The Deep Sea Mining System

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Introduction

In seeking a more sustainable, lower emissions energy future, solar panels have emerged as a prominent renewable energy source. Installed solar capacity in the U.S. alone has surged in recent decades with an estimated capacity of 64.2 GW of solar capacity or 1.47 million solar panels in 2018. These solar panels can offset nearly 70 million metric tons of carbon emissions compared to traditional energy sources each year[1]. However, this surge in solar panel use, along with increasing electronic use, has led to an increasing need for the necessary component minerals. Deep sea mining has emerged as a potential solution to meeting this mineral demand. However, deep sea mining is a largely untested technology with complications surrounding the use of international waters. Additionally, environmental scientists and marine ecologists have called for a moromortium on seafloor mining until the environmental impacts and deep sea mining's potential to disrupt marine ecosystems are better understood.

System Components

*Following the human-technical-environmental systems framework, **human**, **technical**, **environmental**, **institutional**, and **knowledge** components are identified by italics.*

Deep sea mining is a form of mining focusing on extracting ***minerals*** including copper, cobalt, nickel, zinc, silver, gold, lithium, and other rare-earth metals from the ***seafloor***. The ***Clarion-Clipperton Zone*** is a subfracture region in the Pacific Ocean spanning approximately 4,500,000 square kilometers. It is a region of economic importance owing towards its especially high concentration of ***polymetallic nodules*** containing minerals critical to the development of ***downstream technology*** such as solar panels and electronic devices such as laptops and smartphones. However, little is known about ***seafloor*** and deep sea ecosystems due to their remote locations making studies more difficult. However, scraping the seafloor by ***mining machines (collectors)*** to recover ***polymetallic nodules*** could affect those ecosystems consisting of a variety of sea creatures including ***microbes***, octopi, fish, and sea cucumbers for over 25 years after damage.[2] Additionally, seafloor mining could disrupt unique ecosystems that form only around ***hydrothermal vents*** on the ***seafloor*** including rare extremophilic bacteria and other organisms that live there. Deep sea mining also impacts ecosystems higher up in the ocean due to the ***sediment plums*** that extraction of the ***minerals*** creates. ***Mining machines*** at the sea floor disrupt sediment, creating ***sediment plums*** that

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1 https://solstice.us/solstice-blog/solar-energy-statistics/#:~:text=installed%2010.6%20GW%20of%20solar,learning%20from%20researchers%20at%20Stanford.

2 https://eos.org/articles/the-long-lasting-legacy-of-deep-sea-mining

affect nearby fish and ***microbes***. Sediment accumulates at a rate of 1 millimeter per millennium, making it difficult for ecosystems to recover over a realistic time scale.[3] The connections between the ***mining machines*** and ***ore vessels*** floating on the surface create significant ***light and noise pollution*** affecting animals that live in swim in the ocean layers above the ***seafloor***[4]. The noise and light pollution has especially significant impacts on animals dependent on ***bioluminescence***, like many deep sea creatures, or ***echolocation***, such as whales and dolphins.

The environmental impacts of deep sea mining also have implications for people living in coastal areas. Even in the initial exploration phase, deep-sea mining ships have dispersed fish populations and negatively impacted water quality, disrupting commercial **fishing industries** and **ritual practices** of **indigenous people**. Environmental disturbances from deep sea mining are especially likely to affect indigenous populations, as areas known to be rich in underwater minerals are near Pacific island nations such as Tonga and Papua New Guinea. The first commercial deep-sea mining company in the world began operating in Papua New Guinea's territory last year.[5] Some leaders argue that decisions involving seabeds should remain in the jurisdiction of the government, but emerging environmental laws require states to secure **free, prior, and informed consent (FPIC)** from indigenous people when initiating projects affecting their lands.[6] In other Pacific countries such as Fiji, studies show that implementing deep-sea mining could discourage tourists from traveling there because of their perception that deep-sea mining degrades coral reefs and other marine life.[7]

Deep-sea mining is essential for ***markets*** in vehicle electrification and renewable energy, which have driven up demand for copper, cobalt, nickel, zinc, silver and gold, as well as lithium and rare-earth elements. This has grown as the use of ***downstream technology*** solar panels, lithium-ion batteries, and other electronic devices have rapidly increased in recent years. While these resources are pushing motivations for deep-sea mining now, the first discussions about rights and regulations for control over the ocean's resources began in the 1970s in response to protecting marine reserves and ocean missile launch pads. This led to the creation of the United Nations Convention on the Law of the Sea (UNCLOS), the primary ***international agreement*** on nautical law signed in 1982. UNCLOS provides laws for the area known as the Exclusive Economic Zone (EEZ), which is the area extending beyond 200-miles from any country's shoreline.[8]

The primary ***regulatory authority*** overseeing and implementing agreements set forth by UNCLOS is the International Seabed Authority (ISA). The ISA has 168

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3 https://news.mit.edu/2019/understanding-impact-deep-sea-mining-1206#:~:text=Much%20of%20this%20mining%20occurs,and%20soil%20and%20water%20contamination

4 https://eos.org/articles/deep-sea-mining-may-have-deep-economic-environmental-impacts

5 https://harvardelr.com/2018/04/16/broadening-common-heritage/#_ftn60

6 https://perma.cc/D87D-6S86

7 https://www.sciencedirect.com/science/article/abs/pii/S0308597X18300836

8 https://www.marineinsight.com/maritime-law/nautical-law-what-is-unclos/#:~:text=UNCLOS%20is%20an%20acronym%20for,from%2016th%20November%201982.

members and has approved 30 exploration contracts since 2001. The ISA consists of the Council and the Legal Technical Commission (LTC), who are responsible for further implementing exploration, monitoring, enforcing laws, etc. When it comes to nautical law and the deep-sea mining process, there are 3 main components. ***State laws*** are as effective as international regulations. ***State permits*** are issued by states and allow for exploration and research into mining viability for exploitation by states, enterprises, and companies. ***Licenses*** for deep seabed mineral exploitation are granted by states.

Deep-sea mining methodologies have been in development since the 1960s. However, knowledge about ***environmental impact*** is continuing to evolve and is still uncertain. Environmental impact strategies include Regional Environmental Management Plans (REMPs) developed by the ISA to protect Areas of Particular Environmental Interest (APEIs) determined by UNCLOS. Environmental Impact Assessments (EIAs) may include perceived biodiversity of a candidate dredging region, environmental recovery times, and remediation strategy. EIAs tend to be uncertain and come with many knowledge gaps. Knowledge gaps on ***human impact*** also exist, such as determining the cost of deep-sea mining operations and the effect it will have on local communities.

Interactions

*Interactions between the three sets of material components (**human**, **technical**, and **environmental** components) in the context of the non-material components (**institutions** and **knowledge**) are organized here into pathways focused on key interactions.*

Deep-Sea Mining and Renewables Markets

Renewable energy is the fastest growing energy source in the United States, and transitioning to be fully reliant on renewable energy is a key factor in meeting the goals of the Paris Climate Agreement and keeping global temperature rises below 1.5 degrees. Renewable technologies, batteries, and electric vehicles are mineral-intense, and as renewable energy systems expand, the world has observed heightened demand for copper, cobalt, nickel, zinc, silver and gold, as well as lithium and rare-earth elements. Studies have shown that mining these minerals for use in renewable technology has the power to negatively impact biodiversity in regions where mining takes place.[9] Historically, certain developing countries rich in these minerals have suffered human rights violations and civil unrest at the hands of powerful extractives companies. Some experts see deep-sea mining, which releases less carbon dioxide than terrestrial mining, as a potential opportunity to answer growing demand for minerals involved in renewables.

However, due to the environmental sensitivity and value of these minerals, the impacts of deployment of deep-sea mining technologies on mineral supply chains must be carefully weighed before deep-sea mining can be implemented at scale. While the

[9] https://doi.org/10.1038/s41467-020-17928-5

introduction of this new technology and harvesting methodology will spur innovation and create jobs in some areas, economists fear that the influx of minerals from deep-sea mining may have negative consequences for the developing countries which rely on terrestrial mining of those same metals. In May 2020, the International Seabed Authority released a report documenting the developing countries deemed most vulnerable to deep-sea mined minerals entering the market.[10] The report found that Zambia, Democratic Republic of Congo, Eritrea, Chile, Lao People's Democratic Republic, Mongolia, and Peru stood to face economic hardship due to deep-sea mining of copper and cobalt. Mining of nickel, which is heavily used in manufacturing of electric vehicles and batteries, was particularly detrimental to Madagascar and Zimbabwe. More generally, the intersection of all minerals extracted through deep-sea mining pose a significant risk to Mauritania, Namibia, and Papua New Guinea.

To mitigate economic losses in these developing countries with the rise of deep-sea mining, the ISA supports an initiative to compensate these countries using funds from proceeds of deep-sea mining.[11] This initiative is not universally supported, for some stakeholders have expressed concern that only specific designated countries stand to benefit from the associated mineral royalties, as the seabeds in question are not part of any one country's EEZ. Critics also worry that the sum allocated to the assistance fund would likely be small, unless deep-sea mining was so widely deployed that it would cause great disturbance to ocean ecosystems. Meanwhile, others contend that monetary costs of implementing deep-sea mining systems will likely be higher than a highly efficient terrestrial mine.

Socio-economic Implications of Institutional Structure and Policy

Deep-sea mining carries complex implications for international negotiations, perpetuating the history of exploitation of developing nations by extractive industries, and marginalizing coastal and indigenous communities. Terrestrial mining has led to toxic elements entering local food and water supply, poor worker safety and child labor, conflict over minerals, and socioeconomic inequality in developing nations.[12] Deep-sea mining may serve as an alternative form of extraction to mitigate some of these issues. However, although the ISA intends to protect the needs of developing countries, Algeria, on behalf of the African Group, has released a statement to the ISA expressing that developing nations must be fairly compensated.[13] Economic benefits toward local communities include job creation and redistribution of royalties, but the jeopardization of tourism and fishing industries, as well as environmental costs, may also be realized.[14]

The Clarion-Clipperton Fracture Zone is located in the Pacific Islands, making nations in this region lucrative for potential DSM operations. The world's first deep-sea mining lease within an EEZ was issued in 2011 by Papua New Guinea to Canadian-owned Nautilus Minerals. Since then, the absence of sharks has prevented indigenous communities from traditional practice of shark calling. In Tonga, the

[10] https://www.isa.org.jm/files/documents/impactstudy.pdf
[11] https://eos.org/articles/deep-sea-mining-may-have-deep-economic-environmental-impacts
[12] https://onlinelibrary.wiley.com/doi/full/10.1002/fes3.109
[13] https://www.isa.org.jm/document/statement-algeria-obo-african-group-2
[14] https://www.frontiersin.org/articles/10.3389/fmars.2018.00480/full#h3

presence of DSM vessels on exploratory missions has led to the disturbance of local fish populations.[15]

Currently, exploration to assess mining viability is issued by state permits and licenses for deep seabed mineral exploration are granted by states. A social license to operate (SLO) is meant to be ongoing approval from local communities and other stakeholders. SLO's, as has been seen in Nautilus Minerals' operations in Papua New Guinea, are too easy to deceive possession of and cost-benefit analyses carried out by corporations can be swayed to be more persuasive about the benefits than objective about the impacts of a mining project.[16]

Environmental Impact and Uncertainty

Deep sea mining operations harm the fragile and diverse ecosystem of the deep sea. Polymetallic nodule mining operations consist of an ore vessel sending a collector vehicle over four thousand meters to the ocean floor, connected by an intake pipe. The mining collector removes the top 15 centimeters of the seabed to collect nodules to pump back up to the surface vessel. Unwanted sediment at the surface is dispelled through a second pipe after the nodules have been collected[17].

Overall, the environmental effects from deep sea mining are highly uncertain as ecosystems on the ocean floor are difficult to monitor and quantify due to their remoteness. Although the ecosystem is thought to be highly fragile, scientists are still only beginning to understand the full nature of the deep sea flora and fauna. Furthermore, deep sea mining practices are still being understood in the effects that the discharge and operation has on an ocean environment[18].

Environmental impacts stem from the sediment plumes, noise, and seabed compression from the mining operation. Sediment plumes that are dispelled from the removal of nodules at the seabed (collecting plume) affects the habitat drastically, as sediment plumes make it difficult for animals like jellyfish and plankton to filter for organic particles critical for sustenance. The weight and tracks of the collector increase compression of the seabed making it difficult for organisms to dig for food and burrow for shelter. The seabed is highly fragile to damaging effects, as it receives significantly low levels of sediment dropping to the floor. Yet the effects of the deep sea mining extend beyond the deep sea ecosystems. Noise pollution and sediment plumes from the discharge pumps at high elevations affect other ocean ecosystems. The estimated 50,000 cubic meter of daily sediment plumes is dangerous for ecosystems and can travel long distances away from the mining sites. Noise pollution from the mining

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[15] https://harvardelr.com/2018/04/16/broadening-common-heritage/

[16] https://www.sciencedirect.com/science/article/pii/S0308597X16306625

[17] https://www.scientificamerican.com/article/deep-sea-mining-how-to-balance-need-for-metals-with-ecological-impacts1/

[18] https://news.mit.edu/2019/understanding-impact-deep-sea-mining-1206#:~:text=Much%20of%20this%20mining%20occurs,and%20soil%20and%20water%20contamination.

machine, ore vessel, and pumps create signals that interfere with wildlife like dolphins and whales[19].

Interventions

This section identifies ways in which different ***interveners*** *can act to modify interactions in the system. Potential interveners in the deep sea mining system include national and* ***local governments****,* ***international organizations****,* ***industry groups****,* ***environmental organizations****,* ***mining companies****,* ***solar PV companies****, and* ***energy consumers****. This section summarizes three different types of potential interventions.*

Policy and Process Reform

Transparency between impacted communities, mining organizations, and governments must be enhanced to include impacted communities in the decision-making process. Free, prior, and informed consent (FPIC) has not been widely implemented. Community engagement and a thorough cost-benefit analysis is a necessary part of FPIC. Though FPIC has been incorporated in the 2007 UN Declaration on the Rights of Indigenous People, it is non-binding and has only been signed by 3 out of 15 Pacific ACP states, not including leading DSM candidates such as Tonga, Fiji, and Papua New Guinea.[20]

The licensing process for DSM requires extensive, costly monitoring and research which can be hard to regulate if left up to individual contractors. A potential policy intervention is a common fund to encourage proper research, monitoring, and contingency for environmental damage as part of a new agency in the UN. Policy must be driven by guidelines that paint a more complete picture of the complex networks of marine ecosystems. This may be done by establishing a coherent network of marine protected areas (MPAs) and standardizing environmental impact assessments (EIAs) such that they factor in the full breadth of stressors on marine ecosystems.[21] The ISA Mining Code is still in development and undergoing negotiations, which were sought to be completed by 2020 but have been delayed due to COVID-19. It is urgent that fair and proper policies are decided upon soon, because companies who already have contracts permitting them to begin mining operations in the next few years have the right to do so even if regulations are still in development.[22]

Environmental Impact and Uncertainty

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[19] https://www.scientificamerican.com/article/deep-sea-mining-how-to-balance-need-for-metals-with-ecological-impacts1/

[20] https://www.researchgate.net/publication/333608904_Anticipating_Social_and_Community_Impacts_of_Deep_Sea_Mining

[21] https://www.frontiersin.org/articles/10.3389/fmars.2018.00480/full#h3

[22] https://chinadialogueocean.net/13685-covid-19-could-throw-seabed-mining-negotiations-off-track/#:~:text=The%20International%20Seabed%20Authority%20

The first step to mitigating the impacts of deep-sea mining is to understand and research how its practices interact with the diverse seabed ecosystem. Not only are the current practices of deep-sea mining relatively new, but the deep-sea ecosystem is one scientists are still striving to understand. The intervention of developing knowledge on this interaction is currently being fueled by environmental groups, ocean mining companies. Since these stakeholders are inherently biased in their perspective and goals, independent researchers such as Thomas Peacock of MIT Mechanical Engineering are important in creating unbiased information to inform groups in how to prioritize and develop further mitigation and intervention strategies.

Currently, mining companies are incorporating intervention techniques that are promising in their ability to mitigate and prevent the damage that the operations can have on the ecosystems. Current technology interventions focus around mitigating the effects of the sediment plume, noise, location selection. Researchers in the MIT Environmental Dynamics Lab are currently researching the extent to which sediment plumes travel and how they can be reduced. Currently, mitigation in this area focuses on manufacturing reliable equipment and controls that ensure sediment is discharged into the same area and that discharge pipes are in optimal locations away from high currents. Coupled with quality manufacturing, acoustic monitoring is being employed to ensure generated frequencies do not disturb wildlife. Furthermore, intervention is being employed in the mapping and routes of the operations to avoid areas especially susceptible to deep sea mining. Current technological intervention is so focused in improving the performance of the sediment flow and seabed driving due to the high fragility and responsiveness of the seabed ecosystem[23].

Due to the lack of knowledge, the most effectives intervention techniques consist of developing ecological and topological understanding of the seabed ecosystem to inform mining operations in areas of heightened fragility. Specifically, autonomous underwater vehicles (AUVs) and profiling buoys are crucial to provide information of biodiversity, concentration levels, and topology that are important metrics to develop risk mapping of the seabed to inform safe mining practices. Research centers like the Monterey Bay Aquarium Research and the National Oceanography Center Institute have used new video monitoring techniques coupled with underwater propes to increase precision in biodiversity measurement by ten times. These measurements are being used to inform the routes that ocean mining machines utilize and the policy that develops regions of protection[24] [25].

While developing knowledge is crucial to mitigating the effects of increased deep sea industrialization, restoration intervention methods due exist. Restoration is the process of assisting the recovery of a damaged ecosystem with the intention of reintroducing an ecological trajectory comparable to pre-human intervention. Although used in other ocean ecosystems, restoration is not practiced significantly in the deep sea. Knowledge into the nature of these ecosystems is paramount to introduce these

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[23] https://www.nature.com/articles/s41598-020-61837-y
[24] https://www.sciencedirect.com/science/article/pii/S0308597X18306407
[25] https://www.sciencedaily.com/releases/2015/01/150112093125.htm

techniques, as well as the accessibility of reaching these environments. The fragility of these environments makes restoration success difficult, yet with expanding surveying technology, this intervention is not impossible[26].

Recycling of solar and electronic components

As solar energy generation continues to grow in the coming years, so does the need for the minerals to develop solar panels making deep sea mining a potentially attractive solution to meeting growing mineral needs. However, given the complexities and uncertainties surrounding deep sea mining, it is important to consider other alternatives to sourcing these materials most notably, traditional onshore mining and recycling of electronics and solar panels. Traditional mining is what is currently used to produce the metals critical to solar panel production. However, traditional mining has significant environmental problems including air pollution, water contamination, and the formation of sinkholes due to earth hollowing. Traditional mining also has significant health impacts for those that work in mines, including lung damage from particulate matter. Additionally, many critical minerals for solar panels including cobalt, copper, and magnesium are mined by children[27].

A more sustainable solution is to recover these critical minerals from waste electronics and solar panels. Every year nearly 42 million tonnes of e-waste[28] are produced worldwide. Solar panel waste is also rapidly becoming a significant environmental problem as the earliest solar panels begin to age, solar panels have a lifetime of 20-25 years. The rapid growth of solar energy coupled with the aging of current panels will lead to a projected 78 million tonnes of solar panel waste by 2050[29]. This solar and electronic waste contains copper, cobalt, nickel, zinc, silver, gold, lithium, and other rare-earth metals. Currently, this electronic and solar waste is inadequately tracked and processed with much of it ending up in landfills in developing countries where chemicals leach into the ground poisoning water sources[30]. However, stricter regulations around the proper recycling of electronic and solar waste in the European Union has led to the establishment of the first electronic and solar recycling plants. The first solar recycling plant opened in Rousset, France in 2018 and is able to recycle

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[26] https://www.sciencedirect.com/science/article/pii/S0308597X13001486

[27] https://www.thestar.com/news/world/2013/05/23/children_as_young_as_8_working_in_congo_copper_mines_in_democratic_republic_of_congo.html

[28] https://interestingengineering.com/how-to-recycle-42-million-tonnes-of-e-waste

[29] https://www.sciencedirect.com/science/article/pii/S2211467X19301245#:~:text=Considering%20an%20average%20panel%20lifetime,issue%20in%20the%20next%20decades.

[30] https://www.wired.com/story/solar-panels-are-starting-to-die-leaving-behind-toxic-trash/#:~:text=Solar%20panels%20are%20composed%20of,also%20creates%20new%20environmental%20hazards.

approximately 4,000 tonnes of solar waste each year[31]. The International Renewable Energy Association estimates over $15 billion worth of materials could be recovered from solar panels by 2050. Greater public knowledge of the importance of properly recycling solar panels and electronic waste along with increased governmental regulation of this waste is critical in order to develop sustainable recycling systems for solar and electronic waste. Additionally, governmental investment in the development of solar waste recycling plants is crucial to bring this technology to a large scale. However, with public and governmental support and further R&D development the recycling of metal compounds from solar and electronic waste could reduce the need for new mining operations both on the seafloor and around the world.

31 https://www.reuters.com/article/us-solar-recycling/europes-first-solar-panel-recycling-plant-opens-in-france-idUSKBN1JL28Z