Institutional Dynamics and Challenges in the Seaweed Industry: A Global Perspective

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ABSTRACT

The seaweed industry has experienced rapid growth and has evolved into a strategic sector within the global economy, contributing to food security, the bioeconomy, climate change mitigation, and the substitution of fossil-based materials. This review aimed to clarify the main institutional challenges in the seaweed value chain, compare governance approaches across regions, and propose evidence-based recommendations for inclusive and sustainable policy reform. A systematic literature review of peer-reviewed articles from the Scopus, Web of Science, and FAO databases was conducted, followed by a thematic analysis to distill key governance challenges and transformation strategies. Significant barriers identified include regulatory overlaps, stakeholder conflicts, and unequal access to information and technology. Comparative insights indicate that aligning national policies with local community practices and harmonizing certification schemes can enhance competitiveness and promote downstream value addition. However, social dimensions—particularly gender equity and the inclusion of marginalized groups—remain insufficiently addressed. The findings emphasize the need for adaptive and participatory governance frameworks that integrate both top-down and bottom-up approaches. Key recommendations include fostering transparent multi-actor dialogue, achieving regulatory harmonization, and developing social equity metrics to support inclusive, resilient, and sustainable growth.

INTRODUCTION

The seaweed industry has undergone rapid growth and has become one of the strategic sectors in the global economy **(Wang *et al*., 2023)**. Its role extends beyond being a mere export commodity, encompassing dimensions of food security, bioeconomy development, climate change mitigation, and the substitution of fossil-based materials through bioplastics **(Jagtap & Meena, 2021; Nilsson *et al*., 2022; Wang *et al*., 2025)**. Within the framework of sustainable development, this sector holds a vital position in both the green economy, which focuses on resource efficiency and carbon emission

reduction, and the blue economy, which emphasizes the sustainable use of marine resources for economic growth, improved livelihoods in coastal communities, and the preservation of marine ecosystems. In alignment with global commitments to the Sustainable Development Goals (SDGs), particularly SDG 1 (No Poverty), SDG 2 (Zero Hunger), SDG 8 (Decent Work and Economic Growth), SDG 12 (Responsible Consumption and Production), SDG 13 (Climate Action), and SDG 14 (Life Below Water), the development of the seaweed industry emerges as a key element in the transition toward an inclusive and equitable blue economy.

This sector not only serves as a cornerstone for coastal nations to enhance local community welfare, but also plays a critical role in supporting global food security, expanding employment opportunities, and strengthening the diversification of the maritime economy **(Cooke, 2004; Sultana** *et al.,* **2023)**. However, this rapid growth comes with complex challenges. According to a report by the Food and Agriculture Organisation **(FAO, 2024)**, global seaweed production has surpassed 37.8 million tons annually, with Asia contributing approximately 97% of the total. Countries such as Indonesia, the Philippines, and China dominate the global market, with export values reaching billions of U.S. dollars. While these figures reflect the tremendous potential of seaweed to support economic growth and food security, the high dependency on this commodity also brings significant risks, such as global price volatility, excessive pressure on ecosystems, and unequal distribution of economic benefits **(Mulyati & Geldermann, 2017; Campbell** *et al.,* **2021; Suyo** *et al.,* **2021; Iqbal, 2022)**. Institutional issues further complicate the landscape. Regulatory overlaps, conflicts of interest among stakeholders, and unequal access to information and technology represent significant barriers within the supply chain. This ineffective governance not only hinders local economic development but also poses threats to marine ecosystems, contradicting the principles of the blue economy, which emphasize a balance between economic growth, social inclusivity, and environmental sustainability.

In this context, institutions are understood as the entire system encompassing legal frameworks, policies, social norms, local practices, and actor networks that shape patterns of interaction within the seaweed industry value chain. The effectiveness of governance is strongly influenced by the synergy between formal institutions, such as regulations and international standards, and informal institutions, which include local community practices and traditional knowledge. A lack of harmony between these systems often results in policy implementation gaps, reduced operational efficiency, and the emergence of on-the-ground conflicts. These issues are further complicated when global regulations and international market demands are misaligned with local capacities, thereby hindering efforts to achieve the Sustainable Development Goals (SDGS) and implement the principles of the blue economy effectively. However, despite numerous studies on specific technical and environmental aspects, comprehensive reviews that integrate

formal and informal governance dimensions across diverse regional contexts remain scarce.

This literature review aims to provide an in-depth understanding of institutional dynamics within the seaweed industry by systematically reviewing, analyzing, and critiquing previous studies. In the face of a dynamic global context, characterized by shifting international regulations, technological advancements, and evolving market preferences, institutional adaptation must be reactive and proactive in addressing these challenges. Within the blue economy framework, assessing how national policies and local practices align with international commitments to sustainable marine resource management is essential. Local social, economic, and political factors must be carefully considered when analyzing institutional responses at both national and local levels, as the success of any policy is highly dependent on the context in which it is implemented.

Most existing studies have focused on technical aspects such as cultivation methods, productivity enhancement, and processing of seaweed-derived products. Research addressing environmental dimensions and sustainability certifications is also relatively abundant, particularly due to their relevance to SDGS 12 and 14. However, comprehensive analyses of institutional dynamics, especially those involving cross-country comparisons, remain limited. The available literature tends to be fragmented, often concentrating on isolated aspects without considering the interactive relationships among actors, which are crucial for the successful implementation of policies. The lack of studies integrating formal and informal institutional dimensions underscores the need for further investigation. Given the complexity of the issues, a deeper understanding of both synergies and potential conflicts among actors within institutional systems is essential for formulating effective and adaptable strategies to local and global dynamics.

Social elements also remain largely overlooked. Recent findings further reveal the importance of social dimensions, represented by aspects such as job creation, primary producer participation, food and energy security, stakeholder engagement, community acceptance, impacts on local populations, worker welfare, education, gender equality, cultural values, and the potential for conflict (**Cerca *et al*., 2022**). Without comprehensive institutional reform, the seaweed industry risks stagnation or regression amid intensifying global market competition. Obstacles such as bureaucratic inefficiencies, incoherent policies, and poor interagency coordination may hinder the sector's potential.

Therefore, this literature review aimed to synthesise and analyze key findings from institutional studies of the seaweed industry; identify dynamics that influence institutional effectiveness; uncover key challenges and best practices from diverse global contexts; and offer evidence-based recommendations to strengthen institutions with a focus on innovation, sustainability, and inclusivity. By addressing the identified gap, this review contributes to the theoretical advancement of institutional ocean-governance literature

and practical policy guidance for stakeholders in the seaweed sector. In line with global commitments to the SDGS and the implementation of the blue economy, the results of this literature review are expected to serve as a strategic reference for shaping policies that promote economic growth, ensure marine ecosystem sustainability, and improve the welfare of coastal communities. Through a more holistic understanding of institutional dynamics, this review seeks to foster collaborative strategies that support a fair, adaptive, and resilient seaweed industry in the face of global challenges.

REVIEW OF THE LITERATURE

This literature review includes publications up to March 2025, emphasizing the latest empirical and review studies on institutional governance in the seaweed industry. For clarity, the discussion is organized into five themes.

1. Institutional issues and challenges in the seaweed industry

The global seaweed industry faces complex institutional challenges, primarily due to the absence of a clear, consistent, and comprehensive regulatory framework **(FAO, 2024; Muflikh** *et al***., 2024)**. In many countries, existing regulations have not kept pace with the sector's rapid development, particularly in aquaculture, food safety, and cross-border trade. This regulatory gap significantly hinders the creation of a stable investment climate and impedes technological advancement and industrial innovation. For example, in Iceland, although regulations exist for harvesting wild seaweed, no specific policies govern offshore seaweed farming, creating legal uncertainty for industry stakeholders **(Purcell & Quintero, 2024)**. Similar situations occur in developing countries such as Indonesia, where national policies often misalign with local practices, leading to overlapping regulations and difficulties in implementation **(Tombolotutu** *et al***., 2019; Nuryartono** *et al***., 2021)**. These conditions highlight weak inter-agency coordination and the limited involvement of local communities in policy-making processes.

Moreover, tensions between adaptive management approaches and conservation preservation frequently emerge in marine policy contexts, where many legal frameworks lack the flexibility to respond to the fast-changing dynamics of ecosystems and markets **(Camacho & Glicksman, 2016)**. This misalignment is especially pronounced in developed and developing regions, hindering timely policy adaptation and stakeholder trust. Rigid conservation policies that fail to account for environmental or social changes may exacerbate legal uncertainty and restrict the operational scope of industry actors. The challenges become even more pronounced when multiple actors—including governments, industries, and local communities are involved, often resulting in conflicts of interest over seaweed resource governance **(Pandleton & Carr, 2022)**. In Indonesia, for instance, the involvement of a wide range of stakeholders has complicated the implementation of industry roadmaps and efforts to manage price fluctuations **(Busthanul** *et al***., 2020)**. The absence of transparent and equitable conflict resolution mechanisms contributes to stagnation in the execution of development programs.

This situation is further compounded by a highly centralized institutional structure, with over one-third of policies issued at the presidential level, raising concerns about the effectiveness of top-down approaches in marine resource management **(Permani *et al*., 2024)**.

The seaweed industry in Indonesia also faces difficulties in creating a conducive policy environment to support the growth of this sector **(Permani, 2024)**. On the other hand, this top-down approach often overlooks local dynamics and the specific needs of coastal communities, which are at the forefront of seaweed cultivation and processing activities. The mismatch between central policies and on-the-ground realities weakens the industry's competitiveness and hinders the acceleration of sustainable sector development.

From technical and social perspectives, disparities in access to information, technology, and digitalization remain significant obstacles. Seaweed farmers in Indonesia generally have low education levels and skills and limited infrastructure support, which hampers their access to market information and more modern cultivation technologies **(Pulubuhu *et al*., 2021)**. This digital gap causes farmers to be isolated from global market developments and the latest technologies, further strengthening their dependence on intermediaries in the supply chain. This results in a mismatch between global standards and local capacities, creating challenges in supply chain governance **(Purcell & Quintero, 2024)**.

Globally, food safety standards for seaweed are still inadequate, with significant gaps in regulations and available technical guidelines. Seaweed has not yet been fully recognized within the international food safety system, even though challenges such as contamination from marine pollutants and integration into Western consumption patterns require more attention **(Banach *et al*., 2020; Guo *et al*., 2024)**. The lack of harmonization of international regulations causes market uncertainty and could hinder seaweed exports from developing countries without globally recognised quality certification systems. Furthermore, the lack of accurate and comprehensive official data on seaweed production, trade, and consumption poses a barrier to evidence-based decision-making for governments and industry players. Investment in better data systems is urgently needed to improve the quality and comparability of information **(Webb *et al*., 2023)**.

The lack of understanding of seaweed production patterns also limits the effectiveness of policy interventions and coordination among actors in this sector **(Langford *et al*., 2020)**. Without valid and reliable data, it is difficult to design long-term strategies to address climate change challenges, market demand, and local capacity development needs.

Institutional challenges also encompass social and sustainability aspects. The economic legitimacy of seaweed depends on integrating ecological, economic, and social pillars. However, in practice, there are disparities in benefit distribution, access conflicts,

and new vulnerabilities in coastal communities. Gender inequality and social justice have also emerged, indicating that sectoral policies need to consider vulnerable groups, including women and indigenous communities **(Steenbergen, 2017; Marino** *et al.***, 2019; Suyo, 2020; Langford, 2023)**. These aspects are often not part of institutional performance indicators, yet they are crucial for the long-term success and inclusivity of the marine sector's development.

Furthermore, developed countries have gone further in the development of functional seaweed-based products for food, cosmetics, pharmaceuticals, and bioenergy. In contrast, developing countries like Indonesia still rely on exporting raw materials with low added value, indicating a structural gap in the global value chain **(Suyo** *et al.***, 2020)**. This highlights the need for stronger institutional interventions to support local innovation, strengthen SMES, and create incentives for downstream seaweed product development.

Institutional mechanisms such as social policies and economic support also play a role in facilitating the welfare of coastal communities. Without strong institutional support, achieving a sustainable and inclusive seaweed industry will be difficult **(Suyo** *et al.***, 2020)**. These institutional functions are vital for creating fair incentive systems, supporting social stability, and encouraging active community involvement in resource management.

2. Innovation and institutional transformation

The seaweed industry in Indonesia faces intense global competition, yet it also holds significant growth opportunities if it can undertake the right institutional transformations. Despite the real threat posed by global competition, Indonesia must enhance its production quality in response to changing demands **(Rimmer** *et al.***, 2019)**. This indicates that transformation must go beyond technical aspects and requires profound institutional reforms to enhance efficiency, transparency, and competitiveness.

From a public policy perspective, various laws and regulations, including national roadmaps, have been issued to support the industry and its sustainable development **(Rimmer** *et al.***, 2019; Muflikh** *et al.***, 2024)**. However, the effectiveness of these policies is often hindered by a lack of cross-sectoral integration and the exclusion of key stakeholders, particularly smallholder farmers and women's groups, from the formulation and evaluation processes.

The level of sustainable entrepreneurial behavior among fisheries entrepreneurs is remarkable, reinforced by the crucial roles played by values, innovation, and proactivity. However, a significant barrier remains in the lack of government support and the impact of regulations on this behavior. A comprehensive and integrated strategy that accounts for entrepreneurial orientation, gender inclusivity, value alignment, educational initiatives, and community engagement is essential **(Sobuj** *et al.***, 2024)**. This indicates that institutional transformation is both structural, normative, and cultural, where a bottom-up approach must be integrated with top-down policy frameworks.

Lessons from the first national roadmap reveal that stakeholders were involved only after the draft development, with minimal engagement during and after implementation **(Muflikh *et al*., 2024)**. In reality, the success of implementation heavily depends on a sense of ownership and social legitimacy among field actors. Practical participatory approaches should be considered, such as developing group models as part of systems thinking to identify root problems and their interconnections before developing potential solutions **(Muflikh *et al*., 2024)**. Such approaches can strengthen trust among actors and build more resilient institutional networks.

Governance frameworks should not be static, as adaptive learning is essential. Adaptive governance must also consider the relationship between formal and informal laws, government institutions and coastal communities **(Satria *et al*., 2017)**. This is crucial in Indonesia's diverse social and ecological coastal areas, where local norms often influence more than national laws.

While stakeholder participation and collaboration are key to success, they also present significant challenges in implementation. Decision-making processes must involve diverse groups, ranging from input suppliers to marketing agents, policymakers, and local communities **(Martinkus *et al*., 2019; Alcocer Garcia *et al*., 2022)**. Therefore, a formal and continuous multi-actor dialogue mechanism is essential for effective collaboration and decision-making.

Stakeholder cooperation is crucial for the successful integration of offshore cultivation. Developing joint logistics guidelines and protocols, such as establishing clear maintenance routes and promoting sustainable port expansion plans, can enhance operational efficiency. Furthermore, prioritizing innovation can help mitigate operational and environmental challenges associated with the growth of this industry **(Miranda *et al*., 2025)**. This example highlights the potential for cross-sector synergies in seaweed's multifunctional and sustainable development.

Innovation in seaweed cultivation is also necessary, such as developing disease-resistant strains, enhancing cultivation technologies, and implementing effective mitigation strategies. Establishing disease-resistant macroalgae gene banks and genetic resources is vital for maintaining genetic diversity and ensuring sustainable growth **(Khan *et al*., 2024)**. This becomes increasingly critical amidst growing biological risks due to climate change and intensified production pressures.

Empowering seaweed farming communities can be achieved through well-coordinated public funding that facilitates the commercialization potential and the production of value-added products. Farmers require access to educational programs that address the management of threats and challenges and assistance in acquiring planting supplies and agricultural equipment at lower or subsidized prices **(Khan *et al*., 2024)**. Such programs can help narrow the gap between small and large-scale actors within the seaweed value chain.

The government must enforce globally acceptable norms and protocols for monitoring pest outbreaks and disease propagation. Consistent nationwide practices will minimize risks and promote responsible resource management **(Khan *et al*., 2024)**. Environmentally sustainable targets include achieving specific production levels to meet market demands while promoting carbon neutrality through seaweed cultivation **(Khan *et al*., 2024)**. In this way, seaweed can become part of the global solution to climate and food security crises.

Collaboration between scientists, researchers, policymakers, and industry stakeholders is essential to unlock the full potential of seaweed farming for a sustainable and resilient future. Scientists should prioritize research on specific challenges, policymakers should implement supporting regulations, and investors should embrace seaweed innovation **(Khan *et al*., 2024)**. This cross-disciplinary collaboration must be organized through transparent and accountable institutional mechanisms.

Policies should leverage the expertise of key community members to gain sufficient acceptance and to support for the expansion of sustainable cultivation **(Fong *et al*., 2024)**. Local communities should not merely be subjects of policies but equal partners in institutional innovation. A noteworthy example is Norway, where decision-making has been decentralized to the point that local organizations do not need to go to Oslo to make significant financial decisions regarding loans and credits. Innovation Norway has played a pivotal role in stimulating and catalyzing innovative efforts **(Tett *et al*., 2025)**. This practice can be an important inspiration for Indonesia in designing an efficient and responsive decentralization framework.

Comprehensive and efficient governance that promotes participatory management can enhance the ability to address increasingly unfavorable scenarios for small-scale seaweed farming **(Henríquez Antipa & Cárcamo, 2019)**. It is recommended that government programs providing incentives for biosecurity in rural smallholder agriculture be adapted for the seaweed industry **(Campbell, 2022)**.

3. Comparative study of institutional management in the seaweed industry

Cross-national comparative studies indicate that institutional approaches to seaweed industry management vary widely, reflecting each country's unique social, political, and economic contexts. In Bangladesh, achieving the Sustainable Development Goals (SDGS) is central to the national strategy, with seaweed production as a potential driving force for sustainable development **(Hossain *et al*., 2021)**. However, despite its considerable potential, several countries still lack comprehensive institutional frameworks for managing coastal and marine resources **(Sobuj *et al*., 2024)**. Meanwhile, Indonesia, as the world's leading seaweed producer, faces significant challenges related to regulation and institutional coordination **(Suyo *et al*., 2020; Permani *et al*., 2024)**. The country's policies often overlap and burden industry actors with navigating the complexities of policies spread across multiple sectors, including international trade **(Tombolotutu *et al*., 2019; Nuryartono *et al*., 2021)**. In contrast, the Philippines has

implemented a community-based adaptation strategy and inclusive governance forums that enable meaningful local participation in seaweed management **(Suyo *et al*., 2020; Asri *et al*., 2021)**.

In Europe, regulatory approaches emphasize stakeholder representation and involvement. In Norway, the dynamics between local, regional, and industry interests often lead to tensions among advisory groups during decision-making processes **(Greenhill, 2021)**. In Scotland, various opinions from consultants are presented by regulators without significant mediation efforts in decision-making **(Cleaver & Whaley, 2018)**. A top-down management approach in Ireland conflicts with traditional local seaweed harvesting practices **(Pendleton & Carr, 2022)**. Comparative insights highlight that high institutional trust and decentralized decision-making correlate with more adaptive governance, while overlapping mandates and low stakeholder engagement exacerbate regional coordination failures.

Trust in governmental institutions also plays a crucial role in the effectiveness of management. Nordic countries like Norway generally enjoy high public trust, positively influencing public expectations and behavior. In contrast, in Brazil, central government intervention in regulating the market through production area licensing has been an important step in stimulating growth in the sector **(Tett *et al*., 2025)**.

Social challenges also emerge in migration, where migrants face institutional barriers that limit their participation in the seaweed industry **(Asri *et al*., 2021)**. In France, social acceptance of the industry is higher when it operates on a small scale with strict and transparent environmental regulations. In contrast, the primary focus in Scotland is on creating local employment opportunities and fostering social entrepreneurship **(Billing *et al*., 2021)**.

One of the main barriers to the growth of the seaweed industry in developed countries is the issue of social acceptance and local interactions, which can hinder the expansion of aquaculture ventures **(van Putten *et al*., 2018; Mather & Fanning, 2019)**. Various institutional interventions are needed to address these challenges, considering production and economic aspects, social and ecological benefits, and potential risks. A comprehensive evaluation of policies and investments supporting the seaweed system will be crucial in determining the direction of inclusive and sustainable development **(Fujita, 2023)**.

4. Criticism of seaweed governance

The governance of the seaweed industry across various regions has faced significant criticism, particularly regarding stakeholder dynamics, regulatory effectiveness, and justice dimensions. One of the main challenges is the complexity of managing diverse perspectives, priorities, and conflicting interests among stakeholders **(Muflikh *et al*., 2024)**. Symbolic participation without real influence undermines trust and disengages stakeholders **(Cleaver & Whaley, 2018; Greenhill, 2021)**. Negative

perceptions of the industry can be reinforced by the legacy of poor practices in other aquaculture sectors, including concerns about harmful algal blooms and greenwashing **(Spillas *et al*., 2022)**. The lack of a strong social license remains a significant barrier to the public acceptance of seaweed industry development.

Criticism also arises from the limited empowerment of local stakeholders in decision-making processes. The lack of involvement of local stakeholders not only diminishes opportunities for strengthening adaptive governance but also undermines their future participation, as their experiences and knowledge are not incorporated into policies **(Greenhill, 2021)**. In some cases, such as in Norway and Scotland, participatory processes have failed to meet stakeholders' expectations, leading to disappointment **(Cleaver & Whaley, 2018; Greenhill, 2021)**. Therefore, symbolic participatory involvement without the ability to influence policy is considered insufficient **(Greenhill, 2021)**.

From a regulatory perspective, there is criticism of the inadequate regulatory framework and the lack of coordination between policies. Seaweed consumption regulations remain fragmented and narrowly focused in some regions, such as the European Union and China **(Guo *et al*., 2024)**. Comprehensive risk assessments covering contaminants, invasive species, and climate risks are rarely mandated, exposing gaps in food safety and environmental safeguards **(Banach *et al*., 2020; Liu *et al*., 2024)**. Additionally, the adaptive capacity of legal instruments varies, with Norway showing flexibility in revising regulations, while Scotland tends to limit future policy changes **(Greenhill, 2021)**. Weak coordination between legal instruments with differing mandates further complicates governance **(Greenhill, 2021)**.

Justice remains a critical focal point of criticism in seaweed governance. Conditional justice approaches fail to redress benefits-sharing inequalities, land tenure, and gender equity **(Marino *et al*., 2019; Steenbergen, 2017)**. Addressing these requires embedding distributive, procedural, and recognition justice principles into institutional performance metrics. These disparities are particularly evident in the context of access to resources, land rights, and income distribution, including gender inequality within the industry **(Andriesse, 2017; Steenbergen, 2017; Marino *et al*., 2019; Suyo, 2020; Langford, 2023)**. Existing policies often fail to integrate distributive, procedural, and recognition justice principles in a balanced manner **(Albrecht, 2025)**.

Furthermore, challenges arise from the inherent uncertainty within fisheries and aquaculture systems, whether ecological, economic, social, or institutional **(Benson & Stephenson, 2018; Hsiao, 2022)**. In Indonesia, for example, despite a seaweed development roadmap, its implementation has been weak due to the lack of binding mechanisms and limited coordination and transparency in information sharing **(Busthanul *et al*., 2020)**. The lack of understanding of production patterns further complicates coordination between farmers, traders, and processors, thus limiting the effectiveness of policy interventions **(Langford *et al*., 2020)**. To improve governance, it

is necessary to strengthen mechanisms for dialogue among stakeholders grounded in a standard scientific foundation **(Cabral *et al.*, 2016)**, as well as the integration of scientific and local knowledge in policy formulation. This process requires negotiation spaces that allow for balancing benefits and risks, while considering the social-ecological context of each region.

5. Need for integration of multilevel approaches

The seaweed industry faces complex institutional challenges that require a multilevel and cross-sectoral approach. While stakeholders play a critical role, divergent perspectives and competing interests often hinder effective coordination **(Muflikh *et al.*, 2024)**. Comprehensive governance frameworks that integrate legal, social, and technical dimensions across scales remain limited. At the industry level, navigating fragmented and overlapping policies presents a significant barrier **(Tombolotutu *et al.*, 2019; Nuryartono *et al.*, 2021)**, particularly in the absence of an international legal framework specifically protecting the rights and interests of seaweed farmers **(Liu *et al.*, 2024)**. This governance gap highlights the urgent need for legal instruments that explicitly support smallholder seaweed farmers at both national and international levels. Strengthening international regulatory systems and ensuring their consistent enforcement is therefore a pressing priority.

Institutional weaknesses in environmental protection are also evident. The spread of non-native macroalgae species and increasing marine pollution illustrate the limited capacity of existing institutions to monitor and respond to such threats. Monitoring of invasive marine species has yet to become a regulatory standard in many countries, resulting in minimal preventative action informed by empirical data **(Liu *et al.*, 2024)**. To address this, digital monitoring platforms should be established to enable real-time data sharing and early institutional response. Furthermore, the integration of scientific and local knowledge—a cornerstone of adaptive governance—remains largely unrealized. Stakeholder forums that bridge different knowledge systems are notably absent **(Greenhill, 2021; Mwanyoka, 2025)**. This disconnect underscores the need for reform at both micro and macro levels: locally, by strengthening community involvement in marine spatial planning and zoning; and nationally and globally, by ensuring that conservation laws formally recognize informal practices **(Satria *et al.*, 2017)**.

Persistent social and political gaps also pose challenges, particularly in reaching marginalized groups such as migrant workers and traditional fishing communities, who are often excluded from decision-making processes **(Asri *et al.*, 2021; Mwanyoka, 2025)**. Unequal access to training, technology, and information further hampers the inclusive development of the seaweed industry **(Suyo *et al.*, 2020)**. Social dimensions—including job quality, consumer preferences, and public awareness—are insufficiently considered in current policy frameworks **(Wheeler *et al.*, 2018)**. As such, institutional integration must involve close collaboration among governments, industry actors,

researchers, civil society, and development partners to formulate coherent sectoral strategies, strengthen market infrastructure, and design adaptive, inclusive regulations **(Spillas, 2022; Webb *et al.*, 2023)**.

A multilevel approach must also address the issue of social trust. Top-down decision-making, detached from local realities, often breeds distrust and resistance. Conversely, when government and industry are embedded within communities, they can foster constructive social relationships **(Mabon & Kawabe, 2018; Firestone & Kirk, 2019)**. Transparent, participatory, and science-based communication is thus critical to the success of cross-scale governance efforts **(Cabral *et al.*, 2016; Billing *et al.*, 2021)**.

In conclusion, the sustainable development of the seaweed industry hinges on institutional integration that is multilevel, cross-sectoral, and transdisciplinary—while simultaneously addressing its social, ecological, and economic dimensions **(Henríquez-Antipa & Cárcamo, 2019; Fujita, 2023; Lyons *et al.*, 2023)**. Cohesive governance models must harmonize regulations, embed data-driven monitoring mechanisms, and ensure inclusive stakeholder engagement across all scales.

CONCLUSION

Based on this literature review, the global seaweed industry offers significant opportunities for food security, the blue economy, and climate change mitigation. However, its effectiveness is highly dependent on the quality of institutional governance. Regulatory overlaps, conflicts of interest between government, industry, and local communities, and gaps in access to information and technology remain significant barriers that reduce the inclusivity and sustainability of the seaweed sector. Adaptive institutional transformation that integrates both top-down and bottom-up approaches, combining formal legal frameworks with local practices, and promoting multi-actor participation, has proven essential in enhancing efficiency, transparency, and social legitimacy. Cross-country comparative studies emphasize that the synergy between national policies and local community initiatives, supported by data and global certification protocols, can strengthen competitiveness and drive downstream value-added products. However, without comprehensive institutional reforms, including harmonizing international regulations, fair conflict resolution mechanisms, and integrating social values such as gender justice and coastal community welfare, the seaweed industry risks stagnation and exacerbating inequality in benefits.

Therefore, strengthening institutional integration through multilevel dialogue, cross-sectoral collaboration, and investments in innovation and local capacity is a prerequisite to steering the seaweed industry toward inclusive, resilient, and sustainable growth. This review bridges the identified gap by integrating formal and informal governance dimensions across diverse regional contexts, offering theoretical insights and practical guidance for policymakers and stakeholders in the seaweed sector.

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