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Deep Sea Mining in Social Sciences: A Systematic Review

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ABSTRACT

The effort to reduce carbon emissions and combat global warming has resulted in a significant increase in global demand for copper, cobalt, nickel and manganese, which are crucial components of electric vehicles, solar panels and wind turbines. The extraction of terrestrial mines is becoming increasingly problematic due to environmental challenges and human rights violations. Consequently, there is a growing interest in exploring deep sea mining (DSM) as a viable alternative source. The majority of literature on DSM originates from the disciplines of engineering, environmental science, earth and planetary sciences and agricultural and biological sciences. However, recent years have witnessed a greater focus on DSM in social science research. The objective of the present study is to perform a systematic review of social science articles on DSM. To accomplish this purpose, the screening of articles on DSM published between 1 January 2018 and 27 December 2024 was carried out using the SCOPUS database. Subsequent filters were applied to narrow down the results to include only social science articles. A total of 45 articles met the eligibility criteria. This study provides critical insights into the current landscape of social science research on DSM, shedding light on key aspects of the field. Although various studies address the political, legal, environmental and socio-economic dimensions of DSM, there is a notable absence of perspective from the international relations (IR) discipline. With the increasing relevance of DSM in global trade, politics and security, IR scholars have the unique opportunity to explore new dimensions of power dynamics related to the oceanic realm. This study identifies potential research trajectories in the context of regime theory, norm diffusion processes, spatial theorizing and interdisciplinary approaches that could be explored by IR scholars in the future.

1 | Introduction

The ocean covers more than 70% of the Earth's surface, with approximately 90% of it below a depth of 200 m, known as the deep sea (Kaiser and Williams 2011). Although the oceans have been used for millennia, mineral deposits on the sea floor were only discovered in the 1870s (Sharma 2022). Technological advancements now enable the exploitation of fisheries resources, hydrocarbons and minerals in the deep sea (Ramirez-llodra et al. 2011). According to the United Nations Convention on the Law of the Sea (UNCLOS) (which was adopted in 1982 and became effective in 1994), the seabed beyond the national continental shelf is defined as 'the area'. The area and its mineral resources are designated as the 'common heritage of mankind' (UNCLOS 1982). The International Seabed Authority (ISA) was established in 1994 with the purpose of regulating the exploration and exploitation of deep-sea minerals found in the area (Lodge 2017). In general, the seabed and its mineral resources are governed by an international regime consisting of UNCLOS, the 1994 Implementation Agreement and the rules issued by the ISA (Willaert 2021a).

Deep-sea minerals (including polymetallic nodules, hydrothermal sulphur sulphides and ferromanganese crusts) are

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increasingly being considered as possible substitutes for land-based resources in metal extraction (Sharma 2022; Folkersen et al. 2018). Cobalt, nickel, copper and manganese (which exist in polymetallic nodules in a single ore) could be used in the manufacture of smartphones, electric vehicles, solar panels, wind turbines, batteries, biomedical and consumer goods and many more (Koschinsky et al. 2018; Sharma 2022).

Terrestrial mines are usually located in a few countries, some of which are conflict-ridden (van der Grient and Drazen 2021). Furthermore, the extraction of terrestrial mines is also problematic due to the reliance on child labour in some countries (e.g., the Democratic Republic of Congo) and environmental pollution (see Sovacool 2021; Smolders et al. 2019). Most importantly, terrestrial mines may not be able to meet the world's demand for these resources in the future (van der Grient and Drazen 2021). According to the International Energy Agency (2021), the proportion of cobalt used in clean energy technologies is projected to increase from 15% in 2020 to 69% in 2040. Similarly, the percentage of nickel used in these technologies is expected to increase from 8% to 61%. These developments, along with increasing mineral prices, have sparked more enthusiasm to mine the ocean floor (Folkersen, et al. 2018).

The ISA laid out regulations for the exploration of deep sea mineral deposits (Sharma 2022) and entered into 15-year contracts with 22 contractors sponsored by national governments to explore mineral wealth in the Clarion–Clipperton Fracture Zone and Central Indian Ocean Basin, and Western Pacific Ocean; polymetallic sulphides in the South West Indian Ridge, Central Indian Ridge and the Mid-Atlantic Ridge; cobalt-rich crusts in the Western Pacific Ocean (ISA n.d.-a). As of now, no commercial deep sea mining (DSM) licence is issued. Since 2014, ISA has been developing rules, regulations, and procedures for the stage of DSM exploitation, which are expected to be finalized in 2025 (ISA n.d.-b; Cassotta and Goodsite 2023).

The ISA's role in the Sustainable Development Goals (SDGs) is reflected in its primary mandate: to enhance the rule of law in ocean governance, preventing unrestricted exploitation of deep-seabed mineral resources while ensuring the effective safeguarding of the marine environment and the equal distribution of benefits. The ISA is firmly dedicated to supporting the UN Decade of Ocean Science for Sustainable Development (2021–2030), as declared by the UN General Assembly, to promote scientific research and technology innovation for a more sustainable ocean (Madureira et al. 2023).

Generally speaking, the international community faces both opportunities and potential threats regarding DSM practices (Wilde et al. 2023). Two of the UN SDG encompass 'affordable and clean energy' (Goal 7) and 'sustainable cities and communities' (Goal 11) (United Nations 2024). Large-scale access to metals and mineral resources is necessary to attain these goals, and doing so will help achieve other crucial UN strategy objectives (such as Goal 1, 'no poverty') (Madureira et al. 2023). At first glance, DSM appears to be a viable strategy for achieving development-related goals. Indeed, proponents of DSM argue that the minerals found on the seabed are critical for clean energy transition and the establishment of low-carbon economy, further contending that the expansion of land mining would produce much more environmental damage than the mining of the sea floor (see, e.g., World Ocean Council 2019).

The debate over DSM necessitates careful consideration of both its potential benefits and the ecological risks. When considering DSM from a developmental framework, it is of utmost importance to keep in mind UN Development Goal 14, 'life below water', which emphasizes the importance of conserving and sustainably using the oceans, seas and marine resources (United Nations 2024). According to the most recent UN SDG Report, oceans face significant challenges due to eutrophication, increased acidity, declining fish populations, rising temperatures and widespread pollution. These effects devastate marine habitats, decrease biodiversity and threaten coastal communities as well as the health of marine ecosystems, which are essential for more than 3 billion people (United Nations 2024). Critics of DSM claim that it will cause 'irreversible harm' to marine ecosystems through the discharge of hazardous metals and noise, vibration and light pollution (McVeigh 2024).[1] In response to these concerns, marine science and policy experts from over 44 countries signed a statement calling for a pause to DSM.[2] Furthermore, smaller and more agile robots are currently being designed to minimize damage during nodule extraction.[3]

There has been a growing scholarly interest in DSM across a variety of disciplines. Although most studies on DSM are from the disciplines of engineering, environmental science, earth and planetary sciences and agricultural and biological sciences, relatively little attention has been devoted to the topic in the social sciences disciplines. The last decade has seen a significant increase in social science research focused on DSM. As the DSM industry evolves and faces new challenges, the inputs and insights generated by social scientists are crucial to developing sustainable practices and informed regulations that balance resource extraction with environmental conservation.

The purpose of this paper is to conduct a systematic review of the social science literature on DSM published between 1 January 2018 and 27 December 2024. The studies included in the systematic review were selected from the SCOPUS database based on specific inclusion and exclusion criteria, as detailed in Section 2. The studies were subsequently classified into distinct categories, including policy issues, legal issues, economic management, socio-economic implications, history, risks, geopolitics, and resistance. Although there are studies that focus on policy issues or explore the geopolitical dimension of the topic, the existing literature on DSM lacks significant contributions from scholars and perspectives from the field of international relations (IR). This gap in the literature is particularly notable given the growing importance of DSM in global trade, politics and security. IR scholars can bring unique perspectives to the study of DSM, analysing how it intersects with issues of power, conflict and cooperation among states. This article maps out potential research trajectories that IR scholars might investigate in the future in the context of regime theory, norm diffusion processes, spatial theorizing and interdisciplinary approaches.

More recently, a bibliometric analysis was performed on DSM-related research in the SCOPUS database between 1968 and 2021 (Kleiv and Thornhill 2022). This study provides a general overview of scientific production on DSM by breaking it down into

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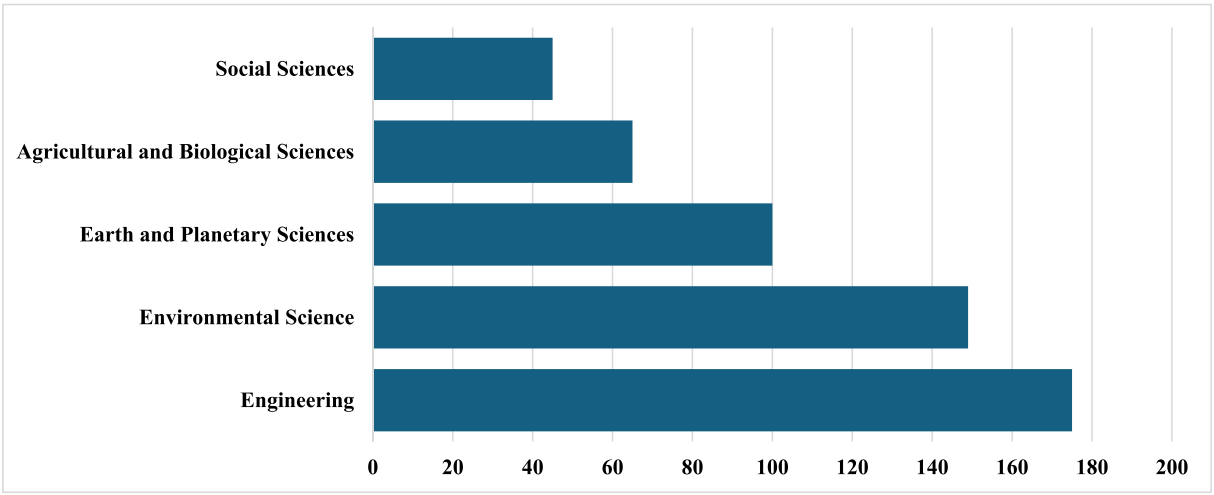


FIGURE 1 | The number of articles written on DSM by discipline (2018–2024).

various disciplines, annual publications, terms of reference and countries that contribute to relevant papers. A detailed content analysis performed between 2017 and 2021 reveals that China, the United Kingdom, the United States and Germany are the leading contributors to scientific production on DSM. Almost half of the publications during this period concentrate on environmental aspects, whereas one-third focus on engineering aspects. Folkersen et al. (2018) performed a systematic review of literature on the economic value of the deep sea. Providing a critical review of geographies associated with DSM, Childs (2022) emphasizes the importance of understanding DSM by taking into consideration a variety of political actors, both human and non-human, that operate beyond the traditional land–capital relationship.

Although the DSM issue is gaining traction among social scientists, no systematic review of the social science literature on the mining of deep sea has yet been conducted. This study, therefore, aims to be the first 'systematic review' of social science research on this topic. By synthesizing and critically evaluating the existing social science research landscape, this study aims to identify knowledge gaps and suggest directions for future research in this important and rapidly evolving field.

The paper is structured as follows: Section 2 details the methodological process of conducting the systematic review, focusing on strategies for data extraction and analysis. Section 3 presents the results of the systematic review, analysing and comparing the studies across specific categories and subcategories. Section 5 provides a critical discussion of the findings, highlighting the comparatively limited engagement of international relations (IR) scholars in the subject matter and underscoring the importance of IR perspectives for DSM-related research. Section 6 explores potential research pathways for IR scholars by linking them to existing research areas within the discipline. Finally, Section 7 summarizes the key findings.

2 | Research Methodology: Systematic Review

This study adopts the methodology of systematic review of literature. In a systematic review, the researcher gathers all available studies on a given topic and then reviews and analyses their results. Some of the major characteristics of a systematic review include clearly defined objectives with predetermined eligibility criteria for research; an explicit methodology; a systematic search that aims to find all relevant studies that fulfil the predetermined criteria for inclusion; and systematic presentation and synthesis of the features and results of the included studies (Higgins and Green 2008). Systematic reviews synthesize the existing body of literature, providing a comprehensive overview of current findings while simultaneously identifying gaps in research and areas that require further exploration (see Petticrew and Roberts 2008). They are particularly important for identifying scholarly interest and research gaps, especially regarding cutting-edge topics such as DSM, space tourism (Zhang and Wang 2020), and big data-driven predictive policing (Lee et al. 2024).

My data originate from SCOPUS, one of the largest abstract and citation databases available that provides a wealth of information across multiple disciplines, including life sciences, social sciences, physical sciences and health sciences. This database enables researchers to perform detailed searches using specific keywords and find and compare relevant scholarly articles. Before conducting a systematic review, I utilized a number of inclusion/exclusion criteria to identify relevant social science articles written on DSM on the SCOPUS database. The eligibility criteria for publication date range were established as between 1 January 2018 and 31 December 2024. A systematic filtering approach was utilized to identify relevant scholarly articles on DSM. The search was exclusively focused on research articles, thereby excluding various other types of publications, including reviews, conference papers, book chapters, conference proceedings, books, short surveys, letters, editorials and data papers. No language criterion was applied. To find articles directly related to the specified research topic, articles were screened using specific keywords: 'deep,' 'sea' and 'mining' in their titles.

During the initial screening phase, no exclusions based on disciplines were applied, resulting in a total of 534 research outputs on the topic. As shown in Figure 1, there is a noticeable disparity in research output on DSM across different disciplines. Social scientists are noticeably behind physical

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scientists regarding research output on DSM. The most productive discipline on the topic is engineering, followed by environmental science, earth and planetary sciences and agricultural and biological sciences. This finding is unsurprising as DSM predominantly encompasses technological and environmental dynamics that typically fall under the domain of physical and applied sciences.

In the second screening phase, the results were further refined to include only articles from the social sciences. This search yielded a total of 45 articles on DSM (SCOPUS 2024). Table 1 presents the articles that are included in the present study. An analysis of the language distribution of the publications reveals that the majority were in English (95.6%), followed by Portuguese (4.4%).

The selection of this time frame in this research is particularly justified by the exponential increase in social science articles published on deep sea mining from 2018 onward. There is a stark contrast between the periods from 1978 to 2017 and from 2018 to 2024. Between 1978 and 2017, the annual average of social science articles was 0.6, reflecting a relatively limited engagement with issues surrounding DSM. Furthermore, no social science articles were published during the following periods: 1996–2001, 2004–2009 and 2011–2014. The jump from one published article in 2017 to nine articles in 2018 highlights a pivotal moment for DSM-related analysis among social scientists. Between 2018 and 2024, the annual average of social science articles increased to 6.43, signifying a considerable increase in the attention social scientists pay to DSM.

There are notable trends in social science research landscape on DSM, particularly in the years 2020 and 2024, with both years seeing a peak of nine articles published. Figure 2 documents the number of social science articles on DSM per year. The annual growth rate of new social science articles on DSM from 2018 to 2024 is approximately 4.27%. Although research production on DSM in the social sciences lags behind that in the physical sciences, there is a relatively growing scholarly interest in the topic among social scientists. This increased attention could be attributed to various interrelated factors: discussions that intensified within the ISA regarding the regulations on DSM activities, advancements in underwater mining technology, the growing demand for minerals, public awareness and activism surrounding deep sea mining. At a broader level, this dynamic can be framed within the context of increasing research interests among social scientists in cutting-edge topics such as technology, artificial intelligence and autonomous weapons, among others (see Ferl 2023; Strauch and Weidmann 2022; Liu 2021; Walsh 2015). As research and technology on DSM continues to evolve, it is probable that a growing number of social scientists will engage this topic, exploring its sociological, economic, international and legal dimensions.

In the following section, I conduct a systematic review of these articles is conducted based on categorizations of the main issue discussed. The studies were classified into policy issues, legal issues, economic management of DSM, social and economic costs and benefits of DSM, risks associated with DSM, history of DSM, anthropological explorations, geopolitical dimensions of DSM and resistance against DSM. The subcategories were used for broader issues, allowing for nuanced insights into specific areas of concern. Although these categories serve as a valuable framework for analysing and comparing the body of literature, it is essential to acknowledge the inherent complexities in establishing clear-cut categorizations. This suggests that categorization should not be viewed as a rigid framework but rather as a flexible tool that can facilitate deeper insights into the interconnectedness of various topics.[4] Figure 3 visualizes the research process through a flowchart.

3 | Systematic Review of Social Science Articles on DSM

The studies that focus on policy issues surrounding DSM differ according to the level of analysis: international and national. Most of these studies analyse DSM at the international level, with particular attention given to ISA. There are only two studies that analyse DSM at the national level.

3.1 | Policy Issues

3.1.1 | International Level

The study by Kirkham et al. (2020) provides policy recommendations to the ISA and the international community in their quest to find a balance between DSM and the protection of deep-sea ecosystems. The authors argue that the strict normative standards laid out by the Antarctic mineral resource regime could offer useful insights in the process of developing DSM regulations. The study draws on policy analysis of key documents from 1980 to the present as well as interviews with experts who were actively involved in the formulation of seabed and Antarctic policymaking. Jones et al. (2022) provide policy recommendations regarding the international regulation of deep-sea mining activities in the specific case of the establishment of reference zones for polymetallic nodule mining. Deberdt and James (2024) argue that the verification system outlined by the ISA does not adequately address the needs for a proactive assessment of environmental impacts. This study points to the importance of a rigid, quantitative auditing culture that aligns with the rapid evolution of deep-sea knowledge.

Blanchard et al. (2023) provide a more general view of the governance of the ISA by examining its mandate and its different organs and focusing on the events and instruments regarding the development of the regulatory framework for mineral-related activities, with particular attention placed on the development of the draft exploitation regulations (DR) (which is designed to regulate the exploitation of mineral resources in the area) in view of an environmental perspective. Pickens et al. (2024) focus on rules, regulations and procedures regarding the exploitation phase of DSM. The authors find that more than 30 significant regulatory issues concerning this phase are still unresolved and explain this by pointing out insufficient time for discussion, divergent opinions among member states and a lack of information and input to further negotiations. Similarly, Ardito and Rovere (2022) evaluate the unresolved environmental

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TABLE 1 | Social science articles included in the systematic review.

Social science articles on deep sea mining	Journal name	Year
Social Cost Benefit Analysis for Deep Sea Minerals Mining	*Marine Policy*	2018
Deep Sea Mining's Future Effects on Fiji's Tourism Industry: A Contingent Behaviour Study	*Marine Policy*	2018
A Comprehensive Approach for a Techno-Economic Assessment of Nodule Mining in the Deep Sea	*Mineral Economics*	2018
Deep-Sea Mining Prospects in French Polynesia: Governance and the Politics of Time	*Marine Policy*	2018
The Common of Heritage of Mankind as a Means to Assess and Advance Equity in Deep Sea Mining	*Marine Policy*	2018
The Fiscal Regime for Deep Sea Mining in the Pacific Region	*Marine Policy*	2018
Managing Deep Sea Mining Revenues for the Public Good—Ensuring Transparency and Distribution Equity	*Marine Policy*	2018
Existing Environmental Management Approaches Relevant to Deep-Sea Mining	*Marine Policy*	2019
A Historical Perspective on Deep-Sea Mining for Manganese Nodules, 1965–2019	*Extractive Industries and Society*	2019
Greening the Blue? Corporate Strategies for Legitimizing Deep Sea Mining	*Political Geography*	2019
Deep-Sea Mining: Policy Options to Preserve the Last Frontier—Lessons From Antarctica's Mineral Resource Convention	*Marine Policy*	2020
Deep-Sea Mining Legislation in Pacific Island Countries: From the Perspective of Public Participation in Approval Procedures	*Marine Policy*	2020
Crafting the Perfect Deep Sea Mining Legislation: A Patchwork of National Laws	*Marine Policy*	2020
Risk Assessment for Deep Sea Mining: An Overview of Risk	*Marine Policy*	2020
Environmental Impact Assessments for Deep-Sea Mining: Can We Improve Their Future Effectiveness?	*Marine Policy*	2020
Environmental Considerations for Impact and Preservation Reference Zones for Deep-Sea Polymetallic Nodule Mining	*Marine Policy*	2020
Developing a Business and Human Rights Treaty: Lessons From the Deep Seabed Mining Regime Under the United Nations Convention on the Law of the Sea	*Business and Human Rights Journal*	2020
On the Legitimacy of National Interests of Sponsoring States: A Deep Sea Mining Conundrum	*International Journal of Marine and Coastal Law*	2020
Extraction in Four Dimensions: Time, Space and the Emerging Geo(-) politics of Deep-Sea Mining	*Geopolitics*	2020
Deep Sea Mining in the Pacific	*Brazilian Journal of International Law*	2020
Protest at Sea Against Deep Sea Mining: Lawfulness, Limits and Remedies	*International Journal of Marine and Coastal Law*	2021
Deep Sea Mining and the United States: Unbound Powerhouse or Odd Man Out?	*Marine Policy*	2021
Poliheuristic Theory and Indonesia's Absence in Deep-Sea Mining (DSM)	*Journal of Current Southeast Asian Affairs*	2021
Under Pressure: The Impact of Invoking the Two Year Rule within the Context of Deep Sea Mining in the Area	*International Journal of Marine and Coastal Law*	2021

(Continues)

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TABLE 1 | (Continued)

Social science articles on deep sea mining	Journal name	Year
Fair Share: Equitable Distribution of Deep Sea Mining Proceeds	*International Journal of Marine and Coastal Law*	2022
Transparency in the Field of Deep Sea Mining: Filtering the Murky Waters	*Marine Policy*	2022
Deep-Sea Mining and the Potential Environmental Cost of 'Going Green' in the Pacific	*Environmental Law Review*	2022
Racing the Clock: Recent Developments and Open Environmental Regulatory Issues at the International Seabed Authority on the Eve of Deep-Sea Mining	*Marine Policy*	2022
'On Board' Deep-Sea Mining. An Ocean-Based Perspective	*Archivio Antropologico Mediterraneo*	2022
Equitable Sharing of Deep-Sea Mining Benefits: More Questions Than Answers	*Marine Policy*	2023
The Current Status of Deep-Sea Mining Governance at the International Seabed Authority	*Marine Policy*	2023
Green Transition Mineral Supply Risks: Comparing Artisanal and Deep-Sea Cobalt Mining in a Time of Climate Crisis	*Extractive Industries and Society*	2023
Aqua/Geopolitical Conjuncture and Disjuncture: Invasion, Resources, and Mining the Deep Dark Sea	*Cultural Studies*	2023
Sustainable and Just Deep-Sea Mining for the Energy Green Transition: A Conundrum Without Legal, Governance or Technological Solutions. The Case of the EU	*European Energy and Environmental Law Review*	2023
History Matters: Societal Acceptance of Deep-Sea Mining and Incipient Conflicts in Papua New Guinea	*Maritime Studies*	2023
Sharing is Caring: Prominent Issues and Considerations Regarding the Equitable Distribution of Deep-Sea Mining Proceeds	*Ocean Yearbook Online*	2023
A Precautionary Tale: Exploring the Risks of Deep-Sea Mining	*Marine Policy*	2024
Mind the Gap and Close It: Regulating Greenhouse Gas Emissions from Deep-Sea Mining in the Area	*Marine Policy*	2024
From What-If to What-Now: Status of the Deep-Sea Mining Regulations and Underlying Drivers for Outstanding Issues	*Marine Policy*	2024
Self-Governance at Depth: The International Seabed Authority and Verification Culture of the Deep-Sea Mining Industry	*Resources Policy*	2024
Protest at Sea Against Deep Sea Mining Revisited: The MV Coco Case	*International Journal of Marine and Coastal Law*	2024
Discussing Sustainability Narratives in the Literature on Deep-Sea Mining and Its Configuration as Resource Frontier	*Finisterra*	2024
Justice, Equity, and Approaches for Sharing Benefits From Deep Sea Mining Operations in the Area	*International Journal of Marine and Coastal Law*	2024
Could Deep-Sea Mining Sustain Sustainability? The International Seabed Authority and the UN 2030 Agenda	*Resources Policy*	2024
Bohemia at the Pacific Seabed: Archiving the Future of Deep-Sea Mining With the Interoceanmetal Joint Organization	*Social Studies of Science*	2024

regulatory issues of the mining code (that are currently being discussed in the ISA) that concern the exploitation phase by paying particular attention to the precautionary principle, the environmental impact assessment (EIA) and the need for an inspection mechanism.

3.1.2 | National Level

By focusing on the political aspects of the decision making process during the administration of President Joko Widodo (2014–2019) and using the poliheuristic theory (PHT) of decision

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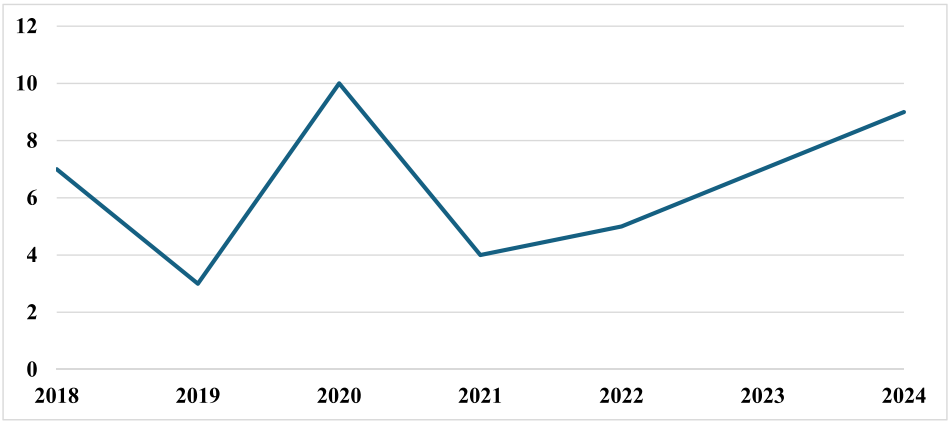


FIGURE 2 | The number of social science research outputs on DSM from 2018 and 2024.

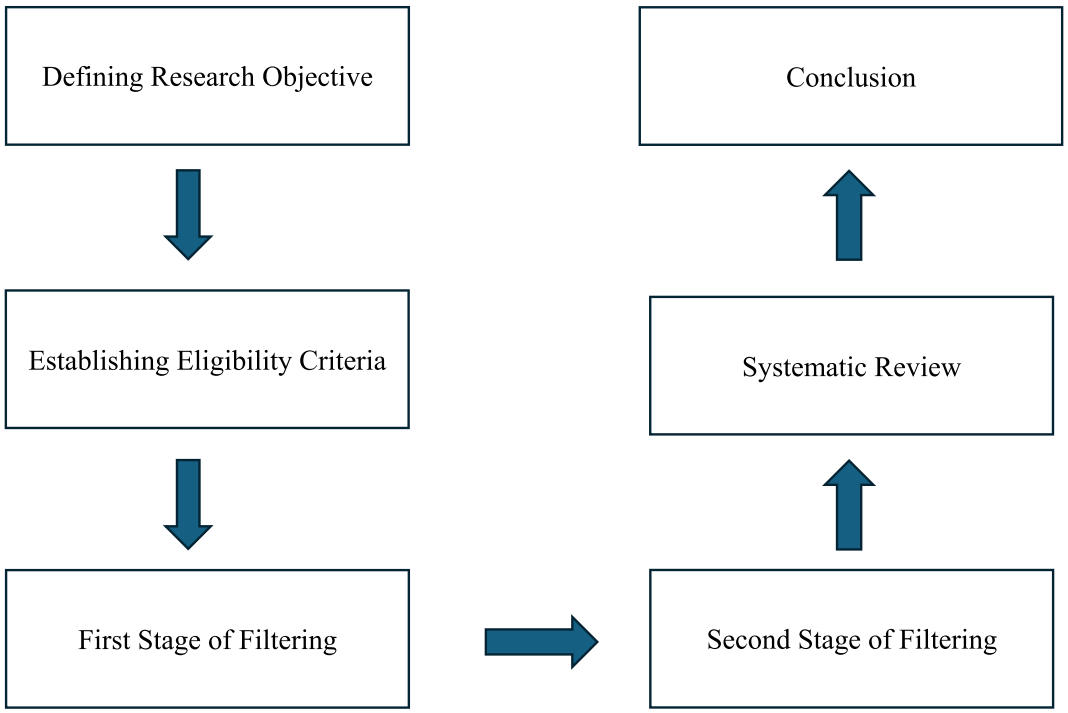


FIGURE 3 | The research process.

making, Karim and Yudha (2021) demonstrate that Indonesia's absence from DSM activities is the result of deliberate choices made by President Widodo to prevent a decrease in public support. Le Meur et al. (2018) assess the potential to establish a DSM mining sector in French Polynesia and offer policy recommendations that could be used as guidelines for the development of a policy framework in the future.

3.2 | Legal Issues

The literature addressing the legal dimension of DSM presents a diverse array of studies grouped into subcategories such as DSM legislation, the exploitation phase, transparency, UNCLOS implications and equitable sharing of benefits.

3.2.1 | DSM Legislation

Among the literature that focuses on legal issues, much attention has been paid to legislation concerning DSM. Particular attention has been devoted to Pacific Island countries as the Clarion–Clipperton Zone, which has an abundant presence of deep sea minerals, is located in the Pacific Ocean. For example, the study by Kakae (2020) provides an analysis of DSM legislation in four Pacific Island countries (the Cook Islands, the Kingdom of Tonga, Fiji and Papua New Guinea) by focusing on the intertwinement between mining and environmental laws. The selection of these countries was based on their suitability for comparison, since they have either granted DSM exploration permits or have granted exclusive rights to a private company to apply for an exploration licence. This study concludes that both

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mining and environmental laws are essential components of the DSM legal framework and complement each other.

Bordahandy (2020) compares the differences in the legal framework between the Pacific states with respect to DSM and focuses on the legal, structural and practical issues that need to be solved before DSM operations. Willaert (2020a) analyses and compares DSM laws of four sponsoring states: Germany, France, Belgium and the Cook Islands. After deconstructing the building blocks of national DSM legislation in these countries, the author discusses DSM provisions that can serve as examples to other states. In another study, Willaert (2020b) examines the domestic legislation of sponsoring states on DSM by taking international law into account. Focusing on the European Union as a case study, Cassotta and Goodsite (2023) examine the extent to which current DSM regulations consider risks and uncertainties in a fair and sustainable way within the existing legal framework on environmental liability.

3.2.2 | The Exploitation Phase of DSM

Willaert (2021a) analyses the legal consequences of the US' non-ratification of UNCLOS with respect to its future DSM activities. The US ratified neither the 1982 Law of the Sea Convention nor the 1994 Implementation Agreement. The article attempts to answer the question of whether the US can exploit natural resources inside the area without prior approval from the ISA. The article concludes that the United States cannot be a sponsoring state. However, US multinational corporations can exploit a legal loophole by engaging in DSM in the Area, using subsidiaries registered in states that have ratified the Law of the Sea Convention. In another interesting study, Willaert (2021b) provides different legal interpretations of what would happen if the ISA could not complete the regulations that concern the exploitation phase of DSM within the required time frame (by 2025).

3.2.3 | Transparency

The study by Willaert (2022a) identifies legal issues surrounding transparency in the field of DSM. Noting that the general public is not provided with sufficient information on DSM activities, the ISA recommends that the ISA improve transparency in the DSM industry.

3.2.4 | UNCLOS

Bernaz and Pietropaoli (2020) discuss how the DSM regime under the UNCLOS can offer useful insights into the current development of the proposed Business and Human Rights Treaty in the domains of the responsibility and liability of states and companies. The authors conclude that UNCLOS can set an example in establishing standards that are directly applicable to the private sector.

3.2.5 | The Equitable Sharing of Benefits

Bourrel et al. (2018) evaluate the value of the principle of the common heritage of mankind and shed light on how its effective implementation can contribute to advance the concept of equity in the context of DSM. The studies by Willaert (2022b) and Willaert (2023) critically examine regulations on equitable benefit sharing, evaluate existing options and provide insightful ideas on the future course of action. Wilde et al. (2023) reviewed the proposals presented to ISA to date on equitable sharing of benefits and analysed them on the basis of the equity considerations identified in UNCLOS. The authors shed light on the issues that states parties and other stakeholders should consider before entering into a specific benefit-sharing arrangement and identify contentious areas. In a comparable study, Friedman (2024) analyses the legal regimes to ascertain the elements of equitable sharing and critically examines proposed modalities of for benefit-sharing.

4 | Economic Management of DSM

Volkmann (2018) propose a spatial planning tool to evaluate the techno-economic requirements and implications of manganese nodule mining on deep sea deposits by using the German exploration area E1, located in the Clarion–Clipperton Fracture Zone, Pacific Ocean as a case study. Mullins and Burns (2018) shed light on the design of the main fiscal instruments pertinent to DSM activities by paying particular attention to royalties, corporate income tax and related withholding taxes and resource rent taxation. Ovesen et al. (2018) offer an overview of main issues in the financial management of revenues and regarding the development of deep sea minerals and identify pathways through which the benefits of DSM wealth could be maximized for citizens.

5 | Socio-Economic Implications of DSM

Folkersen et al. (2018) conducted a study to estimate the possible impacts of DSM activities on reef-related tourism in Fiji. Specifically, the authors employ a contingent behaviour survey to investigate the impact of tourists' expectations of DSM on their future travel decisions and, in turn, the overall tourism demand in Fiji. The results indicate that divers and snorkelers are highly inclined to return to Fiji in the future, as evidenced by their previous travel experiences. However, they would substantially decrease their future visits if DSM were to occur in Fiji.

Wakefield and Myers (2018) evaluated realistic hypothetical scenarios on how DSM would affect countries in the Pacific Island Region. The authors show that the mining of massive sulphide deposits on the seafloor in Papua New Guinea and manganese nodules in the Cook Islands would increase the well-being of local communities, whereas in view of the mining of current technology and commodity prices, the mining of cobalt-rich crusts is unlikely to improve the well-being of residents of the Republic of the Marshall Islands.

Klimašauskaitė et al. (2023) discuss DSM in the context of sustainable development and come to the conclusion that DSM has no clear connection with the UN SDG. The authors underline that meaningful discussions on sustainability regarding deep sea and terrestrial mining require engagement with a diverse array of literature, encompassing anthropology, human geography, policy and governance studies, among others.

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5.1 | Risks Associated With DSM

There is a plethora of research on the risks associated with DSM. Much of this literature is focused on the environmental risks of DSM practices and the governance of these risks. The below study is an exception as it explores risks of DSM mining by examining international obligations and global risk indicators on a country basis.

5.1.1 | General Risk Assessment

Petrossian and Lettieri (2024) provide a risk assessment for 21 countries that signed a contract with the ISA to conduct DSM explorations by looking at whether they have ratified UN treaties and other international agreements related to sea, illegal fishing, climate and organized crime as well as their status in various indexes, such as the Human Freedom Index, World Bank Governance Indicators, 'Corruption Perception Index', 'doing business', 'World Justice Project Rule of Law Index' and 'major money laundering country' scores. The study reveals a general lack of commitment among these countries towards their international obligations. For example, the Russian Federation ranks worst on indicators of 'political stability and absence of violence', 'rule of law', 'control of corruption' and 'regulatory quality'. China is the lowest-ranked country on the 'voice and accountability' indicator. Brazil stands out as the worst performing country in terms of government effectiveness. This paper contends that when granting DSM permits, it is important to take into account various performance indices of risk, as determined by reputable third parties, and the general absence of good-faith commitment demonstrated through the ratification of pertinent international treaties. In other words, states that have not ratified or demonstrated a strong commitment to international treaties may struggle to adhere to global standards that aim to protect marine ecosystems when conducting DSM explorations. Instead of measuring direct environmental impacts of DSM operations, this study explores the potential DSM performances of countries granted permits by the ISA.

5.1.2 | Environmental Risks

Deberdt and Le Billon (2023) compare artisanal and deep-sea cobalt mining in the context of the climate crisis and the accelerating transition of green technology. They highlight the different but related risks of these two extraction methods. They concluded that although DSM can help alleviate some of the social issues associated with artisanal mining, such as child labour, it has the potential to engender new types of environmental risks related to the offshore oceanic nature of extraction. Farran (2022) argues that although the extraction of the metals necessary to produce vehicle batteries in deep seas may seem like a viable method to reduce dependence on fossil fuels, it presents considerable risks of environmental disasters, especially for states on the Pacific Islands.

Leiva (2024) focuses on DSM through the lens of sustainability narratives by employing bibliometric analysis and qualitative content analysis. The author compares two discourses: one that argues that DSM would be less harmful than surface mining and the other that focuses on the negative impacts of DSM on the ocean and human welfare. He argues that the search for new sources of minerals, the need to control resources and the view of the ocean as a zone of unlimited development are the key dynamics that shape DSM as an emerging frontier for sustainability.

5.1.3 | Governance of Environmental Risks

To reduce environmental impacts and risks, Jones et al. (2019) suggested the application of lessons from the offshore oil and gas industry. The authors advise rapid action for the development of the guidance for this emerging industry, as the standards and protocols established at the outset can rapidly become precedents. Cormier and Londsdale (2020) focus on the importance of developing environmental standards for the DSM sector and management strategies in order to protect the marine environment. The authors also highlight the need for a structured risk management process from a regulatory framework point of view and the use of risk criteria to connect scientific and technological information with risk management objectives in order to mitigate the environmental risks associated with DSM.

Clark et al. (2020) identify limitations in EIAs for DSM. These shortcomings include insufficient baseline data, lack of attention given to the mining operation, inadequate synthesis of data and the ecosystem approach, inadequate evaluation of uncertainty and impacts, inadequate treatment of cumulative impacts, inadequate risk assessment and inadequate consideration of the connections between EIAs and other management plans.

Heinrich et al. (2024) touch upon an important environmental issue that is currently unregulated: greenhouse gas emissions (GHG) that will arise in the area from commercial DSM activities. The authors recommend that the ISA prioritizes the development of regulations on this issue, underlying that the ISA appears to be the most suitable forum for regulating GHG, as well as other air pollutants resulting from DSM operations with its potential to establish a harmonized and targeted approach that would be equally applicable to all actors. This study overlaps with studies that focus on the policy perspective.

5.2 | History of DSM

Although the last decade has witnessed growing technological and regulatory developments regarding DSM, DSM activities began in the 1960s and reached an advanced developmental phase by the 1970s, only to be paused in the 1980s (Sparenberg 2019). Sparenberg (2019) analyses 50 years of deep sea mining history and explores how evolving political, legal, economic and socio-cultural policy frameworks influenced its rise, fall and subsequent rise. Utilizing historical and ethnographic methods, Galka (2024) answers the question of how and why East-Central European Interoceanmetal Joint Organization (IOM) has survived as an institution since its establishment 1987.

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The author concludes that 'IOM's history highlights the contingencies of resources in the temporality of indefinite pause, their attendant data, and scientific labour and life under the shifting political, economic, and scientific circumstances of the ongoing not-yet' (Galka 2024, p. 678).

5.3 | Geopolitics of DSM

Probyn (2023) criticizes the lack of scholarly attention to the oceanic geopolitics of DSM. He propels the view that the prospect of exploration and extraction of unfamiliar entities in the mining industry is driving us towards new aqua/geopolitics at this point in the Anthropocene, which necessitates rethinking of 'the different temporalities and timelines, the legal and historical ordering, and the unknown materialities, physicality and histories of the geo and the aqua' (Probyn 2023, p. 699). Deconstructing the conventional 'terra-centric' perspective, Gentilucci (2022) adopts an ocean-based perspective and treats the sea as 'an agent capable of influencing and permeating the economic, political, and scientific flows and expectations that have structured and made possible the exploration and exploitation of the ocean floor' (Gentilucci 2022, p. 7). In other words, the author depicts the sea as a performative actor that influences DSM in a variety of ways, ranging from technology to juridical regulation.

Childs (2019) argues that DSM is more than a site of empirical novelty. It offers a permissive environment for conceptual rethinking of the ways in which the geographies and practices of resource extraction are intertwined with the terms of the 'social'. He highlights how 'the unique characteristics of a deep-seabed mine site (a geologically active and dynamic place situated in a watery, lightless environment nearly a mile beneath the sea's surface) shifts the sense(s) of the sociopolitical terrain at stake' (Childs 2019, 102060). In another study, Childs (2020) argues that the political and legal dimension of DSM requires moving beyond conventional aspects of interstate relations and engaging with recent perspectives in critical social science and theory. He puts forward the idea that a novel spatio-temporal analysis is pivotal in reconceptualizing subterranean geopolitics.

5.4 | Resistance Against DSM

5.4.1 | NGO Activism

Willaert (2021c) examines protests against DSM by giving an example of Greenpeace activists who approached Normand Energy (a ship chartered by Belgian deep-sea mining contractor Global Sea Mineral Resources) and painted slogans on the hull of the vessel and attached banners to the prototype nodule collector in 2021. The author concludes that these practices could be deemed unlawful according to relevant international standards and laws, further pointing out that there is a lack of sufficient enforcement and practical solutions.

In another study, Willaert (2024) analysed the legal dimension of Greenpeace's protest activities against the DSM activities of the Danish-flagged MV Coco on the high seas. Taking into account the ISA response and a decision by an Amsterdam district court, the author again concludes that international law does not provide specific solutions to contractors whose DSM operations are being slowed down by protests.

5.4.2 | Local Resistance

The study by van Putten et al. (2023) focuses on the conflict that occurred over DSM in Papua New Guiana. The authors find that the decrease in social acceptance of DSM played an important role in the conflict situation, ultimately leading to the failure of Solwara 1, a DSM project. The authors explain the decrease in social acceptance by looking at actions of international NGOs, financial concerns involving foreign companies and an imbalance between the country and global companies. Figure 4 illustrates a thematic clustering of the articles analysed in this study.

6 | Insights From a Systematic Review

The primary focus of scholarly attention in the social sciences revolved around exploring policy, legal and socio-economic aspects related to DSM. The prevailing perspective within the policy-oriented literature predominantly emphasizes international regulatory frameworks and the role of international bodies such as the ISA in governing DSM. The dominant perspective within the policy-oriented literature is international. Most studies in this body of literature concentrate on international regulatory frameworks, particularly the role of the ISA in formulating and enforcing regulations pertaining to DSM. In contrast, national-level analyses remain scarce, with only two studies addressing the domestic policy implications of DSM. The disparity in focus between the international and national levels underscores a critical gap in the literature. In this context, more attention should be paid to comparative research evaluating DSM policies in diverse national contexts, with a particular emphasis on countries that are hotspots for deep-sea mining activities.

Existing legal studies on DSM cover different themes, grouped into subcategories such as DSM legislation, the exploitation phase, transparency, UNCLOS implications and equitable sharing of benefits. Further studies of how national interpretations of international DSM regulations show variation will open the door for a more comprehensive understanding of the complexities associated with DSM and its governance. Although equitable benefit sharing has received academic attention, there is a research gap on the legal recognition of indigenous rights in DSM activities. The rapid advancement of technology employed in DSM presents regulatory challenges. Legal researchers should pay more attention to the interaction between existing legal frameworks and innovative technologies in mining practices, especially with regard to automation and artificial intelligence.

Although the environmental risks of DSM have received substantial attention, there is a significant gap in the literature on the examination of potential benefits and drawbacks of DSM activities for local communities, indicating a need for more

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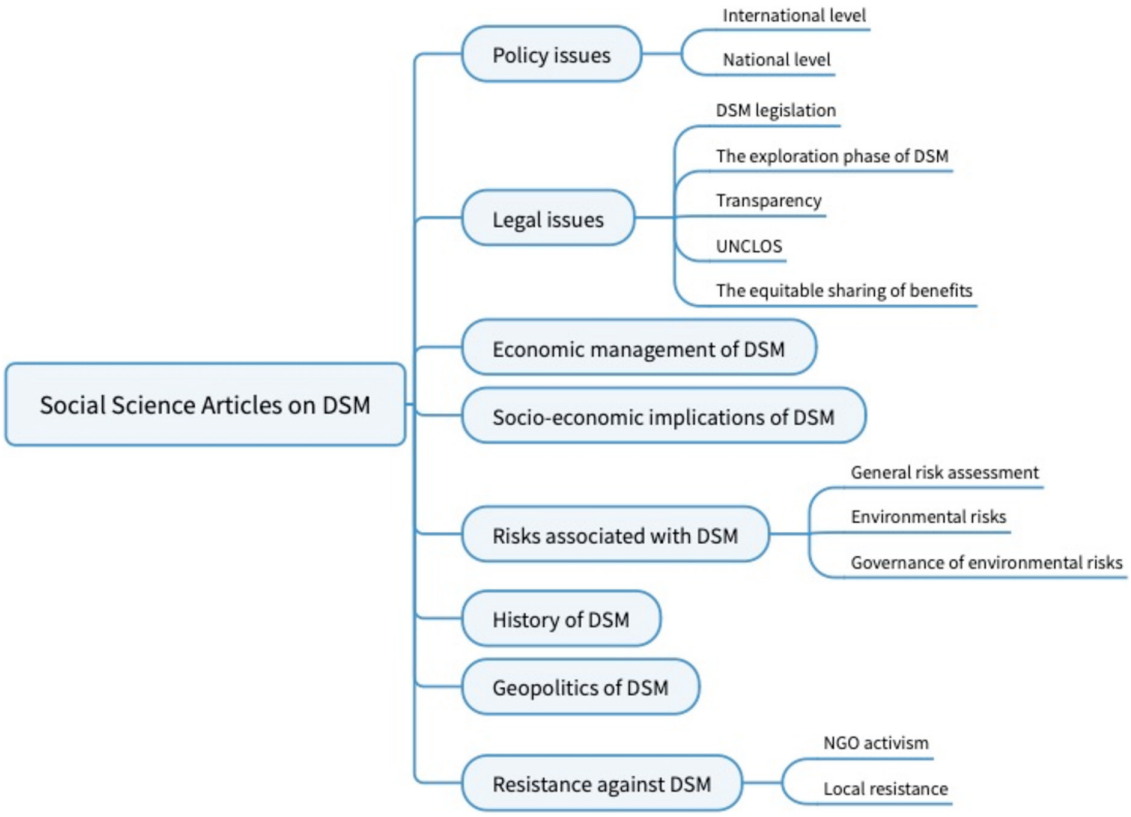


FIGURE 4 | Thematic clustering of social science articles on DSM.

research in this area. Considering that numerous regions designated for DSM activities coincide with indigenous territories, understanding their points of view, rights and suggestions could improve policy frameworks and guarantee more equitable outcomes.

Although there exists a corpus of literature that examines policy issues related to DSM and assesses its geopolitical implications, it is noteworthy that IR scholars are significantly underrepresented in this literature, except for the studies by Karim and Yudha (2021) and Heinrich et al. (2024). Furthermore, there is a notable absence of IR perspectives in the social science literature on DSM. Furthermore, the author's investigation into the presence of DSM articles in the leading IR journals, namely, the *American Journal of Political Science*, the *International Organization* and the *American Journal of Political Science*, did not yield relevant findings when searching for terms related to 'deep', 'sea' and 'mining' within the title of the articles. This absence is surprising given the significant stakes involved in DSM, which intersect with key themes such as maritime security, environmental policy and international cooperation and conflict.

We currently witness an accelerated race to mine the sea floor. DSM might contribute to the alteration of global power dynamics, as countries that have control over key minerals will govern the political economy of the clean energy transition (Coleman 2024; Prasad and Hardy 2023). The intersection of DSM and IR presents a rich terrain for research and analysis. By incorporating IR theories and perspectives, scholars can deepen understanding of the governance, risks and benefits of DSM, as well as DSM-related conflicts.

7 | Direction for Future Research

This section shows potential avenues of contribution of IR scholars by integrating them into current areas of research in the discipline. First, in view of the establishment and evolution of an international deep-seabed regime, the lack of a regime-based analysis hampers the understanding of DSM in a holistic manner. The international deep seabed regime can be effectively analysed through the lens of international regime theories (Hasenclever et al. 1997). IR scholars can analyse and discuss the explanatory power of theories on international regimes (realism, liberalism and cognitivism) in relation to the development of rules and norms associated with the international deep-seabed regime (see Hasenclever et al. 1997). A regime-based analysis can also shed light on potential areas of conflict and cooperation between states involved in DSM activities.

In parallel with greater aspirations to mine the ocean floor, the campaign against DSM is gaining momentum. In the IR discipline, much theoretical attention has been devoted to norm diffusion processes. Initial studies on transnational norm diffusion depicted a linear and progressive trajectory. The norm lifecycle model introduced by Finnemore and Sikkink (1998) identified a three-stage process: norm emergence, norm cascade and internalization. According to the spiral model introduced by Risse and Sikkink (1999), international human rights norms pave the way for a change in policies and laws through a myriad of processes that include adaptation, strategic bargaining, moral consciousness raising, argumentation, persuasion, institutionalization and habitualization.

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Later studies critiqued the linear and progressive perspective of norm diffusion and focused on contestation and backlash in transnational norm diffusion processes (Deitelhoff and Zimmermann 2020; Deitelhoff 2020; Gutterman and Lohaus 2018). Scholars have illustrated that local dynamics play significant roles in preventing the linear diffusion of transnational norms at the domestic level (Checkel 1997; Cortell and Davis 1996; Flockhart 2006).

Cortell and Davis (2000) indicate that national political discourse, the material interests of domestic actors, domestic political institutions and socializing factors operate as pathways that affect the diffusion of transnational norms. Acharya (2004) argues that when there is a great deal of societal resistance, local norm-takers might ensure the congruence of a transnational norm with local beliefs and practices by adjusting it through discourse, framing, grafting and cultural selection (congruence-building). He argues that if the adjusted foreign norm successfully reduces societal resistance, it can even replace its rival domestic norm (Acharya 2004). Restoy and Elbe (2021) illustrate that nonstate actors might pursue successful norm domestication strategies (such as creating political divisions within governments, using legal mechanisms, etc.) even if governments reject transnational norms.

Taking the above-mentioned studies into consideration, it is fair to argue that concepts and theories in the norm diffusion literature provide useful insights into understanding debates that are supportive of and oppose DSM in the international community, NGO campaigns and local resistance against DSM. Furthermore, detailed analyses of the debates and practices against DSM have the potential to generate new theoretical insights in the norm diffusion literature.

Postcolonial theory can provide critical insights into examining the potential implications of DSM on indigenous communities. Furthermore, this theory can be instrumental in analysing the roles of NGOs and local resistance campaigns in the context of DSM. IR scholars can build on and advance the area opened up by the studies of Gentilucci (2022), Childs (2020) and Probyn (2023) that theorize new spatialities that arise with DSM. At this juncture, critical geopolitics provides valuable insight into the theorization of space, spatialities and state power. Critical geopolitics does not view space in neutral and objective terms but rather focuses on its embeddedness in the social reproduction of power (Tuathail and Dalby 1998). It treats space as a complex and dynamic phenomenon, highlighting the dialectical relationship between the social and the spatial (Paasi 2020). It moves beyond traditional understanding of space as 'the plane on which events and objects are located at particular places' (Agnew 2005, p. 81) and 'the study of the geography of politics within pregiven, taken-for-granted, commonsense spaces' (Dalby 1991, p. 274). It rather adopts a relativist perspective by treating space 'as a set of relations between the positions of socially important elements that structure human activities and, at the same time, are structured by human activities' (Pries 2001, p. 16). IR scholars can work at the intersection between critical geopolitics and IR to theorize oceanic space and new spatialities associated with DSM.

Research on DSM has the potential to facilitate a meaningful dialogue between the disciplines of IR and international law. The interwar period witnessed a close dialogue between these two disciplines. During this period, many scholars of international law introduced innovative ideas to the problems of IR (Long 2003) and IR scholars gave pivotal importance to international law in their theorizing. The distance between the disciplines of IR and international law grew in the aftermath of World War II. Against the backdrop of the end of the Cold War and the rise of new, complex global challenges, the two disciplines have engaged in a renewed dialogue (Oztig 2024). DSM has the potential to produce valuable research and new insights at the intersection of these two disciplines.

8 | Conclusions

DSM is gaining popularity both as an industry and as a field of study in parallel with growing demands for metals and minerals and aspirations towards a faster green energy transition. There are heated debates surrounding whether DSM might be a fast-forward solution to energy transition or whether it might accelerate environmental degradation by destroying the oceanic ecosystem. While these debates continue, there are important developments regarding the DSM. By 2025, ISA is expected to complete the Mining Code on the exploitation stage of DSM. As of January 2024, Norway has become one of the first countries in the world to pass a bill to open its continental shelf to commercial DSM (Stallard 2024), an issue that led the European Parliament to express concern.

This study reveals that the social sciences lag behind in exploring and theorizing DSM. Among the social science disciplines that focus on DSM, IR is one of the disciplines that devoted the least attention to the topic. IR scholars' scarce attention to DSM prevents a comprehensive understanding of the implications of DSM and practices related to it on a global scale. Equally important, exploring the uncharted territory of DSM provides IR scholars with a unique opportunity to expand the boundaries of the discipline and introduce new concepts and theoretical perspectives that can enrich our understanding of ocean governance, interstate collaboration and conflict and international organizations. Studies that analyse the linkages between DSM, ocean governance and global security can provide valuable insights for policymakers. More specifically, analysing ocean governance through the lenses of resource scarcity and human rights can inform the development of policies that prioritize sustainable development and equitable access to maritime resources. Given the extraordinary developments and complicated challenges surrounding resource extraction and management, there is a pressing need for collaboration not only between social sciences, but across multiple disciplines that involves both physical and applied sciences as well as social sciences.

Conflicts of Interest

The author declares no conflicts of interest.

Data Availability Statement

Data sharing is not applicable to this article as no new data were created or analyzed in this study.

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Endnotes

[1] Simon-Lledó et al. (2019) demonstrate the long-lasting effects of the simulated polymetallic nodule mining activities conducted in the Peru Basin in 1989, revealing that disturbances continue to affect marine life even after decades, including significant reductions in some organisms.

[2] See https://seabedminingsciencestatement.org.

[3] See Pliant's robots, https://www.pliantenergy.com/robotics. I would like to thank Prof. Victor Tenorio from the Department of Mining and Geological Engineering at the University of Arizona for giving me insight on this topic.

[4] The author acknowledges a potential limitation within the current research framework. Future studies could utilize computational bibliometric tools to analyse the citation impacts of social science articles on DSM (i.e., Mehmetcik et al. 2024). This approach could reveal the extent to which social science articles on DSM are cited both within the social sciences and in other academic disciplines.

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