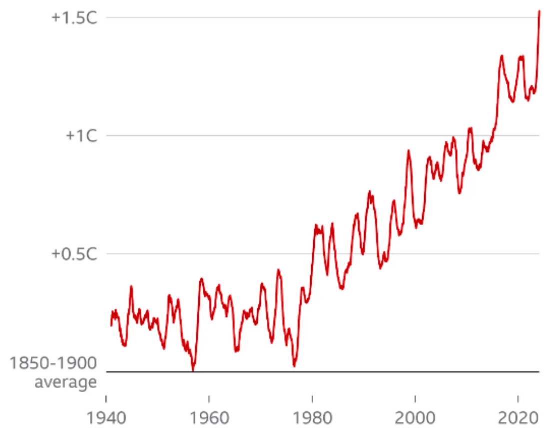

Figure 3. Average global air temperature compared with pre-industrial levels, running average of 365 days.

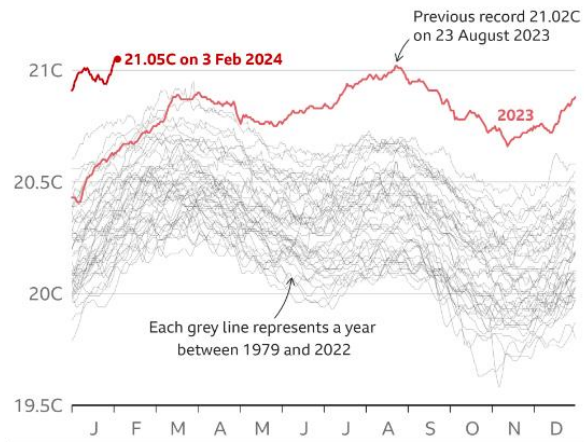

Figure 4. Daily average sea surface temperature between 60º North and 60º South, 1979-2024.

According to the IPCC AA6 (Sixth Assessment Report), only a small subset of emission scenarios will be allowable if we are to limit the probability of passing into a state of no return (Global Tipping Points, 2024). So forth, considering our current situation there are a reduced 'number [or] shapes' of possible emissions pathways that will be adequate to meet the goals of the Paris Agreement (Global Tipping Points, 2024). This underscores the urgency of the situation, a fact that is further supported by The International Renewable Energy Agency (IRENA). They indicated in a 2023 report that to secure the 1.5ºC pathway, the world would need to reduce annual energy-related CO_2 emissions by around 37 gigatonnes (Gt), in response to record high emissions in 2022 (IRENA, 2023). This pattern of records aligns with the conclusion that current Nationally Determined Contributions (NDCs) to meet the targets of the Paris Agreement are not sufficient to limit warming to 1.5ºC (UNFCCC, 2021). A pattern which exposes our diminishing luxury of time to explore diverse pathways to transition. Herein, the climate crisis demands urgent action, that which compels a need to consider solutions that offer deep, near-term impacts (OECD, 2022).

5.1.3 *DSM as a response to climate change*

It is widely known that CO_2 emissions warm the planet and that this increases global temperatures. In response, decarbonization has been increasingly proposed and facilitated to address this problem through the electrification of industry. Simply put, electrification decarbonizes major emitting industries such as transportation, and this in turn reduces emissions, which should reduce the chances of further climate warming. However, this process has taken the shape of an ‘ouroboros’—the snake which consumes itself. This is due to the paradoxical nature of decarbonization through electrification in that electrification (currently) requires CRMs, and this requires mining which itself is environmentally damaging. In this depiction of an ouroboros, mining presents a bottleneck to truly decarbonizing or reaching net-zero as it loops the head of the snake (mining—which should be the solution) back onto its tail (referring to the damaging impacts of mining itself and the problems it is meant to fix).

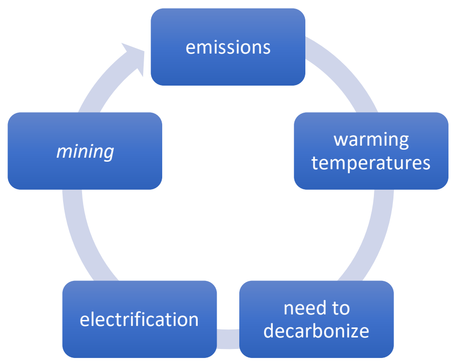

Figure 5. Simplified depiction of the ‘ouroboros’ situation regarding the relationship between climate change and mining (DSM).

Currently, key performance indicators (KPIs) are used to measure alignment with the 1.5ºC scenario using specific metrics that measure progress in the energy sector’s transition to renewable energy and the subsequent reduction of GHGs (IRENA, 2023). In this regard, to align with the 1.5°C warming limit, KPIs stipulate that EVs must comprise over 90% of all road transport by 2050 (IRENA, 2023). To achieve this goal, the report projects that by 2030, the stock of electric and plug-in hybrid light passenger vehicles should reach 255 million units globally, with the corresponding number of EV chargers at 260 million units (IRENA, 2023). By 2050 these figures should be expected to grow to 2 182 million units for vehicles and 2 300 million units for chargers (IRENA, 2023). The manufacture of these products will inevitably require some degree of CRMs (IRENA, 2023). To summarize this scenario, the impacts of climate change have stimulated a need to electrify to decarbonize, and the current process of decarbonization puts pressure on the CRM supply chain. As nations and corporations race toward net-zero, DSM has entered the arena as a contentious yet potentially significant player, driven by the mounting need to secure resources for a low-carbon future.

5.1.4 *In a race to net-zero*

To participate in this race, around 145 countries have or are considering net-zero targets, covering around 90% of global emissions—however not all of them have a 2050 deadline (Climate Action Tracker, 2023). The biggest players (as well as the most intense emitters) are China, the U.S., and the EU.

	China	**U.S.**	**EU**
Emissions reduction plan	No specific action plan, but general goal to reach carbon neutrality (McGrath, 2020)	Inflation Reduction Act (IRA) (McGrath, 2022)	Net-Zero Industry Act (European Commission, 2023)
Time goal	2060	2050	2050
Plan for EVs	Achieve EVs as the dominant market for new vehicle sales by 2035 (Wang et al., 2023; Xinhua News Agency, 2020)	No specific target, but measures to boost EV sales (McGrath, 2022)	Achieve 100% zero emission new car and van sales by 2035
Pressure on CRMs	This will drive demand for NMC batteries from both domestic automakers and international companies localizing EV production in China	This will drive demand for domestic production of CRMs due to tax breaks which reward batteries that contain a certain degree of CRMs produced in the US or by free trade partners (Stone, 2022; Xiao, 2023)	This will drive demand for domestic production of CRMs to meet the Act's specific goals for domestic production of annual demand for batteries by 2030 (European Court of Auditors, 2023)

Potential pressure on DSM	In line with China's agenda, direct pressure on DSM as a means of supply	Indirect pressure on DSM as a potential avenue to domestically source EV battery materials	Indirect pressure on DSM as a potential avenue to domestically source EV battery materials

Table 6. Respective goals of China, the U.S., and the EU for decarbonization, EV deployment, and its potential pressure on DSM.

The decarbonization goals of the big three demonstrate a crude link between the impacts of climate change and the subsequent pressure it places on CRMs relevant to DSM. Despite their simultaneous consideration of alternative battery chemistries (as explored in section 5.2), NMCs remain the dominant chemistry used in EVs due to their high energy density and performance characteristics (Aqib Zahoor et al., 2023). A standard NMC battery contains lithium, and varying ratios of nickel, manganese, cobalt, as well as aluminium and graphite (Shafique et al., 2022). This is of relevance to DSM, and specifically PMN, which are found to be dominant in nickel, manganese, and cobalt (Paulikas et al., 2020). China's strategy at the ISA (as explored in section 4.2) demonstrates the reigning dominance of CRMs relevant to NMCs and DSM. It should be noted therein that China's progressive stance on DSM and further, escalating efforts from the U.S. and the EU to reduce their economic dependence on China have created a new context for evaluating domestic material sourcing options, which could necessitate a consideration of DSM in the event it can be conducted sustainably.

5.2 Alternatives

The Environmental Justice Foundation (2023) concluded that advancements in battery technology will eventually replace those chemistries requiring nickel and cobalt (two of the major targets for DSM). However, whether such alternatives are comparable to the dominant chemistry used in EVs is up for debate. EVs spearheading the transition to net-zero primarily rely on the lithium nickel manganese cobalt oxide (NMC) chemistry, a type of lithium-ion battery that contains lithium and varying ratios of nickel, manganese, and cobalt (Umicore, n.d.; Shafique et al., 2022). They are of significant relevance to DSM given the composition of PMNs (nickel, manganese, and cobalt) (Paulikas et al., 2020). All said, it is still heavily contested whether DSM is needed, considering fluctuations in demand for NMCs.

Currently, demand for NMC batteries is expected to increase by 2030, however, this is refuted in a study from WWF-Germany in which they predict a less substantial increase than originally anticipated due to the growing adoption of alternative battery chemistries (Laabs & Kind-Rieper, n.d.). Though, it should be noted that projections relevant to NMC batteries can vary significantly based on the study's methodology, sources of data consulted, and future scenarios considered. Mordor Intelligence reports that demand for NMC batteries increased by 109.56% from 2017 to 2023 (Mordor Intelligence, 2023). Yet, in the WWF-Germany study, they projected the market share for NMCs to decline from 85% in 2022, to 33% in 2030, due to changes in public perception, volatility of mineral costs relevant to NMCs, and the pursuit of more environmentally friendly, and socially responsible alternatives (Laabs & Kind-Rieper, n.d.). Even so, WWF-Germany itself recognized that these conflicting conclusions are really a reflection of the increasing total demand for batteries to meet net-zero targets (Laabs & Kind-Rieper, n.d.). In other words, despite the declining market share for NMC batteries, the absolute demand for materials used in them, and the need for NMC batteries amongst alternatives, are still subject to increase to meet the needs of the green transition (Laabs & Kind-Rieper, n.d.). In this vein, the Mordor Intelligence review, which estimated the market value for NMC batteries at 34.49 billion USD in 2024, projected that it would reach 60.62 billion USD by 2029 (Mordor Intelligence, 2024). Hence, despite their differing conclusions, WWF-Germany, and Mordor Intelligence both assert a trend of increasing pressure on the global battery supply.

This trend is further supported by the International Energy Agency (IEA), who projected global battery demand to reach 3.5 TWh by 2030 in a scenario considering all the anticipated effects of legislated policies to meet net-zero targets (STEPS Figure 6) (IEA, 2023b). This outlook seems promising with respect to optimistic projections from private sector companies, which anticipate EV battery manufacturing capacity to reach approximately 6.8 TWh by 2030 (IEA, 2023b). However, the 3.5 TWh projection in demand is based on what has been currently legislated, not on what has been achieved or what needs to be done to achieve an ideal scenario. When this is considered, to actually remain consistent with limiting temperatures to 1.5ºC and reaching net-zero by mid-century, the IEA estimates that demand could effectively exceed 5.5 TWh by 2030 (NZE Figure 6.) (IEA, 2023b). In essence, projected manufacturing capacity by 2030 (6.8 TWh) only narrowly covers even the most sensitive demand projections (5.5 TWh). It is a fact therein that staying within the 1.5ºC pathway will require substantial increases in battery manufacturing capacity (IEA, 2023b).

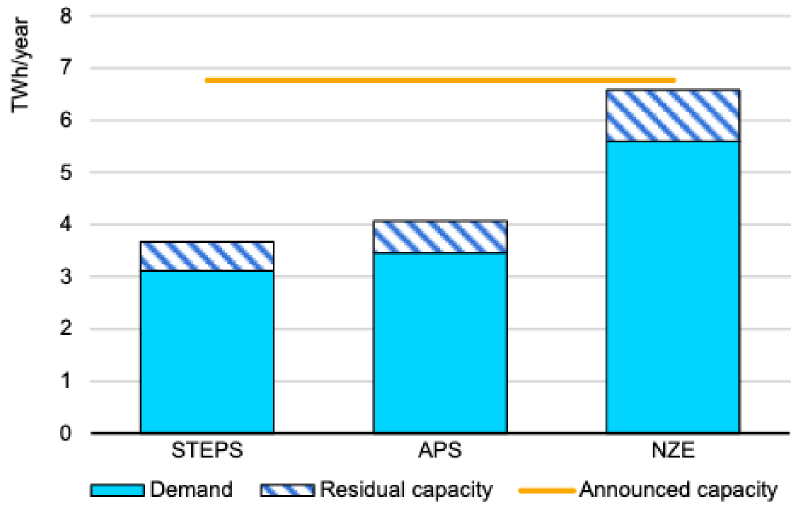

Figure 6. Required and announced expansions of battery manufacturing capacity by scenario, 2030 (IEA, 2023b) (Annex A for notes on STEPS, APS & NZE).

As global efforts to achieve net-zero emissions intensify, both established and emerging battery technologies face unprecedented pressure to scale up to meet growing demands. Consequently, a comprehensive assessment of various battery options is essential to ensure that the utility of available chemistries are maximized based on their technical capacity, environmental sensitivity, and current hold on the market. The following section will thus compare these facets of prominent alternative battery chemistries to NMCs.

5.2.1 **Lithium Iron Phosphate (LFP)**

Lithium Iron Phosphate batteries **(**LFPs) require neither nickel nor cobalt, and are instead composed of lithium, iron, and phosphate (Tracy, 2022; Hotter, 2023).

Technical Comparability

	NMC	LFP
Energy Density	150-200 Wh/kg (Mohanty et al., 2016)	90-150 Wh/kg (Environmental Justice Foundation, n.d.)

Thermal Stability	Thermal runaway of around 150-200^{o}C (UPS Battery Center, 2024)	Thermal runaway of around 270^{o}C (El Moutchou et al., 2022)
Cycle Life	1000-2000 cycles before reaching 80% capacity (Ovrom, 2023)	2000-3000 cycles before reaching 80% capacity (Environmental Justice Foundation, n.d.)

Table 7. Technical comparison between NMC and LFP batteries.

Overall, LFPs have lower energy density, but higher thermal stability and longer life cycles.

Economic Comparability

As of January 2020, LFP batteries had only a 1% market share (Laabs & Kind-Rieper, n.d.). In recent years there has been a growing preference for LFP batteries, largely driven by economic considerations, since they rely on more affordable materials like iron and phosphate (Laabs & Kind-Rieper, n.d.). This preference is demonstrated and reinforced by substantial industry investments, which in turn enhances their economic competitiveness. Tesla has already shifted to LFP batteries in its standard-range vehicles and BYD announced in April 2021 that it would remove cobalt, nickel, and manganese from its vehicle batteries entirely through a shift to LFP in 2024 (Laabs & Kind-Rieper, n.d.; Randall, 2024). Investments in LFP have also been supported by other prominent activities such as the US government's grant to chemical company ICL-IP America to develop an LFP cathode facility in the country, and Canadian-based Nano One's plans to scale up a former Johnson Matthey LFP production facility (ICL, 2023; Luo, 2023; MANLY, 2023). All such activity has led to an increase in LFP market shares by 31% as of September 2022.

LFPs are now 15-18% less expensive than NMCs (Laabs & Kind-Rieper, n.d.).

Environmental Comparability

LFP batteries do not require environmentally and socially controversial minerals such as cobalt, or any of the materials which are currently targeted for PMN mining in the deep-sea. Therein, with respect to potential environmental damages associated with DSM, LFP batteries are comparatively non-threatening.

However, in making this comparison, their size and energy density should be considered. For the same energy storage capacity, LFP batteries would have to be larger and heavier, meaning they would require a larger supply of materials and energy during their manufacture (Laabs & Kind-Rieper, n.d). In this regard, LFP batteries display the highest average emission factor at 91 kg CO_2 equivalent per kWh of energy produced, when compared to other chemistries (Laabs & Kind-Rieper, n.d). Therefore, while LFP batteries are composed of materials with a lower environmental impact than NMCs, their larger size due to their lower energy density leads to increased emissions during their production (Laabs & Kind-Rieper, n.d).

There are also prevailing concerns about the sourcing of phosphate, and the pressure that increased demand for LFPs places on this resource. There is no shortage of the rock itself, but rather a shortage of the specific kind of rock required for EV batteries. Global phosphate reserves are extremely abundant, weighing in at around 72 billion metric tons and coming in two main varieties—sedimentary and igneous (Di Grandi & Aboulazm, 2023). About 95% occurs as sedimentary phosphate rock, which goes through a purification cycle to become Merchant Grade Acid (MGA) (suitable for fertilizer and animal feed) (Hotter, 2023). LFP batteries, however, require igneous phosphate rock, which only makes up around 5% of total phosphate reserves (Hotter, 2023). That said, about 90% of igneous rock can undergo processing to produce Purified Phosphoric Acid (PPA) (suitable for EVs, versus the mere 10% that can be purified out of the total reserves of sedimentary rock) (Hotter, 2023).

	Sedimentary	**Igneous**
Total phosphate occurring as	95%	5%
Use for LFPs	10%	90%

Table 8. Summary of phosphate rock available for use in LFPs.

While global phosphate reserves are abundant, the specific high-purity igneous rock required for battery-grade PPA is exceptionally scarce. This limited availability of suitable feedstock presents a significant bottleneck to the large-scale manufacturing of LFP batteries for EVs, potentially impacting this chemistry's ability to meet growing demand.

5.2.2 Sodium Ion Batteries (SIB)

Sodium-ion batteries (SIBs) come in several variations. These include:

- NaNMMT (Sodium Nickel Manganese Magnesium Titanium Oxide)
- NaMMO (Sodium Manganese Magnesium Oxide)
- NaNMC (Sodium Nickel Manganese Cobalt Oxide)
- NaPBA (Sodium Prussian Blue Analogue)
- NaMVP (Sodium Manganese Vanadium Phosphate)

Each SIB type is characterized by different cathode materials, which influences their individual electrochemical properties and environmental impacts (Kim, 2023). That said, varieties containing manganese and iron are particularly attractive due to the lower cost and greater abundance of these materials compared to cobalt and nickel (Kim, 2023). Further, sodium, which is the key element of these batteries, is one of the most abundant elements on earth (Kim, 2023).

Technical Comparability

	NMC	SIB
Energy Density	150-200 Wh/kg (Mohanty et al., 2016)	Currently 130-160 Wh/kg, with expectations to reach over 200 Wh/kg in the future (Riley, 2024)
Thermal Stability	Thermal runaway of around 150-200°C (UPS Battery Center, 2024)	Thermal runaway varies between SIB compositions, but in general, they enter thermal runaway at higher temperatures compared to NMCs (Kim, 2023)
Cycle Life	1000-2000 cycles before reaching 80% capacity (Ovrom, 2023)	1000-2000 cycles, however reaching the upper limit varies depending on charge/discharge conditions and specific composition (Yang et al., 2024; Delong, 2024)

Table 9. Technical comparison between NMC and SIB batteries.

Overall, SIBs currently have lower energy density, but higher thermal stability, and roughly the same life cycle not accounting for charge/discharge conditions.

Economic Comparability

SIBs can use low-cost materials such as manganese and iron for their cathodes, which significantly reduces their material costs compared to NMCs that require cobalt and nickel (Laabs & Kind-Rieper, n.d.). More importantly, the main component of SIBs, sodium, is a widely available and easily extracted resource, contributing to their being up to 20-30% less expensive than LFPs (Laabs & Kind-Rieper, n.d.). SIBs also have a unique advantage in that they can be produced with the same manufacturing lines already in use for lithium-ion batteries (of which NMCs are a part), a claim of interest to companies like CATL and Northvolt who are seeking to commercialize SIB production (ING, 2023).

Herein, SIBs are considered a cost-effective alternative to NMCs due to readily available manufacturing capacity and further, the relatively low cost of materials they require. However, they cannot currently be considered directly competitive with the more widespread application of lithium-ion batteries because of their lower energy density restricting them to light urban commercial vehicles and stationary energy storage (Zhukov, 2023). This restriction might hinder their direct economic competitiveness with NMCs since their application might not be as immediately widespread until their energy capacity can be increased.

Environmental Comparability

The environmental competitiveness of SIBs is one of their most promising aspects. Not only are the batteries lithium free, but their main material—sodium, does not require mining since it can be obtained from seawater or brine (Laabs & Kind-Rieper, n.d.). NaMMO (Sodium Manganese Magnesium Oxide) and NaPBA (Sodium Prussian Blue Analogue) SIBs show lower impacts than NMCs with respect to abiotic resource depletion since they avoid materials such as cobalt and nickel all together (Kim, 2023).

GHGs

Certain SIB types show lower production related GHG emissions. This is most evident in NaMMO (Sodium Manganese Magnesium Oxide) and NaNMMT (Sodium Nickel Manganese Magnesium Titanium Oxide) chemistries, which are either approaching or surpassing the environmental performance of NMCs (Kim, 2023). However, it is noted that SIBs currently have lower technological maturity compared to lithium-ion batteries, and further improvements are needed to close the gaps in their environmental performance (considering their current lower energy density to NMCs) (Kim, 2023).

Acidification Potential

Acidification potential (AP) is a measure of how the battery contributes to environmental acidification mainly through the release of sulphur dioxide (SO_2) and nitrogen oxides (N_2O) (Kim, 2023). The NaMVP (Sodium Manganese Vanadium Phosphate) cell has a higher AP impact when compared with NMCs due to the SO_2 emissions from its vanadium production process (Kim, 2023). Further, The NaNMC (Sodium Nickel Manganese Cobalt Oxide) cell is identified as having a particularly high AP impact due to its cobalt and nickel content and relatively low energy density (Kim, 2023). Other SIBs generally show AP impacts that are slightly higher than those of the NMC cell (Kim, 2023).

Human Toxicity Potential

Human Toxicity Potential (HTP) refers to the battery's potential toxic impacts on humans. Most SIBs have a relatively low HTP, with NaMMO (Sodium Manganese Magnesium Oxide) and NaNMMT (Sodium Nickel Manganese Magnesium Titanium Oxide) chemistries showing potential to outperform NMCs even with their lower energy densities (Kim, 2023). The NaNMC (Sodium Nickel Manganese Cobalt Oxide) and NaMVP (Sodium Manganese Vanadium Phosphate) chemistries make an exception to this trend and are not as favourable. This is likely due to the presence of cobalt and nickel in the NaNMC (Sodium Nickel Manganese Cobalt Oxide) cell, and the specific production processes associated with vanadium in the NaMVP (Sodium Manganese Vanadium Phosphate) cell (Kim, 2023).

5.3 Scalability

For DSM to be considered 'scalable', two fundamental criteria must be met. First, it has to be technologically feasible, but more importantly, it must be environmentally sensitive (Bang & Trellevik, 2022).

5.3.1 *Technical Innovation and NORI-D*

Achieving and demonstrating technical feasibility is a primary motive for Nauru Ocean Resources Inc. (NORI), the subsidiary of The Metals Company (TMC). To fulfil this venture, they have conducted several trials under their NORI-D mining project in the CCZ using Hidden Gem, a 61 000-deadweight tonnage vessel belonging to Allseas, another DSM company based in the Netherlands (The Maritime Executive, 2022; TMC, 2024b). In October 2022, Hidden Gem completed a successful pilot test for deep-sea nodule collection, with a total recovery of 4 500 tonnes of PMN from the CCZ (TMC, 2024b). Despite this successful test, the project remains constrained to its technical feasibility—it has yet to prove that it can operate commercially to an environmental standard high enough for public acceptance. As Bang & Trellevik (2022) noted, without environmental sensitivity, any technical feasibility is rendered null through pushback from the global community. Such opposition was demonstrated by Greenpeace during one of Hidden Gem's scientific expeditions in November 2023 in which several activists attempted to disrupt the vessel by boarding during operations (TMC, 2023d). This was ultimately a response to the fact the vessel still relies on a heavily criticized approach to DSM, the crawler vehicle—a dredging, and riser-system that does little to minimize environmental disruption (TMC, 2023d). This method generates sediment plumes and leaves scar tracks in its wake as it grazes the seafloor for PMN, pumping them back up to the surface through a pipe using compressed air (TMC, 2024b).

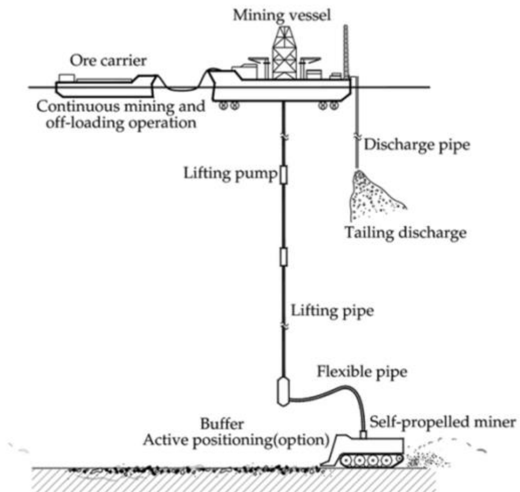

Figure 7. Schematic diagram of an integrated DSM system (crawler-riser) (Lee et al., 2012).

To address these environmental concerns, TMC has been taking a phased approach to the NORI-D project through periodically submitting their research from exploration efforts to DeepData—the ISA's open database for contractors concerning the impacts of DSM on the marine environment (TMC, 2024a). This methodology should allow the company to gradually develop an operational fleet that is based on comprehensive environmental data and further, may serve the secondary purpose of fulfilling their application for the NORI-D exploitation contract (TMC, 2024b).

In March 2023, TMC submitted their findings to the database from a total of 17 offshore resource definition and environmental baseline campaigns for the NORI-D area (TMC, 2024a). This extensive submission of over 14 000 biological samples and 8 000 images analysed for benthic fauna works to enhance DeepData's credibility as a comprehensive environmental baseline (TMC, 2024a). Since then, TMC initiated its comprehensive 'feasibility' study, marking a crucial milestone in the development of the NORI-D project. As of May 2024, TMC submitted their largest collection of data to the ISA to date (TMC, 2024c). This submission encompassed environmental baseline data collected from a total of 22 offshore campaigns in the NORI-D area (TMC, 2024c). This data is intended to validate the environmental sensitivity of the NORI-D project through providing in-depth environmental baselines that the impacts of their operations can be measured against (TMC, 2024c). Overall, the submission included observations of 32 617 benthic and 42 036 pelagic biological occurrences, over 12 000 seafloor images, and extensive time-series data from three years of monitoring activities (TMC, 2024c). Of salience, these studies were primarily conducted by independent scientists and expert industry partners to ensure a high degree of objectivity and scientific integrity in the data collection and analysis process (TMC, 2024c). While such effort does not definitively prove the environmental feasibility of TMC's operations, it does demonstrate a commitment to data-driven decision-making and scientific rigor in assessing the potential ecological impacts of their operations.

Ultimately, this extensive body of research is meant to inform their justification for future commercial operations starting with Project Zero in 2025, with a predicted collection capacity of 1.3 Mtpa (wet), and later Project One in 2026, with a collection capacity of 12.5 Mtpa (wet) (TMC, 2024a). It is crucial to note, however, that these timelines are still contingent upon the evolution of DSM regulations for exploitation (Bang & Trevellik, 2022). Such regulatory uncertainty illustrates the importance of TMC's step-by-step approach, since any future commercial scaling will hinge entirely on data collected during these preliminary exploration phases to demonstrate the environmental sensitivity of their projects.

5.3.1 *Sustainable Innovation and Impossible Metals*

On a different front, Impossible Metals is pioneering DSM technology that is environmentally conscious in its design. Their mission is to address environmental concerns through a minimally impactful DSM fleet.

Addressing environmental concerns

Herein, the company has been developing autonomous vehicles for PMN collection that rely on selective harvesting and buoyancy (Impossible Metals, 2024a; Impossible Metals, 2024b). The vehicle is equipped with precision-engineered mechanical arms that can pick up individual nodules (Impossible Metals, 2024b). This process is guided by advanced computer vision and artificial intelligence, allowing the vehicle to detect and avoid visible marine life, minimizing any disturbance to nodule-dependent megafauna (Impossible Metals, 2024b). The independent vehicle could also be preprogramed to leave behind a certain percentage and pattern of nodules in adherence to the requirements of an environmental impact assessment (Impossible Metals, 2024b). Further, this method for nodule collection would minimize plume generation and sediment disturbance since the vehicle would 'float' rather than 'crawl' for nodule collection, preventing the significant release of sequestered carbon from the deep-sea floor (Impossible Metals, 2024b). This buoyant design also eliminates the need for riser-pump technology, meaning that the vehicle would store collected nodules and return to the surface for offloading, reducing the potential for noise pollution (Impossible Metals, 2024b).

Figure 8. Demonstration of mechanical arms on the Eureka prototype (Parker, 2022).

Hypothetically speaking, while the design may not eliminate all environmental concerns—as any resource extraction is inherently impactful—it does present a more sustainable alternative to the conventional crawler-riser method. This technology theoretically balances the need for CRMs with environmental preservation, representing a significant step towards more responsible deep-sea resource management.

Addressing technical concerns

Impossible Metals has successfully transitioned their theoretical design into practical reality through a series of successful trials. In May 2023 the company completed its fourth round of tests featuring the Eureka 1 version 3, their small autonomous vehicle (Setså, 2023). The prototype showcased its ability to execute short 25-meter dives, remain buoyant above the seafloor, operate a single deployable arm with only minor sediment disturbance, and carry a 5kg payload back to the surface (Setså, 2023).

The company later went on to its sixth round of tests in May 2024 with Eureka 2 version 4, their medium sized autonomous vehicle with a depth capacity of 6km, 3 deployable arms and a 100kg payload (Impossible Metals, 2024c). The test yielded successful results, demonstrating that the vehicle was operational at depths required for commercial DSM, and that it could handle more cargo (Impossible Metals, 2024c).

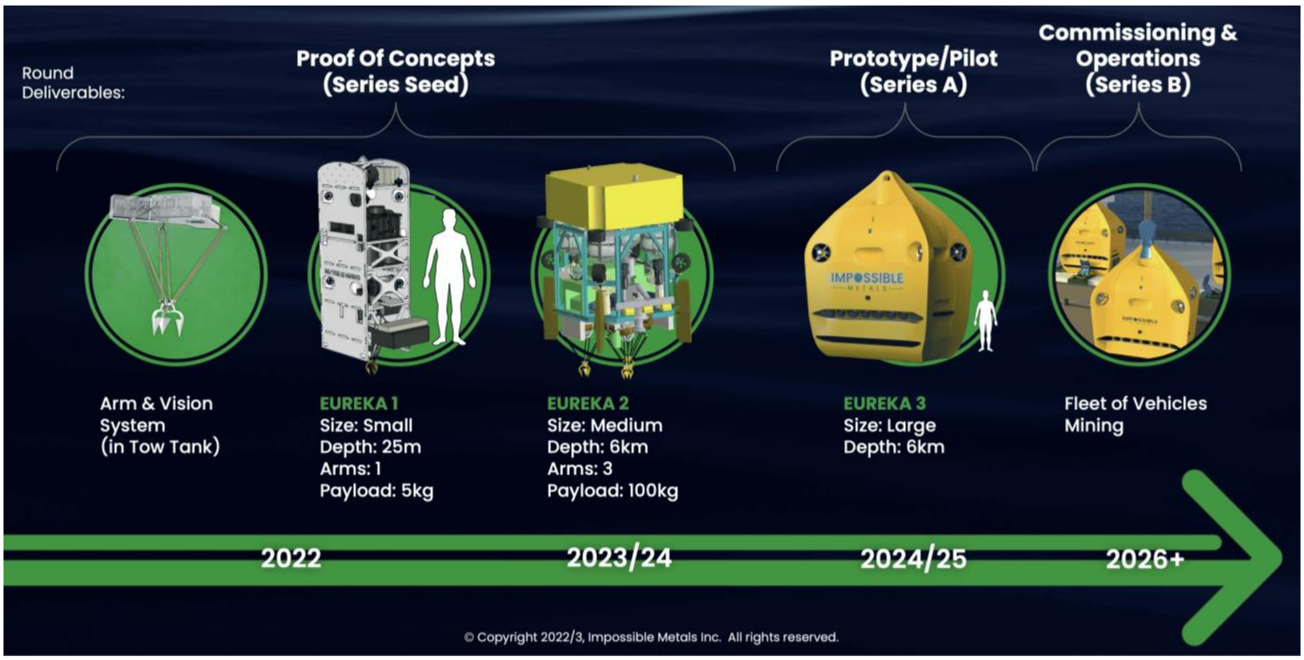

Figure 9. Impossible Metals roadmap for operations (Impossible Metals, 2023d).

Since the trial in May 2024, the company has proactively engaged in operations to determine the optimal collection speed-to-sediment ratio for the deployable arms (Impossible Metals, 2024c). This factor is crucial to balance the vehicle's efficiency with ecological preservation since the higher the speed of nodule collection, the more efficient it would be in terms harvesting, but also the less accurate and environmentally sensitive (Impossible Metals, 2024c). Their primary objective with this testing is to achieve a delicate equilibrium that maximizes operational efficiency while minimizing ecological impact. The company also has plans to conduct high-resolution, multi-lane AUV-based surveys or photogrammetric mapping of all operational areas so that vehicles would be able to navigate around environmentally sensitive zones and challenging terrains more effectively (Impossible Metals, 2024c). This approach markedly diverges from conventional crawler-riser operations. The vehicle's enhanced flexibility enables precise, real-time adjustments for optimized performance across diverse project areas. Building on these facts, Impossible Metals is committed to principles of transparency and scientific collaboration. The company uses their data not only to help train their own technology, but also to support broader scientific research (Impossible Metals, 2024c). In this vein, they address industry-wide concerns regarding operational opacity through serving a greater purpose than simply putting themselves at a competitive edge, and instead, contribute their expertise to making overall improvements to the industry (Impossible Metals, 2024c). This open approach to data sharing and environmental consideration in the construction of their fleet is integral to the company's strategy to position themselves as a leader for commercial scaling by 2026 (Impossible Metals, 2024c). However, it is still important to note that this timeline does not yet account for potential regulatory hurdles. While both technically capable and environmentally sensitive, like TMC, their path forward remains subject to the development and implementation of relevant legislation for the governance of deep-sea resource extraction (Impossible Metals, 2024c).

6 Analysis

Refer to Annex B for coding analysis as seen in in Figure 10.

Refer to Annex C for coding of the literature review based on the analysis key as seen in Figure 1.

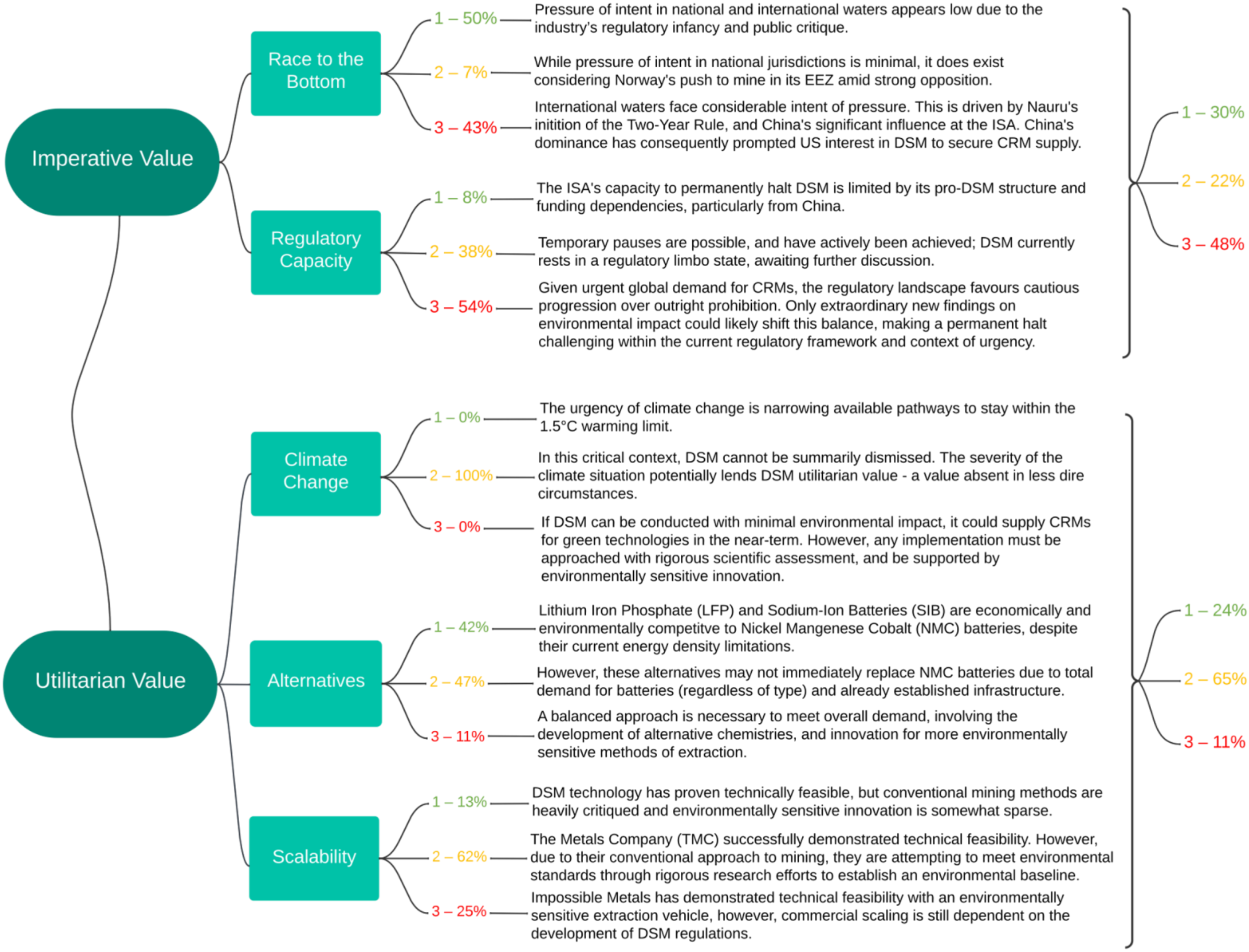

Figure 10. Final analysis of facets, and subsequent Values.

Imperative Value

Deep-sea mining has a relatively high imperative value, indicating the industry's imminence. One of the driving forces behind this imperative is the presence of a "race to the bottom" scenario, where a small number of influential actors push for, or draw attention to DSM, despite public opposition. This in turn exerts pressure on the ISA's regulatory capabilities, which are already constrained due to its somewhat pro-DSM structure and funding dependencies. While the ISA can implement a moratorium, its capacity to establish a permanent ban is unlikely, unless in the face of overwhelmingly clear data refuting the industry's potential. Given the industry's established presence, complete cessation of DSM activities will likely prove challenging. Existing investments, exploration research, pressure to meet net-zero, and economic interests all create inertia against a full shutdown.

Utilitarian Value

Deep-sea mining offers a potential, albeit controversial, source of CRMs for renewable technologies, indicating modest capacity to contribute on the path to net-zero. The intensifying impacts of climate change and related mitigation efforts have dramatically increased demand for CRMs. It is this surge in demand that necessitates a consideration of DSM's potential contributions, provided it can be developed and regulated responsibly. While emerging alternatives to DSM-relevant battery chemistries somewhat diminish its relative utility, the increasing total demand for batteries still creates a niche where DSM could act as a temporary bridge for supply gaps. Its hypothetical stopgap role would persist while alternative technologies are being innovated and scaled to meet global needs. Such utility is supported by the fact that DSM technology demonstrates a degree of scalability, given the presence of environmentally sensitive innovations in the industry. However, ongoing environmental concerns, particularly the lack of comprehensive baseline data, still need to be addressed (which TMC is working towards).

7 Discussion

7.1 *Preliminaries*

7.1.1 *On the brink of net-zero*

The race to net-zero by mid-century is on. As viable pathways to mitigate climate warming become increasingly limited, there is mounting pressure to assess all potential options—including those that face public scepticism or opposition. In less dire conditions, the most preferable path to net-zero would be to avoid extraction all together, however, mining presents itself as a double entendre—the tail of the ouroboros—both problem and solution. This dilemma reflects a fundamental aspect of human progress in that our solutions often spawn new problems, propelling us forward through a series of imperfect innovations. In an extension of this dilemma, attention has shifted seaward to expand our resource extraction to the sea floor. Thus, DSM illustrates the stark reality of what it might mean to reach net-zero. Herein, its imminence forces us to confront an uncomfortable, human truth—our history of exploitation, and how such practices now fit on our path to a more sustainable future. In this regard, DSM is simply an example of an imperfect innovation, a representation of this process of 'failing upward'. Only through rigorous examination can we determine if DSM offers a viable way forward to where we, as [hu]mankind, want to go.

7.2 *Interpretation of Results*

7.2.1 *Answering the research question*

Does deep-sea mining have a role on the path to net-zero, considering factors of urgency?

DSM has a high imperative value, indicating significant pressure to finalize the Mining Code to address its imminence. This reality is a result of two key reasons: persistent forces from influential industry stakeholders resistant to its complete cessation, and the inherent challenges in regulating a resource that lies beyond national jurisdiction. So forth, DSM would benefit from guidance, not to unleash an extractive industry unchecked, but to proactively chart its course. Such an approach would allow us to shape the industry along the lines of where we want to go, in pursuit of maximizing the presence of its moderate utility in the context of climate urgency and nearing net-zero targets.

In short, there is a high imperative to maximize DSM's moderate utility when considering factors of urgency.

In line with Stabell's (2019) conclusions, any Utilitarian Value hinges on the realization of a strong regulatory framework that encourages environmentally sensitive innovation and prevents industry immortality. In this vein, regulations to address the Imperative Value of DSM must be coupled with a well-defined exit strategy. By conceptualizing and regulating DSM as a transitory aid rather than a permanent fixture, we can maximize its potential benefits while safeguarding against long-term environmental degradation. This approach extends beyond merely ensuring that DSM technologies are environmentally sound in their design; it demands that the industry's entire trajectory be sustainable. Hence, DSM does have a role on the path to net-zero in the event regulatory frameworks can encourage environmentally sensitive innovation and ensure that it is only used as a transitory method.

7.2.2 *Implications for policy*

To address the industry's imminence and maximize its moderate utility, regulations for the exploitation of deep-sea resources should:

Prioritize environmentally sensitive technological advancements for deep-sea resource extraction. This objective should catalyse eco-centric innovation through incentivizing the development of technologies that actively safeguard deep-sea ecosystems. The primary objective of this approach should move beyond the conventional paradigm of merely advocating for regulations based on our current understanding of marine ecosystems and extraction methods. Instead, it demands a fundamental reimagining of DSM technology. Rather than accepting current standards as immutable, efforts should focus on innovating the design of mining vehicles and related equipment to ensure they are inherently eco-conscious and minimally invasive. By championing functional and environmentally sensitive design, DSM could secure the broader public acceptance and crucial social license it will require if it is to go forward. This proactive approach aims to create a new foundation where environmental stewardship is built into the core functionality of DSM operations, rather than remaining an afterthought or regulatory hurdle.

Incorporate clear sunset provisions into licenses for exploitation. Since DSM shows considerable but not definitive utility, it should be viewed as a temporary solution to meet urgent net-zero targets. Regulations should be designed with built-in flexibility to maximize the potential benefits of DSM, while simultaneously accounting for the industry's eventual cessation. This adaptive framework should ensure that DSM operations are responsive to technological advancements and shifting resource landscapes. Specifically, it should allow for dynamic adjustments regarding the need for DSM as we progress toward net-zero material goals, achieve higher levels of resource recyclability, and/or alternatives to DSM-relevant battery chemistries become more competitive. Such a framework would ensure that the industry remains in alignment with our broader sustainability objectives and not outlive its utility. Ultimately, this strategy recognizes that resource exploitation, including DSM, shall not be viewed as a permanent solution, but rather as a carefully managed, temporary intervention necessitated by urgent global needs. By framing DSM within this context, it creates a powerful incentive for continuous innovation in alternative technologies and practices, potentially hastening the transition to a truly circular economy.

7.2.3 *Limitations and the way forward*

This research deliberately eschews an in-depth analysis of the environmental impacts of DSM or a comparison to its land-based counterpart, acknowledging that all extractive practices are inherently impactful. It is not the aim of this research to refute the validity of this fact. In regard to land-based mining, its omission is in recognition of the popular argument made against DSM: that DSM should not be framed as an environmentally sustainable alternative to land-based extraction because it would likely supplant rather than replace it. By refraining from this comparative analysis, the thesis recognizes the economic reality that a new extractive industry would be highly unlikely to eliminate an existing one, especially in the context of urgent resource needs. Through reaching this understanding, the research conclusions seek to elucidate the potential future role of DSM given the context of our current situation. Recognizing the likely persistence of DSM due to industry momentum and resource demands, the study aims to bridge a critical gap in the discourse. It moves beyond the debate over whether DSM should exist, and instead acknowledges its presence as an imminent reality and attempts to offer insights on how to proceed responsibly within this contentious domain.

The main outcomes of this research therefore:

1) Provide an assessment of the current landscape surrounding DSM
2) Look for middle ground between industry proponents and opponents
3) Propose an optimal path forward that maximizes positive outcomes in the face of DSM's potential implementation

8 Conclusion

8.1 *Summary of findings*

The inherently extractive nature of DSM often conflicts with public perceptions on environmental stewardship, creating significant challenges in communication. This thesis attempts to remedy this challenge by simplifying the industry’s complex facets and putting them in the context of climate urgency. Examining DSM in this manner ultimately reveals a reality that is far more nuanced than standard characterizations of exploitative practices.

For this examination, the study focused on the industry’s Imperative and Utilitarian Values. Imperative Value assessed the industry's imminence. Specifically, the potential for a "race to the bottom" scenario, with data revealing the presence of moderate pressure from various countries to pursue DSM in national and international waters. Additionally, the ISA’s regulatory capacity was examined, with the review indicating that while it has robust mechanisms to enact and maintain temporary suspensions against exploitation, its ability to enforce any permanent halt is constrained due to the organization’s structure and funding. The convergence of these facets indicate a high Imperative Value for DSM, signalling its imminent development. This impending reality suggests a need to finalize the regulations to oversee exploitation in a manner that is environmentally sensitive. Without proactive oversight, we risk a 'worst-off scenario' in which the rules are either written poorly, and fail to guide the industry, or not written at all, thus missing the opportunity to maximize its potential utility.

The Utilitarian Value of DSM was examined through several key aspects. First, climate change as a potential driver for the consideration of DSM was explored. The findings suggested that the escalating severity of climate change might position DSM as a tool on the path to net-zero. More specifically, the urgent need for CRMs for green technologies could drive the development of this controversial industry. Second, the analysis considered alternatives to DSM-relevant battery chemistries. The results revealed that while emerging battery chemistries show promise, they still face their own challenges, suggesting that DSM-relevant chemistries are likely to remain significant in the medium term. In this situation, DSM-relevant chemistries could help to bridge supply gaps while alternative competitors are being innovated for commercial scale. Finally, the study examined the scalability of DSM itself, using case studies on The Metals Company and Impossible Metals. Both demonstrated technical feasibility of operations, with Impossible Metals making standout progress in the development of environmentally sensitive mining vehicles. This progress exemplifies the industry's evolution towards meeting stringent environmental standards, potentially mitigating some of the environmental concerns associated with DSM. The analysis of these three facets revealed that DSM holds moderate utility. Although, it should be noted that this utility is contextualized within the time-sensitive nature of climate urgency, which lends DSM its relevance and value.

In summary, the apparent imperative and moderate utility of DSM indicate that its complete cessation in the near future remains unlikely. That said, while it can address CRM demands—particularly in the context of achieving net-zero emissions—its ultimate viability hinges on significant technological innovations to enhance the industry’s environmental sensitivity.

8.2 *Recommendations*

This study concludes that DSM remains a viable, albeit controversial, strategy in the transition to net-zero. Hence, regulations governing the exploitation of deep-sea resources should encourage eco-centric technological innovation and include strong sunset provisions. This framework should guide the industry in alignment with our societal goals by maximizing its utility in the short-term while still acknowledging the unsustainable nature of resource exploitation. Ultimately, the aim is to provide a practical way forward that is adaptive to our current climate challenge, while maintaining sight of what our legacy for future generations should look like.

8.3 *Contributions*

This research ultimately acts as a response to Wilkerson & Trellevik's (2021) call for a systems analysis of the industry. In effect, it addresses some of the opacity surrounding DSM, recognizing that a comprehensive understanding of its complexities to this point remain largely confined to academic circles and those directly involved in the field. Through synthesizing and disseminating this analysis of the industry, this study seeks to broaden public awareness and inform policy discussions, ensuring that decisions made about DSM are based on a more widely shared, nuanced comprehension of its implications.

In this context, the development and mandated phase-out of DSM should signify a pivotal moment in our relationship to the Earth's resources, marking a final chapter in their exploitation. Accordingly, advocating for the finalization of the Mining Code in this thesis should not be seen as a blatant endorsement of exploitative practices. Rather, this conclusion represents a pragmatic approach to fulfilling our resource needs through one last, meticulously regulated effort. With strong sunset provisions, we can harness the resources necessary for our transition to net-zero while firmly committing to a future where such practices are obsolete; a solution that is both cognizant of our current reality and sensitive to the environment. Ultimately, this framework seeks to navigate the intricate challenges of regulating a resource that belongs to no one—a situation that has effectively stalled industry progress into what seems like an interminable debate. That which might prevent the maximization of its potential utility, in the event regulations can be written and enforced in a manner that is mindful of our future. Herein, this thesis attempts to clarify the profound implications of endorsing DSM, positioning it as a potential end to humanity's long history of resource exploitation—breaking from the ouroboros cycle.

Bibliography

Alberts, E. (2023). *Deep-sea mining rules delayed two more years; mining start remains unclear.* Mongabay Environmental News. https://news.mongabay.com/2023/07/deep-sea-mining-rules-delayed-two-more-years-mining-start-remains-unclear/

Aqib Zahoor, Yu, Y., Saima Batool, Idrees, M., & Mao, G. (2023). The Carbon-Neutral Goal in China for the Electric Vehicle Industry with Solid-State Battery's Contribution in 2035 to 2045. *Journal of Environmental Engineering, 149*(12). https://doi.org/10.1061/joeedu.eeeng-7340

Ardito, G. (2023). The European Union at the International Seabed Authority: A Question of Competence on the Brink of Deep-Sea Mining. *Maritime Safety and Security Law Journal, 11*, 20-39.

Bang, R. N., & Trellevik, L.-K. L. (2023). Reserve-dependent capital efficiency, cross-sector competition, and mineral security considerations in mineral industry transition. *Mineral Economics, 36*(3), 383–400. https://ideas.repec.org/a/spr/minecn/v36y2023i3d10.1007_s13563-022-00329-z.html

Bessol, M. (2024). *Norway Opens Door to Deep-Sea Mining Exploration.* Earth. https://earth.org/norway-deep-sea-mining-exploration-environmental-cost/#:~:text=This%20proposal%20was%20finally%20approved

Blanchard, C., Harrould-Kolieb, E., Jones, E., & Taylor, M. L. (2023). The current status of deep-sea mining governance at the International Seabed Authority. *Marine Policy, 147*, 105396. https://doi.org/10.1016/j.marpol.2022.105396

Canals Casals, L., Amante García, B., & Cremades, L. V. (2017). Electric vehicle battery reuse: Preparing for a second life. *Journal of Industrial Engineering and Management, 10*(2), 266. https://doi.org/10.3926/jiem.2009

Climate Action Tracker. (2023). *CAT net-zero target evaluations.* Climate Action Tracker. https://climateactiontracker.org/global/cat-net-zero-target-evaluations/

Congressman Ed Case. (2023). *Case Introduces Measures To Halt Deep-Seabed Mining Until Full Consequences Understood And Protective Regulatory Regimes Established*. Congressman Ed Case. https://case.house.gov/news/documentsingle.aspx?DocumentID=2211

Delong. (2024). *Sodium Ion Battery vs. Lithium-Ion Battery.* Delong Energy. https://www.delongtop.com/sodium-ion-battery-vs-lithium-ion-battery/

Di Grandi, T, & Aboulazm, Z. (2023). *Mapped: Where is the Best Phosphate For LFP Batteries?* Visual Capitalist. https://www.visualcapitalist.com/sp/mapped-where-is-the-best-phosphate-for-lfp-batteries/

Dobush, B.-J., & Warner, M. (2024). *Deep Sea Mining Isn't Worth the Financial Risk.* The Ocean Foundation. https://oceanfdn.org/wp-content/uploads/2024/02/dsm-finance-brief-2024.pdf

EASAC. (2023). *Deep-Sea Mining: assessing evidence on future needs and environmental impacts Contents.* European Academies Science Advisory Council. https://easac.eu/fileadmin/user_upload/EASAC_Deep_Sea_Mining_Web_publication_.pdf

El Moutchou, S., Aziam, H., Mansori, M., & Saadoune, I. (2022). Thermal stability of Lithium-ion batteries: Case study of NMC811 and LFP cathode materials. *Materials Today: Proceedings, 51*(13), A1–A7. https://doi.org/10.1016/j.matpr.2022.02.324

Engel, P. (2019). Mauro and Elena. *Ploughshares*, *45*(2), 33–48. https://doi.org/10.1353/plo.2019.0048

Ennovi. (2024). *Complete Guide to Electric Vehicle Batteries.* Ennovi https://ennovi.com/electric-vehicle-batteries-complete/

Environmental Justice Foundation. (2023). *How the rush to deep-sea mining threatens people and our planet.* Environmental Justice Foundation. https://ejfoundation.org/resources/downloads/towards-the-abyss-ejf-deep-sea-mining-report.pdf

Environmental Justice Foundation. (n.d). *Critical Minerals and the Green Transition: Do we need to mine the deep seas?*. Environmental Justice Foundation. https://eurmc.org/?jet_download=491724eebfafecb1da5834beb0c6c5790ab92efa

European Commission. (2023). *Net Zero Industry Act.* Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs. https://single-market-economy.ec.europa.eu/publications/net-zero-industry-act_en

European Commission. (2023). Proposal for a Regulation of the European Parliament and of the Council establishing a framework for ensuring a secure and sustainable supply of critical raw materials (COM(2023) 144 final). https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52023PC0144

European Court of Auditors. (2023). *Special report The EU's industrial policy on batteries.* European Court of Auditors. https://www.eca.europa.eu/ECAPublications/SR-2023-15/SR-2023-15_EN.pdf

Friedlingstein, P., O'Sullivan, M., Jones, M. W., Andrew, R. M., Bakker, E., Hauck, J., Landschützer, P., Corinne Le Quéré, Luijkx, I. T., Peters, G. P., Peters, W., Pongratz, J., Clemens Schwingshackl, Sitch, S., Canadell, J. G., Philippe Ciais, Jackson, R. B., Alin, S. R., Anthoni, P., & Barbero, L. (2023). Global Carbon Budget 2023. https://doi.org/10.5194/essd-2023-409

Gale, S. J. (2019). Lies and misdemeanours: Nauru, phosphate and global geopolitics. *The Extractive Industries and Society, 6*(3), 737–746. https://doi.org/10.1016/j.exis.2019.03.003

Geng, L., Liu, J., David Lee Wood, Qin, Y., Lu, W., Jafta, C. J., Bai, Y., & Ilias Belharouak. (2020). Probing Thermal Stability of Li-Ion Battery Ni-Rich Layered Oxide Cathodes by means of Operando Gas Analysis and Neutron Diffraction. *ACS Applied Energy Materials, 3*(7), 7058–7065. https://doi.org/10.1021/acsaem.0c01105

Global Tipping Points. (2024). *Governance of Earth system tipping points: 3.2.3.1 Mitigation.* Global Tipping Points. https://global-tipping-points.org/section3/3-0-governance-of-earth-system-tipping-points/3-2-prevention-of-earth-system-tipping-processes/3-2-3-prevention-approaches-and-institutional-options/3-2-3-1-mitigation/

Government of Nauru. (2021). *Nauru requests the International Seabed Authority Council to adopt rules and regulations within two years.* The Government of the Republic of Nauru. http://naurugov.nr/government/departments/department-of-foreign-affairs-and-trade/faqs-on-2-year-notice.aspx

Haugan, P. M., & Levin, L. A. (2019). *What Role for Renewable Energy and Deep-Seabed Minerals in a Sustainable Future.* Ocean Panel. www.oceanpanel.org/blue-papers/ocean-energy-and-mineral-sources

Hauner, S. (2024). *Deep-sea mining: Exploration rights under ISA regulation.* Mining Technology. https://www.mining-technology.com/features/deep-sea-exploration-rights-under-international-seabed-authority-regulations/

Hein, J R., Mizell, K., Koschinsky, A., & Conrad, T. A. (2013). Deep-ocean mineral deposits as a source of critical metals for high- and green-technology applications: Comparison with land-based resources. *Ore Geology Reviews*, *51*, 1–14. https://doi.org/10.1016/j.oregeorev.2012.12.001

Hein, J.R., Koschinsky, A. & Kuhn, T. Deep-ocean polymetallic nodules as a resource for critical materials. *Nat Rev Earth Environ*, *1*, 158–169 (2020). https://doi.org/10.1038/s43017-020-0027-0

Hirono, M., Murkowski, L., Kaine, T., Van Hollen, C., Rosen, J., Cassidy, B., King, A., & Whitehouse, S. (2023). *18TH CONGRESS 1ST SESSION.* Hirono Senate. https://www.hirono.senate.gov/imo/media/doc/unclos_resolution_text_20231.pdf

Hotter, A. (2023). *Don't forget phosphate when securing critical raw materials for electrification*. Fastmarkets. https://www.fastmarkets.com/insights/dont-forget-phosphate-for-electrification-andrea-hotter

House of Armed Services Committee. (2023). *Amendment to H.R. 2670 National Defence Authorization Act for Fiscal Year 2024.* https://docs.house.gov/meetings/AS/AS00/20230621/115846/BILLS-118-HR2670-R000575-Amdt-CHMEB1.pdf

Ibid., Section 1(15)(c): If the Council has not completed the elaboration of the rules, regulations and procedures relating to exploitation within the prescribed time and an application for approval of a plan of work for exploitation is pending, it shall nonetheless consider and provisionally approve such plan of work based on the provisions of the Convention and any rules, regulations and procedures that the Council may have adopted provisionally, or on the basis of the norms contained in the Convention and the terms and principles contained in this Annex as well as the principle of non-discrimination among contractors

ICL. (2023). *ICL Breaks Ground on $400 Million Battery Materials Manufacturing Plant in St. Louis.* Investors ICL Group. https://investors.icl-group.com/reports-news-and-events/press-releases/press-releases-details/2023/ICL-Breaks-Ground-on-400-Million-Battery-Materials-Manufacturing-Plant-in-St.-Louis/default.aspx

IEA. (2023b). *Global EV Outlook 2023 Catching up with climate ambitions.* International Energy Agency. https://iea.blob.core.windows.net/assets/dacf14d2-eabc-498a-8263-9f97fd5dc327/GEVO2023.pdf

IEA. (2023c). *Trends in electric light-duty vehicles. International* Energy Agency. https://www.iea.org/reports/global-ev-outlook-2023/trends-in-electric-light-duty-vehicles

IISD. (2015). Summary of the Paris Climate Change Conference: 29 November – 13 December 2015. 12(63), 1-47. https://enb.iisd.org/paris-climate-change-conference-cop21/summary-report

Impossible Metals. (2023d). *Impossible Metals reveals their roadmap to developing the best available technology for deep sea mining*. Impossible Metals. https://impossiblemetals.com/blog/impossible-metals-reveals-their-roadmap-to-developing-the-best-available-technology-for-deep-sea-mining/

Impossible Metals. (2024a). *Impossible Metals application for observer status with the ISA.* Impossible Metals. https://www.isa.org.jm/wp-content/uploads/2024/04/Impossible-Metals-request-for-observer-status.pdf

Impossible Metals. (2024b). *Robotic Collection System.* Impossible Metals. https://impossiblemetals.com/technology/robotic-collection-system/

Impossible Metals. (2024c). *Impossible Metals Webinar Series: Eureka II Deep Sea Test Results by Jason Gillham.* Impossible Metals. https://impossiblemetals.com/blog/impossible-metals-webinar-series-eureka-ii-deep-sea-test-results-friday-may-17-2024/

ING. (2023). *Can sodium-ion batteries replace lithium-ion ones?.* THINK Economic and Financial Analysis. https://think.ing.com/downloads/pdf/article/can-sodium-ion-batteries-replace-lithium-ion-batteries

IPCC. (2023). *Sixth Assessment Report — IPCC (Synthesized).* Intergovernmental Panel on Climate Change. https://www.ipcc.ch/assessment-report/ar6/

IRENA. (2023). *World Energy Transitions Outlook 2023: 1.5o Pathway. International Renewable Energy Agency*. Abu Dhabi. https://mc-cd8320d4-36a1-40ac-83cc-3389-cdn-endpoint.azureedge.net/-/media/Files/IRENA/Agency/Publication/2023/Jun/IRENA_World_energy_transitions_outlook_2023.pdf?rev=db3ca01ecb4a4ef8accb31d017934e97

ISA. (2022a). *The Secretariat.* International Seabed Authority. https://www.isa.org.jm/organs/the-secretariat/

ISA. (2022b). *Organs of the International Seabed Authority.* International Seabed Authority https://www.isa.org.jm/organs/

ISA. (2022c). *The Enterprise*. International Seabed Authority. https://www.isa.org.jm/organs/the-enterprise/

ISA. (2022d). *The Legal and Technical Commission*. International Seabed Authority. https://www.isa.org.jm/organs/the-legal-and-technical-commission/

ISA. (2022e). *The Council.* International Seabed Authority. https://www.isa.org.jm/organs/the-council/

ISA. (2024a). *Frequently Asked Questions (FAQs).* International Seabed Authority. https://www.isa.org.jm/frequently-asked-questions-faqs/

ISA. (2024b). *Exploration Contracts*. International Seabed Authority. https://www.isa.org.jm/exploration-contracts/

Kim, H. (2023). Sodium-Ion Battery: Can It Compete with Li-Ion?. *ACS Materials Science Au, 3*(6), 571–575. https://doi.org/10.1021/acsmaterialsau.3c00049

Kuo, L. (2023). *China is set to dominate the deep sea and its wealth of rare metals*. Washington Post. https://www.washingtonpost.com/world/interactive/2023/china-deep-sea-mining-military-renewable-energy/

Kurzweil, P., & Brandt, K. D. (2009). SECONDARY BATTERIES – LITHIUM RECHARGEABLE SYSTEMS | Overview. Reference Module in Chemistry. *Molecular Sciences, and Chemical Engineering*, 1–26. https://doi.org/10.1016/b978-044452745-5.00185-4

Laabs, E., & Kind-Rieper, T. (n.d.). *Bringing Batteries Production to in a Green and Responsible Way How The EU Can Develop A World Class Battery Industry.* WWF Germany. https://www.wwf.de/fileadmin/fm-wwf/Publikationen-PDF/Wald/wwf-study-green-responsible-batterie-production-eu.pdf

Lee, M., Cho, S., Choi, J., Kim, H., Hong, S., & Lee, T. (2012). Metamodel-Based Multidisciplinary Design Optimization of a Deep-Sea Manganese Nodules Test Miner. *Journal of Applied Mathematics,* (1). https://doi.org/10.1155/2012/326954

Liu, Z., Liu, K., Chen, X., Ma, Z., Zhang, H., Rui Lv, Wei, C., & Ma, K. (2023). Deep-sea rock mechanics and mining technology: State of the art and perspectives. *International Journal of Mining Science and Technology, 33*(9). https://doi.org/10.1016/j.ijmst.2023.07.007

Luo, R. (2023). *The $11.6 Billion LFP Battery Project investment in the United States.* LinkedIn. https://www.linkedin.com/pulse/116-billion-lfp-battery-project-investment-united-states-ricky-luo/

Lusty, P. A. J., & Murton, B. J. (2018). Deep-Ocean Mineral Deposits: Metal Resources and Windows into Earth Processes. *Elements, 14*(5), 301–306. https://doi.org/10.2138/gselements.14.5.301

Lusty, P. A. J., & Murton, B. J. (2018). Deep-ocean mineral deposits: Metal resources and windows into earth processes. *Elements*, *14*(5), 301–306. https://doi.org/10.2138/gselements.14.5.301

MANLY. (2023). *$84.1 Billion LFP Battery Project Lands in the U.S.* MANLY Custom Lithium Battery Pack. https://manlybattery.com/84-1-billion-lfp-battery-project-lands-in-the-u-s/

Mazie Hirono. (2023). *Hirono, Murkowski, Kaine Reintroduce Resolution Calling on U.S. Senate to Ratify UN Convention on the Law of the Sea.* Mazie Hirono. https://www.hirono.senate.gov/news/press-releases/hirono-murkowski-kaine-reintroduce-resolution-calling-on-us-senate-to-ratify-un-convention-on-the-law-of-the-sea

McGrath, M. (2020). *Climate change: China aims for "carbon neutrality by 2060.* BBC News. https://www.bbc.co.uk/news/science-environment-54256826

McGrath, M. (2022). *US climate bill success masks scale of warming challenge.* BBC News. https://www.bbc.co.uk/news/science-environment-62464546

Melin, H. (2020). *The lithium-ion battery life cycle report 2021.* Advanced Energy. https://www.advancedenergy.org/wp-content/uploads/imported-files/Thelithium-ionbatterylifecyclereportsample.pdf

MIDAS. (n.d.). *Polymetallic massive sulphide deposits.* Managing Impacts of Deep-Sea Resource Exploitation. https://www.eu-midas.net/science/sulphides

Mohanty, D., Dahlberg, K., King, D. M., David, L. A., Sefat, A. S., Wood, D. L., Daniel, C., Dhar, S., Mahajan, V., Lee, M., & Albano, F. (2016). Modification of Ni-Rich FCG NMC and NCA Cathodes by Atomic Layer Deposition: Preventing Surface Phase Transitions for High-Voltage Lithium-Ion Batteries. *Scientific Reports*, *6*(1). https://doi.org/10.1038/srep26532

Mordor Intelligence. (2024). *NMC Battery Pack Market Size & Share Analysis - Industry Research Report - Growth Trends.* Mordor Intelligence. https://www.mordorintelligence.com/industry-reports/nmc-battery-pack-market

National Defence Authorization Act for Fiscal Year 2024. (2023). H.R. 2670, 118th Cong. https://www.congress.gov/bill/118th-congress/house-bill/2670

Neno, S. (2021). *Nauru requests the President of ISA Council to complete the adoption of rules, regulations and procedures necessary to facilitate the approval of plans of work for exploitation in the Area*. International Seabed Authority. https://www.isa.org.jm/news/nauru-requests-president-isa-council-complete-adoption-rules-regulations-and-procedures/

OECD. (2022). *Climate Tipping Points: Insights for Effective Policy Action*. OECD iLibrary. https://doi.org/10.1787/abc5a69e-en

OECD. (2023). *Raw Materials Critical for the Green Transition: Production, International Trade and Export Restrictions.* OECD Trade and Agriculture Directorate. https://doi.org/10.1787/18166873

OEWG. (2022). *Fifth Meeting of the Open-ended Working Group of the Council on the financial terms of a contract under article 13, paragraph 1 of Annex III to the United Nations Convention on the Law of the Sea and under section 8 of the Annex to the Agreement relating to the implementation of Part XI of the United Nations Convention on the Law of the Sea of 10 December 1982.* Briefing Note. https://www.isa.org.jm/wp-content/uploads/2022/12/Briefing_Note_OEWG_13_June_2022.pdf

Ovrom, A. (2023). *Comparing NMC and LFP Lithium-Ion Batteries for C&I Applications.* Mayfield Renewables. https://www.mayfield.energy/technical-articles/comparing-nmc-and-lfp-lithium-ion-batteries-for-ci-applications/#:~:text=Cycle%20Life&text=NMC%20batteries%20can%20achieve%201000

Parker, L. (2022). *Impossible Mining - Closes $10.1M in Seed funding and announces its key advisors.* DredgeWire. https://dredgewire.com/impossible-mining-closes-10-1m-in-seed-funding-and-announces-its-key-advisors/

Paulikas, D., Steven, K., Erika, I., & H. Ali, S. (2020). Life cycle climate change impacts of producing battery metals from land ores versus deep-sea polymetallic nodules. *Journal of Cleaner Production, 275*(275), 2–18. https://doi.org/10.1016/j.jclepro.2020.123822

Pedersen, R. B., Olsen, B. R., Barreyre, T., Bjerga, A., Eilertsen, M. H., Haflidason, H., ... Tandberg, A. H. S. (2021). Fagutredning Mineralressurser i Norskehavet - Landskapstrekk, Naturtyper og Bentiske Økosystemer. https://www.npd.no/globalassets/1-npd/fakta/havbunnsmineraler/fagutredning-mineralressurser-norskehavet-naturforhold-uib.pdf

Pelaudeix, C. (2018). *Deep Seabed Mining of Critical Metals*. Strategic and Governance Challenges. Éditoriaux de l'Ifri.

Petersen, S., Krätschell, A., Augustin, N., Jamieson, J., Hein, J. R., & Hannington, M. D. (2016). News from the seabed –Geological characteristics and resource potential of deep-sea mineral resources. *Marine Policy, 70*, 175–187. https://doi.org/10.1016/j.marpol.2016.03.012

Poynting, M. (2024). *World's first year-long breach of key 1.5ºC warming limit.* BBC. https://www.bbc.com/news/science-environment-68110310

Rabalais, N.N., R.J. Diaz, L.A. Levin, R.E. Turner, D. Gilbert, & J. Zhang. (2010). Dynamics and distribution of natural and human-caused hypoxia. *Biogeosciences, 7*(585–619).

Ramirez-Llodra, E., Tyler, P. A., Baker, M. C., Bergstad, O. A., Clark, M. R., Escobar, E., Levin, L. A., Menot, L., Rowden, A. A., Smith, C. R., & Van Dover, C. L. (2011). Man and the Last Great Wilderness: Human Impact on the Deep Sea. *PLoS ONE, 6*(8), e22588. https://doi.org/10.1371/journal.pone.0022588

Randall, C. (2024). *BYD prepares market launch of next-generation blade battery.* Electrive. https://www.electrive.com/2024/04/09/byd-to-prepare-market-launch-of-next-generation-blade-battery/

Riley, R. (2024). *Sodium-ion batteries – a viable alternative to lithium?*. PV Magazine International. https://www.pv-magazine.com/2024/03/22/sodium-ion-batteries-a-viable-alternative-to-lithium

Roberts, A. (2008). *Nauru after phosphate mining.* Teara. https://teara.govt.nz/en/photograph/15838/nauru-after-phosphate-mining

Setså, R. (2023). *Environmentally responsible mining. Not so impossible.* GEO ExPro. https://geoexpro.com/environmentally-responsible-mining-not-so-impossible/

Shafique, M., Rafiq, M., Azam, A., & Luo, X. (2022). Material flow analysis for end-of-life lithium-ion batteries from battery electric vehicles in the USA and China. *Resources, Conservation and Recycling, 178*, 106061. https://doi.org/10.1016/j.resconrec.2021.106061

Silva, E. (2024). *US Congress interest in deep-sea mining grows as China invests*. S&P Global. https://www.spglobal.com/marketintelligence/en/news-insights/latest-news-headlines/us-congress-interest-in-deep-sea-mining-grows-as-china-invests-80292939

Singh, P. A. (2022). The Invocation of the 'Two-Year Rule' at the International Seabed Authority: Legal Consequences and Implications. *International Journal of Marine and Coastal Law, 37*, 375–412, https://doi.org/10.1163/15718085-bja10098.92Ibid.93

Smith, K. (n.d.). *Deep-sea ecosystems affected by climate change.* Monterey Bay Aquarium Research Institute. https://www.mbari.org/news/deep-sea-ecosystems-affected-by-climate-change/

Solberg, E. (2024). *Norway takes legal action against the Norwegian government.* WWF-Norway. https://www.wwf.no/wwf-norway-takes-legal-action-against-the-norwegian-government-2

Stabell, E. (2019). *Deep Sea Uncertainty: Studies in Environmental Ethics and Decision-Making.* Doctoral Thesis at the Norwegian University of Science and Technology (NTNU). https://www.researchgate.net/publication/336561671_Deep_Sea_Uncertainty_Studies_in_Environmental_Ethics_and_Decision-Making

Stone, L. (2022). *How the Inflation Reduction Act Will Spur a Revolution in EV Battery Supply Chains.* RMI. https://rmi.org/how-the-inflation-reduction-act-will-spur-a-revolution-in-ev-battery-supply-chains/

Stortinget. (2024). *Voting overview for case: Mineral operations on the Norwegian continental shelf* - *opening up of area and strategy for management of the resources. Stortinget*. https://www.stortinget.no/no/Saker-og-publikasjoner/Saker/Sak/Voteringsoversikt/?p=94807&dnid=1

Subsea Minerals Act 2-2. (2024). *Act relating to mineral activities on the Continental Shelf (Seabed Minerals Act).* Norwegian Offshore Directorate. https://www.sodir.no/en/regulations/acts/act-relating-to-mineral-activities-on-the-continental-shelf-seabed-minerals-act/#Chapter-2

Tankou, A., Bieker, G., & Hall, D. (2023). *Scaling Up Reuse and Recycling of Electric Vehicle Batteries: Assessing Challenges and Policy Approaches*. The ICCT. https://theicct.org/wp-content/uploads/2023/02/recycling-electric-vehicle-batteries-feb-23.pdf

Tardi, C. (2024). *Utilitarianism: What It is, founders, and Main Principles.* Investopedia. https://www.investopedia.com/terms/u/utilitarianism.asp

Teaiwa, K. (2015). Ruining Pacific Islands: Australia's Phosphate Imperialism. *Australian Historical Studies, 46*(3), 374–391. https://doi.org/10.1080/1031461x.2015.1082609

The Maritime Executive. (2022). *Protestors Demonstrate as Deep-Sea Mining Vessel Completes Trial.* The Maritime Executive. https://maritime-executive.com/article/protestors-demonstrate-as-deep-sea-mining-vessel-completes-trial

TMC. (2023). *Greenpeace's Illegal Attempt to Stop a Legally-Mandated Scientific Research Expedition.* The Metals Company. https://metals.co/greenpeaces-illegal-attempt-to-stop-a-legally-mandated-scientific-research-expedition/

TMC. (2023d). *Greenpeace's Illegal Attempt to Stop a Legally-Mandated Scientific Research Expedition.* The Metals Company. https://metals.co/greenpeaces-illegal-attempt-to-stop-a-legally-mandated-scientific-research-expedition/

TMC. (2024a). *NORI-D Project – Nauru Ocean Resources Inc*. The Metals Company. https://metals.co/nori/

TMC. (2024b). *NORI-D Project – Nauru Ocean Resources Inc.* The Metals Company. https://metals.co/nori-page-v2/

TMC. (2024c). *TMC Subsidiary Submits Its Largest Deep-Sea Environmental Data Set Yet to International Seabed Authority.* The Metals Company. https://investors.metals.co/news-releases/news-release-details/tmc-subsidiary-submits-its-largest-deep-sea-environmental-data

Toro, N., Robles, P., & Jeldres, R. I. (2020). Seabed mineral resources, an alternative for the future of renewable energy: A critical review. *Ore Geology Reviews, 126*(June), 103699. https://doi.org/10.1016/j.oregeorev.2020.103699

Tracy, B. (2022). *Critical Minerals in Electric Vehicle Batteries.* Congressional Research Service. https://crsreports.congress.gov/product/pdf/R/R47227

Trellevik, L.-K. (2023). Exploring Deep-Sea Minerals: Systems modelling for an emerging industry and unknown futures. University of Bergen. https://hdl.handle.net/11250/3106785

Trocan, L. M. (2023). The Interest of the European Union in the Exploration and Exploitation of the Blue Continent'Resources. *International Investment Law Journal, 3*(1), 17-28

U. Rashid Sumaila, Alam, L., Kumara Perumal Pradhoshini, Onifade, T. T., S. Karuaihe, Singh, P., Levin, L. A., & Flint, R. (2023). To engage in deep-sea mining or not to engage: what do full net cost analyses tell us?. *Npj Ocean Sustainability, 2*(1). https://doi.org/10.1038/s44183-023-00030-w [2]

Umicore. (n.d.). *Cobalt powering the green economy*. Umicore. https://www.umicore.com/en/sustainability/responsible-sourcing/sustainable-cobalt/cobalt-powering-the-green-economy/

UNCLOS Part XI. (1994). Agreement relating to the implementation of Part XI of the United Nations Convention on the Law of the Sea of 10 December 1982. https://www.un.org/Depts/los/convention_agreements/texts/unclos/closindxAgree.htm

UNFCCC. (2021). *"Climate Commitments Not on Track to Meet Paris Agreement Goals" as NDC Synthesis Report Is Published.* United Nations Climate Change. https://unfccc.int/news/climate-commitments-not-on-track-to-meet-paris-agreement-goals-as-ndc-synthesis-report-is-published

United Nations Environment Programme (2023). *Emissions Gap Report 2023: Broken Record – Temperatures hit new highs, yet world fails to cut emissions (again)*. UNEP. https://wedocs.unep.org/20.500.11822/43922.

United Nations. (1982). United Nations Convention on the Law of the Sea. Part XI. https://www.un.org/depts/los/convention_agreements/texts/unclos/unclos_e.pdf[1]

United Nations. (2015). *The Paris Agreement.* United Nations Climate Change. https://unfccc.int/process-and-meetings/the-paris-agreement

UPS Battery Center. (2024). *Thermal Runaway in LFP and NMC Batteries.* News about Energy Storage, Batteries, Climate Change and the Environment. https://blog.upsbatterycenter.com/thermal-runaway-in-lfp-and-nmc-batteries/

Van Dover, C. L. (2010). Mining seafloor massive sulphides and biodiversity: what is at risk?. *ICES Journal of Marine Science*, *68*(2), 341–348. https://doi.org/10.1093/icesjms/fsq086

Wang, H., Feng, K., Wang, P., Yang, Y., Sun, L., Yang, F., Chen, W.-Q., Zhang, Y., & Li, J. (2023). China's electric vehicle and climate ambitions jeopardized by surging critical material prices. *Nature Communications, 14*(1). https://doi.org/10.1038/s41467-023-36957-4

Wilkerson, B., & Trellevik, L. K. L. (2021). Sustainability-oriented innovation: Improving problem definition through combined design thinking and systems mapping approaches. *Thinking Skills and Creativity, 42*(May), 100932. https://doi.org/10.1016/j.tsc.2021.100932

Williams, R., Erbe, C., Duncan, A., Nielsen, K., Washburn, T., & Smith, C. (2022). Noise from deep-sea mining may span vast ocean areas. *Science, 377*(6602), 157–158. https://doi.org/10.1126/science.abo2804

World Bank Group. (2020). *Minerals for Climate Action: The Mineral Intensity of the Clean Energy Transition.* World Bank. https://pubdocs.worldbank.org/en/961711588875536384/Minerals-for-Climate-Action-The-Mineral-Intensity-of-the-Clean-Energy-Transition.pdf

WWF. (2024). Deep Seabed Mining: *WWF takes legal action against the government.* WWF. https://www.wwf.no/wwf-takes-legal-action-against-the-state-2

Xiao, M. (2023). *How will the US Inflation Reduction Act affect China's Li-ion battery and EV industry?.* Interact Analysis. https://interactanalysis.com/insight/how-will-the-us-inflation-reduction-act-affect-chinas-li-ion-battery-and-ev-industry/

Xinhua News Agency. (2020). *The General Office of the State Council issued the "New Energy Vehicle Industry Development Plan (2021-2035).* Xinhua News Agency. https://www.gov.cn/xinwen/2020-11/02/content_5556762.htm

Yang, H., Wang, D., Liu, Y., Liu, Y., Zhong, B., Song, Y., Kong, Q., Wu, Z., & Guo, X. (2024). Improvement of cycle life for layered oxide cathodes in sodium-ion batteries. *Energy & Environmental Science, 17*(5), 1756–1780. https://doi.org/10.1039/D3EE02934D

Zhukov, A. (2023). *Sodium-ion Batteries are on the Horizon: How do They Measure up to Lithium-ion?.* Machine Design. https://www.machinedesign.com/materials/article/21274631/sodium-ion-batteries-are-on-the-horizon-how-do-they-measure-up-to-lithium-ion

Annex A: STEPS, APS, & NZE

** Announced capacity to meet projected demand is estimated on a utilisation rate of 85%.*

** Residual capacity refers to manufacturing capacity that would on average, remain unused.*

Stated Policies Scenario (STEPS): This scenario reflects the expected outcomes based on current policies, regulations, and measures that have been legislated by governments around the world. It provides a baseline for understanding the implications of existing policy frameworks on EV deployment.

Announced Pledges Scenario (APS): The APS assumes that all announced ambitions and targets made by governments, including those related to electromobility, are met in full and on time. This includes commitments to 100% zero-emission cars and vans, even if the supporting policies or regulations are not yet in place. The APS highlights the "implementation gap" between stated ambitions and the policies needed to achieve them.

Net Zero Emissions by 2050 Scenario (NZE): This is a normative scenario that outlines a pathway for the global energy sector to achieve net zero CO_2 emissions by 2050, consistent with limiting global temperature rise to 1.5°C. The NZE Scenario represents a more ambitious target and requires additional policies and measures beyond those in the APS to close the "ambition gap" and align with the goals of the Paris Agreement.

Annex B: Coding Analysis

** As seen in in Figure 10.*

Imperative Value

Facet	Code	Description	Frequency	Percent of Total
Race to the Bottom	1	No presence of pressure in national or international waters	7	50%
	2	Presence of pressure in national waters	1	7%
	3	Presence of pressure in international waters	6	43%
Regulatory Capacity	1	Regulatory frameworks can be advanced to permanently halt DSM	1	8%
	2	Regulatory frameworks can only temporarily halt DSM	5	38%
	3	Regulatory frameworks cannot permanently halt DSM	7	54%

Table 1. Individual analysis of facets measuring Imperative Value.

Code	Description	Frequency	Cumulative Percent
1	DSM presents no significant concern, not having a structured regulatory framework for exploitation is negligible	8	30%
2	DSM presents some concern which deserves consideration of developing a structured regulatory framework for exploitation	6	22%
3	DSM presents significant concern and a regulatory framework to govern exploitation is necessary	13	48%

Table 2. Cumulative analysis of facets measuring Imperative Value.

Utilitarian Value

Facet	Code	Description	Frequency	Percent of Total
Climate Change	1	Climate change impacts on the ocean are negligible to consider or necessitate DSM	-	0%
	2	Climate change impacts on ocean are great enough to necessitate the consideration of DSM	10	100%
	3	Climate change impacts on the ocean necessitate DSM	-	0%
Alternatives	1	Alternatives to DSM relevant battery chemistries are comparable to replace any need for DSM	8	42%
	2	Alternatives to DSM relevant battery chemistries are comparable but bottlenecks prevent them from replacing a need to consider DSM	9	47%
	3	Alternatives to DSM relevant battery chemistries are not comparable and DSM must be considered	2	11%
Scalability	1	DSM technology is not technically capable nor is it environmentally sensitive	1	13%
	2	DSM technology is technically capable but is not environmentally sensitive	5	62%
	3	DSM technology is both technically capable and environmentally sensitive	2	25%

Table 3. Individual analysis of facets measuring Utilitarian Value.

Code	Description	Frequency	Cumulative Percent
1	DSM has no use in the path to net-zero	9	24%
2	DSM has considerable use in the path to net-zero	24	65 %
3	DSM has definitive use in the path to net-zero	4	11%

Table 4. Cumulative analysis of facets measuring Utilitarian Value.

Annex C: Coding of the Literature Review

** Based on the analysis key as seen in Figure 1.*

Imperative Value

Race to the Bottom

1 – No presence of pressure in national or international waters

2 – Presence of pressure in national waters

3 – Presence of pressure in international waters

For exploitation

Nauru

Nauru's decision to invoke the Two-Year Rule stems from its long history of exploitation by colonial powers. The Government of Nauru—sponsoring state of NORI (Nauru Ocean Resources Inc.), and a subsidiary of The Metals Company (TMC), stated that they would "proudly [be] taking a lead role" in developing the legal framework to govern exploitation in the Area (Government of Nauru, 2021). This trigger was meant to help establish a clear regulatory framework for DSM exploitation, which Nauru argued it could use to revitalize its struggling economy (Government of Nauru, 2021). To fully grasp this motive however, it is essential to understand the nation's complex history with phosphate mining.

Phosphate, once an abundant and highly lucrative resource on the Island, was unsustainably exploited for decades, destroying over 80% of its ecosystems. (Government of Nauru, 2021). The Pacific Phosphate Company of Australia and later the British Phosphate Commission of Great Britain were predominantly responsible for this exploitation throughout the 20th century (Roberts, 2008). Both countries took part in the exploitation of Nauru's phosphate reserves for the benefit of the British Empire and its dominions (Australia and New Zealand at the time) (Roberts, 2008; Teaiwa, 2015). Nauru eventually gained its independence in 1968, however, this hardly put a stop to phosphate mining on the Island. Many were led to believe that the Nauruan government struggled to manage mining revenues or shift away from exploitive activity by its own faults. However, post-independence, Nauru's continued exploitation of its phosphate reserves was largely driven by persistant external demand from Australia and New Zealand

(Teaiwa, 2015; Gale, 2019). This pattern of external exploitation led to the near depletion of Nauru's phosphate reserves by the year 2000 (Teaiwa, 2015; Gale, 2019). Now, the Island State heavily depends on financial aid from its former beneficiaries, Australia, and New Zealand, to compensate for its losses (Roberts, 2008; Teaiwa, 2015). Here, it becomes clear that Nauru's reason for invoking the Two-Year Rule was not so simple as a means to boost its economy, but rather a symptom of its colonial history. It is a vulnerable country that has been driven to its last resort by centuries of exploitation, leaving the Island State at a crossroads between climate change, and economic downfall.

Nonetheless, the Government of Nauru maintains that invoking the Two-Year Rule was motivated by their desire to eventually apply for an exploitation license (Government of Nauru, 2021). While this move may potentially perpetuate a cycle of resource exploitation, Nauru's efforts to generate revenue from the Area's resources are, in light of its historical context, at least theoretically comprehensible. This is especially true given the importance of these resources for the green transition and the Island's vulnerability to climate change. Understanding this motive is crucial to grasp the nuanced reality of the Island State's intent to mine in international waters. Although invoking the Two-Year Rule has not yet resulted in any actualized Mining Code, their efforts have exerted legitimate pressure on the ISA to intensify negotiations on the matter.

Norway

In December 2023, the Norwegian Labour Party and the Centre Party achieved a majority vote in the Norwegian Parliament (Storting) to advance DSM in the country's Exclusive Economic Zone (EEZ) (Bessol, 2024). This would make Norway the first country to accept extraction applications in their national waters, demonstrating pressure of intent (Bessol, 2024). However, some of this pressure is nulled by the content of the decision itself. Within the agreement to open Norway's EEZ for DSM exploitation, it mandates that applications will only be accepted if the rules for future activity are first strengthened (Bessol, 2024). This development was recommended by the Norwegian Ministry of Petroleum and Energy—the Ministry that is intended to eventually oversee the assessment and approval of extraction licenses (Bessol, 2024). To strengthen the rules and increase the scrutiny of assessment for applications, it was proposed in January 2024 that in addition to assessment by the Ministry, potential applications must also be assessed and approved by the Norwegian Parliament (Storting) (Stortinget, 2024). This process would subject exploitation applications to two distinct levels of scrutiny, creating a more rigorous evaluation framework. In effect, the first licences will only be granted for exploration until the knowledge gaps required to justify a mining operation are fulfilled. This heightened scrutiny alleviates some pressure of intent in Norway's national waters by reducing the likelihood of application approval, which aims to ensure that only the most meritorious and environmentally sound projects advance.

Beyond Norway's self-imposed regulatory stringency, mounting public criticism and activism against DSM further mitigates their pressure of intent to exploit national waters. In response to the country’s decision to open their EEZ for exploitation, WWF-Norway released a statement criticizing the environmental impact assessment conducted by the Ministry of Energy in Norway. According to WWF-Norway, the assessment, which forms the basis for the government’s decision, fails to meet the minimum standards set by the Subsea Minerals Act 2-2 (WWF, 2024; Subsea Minerals Act 2-2, 2024). WWF-Norway, backed by the Norwegian Environment Agency (a division of the Ministry of Climate and Environment), contends that the Norwegian government's decision to open its EEZ for DSM exploitation lacks any legal foundation (Bessol, 2024). Specifically, their statement is based on the assertion that the impact assessment revealed "notable knowledge gaps regarding the nature of the marine environment, technologies for exploitation, and their associated environmental impacts” (Bessol, 2024). This internal and immediate response from national entities in Norway demonstrates that despite the government’s move to pave the way for DSM exploitation in national waters, the country is by no means relieved of its responsibility to sustainably manage its own resources.

In response to WWF-Norway's legal challenge, the Norwegian government defended its position on DSM. Herein, Energy Minister Terje Aasland emphasized their commitment to understanding the environmental conditions of potential mining areas through a "step-by-step approach" (Bessol, 2024). A process that is meant to ensure extraction activities have acceptably minimal impacts before committing to any application for exploitation (Bessol, 2024). Herein, companies must first conduct obligatory exploration of the areas they wish to exploit (Bessol, 2024). Exploitation licenses would only be granted if approved by both the Ministry of Energy and

Petroleum and the Norwegian Parliament, based on the Ministry's recommendations to tighten the rules for application (Bessol, 2024). This approach serves as a rebuttal to the criticism from WWF-Norway and the Norwegian Environment Agency regarding the government's failure to meet the standards of the Subsea Minerals Act 2-2. By opening the EEZ to exploration with the potential for future exploitation, the government asserts it is not embarking on a reckless or haphazard course (Bessol, 2024). Instead, it argues for a methodical, evidence-based approach characterized by incremental steps to thoroughly assess and validate the feasibility and environmental impacts of extraction activities before proceeding with any full-scale exploitation (Bessol, 2024). Whether this is a legitimate or solid enough argument, however, remains an ongoing debate, as WWF-Norway presses forward in taking the Norwegian government to court over the matter. As of now, pressure of intent is present in Norway's national jurisdiction, however, this pressure exists in limbo until further action is taken on the case between the Norwegian government and WWF-Norway (Solberg, 2024).

For power

China

China began its journey into DSM at the behest of President Xi Jinping's order for the country to 'master the key technologies for entering the deep-sea' back in 2016 (Kuo, 2023). Since the implementation of his directive, the nation has established at least 12 operational institutions for deep-sea research (Kuo, 2023). Among these, the largest facility located in Wuxi, Jiangsu Province, has ambitious plans to employ a workforce of 4,000 by 2025 (Kuo, 2023). This strategic initiative illustrates the country's commitment to advance its capacity for exploration, and potential exploitation of the deep-sea. A commitment which is supported by their holding the right to the most exploration licenses of any country at the ISA, accounting for up to 92 000 square miles of the Area (17% of the total area under the ISA's jurisdiction) (Kuo, 2023). This activity has sparked global concern, particularly among nations who also find themselves at the forefront of efforts to decarbonize by mid-century. As Carla Freeman, a senior expert on China at the United States Institute of Peace put, "If China can take the lead in seabed mining, [they] really [have] the lock on access to all the key minerals for the 21st century green economy." (Kuo, 2023). For China, the deep-sea is not just about resources, but security. To assert themselves as a global power underlies their very seat at the ISA (Silva, 2024).

When researchers first discovered the resource potential of the international seabed, it created ideological concern and global debate over the equitable distribution of the potential profits from exploitation (Silva, 2024). The U.S., a developed country, sought to operate on a first-come-first-serve basis, which was subsequently challenged by China, which, identifying as a developing country at the time, aligned itself with the interests of the Global South and argued that the benefits from these resources should be shared with all of [hu]mankind. (Silva, 2024). China's ideological approach received majority favour, and in 1982, their ideology formed the basis of the United Nations Convention on the Law of the Sea (Silva, 2024). In response, the U.S. maintained a non-participatory stance on UNCLOS and later in 1994, when the ISA was formed, they furthered this position, arguing that becoming a member would impede on U.S. sovereignty of the high seas (Silva, 2024). China took this response as a great victory against the 'maritime hegemony' by the West—indicative of 'a new international maritime order', in which China would play a pivotal role (Silva, 2024).

In this regard, China has actively asserted its position at the ISA to maintain its role in shaping the emergent maritime order. It remains the single most active country at the ISA, with a transparent, long-term, and strategic agenda set towards exploitation (Silva, 2024). As the world's largest processor of lithium, cobalt, copper and graphite, the country's current five-year economic and social development plan is to progress its DSM capabilities, an initiative which has already garnered national scientific interest (Silva, 2024). This plan is reflected in China's strategic agenda at the ISA's meeting as of July 2023, in which they blocked any debate on maritime protection or the moratorium on DSM activities (Silva, 2024). Furthermore, the Chinese representatives cautioned the ISA against imposing financial sanctions on contractors who might violate established rules (Silva, 2024). This was supported by Gou Haibou, a Chinese delegate to the ISA who openly criticized the outcome of the meeting, which sought to extend the soft deadline for the Mining Code to 2025 (Silva, 2024). Haibou argued that the Chinese delegation preferred more definitive language and a fixed timeline for completing the regulations, stating that it "otherwise…seems a little unclear what we are going to do in the coming months or in the coming years" (Silva, 2024). This behaviour at the meeting, and conclusion on its results demonstrate a clear and proactive approach to DSM. Rather than merely expressing interest, China is actively pushing for concrete steps to open the international seabed for exploitation. Through taking a lead role in ISA discussions, making large financial contributions to the organization, and being transparent about its goals, China is preparing for potential future mining operations, and exerting pressure of intent in international waters.

All said, their vocal advocacy and aggressive strategy will not be enough to realize their vision of the DSM industry. One of the strongest mandates in the UNCLOS prevents any haphazard progression, regardless of motive or intent. As Gina Guillen-Grillo, head of the Costa Rican delegation at the ISA, emphasized, there will be no mining without compliance to Article 145, which ultimately requires the protection of the marine environment from the harmful impacts of mining (Silva, 2024). Regardless of China's influence, any advancements will be contingent on adhering to these stringent environmental standards, which are collectively upheld by the ISA's other Member States. As China formulates its strategy for seabed exploitation thus, it must carefully consider these international environmental requirements, otherwise they will ultimately make little progress.

For security

The U.S.

Even if China's strategy to mine the Area will require more fine-tuning if it is to go forward, the U.S. has become increasingly aware of their objectives at the ISA. In response, the U.S. is showing interest to mitigate Chinese dominance through ISA membership. This move would theoretically allow the U.S. to exert influence on tentative DSM policies, and thus contribute to the global pressure of intent to pursue DSM in international waters. In June 2023, the U.S. Congress responded to China's activities by sending letters to the Pentagon requesting a new analysis of the U.S.'s role in DSM (Silva, 2024). Specifically, the House of Armed Services Committee requested that the Pentagon deliver in their 2024 National Defence Authorization Act (NDAA) an assessment on the U.S.'s capacity for domestic processing of PMN found at sea (House Armed Services Committee, 2023). In line with this, Jocelyn Trainer, a research assistant for the Energy, Economics, and Security Program at the Center for a New American Security, emphasized that China's preparedness for exploration and potential exploitation is increasingly becoming a U.S. national security concern (Silva, 2024). Despite the U.S. Senate's continued reluctance to ratify the UNCLOS, these developments demonstrate the tangible impact of China's stance on DSM. Although to date, the NDAA 2024 contains no significant analysis of the U.S.'s domestic processing capacity for PMN derived from the Area (National Defence Authorization Act for Fiscal Year 2024, 2023).

In light of U.S. attention on China, in November 2023, a direct urge to ratify the UNCLOS was initiated by a bipartisan coalition led by Senator Lisa Murkowski (R-Alaska) (Silva, 2024). This initiative urged the U.S. Senate to approve the long-pending treaty, in consideration of its strategic importance to counter China's maritime ambitions (Silva, 2024). This resolution was further supported by US Senators Mazie K. Hirono (D-HI), Tim Kaine (D-VA), and composed by Senators Angus King (I-ME), Jacky Rosen (D-NV), Bill Cassidy (R-LA), Chris Van Hollen (D-MD) and Sheldon Whitehouse (D-RI) (Mazie Hirono, 2023; Hirono et al., 2023). In December of the same year, a group of 31 Republican members of Congress requested that Secretary of Defence Lloyd Austin consider strengthening the supply chain for CRMs in the U.S., with the deep-sea emphasized as a "new vector of competition" out of direct concern for China's advancements in the Area (Silva, 2024). Although these recent developments for UNCLOS ratification have yet to receive any formal response, the urge to ratify demonstrates the significant impact of China's maritime agenda on American interests. This renewed interest reflects an increasing awareness in the U.S. that they risk being side-lined from crucial decision-making processes regarding activities in the Area and their subsequent intent to partake in exploitation to maintain control over the CRM supply chain if it is to be supplemented by DSM.

No presence of pressure in national or international waters	Presence of pressure in national waters	Presence of pressure in international waters
7	1	6

Regulatory Capacity

1 – Regulatory frameworks can be advanced to permanently halt DSM

2 – Regulatory frameworks can only temporarily halt DSM

3 – Regulatory frameworks cannot permanently halt DSM

Democratic representation at the ISA

The ISA's regulatory capacity refers to its effectiveness and suitability in fulfilling its intended role. In this context, it is a measure of whether the ISA operates on sound democratic principles, ensuring that the opinions of all Member States carry equal weight in consultations regarding DSM in the Area.

The ISA has three main organs to facilitate regulation of the Area—the Assembly, the Secretariat, and the Council (Environmental Justice Foundation, 2023).

The Assembly

The Assembly is made up of 168 Member States plus the EU and acts as the supreme decision-making body of the ISA (Blanchard et al., 2023). Within this, each Member State has equal voting power as it functions on a 1 state, 1 vote structure (Blanchard et al., 2023). The purpose of this structure is to ensure that final decisions made by the ISA are made democratically. The Assembly is also responsible for electing the Finance Committee, which in turn oversees the ISA's finances (Environmental Justice Foundation, 2023). In this regard, financial matters within the ISA are handled 'democratically' as they are managed by proxy of the Assembly's elections, and the Assembly itself is democratic in structure. With that being said, the 15 elected members of the Financial Committee to the ISA include its 5 largest financial contributors (Environmental Justice Foundation, 2023). One such contributor, China, therefore wields considerable influence over the allocation of ISA funds (Environmental Justice Foundation, 2023). A leverage that aligns with China's progress-oriented agenda in DSM, potentially hindering efforts to impose any permanent halt against operations (Environmental Justice Foundation, 2023).

Importantly, the Assembly works in collaboration with the Council. Despite the Assembly's primary policy-making role, its practical function is to approve regulations recommended to it by the Council (Blanchard et al., 2023). This effectively undermines the democratic legitimacy of the Assembly because it is technically subordinate to Council recommendations (and the Council is not entirely democratic, as explored in section 4.2.4). Such an arrangement could significantly impact the ISA's ability to implement a permanent moratorium on DSM. The Assembly's limited autonomy in policy initiation means that any move to indefinitely halt DSM operations would likely need to originate from or gain support within the Council before reaching the Assembly for final approval.

The Secretariat

The Secretariat serves as the administrative backbone of the ISA. It assists the ISA through managing the organization's legal affairs and providing general operational support to its governing bodies (ISA, 2022a). The Secretariat is led by the Secretary-General who functions as the Chief Administrative Officer of the ISA (ISA, 2022a). The Secretary-General is democratically legitimized by proxy of their election by the Assembly, thus in theory, they should be able to represent and shift opinions at the ISA in reflection of its Member States and the EU (ISA, 2022a).

The Secretary-General is assisted by the Executive Office to coordinate the Secretariat (ISA, 2022a). However, the Executive Office functions under relevant directives made by the Council and further approved by the Assembly (ISA, 2022a). In practice this means that the Executive Office supports the Secretary-General based on recommendations made to it by the Council which are then ratified by the Assembly, and not based on independent recommendations from the democratically legitimized Assembly itself. This could implicate the democratic impartiality of the Executive-Office as it must function on Council recommendations (and the Council is not entirely democratic, as explored in section 4.2.4).

Functioning within the Secretariat is the Enterprise—the operational arm of the ISA, responsible for ensuring that activities in the Area are carried out in respect of the CHM principle (Blanchard et al., 2023). If it were independently operational, it would be represented by a democratically elected individual. However, due to funding constraints, it does not function independently from the Secretariat and from 2018 to 2023, was led by a special representative of the Secretary-General (ISA, 2022c). Since 2024 it has been staffed by an interim director, who functions in tandem with (and not independently of) the Secretariat (ISA, 2022c). This individual is therein subject to the powers of the Assembly and the Council, and due to the Council's own lack of democratic representation (refer to section 4.2.4), this could implicate the ISA's capacity to enforce a permanent ban on DSM.

The Office of Legal Affairs, the Office of Environmental Management and Mineral Resources, and the Office for Administrative Services were omitted from this review since they did not pose any significant contentions relevant to the analysis of the ISA's democratic representation.

The Council

The Council is the executive organ of the ISA (Blanchard et al., 2023). Its role is to recommend rules, regulations, and procedures to the Assembly, and so its power is in its capacity to initiate change (Blanchard et al., 2023). Its 36 members are elected by the ISA's democratically legitimized body—the Assembly, which in theory would mean that it itself is democratically legitimized. However, the structure of its member representation implicates this legitimization (Blanchard et al., 2023). The 36 members are elected based on their representation of the following interest groups (Blanchard et al., 2023):

- Group A – Major Consumers (4)
- Group B – Major Investors (4)
- Group C – Major Exporters (4)
- Group D – Developing States and Special Interests (6)
- Group E – Equitable Geographic Representation (18)

Major Consumers (Group A – 4 members) are those State Parties which consume or import more than 2% of the world's total imports of the same commodities which would be theoretically derived from the Area (ISA, 2022e). Further, Major Investors (Group B – 4 members) are members belonging to the 8 Member States that have made the largest investments in the ISA's preparation for work in the Area (ISA, 2022e). So forth, the Council's composition includes a subset of 8 members selected through criteria that prioritize mining interests. This is to ensure there is fair representation of entities which could eventually benefit from exploitation; however, it also means that a valid 22% of the Council's composition is representative of interests tilted in favour of DSM (Blanchard et al., 2023). To add, the criteria for electing representatives of Developing States and Special Interests (Group D – 6 members) also includes among 'States with large populations, that are landlocked, or geographically disadvantaged Island States', States which are major importers of the same minerals which would be derived from the Area, and States that are potential producers of such minerals (Blanchard et al., 2023; ISA, 2022e). This is not to say that all members belonging to Group D would have pro-mining interests but considering these criteria to include members from States that do, the composition of Group D has at least the potential to tilt in favour of pro-mining interests. In summary, the election criteria for Groups A, B, and partially D of the ISA Council favour pro-mining interests, potentially compromising the impartiality of its decisions on eventual DSM exploitation applications. This situation ultimately casts doubt on the ISA's capacity to impose a permanent halt on DSM in the event it were necessary.

The Legal and Technical Commission

The Legal and Technical Commission (LTC) is an advisory subsidiary organ formed by the Council. In practice, the Council is the main decision-making organ that initiates recommendations to the Assembly, but before then, the LTC makes its recommendations to the Council (Blanchard et al., 2023). The role of the LTC is to carry out the technical work of the ISA through reviewing plans of work for activities in the Area, form the ISA's rules, regulations, and procedures, and from a legal perspective, consider the protection of the deep-sea (ISA, 2022d). In summary, the power of the Assembly to vote and decide on rules, regulations and procedures is based on work conducted by the LTC, which then makes recommendations to the Council, and finally, the Council to the Assembly.

The LTC is made up of 41 members who are elected by the Council for a standing period of 5 years (Blanchard et al, 2023; ISA, 2022d). In theory, the Council is obligated to appoint members to the LTC based on their individual qualifications relevant to exploration and exploitation activities in the Area (ISA, 2022d). This measure is to ensure that the LTC's recommendations are informed by a multidisciplinary team with diverse expertise, in vain of upholding rigorous standards for the legal and environmental protection of the deep-sea and its resources (ISA, 2022d). However, since the Council nominates members of the LTC and the Council itself is structured with some level of bias towards pro-mining interests, the LTC is at some mercy of non-democratic representation which could hinder its capacity to initiate or maintain a permanent halt against DSM.

As of Article 165 of the UNCLOS, the LTC is responsible for the first drafts of the Mining Code, and as an important addition to their current responsibility to assess applications for exploration activities, they will eventually be responsible for assessing applications for exploitation in the Area (Blanchard et al., 2023). It is thus the most fundamental organ of the ISA given its purpose to advise the Council on whether to approve or deny mining contracts. This however has a caveat, such that if and when the LTC makes a recommendation for the Council to approve an application, it is effectively approved (after a certain duration) *unless* a majority (two thirds) of the Council decide to reject it (Blanchard et al., 2023). Simply put, 24 of the 36 members of the Council need to reject the application for it to be denied and since the Council's composition is, to some extent, tilted towards DSM interests, it raises doubts about whether the required majority to reject an application could ever be reached. This structural imbalance potentially compromises the ISA's capacity to prioritize environmental protection over mining interests when necessary. In this regard, the Council has yet to reject a plan of work for exploration that the LTC has recommended for approval (Blanchard et al., 2023).

Prerogatives of the ISA

Currently, the ISA is financed through contributions from its Member States, however, the long-term plan is for the organization to be self-sustaining, deriving its revenue from the contracts it issues (Blanchard et al., 2023). In response, the UK Parliament's House of Commons Environmental Audit Committee reflected that, "The fact the ISA, the licensing body for seabed exploration, also stands to benefit from revenues…is a clear conflict of interest" (Environmental Justice Foundation, 2023). Put plainly, the ISA's long-term financial viability is inextricably linked to the initiation of commercial DSM operations. Without exploitation contracts, the ISA remains reliant on Member State funding, which places the institution in limbo since its institutional survival would otherwise depend on the advancement of DSM activities. Herein, the ISA's funding structure, reliant on contributions from Member States and future revenues from exploitation, undermines its capacity to permanently halt DSM. The lack of interest in ceasing exploration or establishing a permanent ban is evident in the design of its exploration contracts. The contracts are initially awarded for 15 years, and it is mandated in the Implementation Agreement that the contracting party must apply for an exploitation license once this period ends (Environmental Justice Foundation, 2023). The only exceptions to this obligation would be within circumstances beyond the contractor's control or situations in which it is not economically viable to move forward with exploitation (the current situation). That said, 7 contracts have already been extended for an additional 5-year period and 6 of these have been extended for a second time (Environmental Justice Foundation, 2023).

Finally, the ISA is required to conduct an institutional review every five years (Environmental Justice Foundation, 2023). This periodic assessment is meant to evaluate the organization's effectiveness in fulfilling its mission and to identify and implement necessary changes in the event of subpar performance. In spite of this, the most recent review was completed in 2017, and as of 2022, a subsequent evaluation has not yet been conducted. This delay suggests a stagnation in the ISA's efforts to address critical aspects of its regulatory framework. Such inertia in institutional self-assessment and reform could potentially limit the ISA's capacity to effectively manage DSM activities, particularly in scenarios where a complete halt may be necessary.

On drafting regulations for exploitation

In June 2021, Nauru, the sponsoring state for the exploration contract held by NORI, and subsidiary of The Metals Company (TMC) triggered the Two-Year Rule (Blanchard et al., 2023). As a reminder, according to the Implementation Agreement, triggering this rule mandates that the Council "shall" finalize the relevant rules, regulations, and procedures of the Mining Code by July 2023. In theory, if the ISA failed to meet its deadline, it would mean that any Member State or the EU could apply for the approval of a 'plan of work' for exploitation, regardless of the incomplete regulations (Blanchard et al., 2023). Specifically, the Implementation Agreement dictates that the Council must "nonetheless *consider* and *provisionally approve* such plans of work based on the provisions of the Convention, and any rules, regulations and procedures that the Council may have adopted provisionally, or on the basis of the norms contained in the Convention and the terms and principles contained in this Annex as well as the principle of non-discrimination among contractors (Section 1(15)(c) of the Annex to the Implementation Agreement)" (Blanchard et al., 2023). However, to interpret this provision as a green light for unregulated mining would be a gross misunderstanding, as concluded by Pradeep Singh, a prominent consultant to the ISA specializing in ocean governance, and the law of the sea.

He asserts that Section 1(15)(c) refers to the "elaboration [on]" as opposed to the "adoption [of]" the rules, regulations, and procedures of the Mining Code (Singh, 2022). In this context, the Two-Year Rule should be understood to mean that the rules of the Mining Code need only be 'elaborated' within the two-year deadline, rather than be fully finalized and/or adopted. (Singh, 2022). This interpretation demonstrates the ISA's control over the pace and implementation of mining activities, even in the face of seemingly aggressive legal provisions. Further, 'consider and provisionally approve' within this excerpt of the Implementation Agreement implies that even in the absence of a finalized Mining Code, the ISA would still be responsible for assessing any plan of work for its adherence to the UNCLOS, the Implementation Agreement and any other applicable rules, regulations and procedures that exist (Singh, 2022). Moreover, it would have to be assessed by the relevant ISA organ—the LTC (Singh, 2022; ISA 2022d). It is important to remember however, that if the LTC were to receive a plan of work for exploitation, deem it adequate, and recommend its approval to the Council, it would effectively be approved (after a certain duration) unless rejected by 24 of the 36 Council members. This does not confer unilateral authority to the LTC over such decisions, but again, does raise some reasonable concerns. It should be further reminded that that LTC members are elected by the Council, which itself has a discernible pro-mining bias. This structural arrangement could hinder the objectivity of the decision-making process regarding DSM exploitation applications. While temporary halts have been implemented and are feasible, the ISA may not be capable of enacting a permanent ban against exploitive activity in the future due to this framework.

Despite these difficulties, there is still another layer of escalation that could prevent a default approval. If a plan of work were approved by the LTC, recommended to the Council, and approved either by default or legitimately in the absence of the Mining Code, the ISA could face a compulsory dispute resolution from any one of its Member States. This could be initiated due to concerns regarding the adequate protection of the marine environment from exploitation activities, insufficient environmental information or impact assessments, or a failure to apply the precautionary principle to planned activities (Singh, 2022). Ultimately, this measure illustrates the ISA's ability to enforce, at minimum, a temporary extended halt on DSM pending resolution of these critical issues.

Regulatory frameworks can be advanced to permanently halt DSM	**Regulatory frameworks can only temporarily halt DSM**	**Regulatory frameworks cannot permanently halt DSM**
1 (2 nulled)	5	7

Utilitarian Value

Climate Change

1 – Climate change impacts are negligible to consider or necessitate DSM

2 – Climate change impacts are great enough to consider DSM

3 - Climate change impacts necessitate DSM

DSM in the context of climate change

DSM presents a complex duality in the context of climate change. Illustrating this duality requires a comprehensive analysis of the multifaceted impacts of climate change, encompassing both its global ramifications and specific consequences for marine ecosystems. Through an understanding of the severity of climate change in this vein, it can be better understood why DSM might at all be considered. Broadly, the anthropogenic impacts of climate change on the deep-sea are categorized into three main groups: disposal, exploitation, and ocean acidification & warming. Disposal refers to the historical dumping of various wastes into the deep-sea, while exploitation includes immediately impactful, extractive activities, of which DSM would fall under (Ramirez-Llodra et al., 2011). Ocean acidification & warming on the other hand, encompass the more general effects of increasing atmospheric CO_2, changing temperatures, and their impacts on the ocean's oxygen capacity (Ramirez-Llodra et al., 2011; Rabalais et al., 2010). The importance of outlining these categories lay within their 'synergistic impacts'. With respect to the deep-sea, Ramirez-Llodra et al. (2011) assert that the compounded impacts of climate change will considerably weaken already fragile deep-sea ecosystems (Ramirez-Llodra et al., 2011). Deep-sea mining could thus have a further weakening effect if conducted haphazardly, but with correct innovation and intent, it also holds the potential to reverse impacts elsewhere (Ramirez-Llodra et al., 2011). The significance of DSM herein, is in the fact that it can both exacerbate and potentially relieve anthropogenic stressors.

In a race against time

The 1.5^{o}C limit set in the Paris Agreement has thrust us into a race against time despite being based on what the IPCC believed would be technically achievable to avoid reaching any tipping points—a state of no return (United Nations, 2015). To maintain global temperatures below this limit, they asserted that greenhouse gas emissions (GHGs) must peak *before* 2024, and decline by 43% by 2030 (United Nations, 2015). However, as of February 2024, the EU's Copernicus Climate Change Service confirmed that the threshold for global warming had been breached for a full 12 month period for the first time (Poynting, 2024). This warming translates directly to the ocean with its respective temperatures recorded at their highest in history, culminating a pattern of steady and consistent increase (Poynting, 2024).

According to the IPCC AA6 (Sixth Assessment Report), only a small subset of emission scenarios will be allowable if we are to limit the probability of passing into a state of no return (Global Tipping Points, 2024). So forth, considering our current situation there are a reduced 'number [or] shapes' of possible emissions pathways that will be adequate to meet the goals of the Paris Agreement (Global Tipping Points, 2024). This underscores the urgency of the situation, a fact that is further supported by The International Renewable Energy Agency (IRENA). They indicated in a 2023 report that to secure the 1.5ºC pathway, the world would need to reduce annual energy-related CO_2 emissions by around 37 gigatonnes (Gt), in response to record high emissions in 2022 (IRENA, 2023). This pattern of records aligns with the conclusion that current Nationally Determined Contributions (NDCs) to meet the targets of the Paris Agreement are not sufficient to limit warming to 1.5ºC (UNFCCC, 2021). A pattern which exposes our diminishing luxury of time to explore diverse pathways to transition. Herein, the climate crisis demands urgent action, that which compels a need to consider solutions that offer deep, near-term impacts (OECD, 2022).

DSM as a response to climate change

It is widely known that CO_2 emissions warm the planet and that this increases global temperatures. In response, decarbonization has been increasingly proposed and facilitated to address this problem through the electrification of industry. Simply put, electrification decarbonizes major emitting industries such as transportation, and this in turn reduces emissions, which should reduce the chances of further climate warming. However, this process has taken the shape of an 'ouroboros'—the snake which consumes itself. This is due to the paradoxical nature of decarbonization through electrification in that electrification (currently) requires CRMs, and this requires mining which itself is environmentally damaging. In this depiction of an ouroboros, mining presents a bottleneck to truly decarbonizing or reaching net-zero as it loops the head of the snake (mining—which should be the solution) back onto its tail (referring to the damaging impacts of mining itself and the problems it is meant to fix).

Currently, key performance indicators (KPIs) are used to measure alignment with the 1.5ºC scenario using specific metrics that measure progress in the energy sector's transition to renewable energy and the subsequent reduction of GHGs (IRENA, 2023). In this regard, to align with the 1.5°C warming limit, KPIs stipulate that EVs must comprise over 90% of all road transport by 2050 (IRENA, 2023). To achieve this goal, the report projects that by 2030, the stock of electric and plug-in hybrid light passenger vehicles should reach 255 million units globally, with the corresponding number of EV chargers at 260 million units (IRENA, 2023). By 2050 these figures should be expected to grow to 2 182 million units for vehicles and 2 300 million units for chargers (IRENA, 2023). The manufacture of these products will inevitably require some degree of CRMs (IRENA, 2023). To summarize this scenario, the impacts of climate change have stimulated a need to electrify to decarbonize, and the current process of decarbonization puts pressure on the CRM supply chain. As nations and corporations race toward net-zero, DSM has entered the arena as a contentious yet potentially significant player, driven by the mounting need to secure resources for a low-carbon future.

In a race to net-zero

To participate in this race, around 145 countries have or are considering net-zero targets, covering around 90% of global emissions—however not all of them have a 2050 deadline (Climate Action Tracker, 2023). The biggest players (as well as the most intense emitters) are China, the U.S., and the EU.

	China	**U.S.**	**EU**
Emissions reduction plan	No specific action plan, but general goal to reach carbon neutrality (McGrath, 2020)	Inflation Reduction Act (IRA) (McGrath, 2022)	Net-Zero Industry Act (European Commission, 2023)
Time goal	2060	2050	2050

Plan for EVs	Achieve EVs as the dominant market for new vehicle sales by 2035 (Wang et al., 2023; Xinhua News Agency, 2020)	No specific target, but measures to boost EV sales (McGrath, 2022)	Achieve 100% zero emission new car and van sales by 2035
Pressure on CRMs	This will drive demand for NMC batteries from both domestic automakers and international companies localizing EV production in China	This will drive demand for domestic production of CRMs due to tax breaks which reward batteries that contain a certain degree of CRMs produced in the US or by free trade partners (Stone, 2022; Xiao, 2023)	This will drive demand for domestic production of CRMs to meet the Act's specific goals for domestic production of annual demand for batteries by 2030 (European Court of Auditors, 2023)
Potential pressure on DSM	In line with China's agenda, direct pressure on DSM as a means of supply	Indirect pressure on DSM as a potential avenue to domestically source EV battery materials	Indirect pressure on DSM as a potential avenue to domestically source EV battery materials

Respective goals of China, the U.S., and the EU for decarbonization, EV deployment, and its potential pressure on DSM.

The decarbonization goals of the big three demonstrate a crude link between the impacts of climate change and the subsequent pressure it places on CRMs relevant to DSM. Despite their simultaneous consideration of alternative battery chemistries (as explored in section 5.2), NMCs remain the dominant chemistry used in EVs due to their high energy density and performance characteristics (Aqib Zahoor et al., 2023). A standard NMC battery contains lithium, and varying ratios of nickel, manganese, cobalt, as well as aluminium and graphite (Shafique et al., 2022). This is of relevance to DSM, and specifically PMN, which are found to be dominant in nickel, manganese, and cobalt (Paulikas et al., 2020). China's strategy at the ISA (as explored in section 4.2) demonstrates the reigning dominance of CRMs relevant to NMCs and DSM. It should be noted therein that China's progressive stance on DSM and further, escalating efforts from the

U.S. and the EU to reduce their economic dependence on China have created a new context for evaluating domestic material sourcing options, which could necessitate a consideration of DSM in the event it can be conducted sustainably.

Climate change impacts are negligible to consider or necessitate DSM	Climate change impacts are great enough to consider DSM	Climate change impacts necessitate DSM
-	10	-

Alternatives

1 – Alternatives to DSM relevant battery chemistries are comparable to replace any need for DSM

2 – Alternatives to DSM relevant battery chemistries are comparable but bottlenecks prevent them from replacing a need to consider DSM

3 – Alternatives to DSM relevant battery chemistries are not comparable and DSM must be considered

The Environmental Justice Foundation (2023) concluded that advancements in battery technology will eventually replace those chemistries requiring nickel and cobalt (two of the major targets for DSM). However, whether such alternatives are comparable to the dominant chemistry used in EVs is up for debate. EVs spearheading the transition to net-zero primarily rely on the lithium nickel manganese cobalt oxide (NMC) chemistry, a type of lithium-ion battery that contains lithium and varying ratios of nickel, manganese, and cobalt (Umicore, n.d.; Shafique et al., 2022). They are of significant relevance to DSM given the composition of PMNs (nickel, manganese, and cobalt) (Paulikas et al., 2020). All said, it is still heavily contested whether DSM is needed, considering fluctuations in demand for NMCs.

Currently, demand for NMC batteries is expected to increase by 2030, however, this is refuted in a study from WWF-Germany in which they predict a less substantial increase than originally anticipated due to the growing adoption of alternative battery chemistries (Laabs & Kind-Rieper, n.d.). Though, it should be noted that projections relevant to NMC batteries can vary significantly based on the study's methodology, sources of data consulted, and future scenarios considered. Mordor Intelligence reports that demand for NMC batteries increased by 109.56% from 2017 to 2023 (Mordor Intelligence, 2023). Yet, in the WWF-Germany study, they projected the market share for NMCs to decline from 85% in 2022, to 33% in 2030, due to changes in public perception, volatility of mineral costs relevant to NMCs, and the pursuit of more environmentally friendly, and socially responsible alternatives (Laabs & Kind-Rieper, n.d.). Even so, WWF-Germany itself recognized that these conflicting conclusions are really a reflection of the increasing total demand for batteries to meet net-zero targets (Laabs & Kind-Rieper, n.d.). In other words, despite the declining market share for NMC batteries, the absolute demand for materials used in them, and the need for NMC batteries amongst alternatives, are still subject to increase to meet the needs of the green transition (Laabs & Kind-Rieper, n.d.). In this vein, the Mordor Intelligence review, which estimated the market value for NMC batteries at 34.49 billion USD in 2024, projected that it would reach 60.62 billion USD by 2029 (Mordor Intelligence, 2024). Hence, despite their differing conclusions, WWF-Germany, and Mordor Intelligence both assert a trend of increasing pressure on the global battery supply.

This trend is further supported by the International Energy Agency (IEA), who projected global battery demand to reach 3.5 TWh by 2030 in a scenario considering all the anticipated effects of legislated policies to meet net-zero targets (STEPS Figure 6) (IEA, 2023b). This outlook seems promising with respect to optimistic projections from private sector companies, which anticipate EV battery manufacturing capacity to reach approximately 6.8 TWh by 2030 (IEA, 2023b). However, the 3.5 TWh projection in demand is based on what has been currently legislated, not on what has been achieved or what needs to be done to achieve an ideal scenario. When this is considered, to actually remain consistent with limiting temperatures to 1.5ºC and reaching net-zero by mid-century, the IEA estimates that demand could effectively exceed 5.5 TWh by 2030 (NZE Figure 6.) (IEA, 2023b). In essence, projected manufacturing capacity by 2030 (6.8 TWh) only narrowly covers even the most sensitive demand projections (5.5 TWh). It is a fact therein that staying within the 1.5ºC pathway will require substantial increases in battery manufacturing capacity (IEA, 2023b).

As global efforts to achieve net-zero emissions intensify, both established and emerging battery technologies face unprecedented pressure to scale up to meet growing demands. Consequently, a comprehensive assessment of various battery options is essential to ensure that the utility of available chemistries are maximized based on their technical capacity, environmental sensitivity, and current hold on the market. The following section will thus compare these facets of prominent alternative battery chemistries to NMCs.

Lithium Iron Phosphate (LFP)

Lithium Iron Phosphate batteries **(**LFPs) require neither nickel nor cobalt, and are instead composed of lithium, iron, and phosphate (Tracy, 2022; Hotter, 2023).

Technical Comparability

Overall, LFPs have lower energy density, but higher thermal stability and longer life cycles.

Economic Comparability

As of January 2020, LFP batteries had only a 1% market share (Laabs & Kind-Rieper, n.d.). In recent years there has been a growing preference for LFP batteries, largely driven by economic considerations, since they rely on more affordable materials like iron and phosphate (Laabs & Kind-Rieper, n.d.). This preference is demonstrated and reinforced by substantial industry investments, which in turn enhances their economic competitiveness. Tesla has already shifted to LFP batteries in its standard-range vehicles and BYD announced in April 2021 that it would remove cobalt, nickel, and manganese from its vehicle batteries entirely through a shift to LFP in 2024 (Laabs & Kind-Rieper, n.d.; Randall, 2024). Investments in LFP have also been supported by other prominent activities such as the US government's grant to chemical company ICL-IP America to develop an LFP cathode facility in the country, and Canadian-based Nano One's plans to scale up a former Johnson Matthey LFP production facility (ICL, 2023; Luo, 2023; MANLY, 2023). All such activity has led to an increase in LFP market shares by 31% as of September 2022.

LFPs are now 15-18% less expensive than NMCs (Laabs & Kind-Rieper, n.d.).

Environmental Comparability

LFP batteries do not require environmentally and socially controversial minerals such as cobalt, or any of the materials which are currently targeted for PMN mining in the deep-sea. Therein, with respect to potential environmental damages associated with DSM, LFP batteries are comparatively non-threatening.

However, in making this comparison, their size and energy density should be considered. For the same energy storage capacity, LFP batteries would have to be larger and heavier, meaning they would require a larger supply of materials and energy during their manufacture (Laabs & Kind-Rieper, n.d). In this regard, LFP batteries display the highest average emission factor at 91 kg CO_2 equivalent per kWh of energy produced, when compared to other chemistries (Laabs & Kind-Rieper, n.d). Therefore, while LFP batteries are composed of materials with a lower environmental impact than NMCs, their larger size due to their lower energy density leads to increased emissions during their production (Laabs & Kind-Rieper, n.d).

There are also prevailing concerns about the sourcing of phosphate, and the pressure that increased demand for LFPs places on this resource. There is no shortage of the rock itself, but rather a shortage of the specific kind of rock required for EV batteries. Global phosphate reserves are extremely abundant, weighing in at around 72 billion metric tons and coming in two main varieties—sedimentary and igneous (Di Grandi & Aboulazm, 2023). About 95% occurs as sedimentary phosphate rock, which goes through a purification cycle to become Merchant Grade Acid (MGA) (suitable for fertilizer and animal feed) (Hotter, 2023). LFP batteries, however, require igneous phosphate rock, which only makes up around 5% of total phosphate reserves (Hotter, 2023). That said, about 90% of igneous rock can undergo processing to produce Purified Phosphoric Acid (PPA) (suitable for EVs, versus the mere 10% that can be purified out of the total reserves of sedimentary rock) (Hotter, 2023).

While global phosphate reserves are abundant, the specific high-purity igneous rock required for battery-grade PPA is exceptionally scarce. This limited availability of suitable feedstock presents a significant bottleneck to the large-scale manufacturing of LFP batteries for EVs, potentially impacting this chemistry's ability to meet growing demand.

Sodium Ion Batteries (SIB)

Sodium-ion batteries (SIBs) come in several variations. These include:

- NaNMMT (Sodium Nickel Manganese Magnesium Titanium Oxide)
- NaMMO (Sodium Manganese Magnesium Oxide)
- NaNMC (Sodium Nickel Manganese Cobalt Oxide)
- NaPBA (Sodium Prussian Blue Analogue)
- NaMVP (Sodium Manganese Vanadium Phosphate)

Each SIB type is characterized by different cathode materials, which influences their individual electrochemical properties and environmental impacts (Kim, 2023). That said, varieties containing manganese and iron are particularly attractive due to the lower cost and greater abundance of these materials compared to cobalt and nickel (Kim, 2023). Further, sodium, which is the key element of these batteries, is one of the most abundant elements on earth (Kim, 2023).

Technical Comparability

Overall, SIBs currently have lower energy density, but higher thermal stability, and roughly the same life cycle not accounting for charge/discharge conditions.

Economic Comparability

SIBs can use low-cost materials such as manganese and iron for their cathodes, which significantly reduces their material costs compared to NMCs that require cobalt and nickel (Laabs & Kind-Rieper, n.d.). More importantly, the main component of SIBs, sodium, is a widely available and easily extracted resource, contributing to their being up to 20-30% less expensive than LFPs (Laabs & Kind-Rieper, n.d.). SIBs also have a unique advantage in that they can be produced with the same manufacturing lines already in use for lithium-ion batteries (of which NMCs are a part), a claim of interest to companies like CATL and Northvolt who are seeking to commercialize SIB production (ING, 2023).

Herein, SIBs are considered a cost-effective alternative to NMCs due to readily available manufacturing capacity and further, the relatively low cost of materials they require. However, they cannot currently be considered directly competitive with the more widespread application of lithium-ion batteries because of their lower energy density restricting them to light urban commercial vehicles and stationary energy storage (Zhukov, 2023). This restriction might hinder their direct economic competitiveness with NMCs since their application might not be as immediately widespread until their energy capacity can be increased.

Environmental Comparability

The environmental competitiveness of SIBs is one of their most promising aspects. Not only are the batteries lithium free, but their main material—sodium, does not require mining since it can be obtained from seawater or brine (Laabs & Kind-Rieper, n.d.). NaMMO (Sodium Manganese Magnesium Oxide) and NaPBA (Sodium Prussian Blue Analogue) SIBs show lower impacts than NMCs with respect to abiotic resource depletion since they avoid materials such as cobalt and nickel all together (Kim, 2023).

GHGs

Certain SIB types show lower production related GHG emissions. This is most evident in NaMMO (Sodium Manganese Magnesium Oxide) and NaNMMT (Sodium Nickel Manganese Magnesium Titanium Oxide) chemistries, which are either approaching or surpassing the environmental performance of NMCs (Kim, 2023). However, it is noted that SIBs currently have lower technological maturity compared to lithium-ion batteries, and further improvements are needed to close the gaps in their environmental performance (considering their current lower energy density to NMCs) (Kim, 2023).

Acidification Potential

Acidification potential (AP) is a measure of how the battery contributes to environmental acidification mainly through the release of sulphur dioxide (SO_2) and nitrogen oxides (N_2O) (Kim, 2023). The NaMVP (Sodium Manganese Vanadium Phosphate) cell has a higher AP impact when compared with NMCs due to the SO_2 emissions from its vanadium production process (Kim, 2023). Further, The NaNMC (Sodium Nickel Manganese Cobalt Oxide) cell is identified as having a particularly high AP impact due to its cobalt and nickel content and relatively low energy density (Kim, 2023). Other SIBs generally show AP impacts that are slightly higher than those of the NMC cell (Kim, 2023).

Human Toxicity Potential

Human Toxicity Potential (HTP) refers to the battery's potential toxic impacts on humans. Most SIBs have a relatively low HTP, with NaMMO (Sodium Manganese Magnesium Oxide) and NaNMMT (Sodium Nickel Manganese Magnesium Titanium Oxide) chemistries showing potential to outperform NMCs even with their lower energy densities (Kim, 2023). The NaNMC (Sodium Nickel Manganese Cobalt Oxide) and NaMVP (Sodium Manganese Vanadium Phosphate) chemistries make an exception to this trend and are not as favourable. This is likely due to the presence of cobalt and nickel in the NaNMC (Sodium Nickel Manganese Cobalt Oxide) cell, and the specific production processes associated with vanadium in the NaMVP (Sodium Manganese Vanadium Phosphate) cell (Kim, 2023).

Alternatives to DSM relevant battery chemistries are comparable to replace any need for DSM	**Alternatives to DSM relevant battery chemistries are comparable but bottlenecks prevent them from replacing a need to consider DSM**	**Alternatives to DSM relevant battery chemistries are not comparable and DSM must be considered**
8	9	2

Scalability

1 – DSM technology is not technically capable nor is it environmentally sensitive

2 – DSM technology is technically capable but is not environmentally sensitive

3 – DSM technology is both technically capable and environmentally sensitive

For DSM to be considered 'scalable', two fundamental criteria must be met. First, it has to be technologically feasible, but more importantly, it must be environmentally sensitive (Bang & Trellevik, 2022).

Technical Innovation and NORI-D

Achieving and demonstrating technical feasibility is a primary motive for Nauru Ocean Resources Inc. (NORI), the subsidiary of The Metals Company (TMC). To fulfil this venture, they have conducted several trials under their NORI-D mining project in the CCZ using Hidden Gem, a 61 000-deadweight tonnage vessel belonging to Allseas, another DSM company based in the Netherlands (The Maritime Executive, 2022; TMC, 2024b). In October 2022, Hidden Gem completed a successful pilot test for deep-sea nodule collection, with a total recovery of 4 500 tonnes of PMN from the CCZ (TMC, 2024b). Despite this successful test, the project remains constrained to its technical feasibility—it has yet to prove that it can operate commercially to an environmental standard high enough for public acceptance. As Bang & Trellevik (2022) noted, without environmental sensitivity, any technical feasibility is rendered null through pushback from the global community. Such opposition was demonstrated by Greenpeace during one of Hidden Gem's scientific expeditions in November 2023 in which several activists attempted to disrupt the vessel by boarding during operations (TMC, 2023d). This was ultimately a response to the fact the vessel still relies on a heavily criticized approach to DSM, the crawler vehicle—a dredging, and riser-system that does little to minimize environmental disruption (TMC, 2023d). This method generates sediment plumes and leaves scar tracks in its wake as it grazes the seafloor for PMN, pumping them back up to the surface through a pipe using compressed air (TMC, 2024b).

To address these environmental concerns, TMC has been taking a phased approach to the NORI-D project through periodically submitting their research from exploration efforts to DeepData—the ISA's open database for contractors concerning the impacts of DSM on the marine environment (TMC, 2024a). This methodology should allow the company to gradually develop an operational fleet that is based on comprehensive environmental data and further, may serve the secondary purpose of fulfilling their application for the NORI-D exploitation contract (TMC, 2024b).

In March 2023, TMC submitted their findings to the database from a total of 17 offshore resource definition and environmental baseline campaigns for the NORI-D area (TMC, 2024a).

This extensive submission of over 14 000 biological samples and 8 000 images analysed for benthic fauna works to enhance DeepData's credibility as a comprehensive environmental baseline (TMC, 2024a). Since then, TMC initiated its comprehensive 'feasibility' study, marking a crucial milestone in the development of the NORI-D project. As of May 2024, TMC submitted their largest collection of data to the ISA to date (TMC, 2024c). This submission encompassed environmental baseline data collected from a total of 22 offshore campaigns in the NORI-D area (TMC, 2024c). This data is intended to validate the environmental sensitivity of the NORI-D project through providing in-depth environmental baselines that the impacts of their operations can be measured against (TMC, 2024c). Overall, the submission included observations of 32 617 benthic and 42 036 pelagic biological occurrences, over 12 000 seafloor images, and extensive time-series data from three years of monitoring activities (TMC, 2024c). Of salience, these studies were primarily conducted by independent scientists and expert industry partners to ensure a high degree of objectivity and scientific integrity in the data collection and analysis process (TMC, 2024c). While such effort does not definitively prove the environmental feasibility of TMC's operations, it does demonstrate a commitment to data-driven decision-making and scientific rigor in assessing the potential ecological impacts of their operations.

Ultimately, this extensive body of research is meant to inform their justification for future commercial operations starting with Project Zero in 2025, with a predicted collection capacity of 1.3 Mtpa (wet), and later Project One in 2026, with a collection capacity of 12.5 Mtpa (wet) (TMC, 2024a). It is crucial to note, however, that these timelines are still contingent upon the evolution of DSM regulations for exploitation (Bang & Trevellik, 2022). Such regulatory uncertainty illustrates the importance of TMC's step-by-step approach, since any future commercial scaling will hinge entirely on data collected during these preliminary exploration phases to demonstrate the environmental sensitivity of their projects.

Sustainable Innovation and Impossible Metals

On a different front, Impossible Metals is pioneering DSM technology that is environmentally conscious in its design. Their mission is to address environmental concerns through a minimally impactful DSM fleet.

Addressing environmental concerns

Herein, the company has been developing autonomous vehicles for PMN collection that rely on selective harvesting and buoyancy (Impossible Metals, 2024a; Impossible Metals, 2024b). The vehicle is equipped with precision-engineered mechanical arms that can pick up individual nodules (Impossible Metals, 2024b). This process is guided by advanced computer vision and artificial intelligence, allowing the vehicle to detect and avoid visible marine life, minimizing any disturbance to nodule-dependent megafauna (Impossible Metals, 2024b). The independent vehicle could also be preprogramed to leave behind a certain percentage and pattern of nodules in adherence to the requirements of an environmental impact assessment (Impossible Metals, 2024b). Further, this method for nodule collection would minimize plume generation and sediment disturbance since the vehicle would 'float' rather than 'crawl' for nodule collection, preventing the significant release of sequestered carbon from the deep-sea floor (Impossible Metals, 2024b). This buoyant design also eliminates the need for riser-pump technology, meaning that the vehicle would store collected nodules and return to the surface for offloading, reducing the potential for noise pollution (Impossible Metals, 2024b).

Hypothetically speaking, while the design may not eliminate all environmental concerns—as any resource extraction is inherently impactful—it does present a more sustainable alternative to the conventional crawler-riser method. This technology theoretically balances the need for CRMs with environmental preservation, representing a significant step towards more responsible deep-sea resource management.

Addressing technical concerns

Impossible Metals has successfully transitioned their theoretical design into practical reality through a series of successful trials. In May 2023 the company completed its fourth round of tests featuring the Eureka 1 version 3, their small autonomous vehicle (Setså, 2023). The prototype showcased its ability to execute short 25-meter dives, remain buoyant above the seafloor, operate a single deployable arm with only minor sediment disturbance, and carry a 5kg payload back to the surface (Setså, 2023).

The company later went on to its sixth round of tests in May 2024 with Eureka 2 version 4, their medium sized autonomous vehicle with a depth capacity of 6km, 3 deployable arms and a 100kg payload (Impossible Metals, 2024c). The test yielded successful results, demonstrating that the vehicle was operational at depths required for commercial DSM, and that it could handle more cargo (Impossible Metals, 2024c).

Since the trial in May 2024, the company has proactively engaged in operations to determine the optimal collection speed-to-sediment ratio for the deployable arms (Impossible Metals, 2024c). This factor is crucial to balance the vehicle’s efficiency with ecological preservation since the higher the speed of nodule collection, the more efficient it would be in terms harvesting, but also the less accurate and environmentally sensitive (Impossible Metals, 2024c). Their primary objective with this testing is to achieve a delicate equilibrium that maximizes operational efficiency while minimizing ecological impact. The company also has plans to conduct high-resolution, multi-lane AUV-based surveys or photogrammetric mapping of all operational areas so that vehicles would be able to navigate around environmentally sensitive zones and challenging terrains more effectively (Impossible Metals, 2024c). This approach markedly diverges from conventional crawler-riser operations. The vehicle's enhanced flexibility enables precise, real-time adjustments for optimized performance across diverse project areas. Building on these facts, Impossible Metals is committed to principles of transparency and scientific collaboration. The company uses their data not only to help train their own technology, but also to support broader scientific research (Impossible Metals, 2024c). In this vein, they address industry-wide concerns regarding operational opacity through serving a greater purpose than simply putting themselves at a competitive edge, and instead, contribute their expertise to making overall improvements to the industry (Impossible Metals, 2024c). This open approach to data sharing and environmental consideration in the construction of their fleet is integral to the company's strategy to position themselves as a leader for commercial scaling by 2026 (Impossible Metals, 2024c). However, it is still important to note that this timeline does not yet account for potential regulatory hurdles. While both technically capable and environmentally sensitive, like TMC, their path forward remains subject to the development and implementation of relevant legislation for the governance of deep-sea resource extraction (Impossible Metals, 2024c).

DSM technology is not technically capable nor is it environmentally sensitive	DSM technology is technically capable but is not environmentally sensitive	DSM technology is both technically capable and environmentally sensitive
1	5	2