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Leaving the shore

Marine-based substitutes and alternatives to plastics

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Abbreviations

ABS	access and benefit-sharing
ASC	Aquaculture Stewardship Council
ASTM	American Society for Testing and Materials
AVE	ad-valorem equivalents
CAGR	compound annual growth rate
CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora
CSOs	civil society organizations
FTA	Free trade agreement
GSC	Global Seaweed Coalition
HS	Harmonized Commodity Description and Coding System
ISA	International Seabed Authority
KIIs	key informant interviews
LCA	life cycle assessment
MBSAs	marine-based non-plastic substitutes and alternatives
MEAs	multilateral environmental agreements
MFN	most favoured nation
MSC	Marine Stewardship Council
NTMs	non-tariff measures
P&C	Principles and Criteria (of UNCTAD BioTrade)
PE	polyethylene
PHAs	polyhydroxyalkanoates
PPMs	process and production methods
PS	polystyrene
SIDS	Small Island Developing States
SMEP	Sustainable Manufacturing and Environmental Pollution Programme
SPS	sanitary and phytosanitary (measures)
TBT	technical barriers to trade
TrPMs	trade-related policy measures
TÜV	Technischer Überwachungsverein (Technical Inspection Association)
VSS	voluntary sustainability standards
WCO	World Customs Organization
WIPO	World Intellectual Property Organization
WTO	World Trade Organization
WWF	World Wildlife Fund

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Executive summary

Executive summary

Plastic pollution threatens marine ecosystems, human health, and economic development. The excessive use of plastics, coupled with inadequate waste management systems, has led to the accumulation of plastic debris and plastic particles in oceans, posing risks to marine life and coastal communities.

In response to this growing crisis, a United Nations Global Plastics Treaty is under negotiations. UNCTAD has been conducting research and advocating for the recognition of non-plastic substitutes and alternatives in the future treaty.

This report builds on previous research and explores the role of marine-based non-plastic substitutes and alternatives (MBSAs). These alternatives, derived from marine resources such as seaweed, algae, and marine minerals, offer potential to replace conventional plastics in various applications, thereby reducing plastic waste and supporting sustainable development. Unlike conventional plastics, MBSAs are of natural origin, ranging from algae-based polymers for bioplastics to mineral compounds used as fillers in glass and ceramics.

Using a mixed-methods approach combining desk research, original data analysis, and key informant interviews (KIIs) (see Annex 1), this study investigates the economic feasibility, benefits, and trade implications of MBSAs, emphasizing their dual role in mitigating plastic pollution and promoting socioeconomic development, particularly in coastal regions and Small Island Developing States (SIDS). It also identifies and discusses key challenges related to the development of global MBSA industries in all three dimensions of sustainable development: economic, social, and environmental, assessing the maturity and overall fitness of enabling policy frameworks.

In principle, marine-based materials can be viable alternatives to fossil fuel-based plastics due to their biodegradability, good functionality (e.g., strength, flexibility) and relatively low environmental footprint. Their widespread use in supply chains, such as packaging, could significantly reduce plastic waste and its negative impact on the marine environment. The global commitment to sustainability and the potential of marine natural capital to support transitions to environmentally friendly, equitable and inclusive production systems are also enabling MBSAs. However, well-documented risks associated with marine resource exploitation – such as the depletion of habitats, ocean acidification and chemical pollution, including from unregulated or intrusive seabed mining – require careful consideration.

By reviewing case studies of successful MBSA implementation worldwide, the study demonstrates that MBSAs, such as algae-based biopolymers, can replace conventional plastics in various of applications, including but not limited to packaging and textiles. In this view, the further development and market uptake of MBSAs can also add value to upstream ocean industries, such as seaweed farming. We assess practical viability and market potential providing a basis for further policy and analytical work.

UNCTAD advocates for the recognition of non-plastic substitutes and alternatives in the future Global Plastics Treaty

Global MBSA exports reached $10.8 billion in 2022, growing three times faster than synthetic polymers over the past decade

The socio-economic benefits of MBSAs typically include job creation, economic diversification and improved livelihoods, particularly for youth and women, as well as fostering indigenous innovation, resilience to economic shocks, and food security. Challenges involve the need for technological innovation and diffusion, sustainable harvesting practices, and market access. At present, high costs and unfavourable economics hinder market development in several locations. Robust supply chains need to be established, with targeted investments in research and development and public-private partnerships to support the growth of the MBSA sector.

Sustainability is also a key driver for the development of MBSA industries, requiring policy frameworks that enable fair supply chain relationships and sound natural resource management. In this context, life cycle assessment (LCA) is important to ensure that the environmental benefits of MBSAs, such as the low carbon footprint in production, are not offset by negative impacts at other stages of their life cycle. This is the case with marine bioplastics, which can release greenhouse gases (GHGs) during decomposition in the absence of industrial composting facilities.

Bilateral trade flow data show that the global market for MBSAs is growing with significant potential for expansion. After growing three times faster than synthetic polymers exports between 2012 and 2022, global MBSA exports reached $10.8 billion in 2022. The participation of coastal developing countries in this market has also increased over time, with some becoming trading powerhouses for certain products (e.g., Indonesia for seaweed).

However, tariffs and non-tariff measures (NTMs), including environmental, health and safety requirements, hinder market access for these materials, especially in developing countries. Except for marine minerals, all MBSAs are subject to higher tariffs and more stringent NTMs than conventional plastics. Sanitary and phytosanitary (SPS) measures linked to their trade can result in high compliance costs for companies. This is the case of seaweed, where health rules for edible products also apply to non-food materials used in packaging. Reducing trade barriers and harmonizing rules can enhance the global competitiveness of MBSAs, such as through multilateral trade and environmental agreements and standard-setting initiatives.

In moving forward, multi-stakeholder and international cooperation is essential to address these challenges and fully unlock the potential of MBSAs. These materials offer a viable strategy for tackling plastic pollution while promoting sustainable and inclusive economic development through trade, especially for developing countries. The potential roles of stakeholders in this regard include:

- **Intergovernmental organisations (IGOs) and their members**: consider the incorporation of an enabling innovation and regulatory controls mechanism for MBSAs and other non-plastic substitutes under the ongoing United Nations negotiations for an international legally binding instrument (ILBI) on plastic pollution, including in the marine environment, creating a level playing field with plastic products. The World Customs Organization (WCO) could enhance trade flow accuracy by assigning detailed codes for MBSAs. A United Nations Task Force on seaweed could support R&D and regulatory discussions.
- **Governments**: Establish supportive regulatory frameworks, economic incentives, and public-private partnerships to enable MBSA markets. Additionally, collaborate in R&D to accelerate the adoption of MBSA.
- **Businesses**: Support supply chain and market development through R&D investment, either independently or in partnership with governments; invest in MBSA; adopt sustainable sourcing practices, and advocate for favourable policies.

- **Civil Society**: Raise awareness through campaigns and community projects, sensitizing stakeholders and holding governments and companies accountable for their sustainability commitments.
- **Academia**: Enhance understanding of the risks and opportunities associated with MBSAs through comprehensive, interdisciplinary research and help develop market-ready solutions to advance MBSAs.
- **Consumers**: Foster market growth and drive adoption of MBSAs by mitigating cost barriers and cultivating environmental awareness and a willingness to pay for sustainable blue economy alternatives.

Chapter I

Introduction

Introduction

Plastics have become a fundamental enabler of human economic activity as it is inextricably woven into the fabric of the global economy and trade. Their low cost and unparalleled versatility have driven their widespread adoption across all sectors, from consumer goods to industrial applications, leading the world to be undeniably plastic-dependent. Trade in plastics at all levels of the value chain already reached a record $1.2 trillion in 2022 (UNCTAD, 2023a). Projections do not show a different outlook. Without decisive policy interventions, plastic use is on a trajectory to triple by 2060, with the largest increases expected in developing regions such as Sub-Saharan Africa and Asia (OECD, 2022).

While plastics have been instrumental to economic growth, they have also emerged as an unprecedented threat to the environment and human health due to their persistent nature. In the absence of certain conditions, plastics waste can take between 20 to over 500 years to break down and degrade in the environment, depending on the chemical composition and the product (United Nations, 2021). Ineffective waste management across the globe has exacerbated this crisis, leading to a pervasive pollution problem. From municipal solid waste to microplastics polluting the ocean, the environmental and health consequences are profound. Despite global efforts, plastic waste is expected to permeate ecosystems for decades to come (Winnie, Lau et al., 2020).

The alarming global issue of plastics pollution has created a “pressing case” for natural and environmentally friendly substitutes and alternatives to plastics (UNCTAD, 2023a). While phasing out plastics entirely may not be feasible in the short term, developing and adopting alternative materials could play a crucial role in curbing plastic waste. In this view that countries are being encouraged to transition towards a new plastics economy that reduce polluting plastic use and prioritizes, where possible, sustainable and safe substitutes with comparable functional properties. Traditional materials, such as paper and glass, offer established and readily available options for reducing our reliance on plastics. Innovative approaches have scaled where substitutes such as paper and glass work alongside plastics to create sustainable products. For instance, flexible packaging, combines paper and plastic film offering to provide functionality (e.g., moisture insulation) that is comparable to that of plastic-based solutions. At the same time, less common fibre-based materials, such as bagasse and bamboo, are gaining traction as a renewable and biodegradable alternatives for single-use plastic products (e.g., cups, straws), promoting a circular economy by adding value to excess biomass.

While their scalability is still uncertain, their potential is being explored by materials scientists and sustainability experts, paving the way for new business models that combine value addition and resource efficiency. UNCTAD research shows that non-plastic substitutes and alternatives are attracting more regulatory interest as businesses increasingly recognize the benefits of sustainability. Indeed, sustainable trade can not only support the diffusion of low carbon materials and technologies but also contribute to socio-economic development in producing countries. However, to fully realize this potential, investment must be redirected from fossil fuel-based plastic production towards new business models centred on substitute materials (The Pew Charitable Trusts and SYSTEMIQ, 2020).

Marine and coastal ecosystems are increasingly recognized as pivotal for the sustainable development of coastal regions, particularly SIDS. Their unique natural capital provides a prime opportunity to foster new entrepreneurial ecosystems that can balance economic growth with environmental protection, through trade. Ecosystems, such as farming, processing and marketing of algal products, offer potential access to natural resources (e.g., water, minerals) with reduced competition and land use pressures. However, challenges such as the conservation of biodiversity and marine habitats must be carefully managed through effective policy frameworks to fully realize the potential benefits.

This study presents original research demonstrating the potential for trade in marine-based non-plastic substitutes and alternatives (MBSAs) to address plastic pollution, while promoting sustainable economic development in coastal communities, including in SIDS. By looking at selected ocean-based supply chains and unconventional uses of their products and byproducts, such as the production of bioplastic polymers from algae, it responds to three specific objectives:

1. Identify promising MBSAs, defined as natural resources, bio-based materials and components that have a role or potential in replacing fossil fuel-based plastics, either directly, as building blocks or additives for alternative bioplastics, or indirectly, as inputs to produce non-plastic substitutes (e.g., ceramics, glass).
2. Analyse the potential for trade-led socio-economic development of MBSAs in producing countries vis-à-vis environmental and social risks. Accordingly, discuss the main trade-offs between environmental sustainability and economic feasibility assessed through LCA considerations.
3. Discuss policy frameworks that can incentivize trade in marine-based non-plastic substitutes and alternatives, including e.g., tariff and non-tariff measures, and standards. This is intended to inform the upcoming rounds of negotiations of a United Nations Global Plastics Treaty, with a view to support trade-related policy coherence and harmonization.

Chapter 1 provides context and introduces the overall purpose and objectives of the study, including an overview of marine biomaterials and their downstream uses. Chapter 2 highlights their potential for sustainable trade and presents a novel mapping of MBSAs covering marine resources and their immediate derivatives.

Chapters 3 and 4 examine the micro-economics and local impacts of global MBSA trade. Chapter 3 discusses the main challenges and opportunities for socio-economic development affecting MBSA industries. Opportunities are analysed for key MBSA supply chains, such as seaweed and algae, while three main types of barriers to the development of these industries are considered: market dynamics (e.g., economies of scale), enabling technologies and infrastructure, and sustainability. The chapter also maps out the main environmental impacts originating from the production, marketing, consumption and disposal of MBSAs and uses life cycle thinking to discuss the main trade-offs in the substitution for more sustainable materials.

From a trade perspective, Chapter 4 estimates the size of the global MBSA market using bilateral trade flow data as a proxy for demand. The average applied tariffs and non-tariff measures (NTMs) affecting these materials are also analysed to profile the trade distortions and market access conditions prevailing in MBSA markets. Chapter 5 concludes and provides a narrative on the way forward.

Plastic waste can take between 20 to over 500 years to degrade in the environment

Chapter II

Marine-based non-plastic substitutes and alternatives (MBSAs)

Marine-based non-plastic substitutes and alternatives (MBSAs)

The ocean offers underexplored opportunities to curb plastic waste through marine-based substitutes

2.1. The potential of marine resources to replace plastics

Through its unique mix of natural capital, the ocean has shaped the course of human history and determined the key trajectories of civilization. From ensuring sustainable livelihoods through fisheries to facilitating trade routes, humanity has long relied on oceans to meet its most pressing economic and social needs (Allison et al. 2023). As the world is confronted with the need to transition to more equitable and sustainable production systems, the ocean continues to provide access to invaluable resources and ecosystem services, such as carbon sequestration and biodiversity conservation, with increasing interest from governments in promoting it for the development of their national economies (Martínez-Vázquez, Milán-García and de Pablo Valenciano, 2021).

However, the ocean is not immune to the negative environmental externalities of human activity and the challenges of a changing climate (IPCC, 2019 and IOC-UNESCO, 2022). Due to the non-biodegradable nature of conventional plastics, plastic pollution has become a significant threat to marine ecosystems and coastal communities.[1]

The very environment threatened by plastics might offer previously underexplored opportunities to curb plastic waste and hold the key to a more sustainable future. In fact, many of the bio-based components that can replace fossil fuel-based plastics, such as in food packaging, have a strong marine connection and can be sourced from the marine and coastal environment (Ayyakkalai et al., 2024; Pipuni et al., 2023; Bose et. Al, 2023).

MBSAs encompass the entire material life cycle, from raw material extraction to end-of-life. They range from living organisms found in marine and coastal ecosystems that can be used as feedstock (e.g., seaweed) to by-products of aquaculture or seafood processing as sources of biological compounds (e.g., mollusc shells).

The potential applications for replacing plastics are diverse and vary according to their degree of conversion (Table 1). For instance, microalgae and other microorganisms show strong potential as a source of biopolymers, such as polyhydroxyalkanoates (PHAs), which are directly used as building blocks for bioplastics.[2] Conversely, inorganic compounds such as minerals can indirectly support the substitution of plastics as inputs to produce non-plastic substitutes. For example, high purity silica sands have wide applications in the production of glass.

1 Contrary to popular belief, biodegradable plastics are not a panacea for plastic pollution. They only degrade under specific conditions and their rate of degradation in the natural environment can vary significantly depending on how well these conditions are met. Influencing factors include the type of bioplastics, environmental conditions (e.g., temperature, humidity, availability of oxygen) and the presence of microorganisms that affect degradation. While biodegradable plastics can degrade in the ocean, they may take a long time to degrade or may not break down completely into harmless substances due to factors such as salinity and pollutants. These considerations also apply to marine-based bioplastics.

2 Technically, polymers are large molecules formed by linking numerous smaller molecules, called monomers, through covalent chemical bonds. These monomers act as repeating units, creating a long chain-like structure. The specific properties of a polymer (strength, flexibility, etc.) are determined by the type of monomer used, the length of the chain, and the arrangement of the monomers within the chain. These unique properties allow polymers to be the fundamental building blocks of plastics. By varying the monomer and chain structure, a vast array of plastics can be produced with a wide range of characteristics for countless applications.

Table 1

Potential applications of bio-based components of marine origin for the replacement of plastics

Life cycle stage	Category	Examples	Potential applications
Raw materials	Macroalgae (seaweed)	Kelp, Wakame, Carrageenan moss	Bioplastics, gels for cosmetics and pharmaceuticals, food thickening agents, wastewater reuse
	Microalgae and other microorganisms	Microalgae, bacteria, diatoms	Bioplastics, biofuels, biodegradable detergents
	Minerals, from the seabed or continental shelf	Marine clays, silica sands and quartz, calcite	Fillers in bio composites, ceramics, glass
	Marine invertebrates	Sponge	Filtration and absorption materials (e.g., for water purification)
Processing	Biopolymers	Polyhydroxyalkanoates (PHAs), carrageenan	Biodegradable films, coatings, fibres
	Bioplastic films, foil and sheets	Seaweed-based or PHA-based films	Food packaging, carrier bags, agricultural films
	Gels, foams and creams	Agar-agar	Thickening or gelling agents, emulsifiers
	Natural fibre	Seaweed-based yarn, mangrove-based plaiting material	Textiles, basketwork
	Biofuels	Algae-based biodiesel, ethanol	Transportation fuels
Manufacturing	Paper	Algae-based pulp and paper	Packaging materials, printing paper
	Glass and glassware	Glass, made from silica sand and quartz	Food packaging, construction
	Other manufactures	Chitin-based fishing nets, seagrass basketry	Miscellaneous
End-of-life	Fish waste, for purposes other than food, feed or fertilizer	Mollusc shells, fish scales (e.g., for extracting Chitin)	Fillers in bio composites, bioplastics

Source: UNCTAD analysis based on Ayyakkalai et al. (2024), UNDP (2024), United States Geological Survey (2024), Bose et al. (2023), Jianxin, F. et al. (2023), Pipuni et al. (2023), Yadong et al. (2022), Pacchioni (2022), Holland (2019).

The potential of marine resources for replacing plastics is also evident when looking at their downstream uses. For instance, through a higher level of transformation, coastal and aquatic plants can contribute to the production of sustainable, bio-based alternatives to basic consumer goods while unleashing frugal indigenous innovation. These include, but are not limited to, basketwork made of mangrove fronds and fish leather coasters (UNDP, 2024).

2.2. A first global mapping

UNCTAD has an established track record in analysing substitutes and alternatives to conventional plastics from a trade perspective. Previous research has focused on mapping bio-based materials that can potentially replace plastics in clusters that contribute most to global waste streams (e.g., single-use plastics). A comprehensive list of 282 codes of the Harmonized Commodity Description and Coding System (HS) was compiled and used to analyse global trade trends and import tariffs and NTMs affecting these substitutes (UNCTAD, 2023a). A subsequent effort focused on analysing environmental measures targeting these substitutes and discussing key substitution trade-offs along their life cycle (UNCTAD, 2024a).

Building on this work, and as the first effort of its kind, this study identifies MBSAs that have a role or potential in replacing fossil fuel-based plastics, either directly, as building blocks or additives for alternative bioplastics, or indirectly, as inputs to produce non-plastic substitutes (e.g., ceramics). The analysis focuses on the upstream part of the supply chain and is limited to bio-based components that can be found as natural resources in the marine and coastal environment (e.g., seaweed) or are obtained from primary processing (e.g., biopolymers). Organic materials derived from their waste, such as fishery biomass, are also included.[3]

Many bio-based components meet these criteria. They range from polysaccharides that naturally accumulate in algae to minerals embedded in aquaculture and seafood processing waste (Table 2). This is the case of Chitin, a natural polymer that can be extracted from crab and shrimp shells. It has promising food packaging applications due to its biodegradability, antimicrobial and barrier properties (Bose et al., 2023; Holland, 2019). Similarly, a handful of minerals that can be sourced from the seabed or continent shelves, such as calcite and kaolinite, are widely used as functional fillers in plastics and their substitutes (United States Geological Survey, 2024). Their aim is to improve certain material properties and achieve cost reduction (Houssa, 2003).

3 Processed and finished goods, such as paper and glass, will only be considered as part of the downstream uses of the substitutes and alternatives in scope. In this context, value-added products and marine-led innovation pathways in downstream industries are discussed separately in section 3.1.

Table 2
UNCTAD mapping of marine-based non-plastic substitutes and alternatives (MBSAs)

Category	Source of substitutes or alternatives	Description	Non-exclusive example of substitutes or alternatives
Macroalgae (i.e., seaweed)	Brown algae (Phaeophyta), green algae (Chlorophyta), red algae (Rhodophyta)	Macroscopic, multicellular marine algae found in coastal regions; rich in polysaccharides	Alginic acid, agar-agar, carrageenan
Microalgae and other microorganisms	Bacteria, microalgae (e.g., Chlorella vulgaris), marine fungi	Microscopic, unicellular algae found in freshwater and marine ecosystems; accumulate biopolymers and polyesters	PHAs, polylactic acid (PLA)
Minerals (seabed or continental shelf)	Aragonite, calcite, clay minerals (illite, kaolinite, smectite), diatomite, marine biosilica, pebbles and gravel, silica sands and quartz, sands (other than silica and quartz)	Biogenic, detrital or chemically precipitated minerals and sands; used for their binding properties as functional fillers in plastics and paper, glass components etc.	Calcium carbonate, silicates

Table 2 (cont.)

UNCTAD mapping of marine-based non-plastic substitutes and alternatives (MBSAs)

Category	Source of substitutes or alternatives	Description	Non-exclusive example of substitutes or alternatives
Marine invertebrates	Coral, jellyfish, sponge	Invertebrates living in marine habitats; provide valuable biomolecules as well as water filtration properties	Collagen, spongin
Biopolymers of animal plant and microbial origin	See individual polymers listed in column 4	Natural polymers from living organisms, such as seaweed; biodegradable, with good barrier properties for food packaging	—
Fish waste, for purpose other than food, feed or fertilizer	Mollusc shells and claws, cuttlebone, fish skins	By-products of aquaculture and seafood processing, rich in biopolymers like chitin and collagen.	Chitin, chitosan, fish oil-derived polyurethanes
Other miscellaneous	Mangroves, coconut husk	Coastal trees and shrubs with potential for extraction of biomaterials	Cellulose, starch

Source: UNCTAD analysis based on Ayyakkalai et al. (2024), UNDP (2024), United States Geological Survey (2024), Bose et al. (2023), Jianxin, F. et al. (2023), Pipuni et al. (2023), Yadong et al. (2022), Pacchioni (2022), and Holland (2019).

Note: Material substitutes and alternatives are listed in alphabetical order. Proxy HS codes for each identified MBSAs are presented in Annex 2. The list of polymers and constituents in column 4 is non-exhaustive as it only includes the main examples

Other marine resources have less direct but important applications. Amid growing sustainability concerns, marine gravel and sand have long been mined in coastal regions and are used extensively in the manufacture of concrete, glass and electronic devices (Maribus, 2014). On a smaller scale, the potential of certain marine invertebrates to produce biocompounds for industrial applications is well documented. For instance, certain jellyfish species can yield collagen with functional and physico-chemical properties suited not only for biomaterial applications but also for cosmetic and biomedical uses (Chiarelli et al., 2023)

While research suggests strong potential for these materials to replace traditional plastics, widespread adoption in supply chains is not automatic as scaling up production involves complex considerations beyond scientific feasibility. Enabling factors such as access to technology, responsible sourcing practices and material functionality play a critical role. In addition, price competitiveness and market access, which is notoriously affected by tariffs and NTMs, are key determinants of market development in a world dominated by cheap fossil fuel- based plastics.

Chapter III

Challenges and opportunities for sustainable socio-economic development

Challenges and opportunities for sustainable socio-economic development

In 2022, acquaculture accunted for 51% of aquatic animal production, while algae contributed 94%

3.1. Opportunities and enabling factors

MBSAs differ from their land-based counterparts in that they offer the potential to simultaneously pursue some of the key developmental and sustainability goals that are high on nations' agendas notably Sustainable Development Goals (SDGs) 8 (Decent work and economic growth), 9 (Industry, innovation and infrastructure), 12 (Responsible consumption and production), 13 (Climate action) and 14 (Life below water). From this perspective, the opportunities in MBSA-related industries are diverse, encompassing the three dimensions of sustainable development: social, economic, and environmental. Some, such as job creation, economic growth, and innovation, are opportunities that these industries share with the broader ocean economy (FAO, 2024; Allison et al., 2023; OECD, 2016).[4] Others, such as the economies of scope that can arise from food to material applications, are specific to MBSAs. Both require certain enabling factors as well as financing and investment from both the public and private sectors to unlock their potential (Table 3).

These opportunities can be quantified using bilateral trade flow data as a proxy for demand. After growing at an average annual rate of 3 per cent over the period 2012-22, global MBSA exports totalled $10.8 billion in 2022. Driven by particularly dynamic segments, such as marine biopolymers and seaweed, they represent a vibrant market with untapped opportunities for coastal regions and SIDS.[5]

It should also be noted that there are different supply chains and production systems behind global MBSA trade. These primarily include wild capture fisheries and aquaculture/farming. The latter has become increasingly important in recent years due to growing demand, technological advances, and environmental concerns. Its share in the production of aquatic animals, excluding algae, is estimated to be 51 per cent in 2022, while the share for algae is estimated to be 97 per cent (FAO, 2024). Although estimates are not available, non-mineral MBSAs that are typically farmed for trade also include molluscs and crustaceans and their residues, while wild capture remains the dominant source of corals, jellyfish and sponges.

Sections 3.1.1 to 3.1.3 discuss trade-related opportunities across MBSA supply chains and product groups.

4 UNCTAD defines the ocean economy as "a vehicle toward a more sustainable and inclusive economic path on the marine and coastal environment. It encompasses all industries that sustainably utilize and contribute to the conservation of ocean, seas and coastal resources for human benefit in a manner that maintains all ocean resources over time" (UNCTAD, 2020a).

5 The full trade flow analysis, including estimates of the size of the MBSA market at a material group level, is presented in section 4.2.

Table 3
Opportunities and enabling factors for MBSA-led sustainable development

Dimension	Opportunity	Enabling factor
Socioeconomic development	Food security and nutrition Job creation (e.g., seaweed farming), mineral beneficiation Technological spillovers (e.g., less intrusive mining technology) Economic growth, foreign exchange (e.g., exports) Innovation and value addition (e.g., algae-based fibre, consumer goods) Economies of scope (e.g., algae edibles to materials)	Enabling Infrastructure (e.g., testing labs) Skills development and R&D (e.g., biotechnology) Enabling business environment e.g., rules, licensing) Biodiversity conservation or restoration (e.g., kelp, mangrove forests) Responsible sourcing practices, for example, for endangered species (coral, sponge etc.)
Environmental and social	Material substitution (e.g., bioplastics, mineral fillers) Ecosystem services (e.g., carbon sequestration) Reduction of agricultural and land-based mining emissions, run-offs, land use pressures etc. Diversity and inclusion (e.g., women, indigenous peoples and vulnerable groups) Renewable energy (e.g., from feedstock) Resource efficiency and circularity (e.g., biopolymers from fish waste)	Transparency (e.g., subsidies) Harmonization and reform of non-tariff measures (NTMs) (e.g., non-food seaweed standards) Waste management (e.g., run-offs) Risk management (e.g., climate hazards) Finance and investment (e.g., green foreign direct investment [FDI]) Public-private partnerships Technical assistance and international cooperation

Source: UNCTAD analysis based on UNCTAD (2024a, 2024b, 2023b, 2022), literature referenced in section 3.1. and expert knowledge from KIIs.

Note: The table provides examples of opportunities and enabling factors and may not be exhaustive.

3.1.1. Seaweed and algae

The opportunities associated with MBSAs are better illustrated by the growing interest in algae, increasingly recognised as a key lever for sustainable, ocean-led economic recovery following the pandemic (UNCTAD, 2023b; UNCTAD, 2022a). Indeed, algae are attracting global interest outside traditional Asian producers due to their versatility (i.e., providing food, additives, and supplements), while also serving the non-food sector with thickeners, nutraceuticals, pharmaceuticals and bio-based materials such as fertilizers, feed, biofuels and bioplastics. This is not limited to macroalgae (i.e., seaweed); special biosilica derived from easily cultured single-celled microalgae, such as diatoms, have recently emerged as a sustainable alternative to synthetic mesoporous silica used in drug delivery systems (Lim et al., 2023).

From this perspective, algae can provide sustainable livelihoods for coastal communities, not only by contributing to nutrition and food security, but also through the development of the blue economy, creating employment opportunities for women and youth and value addition in downstream industries (FAO, 2024; UNCTAD, 2024b; UNDP, 2024).

In terms of environmental sustainability, algae provide biomass that can be used to produce biodegradable materials at no additional environmental cost, as well as critical ecosystem services such as carbon sequestration[6]. With approximately 650 million hectares of the world's oceans potentially supporting algae farms, they have great potential to reduce the demand for terrestrial crops, thereby reducing agricultural emissions, as well as competition for arable land and freshwater (FAO, 2024; UNCTAD, 2024b, Spillias et al, 2023a). From this perspective, seaweed is also emerging as a sustainable means of conserving marine biodiversity and the environment.

Against this backdrop, seaweed-related innovation is on the rise in all promising sectors (pharmaceuticals, bioplastics, biostimulants, alginates and cosmetics), as evidenced by the number of scientific publications that have skyrocketed in recent years. This is particularly evident in the case of alginate or ulvan - biopolymers with extensive applications in bioplastics - where the number of scientific publications has more than quadrupled in the last decade, from less than 10 in 2009 to 137 in 2020 (Selnes, Giesbers and van den Burg, 2021). A similar trend can be seen in patenting activity, where the number of patent families with algae-related applications has shown double-digit average annual growth between 1995 and 2005, initially driven by biofuels (WIPO, 2016).

Apart from the biostimulant sector, these sectors are characterized by strong lead firms driving product development and enforcing their standards on upstream suppliers. This is consistent with findings from key informant interviews (KIIs) conducted as part of this study, which pointed to locally led innovation by start-ups in close collaboration with raw material suppliers as an emerging trend in ocean-based entrepreneurial ecosystems (OBEE) (Box 1).

6 Unlike land-based agriculture and traditional industrial processes, algae cultivation often requires minimal or no use of fertilisers or pesticides, reducing the risk of water pollution and soil degradation. Furthermore, algae can be grown in wastewater or salt water, minimizing competition for arable land and fresh water.

Box 1

Local innovation and startups tackling plastic pollution in the seaweed sector: Uluu, The People & Planet Company, and Runa Ray

A new wave of OBEE is emerging, fostering collaboration between scientists, entrepreneurs, and investors to harness ocean resources in a sustainable way. These OBEEs hold great promise for socio-economic development, offering exciting opportunities to create new jobs, strengthen social inclusion (e.g., women, youth) and ensure a healthy and productive ocean for future generations.

As part of this trend, startups and individual entrepreneurs around the world are entering the seaweed sector and developing innovative algae-based products with a wide range of applications. These range from material substitutes for conventional plastics, to healthy foods, textiles and clothing and are being developed in collaboration with raw material suppliers, operating upstream in the supply chain (e.g., aquafarms).

Australian start-up Uluu is using algae to produce injection-mouldable bioplastic pellets with a wide range of applications in manufacturing, from packaging to consumer electronics, furniture and car interiors. At the same time, the start-up is developing fibre-grade pellets that show great potential for yarn production via melt spinning. This will provide a breakthrough alternative to polyester textiles. Uluu is securing high quality raw material supplies by establishing cross-border linkages with seaweed farmers, such as cooperatives in Indonesia, and investing in product traceability and skills development.

These business models offer unprecedented opportunities for sustainable socioeconomic development in SIDS as they have the potential to add local value from increasingly global supply chains while promoting environmental and social development. Over time, companies can also specialize and achieve economies of scope enabling them to transition from producing basic products like seaweed edibles to more sophisticated applications such as bioplastics. By leveraging their growing expertise, these social and environmental-led companies have the potential to leapfrog into advanced sectors, driving innovation and sustainable growth.

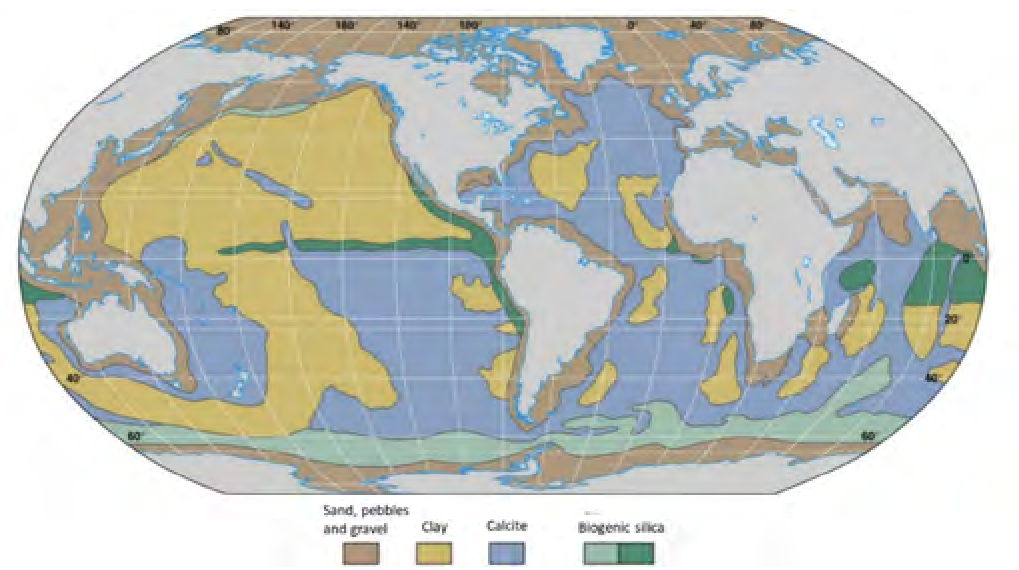
3.1.2. Marine minerals

A wealth of minerals and metals with industrial applications can be found in the seabed or on the continental shelf in concentrations that can exceed those of land-based deposits (Hein, Conrad and Staudigel, 2010). These minerals can be used in the production of many MBSAs, such as fillers and plasticizers to enhance the properties of glass, ceramics and bioplastics, but also in low-carbon technologies such as solar and wind power farms, electric vehicles and batteries (International Seabed Authority, 2022; SPC, 2013). In theory, this represents a viable alternative to land-based mining at a time when nations struggle to procure indispensable resources for the sustainability transitions. Indeed, sea-based mining could provide access to new resource supplies, reducing the environmental externalities that are usually associated with land-based mining (e.g., water pollution, land degradation), but with potential for significant negative impacts on marine ecosystem, as outlined further in this sub-section.

Marine minerals with applications for plastic substitution range from clays (Illite, Kaolinite, Smectite) through silica sands to Aragonite, Diatomite and Calcite. Depending on their origin, these minerals can be found on continental shelves or on the sea floor (Figure 1). For example, sands, pebbles and gravel, can be very abundant on continental shelves. Their abundance and composition are determined by the intrinsic characteristics of the river input and the type of rock in the source area. Conversely, calcite is the most abundant

Figure 1

Global concentrations of marine minerals with applications as substitutes and alternatives to plastics



Source: Adapted from Trujillo and Thurman (2011).

mineral in oceanic sediments and covers large areas of the seafloor at depths of less than 4,000 metres. It derives from biocalcification of different organisms. Marine biosilica are produced by siliceous plankton (e.g., diatoms) and are usually rare in marine sediments, except for high productivity areas where they are dominant. The abyssal plains, deeper than 4000 m, are covered with clays.

Marine minerals have less obvious socio-economic development opportunities than seaweed. On the one hand, this may be because sea-based mining is a relatively new concept. At present, no commercial deep-sea mining is underway and dredging operations only occur at depths of about 200 metres targeting sands, silt and mud of the type used in construction (The Ocean Foundation, 2021).[7] Whatever the pace of development, deep-sea operations will also compete with land-based operations, which rely on well-established economics. Their commercial viability, which is mineral-specific and encompasses both market factors (e.g., demand, technology) and project factors (e.g., capital expenditure, costs), is highly uncertain (Löf, Ericsson and Löf, 2022; Ecorys, 2014). [8]

At the same time, sea-based can also be susceptible to the negative effects of the "resource curse" that has characterized land-based operations for centuries.[9] Indeed, the development outcomes of mining have historically been controversial, with limited domestic value added and foreign-led operations generating significant backward and forward linkages in the domestic economies in limited circumstances (Casella and Formenti, 2022; UNCTAD, 2007).[10]

Furthermore, the true environmental risks and costs associated with deep-sea mining are still poorly understood and, in many cases, remain unknown. Additionally, this activity is not yet regulated in areas beyond national jurisdiction for commercial exploitation purposes, and very few countries have national laws addressing the matter. The impacts of deep-sea mining can be potentially significant and irreversible for many species and marine ecosystems. Therefore, rigorous impact assessments and a precautionary approach must be the foundation for any discussion on the potential of pursuing such activities.

7 Several countries, including China, the Russian Federation, India, and some Pacific Island nations, have been granted exploration licenses by the International Seabed Authority (ISA) to explore specific areas of the international seabed for potential mineral resources. At time of writing, 22 exploration licenses have been granted. An updated list of grand licenses can be found on the ISA website: https://www.isa.org.jm/exploration-contracts/.

8 As most feasibility studies have looked at polymetallic nodules containing high-value metals like copper, cobalt, nickel, and manganese, uncertainty is particularly high for the minerals covered in this study.

9 The "resource curse" describes a situation in which countries rich in natural resources often experience slower economic growth, greater political instability and social inequality than countries without resource endowments. This phenomenon is attributed to a number of factors: Lack of economic diversification due to, inter-alia, currency appreciation from resource exports, rent-seeking behaviour by governments with no incentives to invest in value-added sectors (e.g., manufacturing), the inherent volatility of commodity prices, as well as corruption and conflict. The concept was first proposed and mainstreamed by the seminal contributions of Auty (1993) and Sachs and Warner (2001).

10 This study discusses the potential for socioeconomic development of marine-based non-plastic substitutes and alternatives and does not address the complex relationship between mineral resources and economic development. For a deep dive in that topic, please refer to the seminal contributions of Prebisch (1950), Singer (1950), Corden and Neary (1982), Auty (1993), and Sachs and Warner (2001). By the same token, the study does not address issues pertaining to the development of deep-sea mining, such as operation requirements, the organization of the seabed supervisory authorities, production quotas and licensing, technology transfer and taxation. For an in-depth discussion of deep-sea mining from a trade perspective, please refer to UNCTAD (2024, forthcoming).

3.1.3. Marine invertebrates, plants and waste

MBSAs are also abundant in the biomass of marine invertebrates or plants that are relatively common in the marine environment. In addition to some well-documented sources of chitin, such as sponges, black coral also shows potential for isolating chitinous scaffold, a natural polymer with promising food packaging applications (Nowacki et al., 2020). Similarly, starch can potentially be extracted from propagules of common mangrove species, such as Rhizophora stylosa and Kandelia candel (Hanashiro et al., 2004)

In a more circular way, bio-based components can be extracted from aquaculture by-products such as mollusc shells and seafood processing waste. For example, calcium carbonate (calcite, aragonite), a mineral widely used as a filler in ceramics, can be derived from natural seashells such as clam and oyster where it reaches concentrations of up to 95 per cent (Yamaguchi and Hashimoto, 2022). Similarly, natural calcium phosphate (CaP-N), a sustainable alternative to materials commonly used in medical applications and packaging, can be obtained from fisheries by-products such as fishbones (Righi et al., 2023). Mussel byssus, a by-product of mussel farming, is a potential source of collagen with properties that make it suited for the encapsulation of bioactive molecules (Rodríguez et al., 2017). This property makes it a valuable alternative to plastic-based materials in several applications, including food packaging films and cosmetics.

While these are innovative substitution approaches that allow value to be extracted from solid waste, thereby promoting resource efficiency and circularity, most are currently at the research stage and their commercial viability remains uncertain (Lionetto and Esposito Corcione, 2021). Like the other substitution options discussed in this chapter, they have great potential for sustainable socioeconomic development. However, realising this potential depends not only on scientific feasibility but also on key enabling factors, such as technical capacity and market readiness. These issues are discussed comparatively in the section 3.2.

3.2. Barriers to market development

Despite their strong potential, there are certain barriers hindering market development that MBSA share with the wider ocean economy. These barriers are most common in developing countries and add up to the challenges related to over-exploitation, pollution, threatened biodiversity and climate change that are already affecting ocean ecosystems (OECD, 2016). These include, but are not limited to, underdeveloped markets for enabling goods and services, limited access to finance and technology, poor policy coherence and stakeholder capacity as well as significant trade barriers including tariffs and technical barriers to trade (TBT) (OECD, 2024; UNCTAD, 2022a).

Some of these barriers are particularly relevant to the development of efficient markets for marine-based alternative plastics and non-plastic substitutes. Barriers typically relate to fundamental market dynamics such as supply and demand, economies of scale and the resulting competitiveness of marine biomaterials vis-à-vis conventional plastics. Additionally, the R&D, technologies and infrastructure needed to develop, produce and market these materials are often lacking, particularly in developing countries. The sustainability imperative also requires robust legal frameworks to ensure that supply chains operate in ways that minimize environmental damage and prevent human rights abuses, even in indirect supplier relationships (Table 4).

Black coral shows potential for isolating chitinous scaffold, a natural polymer with promising food packaging applications

Table 4
Top barriers hindering market development in MBSAs and policy options for consideration

Type	Challenge/barrier	Policy options for consideration
Market dynamics	Demand, scale (or scalability) etc. Price, cost efficiency (e.g., PHAs) Competition (e.g., from fossil fuel-based plastics), diversification	Direct support measures (e.g., tax concessions, price control) Green public procurement Multiproduct clusters, biorefineries (food, bioplastics etc.) Recognition of social and environmental entrepreneurs
Enabling technology and infrastructure	Marine-based biotechnology (e.g., bioreactors for algae fermentation etc.) Critical equipment (e.g., subsea mining vehicles, farmed seaweed conveyers) Biomaterials R&D (e.g., for bioplastic applications, marine mineral fillers etc.)	Public R&D, including joint R&D University-industry collaborations Direct support to business (e.g., loans) Supplier development programmes (e.g., within cooperatives, led by lead firms) Public or communal facilities (e.g., testing labs)
Sustainability and governance	Endangered species (i.e., risks to biodiversity conservation) Water pollution (e.g., fertilizer run-offs, waste) Ecosystem damage (e.g., seabed dredging) Responsible sourcing practices, including human rights Traceability (e.g., seaweed farming)	Risk management and biodiversity safeguards Sound regulatory frameworks and enforcement (e.g., CITES) Carbon markets, blue carbon credits Environmental and human rights principles and criteria and due diligence (i.e., supply chains) Risk assessments credits

Source: UNCTAD analysis based on UNCTAD (2024a, 2024b, 2023b, 2022), literature referenced in section 3.2. and expert knowledge from KIIs.

Note: The table provides examples of challenges/barriers and may not be exhaustive.

In addition to the economic costs of these inefficiencies, the foregone environmental benefits can be significant in the absence of timely policy responses. This is particularly valid for the sustainable use of ocean resources, which are under increasing pressure from a changing climate and unsustainable extraction and require governance, principles, and frameworks that may not be available or effectively enforced locally (UNCTAD, 2023b). These include regulations and voluntary standards, such as UNCTAD's Blue BioTrade Principles and Criteria, which are discussed in section 3.2.3.

3.2.1. Market dynamics

Despite growing interest and demand, marine bioplastics may face adverse market dynamics and low economies of scale, making them only partially competitive with conventional plastics. In fact, the latter benefit from significant cost efficiencies, including large volumes (e.g., bulk purchasing), workforce specialisation, mature and cheaper technologies and established industry networks, not to mention significant subsidies to fossil fuels. These benefits are limited for nascent marine bioplastics industries.

Consider PHAs, a promising biopolymer that can be derived from microalgae. The large-scale cultivation of these microbes requires specialised facilities, optimized growth conditions and efficient harvesting methods. For these reasons, the initial investment for them can be significantly higher than that required to produce comparable volumes of fossil fuel- based polymers and may only be justified by strong demand. However, price negatively affects demand. The unit price of PHAs is on average 2 to 3 times higher than that of fossil fuel-based polymers (e.g., polyethylene (PE), polypropylene (PP), polystyrene (PS)), at least partly for the reasons just discussed.[11] Consumers may be unwilling to pay this price premium, pushing demand down and perpetuating a mechanism that hinders the development of marine bioplastics. This may also explain why several marine biomaterials are currently produced in limited quantities. This is where government procurement can help stimulate demand and reduce costs for consumers.

This assumption is supported by qualitative evidence from KIIs with business executives, who cited the high price of PHAs compared to synthetic polymers as a major challenge, limiting their use primarily in high-value products such as gift and cosmetic packaging. They also stressed the need to "internalize the externalities" of conventional plastics e.g., by removing subsidies to fossil fuels. The same respondents also described the marine bioplastics business as being research and development (R&D) driven, with R&D expenditure pushing bioplastics prices up.

On the costs side, the costs of feedstock used to produce PHAs are estimated to account for 30 to 50 per cent of total production costs (Song et al., 2022). At the same time, algae tend to have relatively high conversion rates, achieving efficiencies of up to 90 per cent from raw biomass to bioplastic. In this context, exploring low-cost marine sources of biomass for extracting PHAs, such as microalgae, could substantially reduce production costs and enable environmentally-sound procurement. This may also exert a downward pressure on wholesale prices and make PHAs a scalable and competitive alternative.[12]

3.2.2. Enabling technology and infrastructure

The issues discussed in section 3.2.1 may be further exacerbated by the limited availability of enabling technologies and infrastructure and the low absorptive capacity of firms. Indeed, the isolation of biopolymers from algal biomass is a complex business involving several steps, from feedstock production to mixing, processing and purification (Figure 2). The technological requirements are many and different at each step. For example, microalgae cultivation requires algal ponds or photobioreactors, while PHA extraction typically combines chemical, mechanical and biological methods. Further downstream, purification requires washing, centrifugation and grinding equipment while drying equipment and extruders are used to melt and shape the PHA into pellets or films (Adetunji and Erasmus, 2024; Bezirhan Arikan et al., 2021).

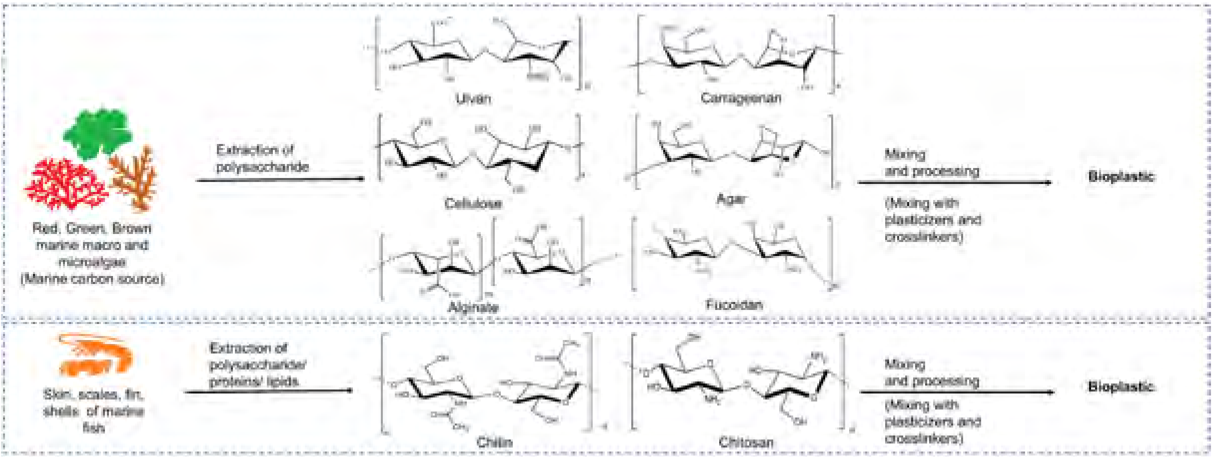
The unit price of PHAs is 2 to 3 times higher than that of fossil fuel-based polymers

As in other ocean industries such as fisheries and aquaculture, a complex technological mix can be a barrier to entry for new players or a constraint to scaling up for incumbents, especially in developing countries. In fact, assets may not be readily available or may be too expensive to acquire as companies lack sufficient finance or technical capacity to handle them. Additionally, the proliferation of patents can create further hurdles for new entrants, as they may need to negotiate licensing agreements or develop alternative technologies to avoid infringing

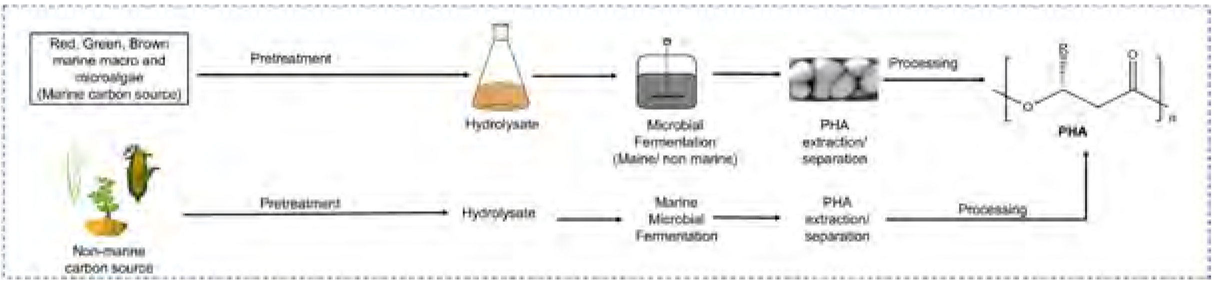
11 PHA: 3700 $/MT. PE, PP, PS: 800-1600 $/MT. High level estimate based on polymer prices published by different sources, including: IMARC Group (https://www.imarcgroup.com/), ICIS (https://www.icis.com/explore/), Platts (https://www.spglobal.com/en), ChemOrbis (https://www.chemorbis.com/en/).

12 Similar considerations cannot be made for marine minerals, whose extraction from the marine environment is, with few exceptions, at the exploration stage. Nevertheless, it is reasonable to hypothesise a similar scenario for the economics of marine minerals when and if marine exploitation gains traction.

Figure 2
Simplified production process of marine-derived bioplastics
a. Overall



b. Polyhydroxyalkanoates (PHAs)



Source: Pipuni et al., 2023.

on existing patents. Rapid technological advances such as those in artificial intelligence and machine learning are also revolutionizing marine bioplastics production and may render several technologies obsolete (Adetunji and Erasmus, 2024).

Technology intensity emerges as one of the key features of the marine bioplastics sector in KIIs carried out with private sector and academic actors. More specifically, references were made by interviewees to a "high bar technology", "deep tech" and "biotechnology readiness" to describe a situation where the high upfront cost of bioplastic technology does not allow it to spread in the market and makes it difficult for start-ups to scale up. Similar constraints have been identified upstream in the supply chain, where low technological readiness affects the volume and quality of seaweed harvests. In some cases, efforts are being made within cooperatives and producer associations to improve technical capacity and facilitate access to critical equipment (Box 2).

Interviewees also identified a strong potential for economies of scope within the sector - specifically for edible seaweed producers to switch to bioplastics production. This potential arises from the fact that some edible seaweed species, such as those used to produce carrageenan, are also suitable for biopolymer production. However, concerns were raised about the immediate viability of this shift due to technological constraints and the higher minimum production scale required for bioplastics, which exceeds that of traditional food applications.

Box 2

Shared technology and know-how in seaweed farming cooperatives: Mina Agar Makmur and SeaSae

Mina Agar Makmur is an Indonesian cooperative based in East Java that produces dried seaweed and seaweed gels. In 2023, the cooperative had 150 farmers cultivating 1,200 hectares of Gracilaria seaweed. The cooperative has long facilitated its members' access to critical technology and infrastructure, including communal facilities and post-harvest machinery (e.g., conveyors, excavators, etc.), while providing technical assistance on good harvesting practices. Similarly, it is now developing a site and demonstration plant with seaweed processing equipment aiming to scale up production to up to 1,000 tonnes of fully traceable seaweed.

The cooperative has signed a Memorandum of Understanding with Uluu, an Australian start-up that uses algae to produce injection mouldable bioplastic pellets for the supply of seaweed. This agreement has led to the establishment of SeaSae, an Indonesia-based joint venture that will source certified seaweed to produce biomaterials. The partnership aims to further improve local livelihoods while supporting the diversification of the region's economy. By purchasing large quantities of seaweed from Mina Agar Makmur, including by \-products and waste, the venture not only supports sustainable income generation for local farmers but also actively promotes a circular economy.

Source: UNCTAD (2024) compilation based on KIIs with seaweed businesses and company websites.

Mineral extraction and value-addition are also typically technology-intensive activities. In the case of marine minerals, the capital-intensive nature of the equipment and the varying mechanical properties and water content of the rocks add to the technological complexity. Also, technology requirements differ depending on where the mining takes place (i.e., in the deep seabed, offshore in shallow water, on beaches or from seawater). From this perspective, barriers to entry may be lower for more established activities that take place offshore, such as sand and gravel extraction, which is typically carried out using dredgers (Garel et al., 2019). Conversely, the extreme conditions associated with deep-sea mining, including high pressure and the potential for underwater volcanic activity, require state-of-the-art seawater equipment (Löf, Ericsson and Löf, 2022).

Deep-sea mining systems are complex and involve multiple processes, including resource extraction, ore transport, mineral processing and ore recovery. These processes require a variety of capital equipment, ranging from subsea mining vehicles to mineral lifting systems and surface support technologies that are be expensive to develop and acquire. This is one of the reasons why land-based mining has traditionally been dominated by multinational enterprises (MNEs) undertaking large-scale extraction projects in mineral-rich countries. These M&Es possess the advanced skills, technologies and capital required to manage these projects, often relying on local firms mainly for services or basic equipment supply (Casella and Formenti, 2022; UNCTAD, 2007).

In addition to the relatively diverse technology mix and capital-intensive nature of deep-sea mining, technological progress may pose barriers to entry, particularly for developing countries. Indeed, the technological trajectory of deep-sea mining is uncertain due to the early stage of development of the industry. However, several technologies from neighbouring industries, such as oil and gas, can be integrated into deep-sea mining and provide a reference for its technological requirements. For example, the maturity of subsea drilling technology may facilitate the successful collection of subsea mineral samples (Liu et al., 2023).

Given these complexities, offshore activities such as sand and gravel extraction may be of more immediate interest to developing countries than deep-sea mining. For instance, mining in shallow water requires readily available technologies and has important synergies with offshore oil and gas extraction, a sector in which many developing countries have well-functioning supply chains and solid market links (Löf, Ericsson and Löf, 2022; Teka, 2011).

3.2.3. Social and environmental governance

In addition to market-related constraints, there are several sustainability-related risks associated with sourcing MBSAs. Negative impacts are MBSA-specific and range from the environmental externalities of production (e.g., runoffs) to unsustainable harvesting practices, including social risks (Table 5). As the economies are in transition to more sustainable practices, underperforming industries or the lack of appropriate frameworks to address these risks can hinder market demand and development as much as more common market forces (see section 3.2.2.). They therefore require careful consideration.

Table 5
Environmental and social sustainability risks of sourcing MBSAs

MBSA	Environmental risk	Social risk
Seaweed and algae	Ecological imbalances in marine ecosystems due to mono or poly culture Accelerated spread of disease Depletion of nutrient stocks Reduction of seafloor light	Human rights violations, e.g., harassment and sexual abuse Sanitation and health issues Constrained tenure rights, e.g., land and water access Unfair remuneration
Marine minerals (deep-sea, shallow water, continent shelf)	Environmental degradation, e.g., from drilling, dredging, etc. Ecosystem damage and loss of biodiversity Seabed disturbance (e.g., noise, light, sediment) Increased seawater temperature Release of toxic elements Land loss, e.g., from erosion	Child labour Exploitation of vulnerable groups, e.g., minorities Forced displacement Exacerbated inequalities, e.g., between social and racial groups Increased costs of living, congestion
Marine invertebrates and plants	Foregone ecosystem services, e.g., water filtration, fish habitats Biodiversity loss Extinction of endangered species (e.g., reef corals) Ecological imbalances in marine ecosystems	Safety issues, e.g., injuries and fatalities Social conflict, unrest Child labour

Source: UNCTAD analysis based on UNCTAD (2024b, 2024 forthcoming), literature referenced in section 3.2.3 and expert knowledge from KIIs.

Note: The table provides examples of sustainability-related risks/impacts and may not be exhaustive.

Table 5 (cont.)
Environmental and social sustainability risks of sourcing MBSAs

MBSA	Environmental risk	Social risk
Fishery byproducts and waste	Oxygen depletion GHG emissions, e.g., methane Water pollution, e.g., run-offs Soil contamination Ecological imbalances in marine and terrestrial ecosystems	Child waste picking, e.g., for informal recycling

Source: UNCTAD analysis based on UNCTAD (2024b, 2024 forthcoming), literature referenced in section 3.2.3 and expert knowledge from KIIs.

Note: The table provides examples of sustainability-related risks/impacts and may not be exhaustive.

Overall, research suggests that the environmental externalities of seaweed farming are relatively low compared to land-based crop systems. However, amidst non-negligible socio-economic benefits and contributions to nutrition and food security (cfr. section 3.1.1), there are several environmental and social risks associated with scaling up seaweed production that are only partially understood. These risks include potential biodiversity impacts, disruption of local ecosystems and socio-economic issues such as unfair and inequitable benefit-sharing. These concerns are increasingly attracting the attention of practitioners and policy makers (Spillias et al., 2023b; UNEP, 2023).

Large-scale seaweed farms, especially those based on invasive species, can disrupt the ecological balance of host habitats and endanger living organisms through accelerated disease, genetic changes and variations in physicochemical properties (Bhuyan, 2023). Poor technical capacity and knowledge of farmers in areas such as genetic management exacerbate these issues (FAO, 2024). Seaweed farms can also reduce the amount of light reaching the seafloor and deplete nutrient stocks, harming other species that rely on the same light and nutrients, such as seagrass (UNEP, 2023; Macrofuels, 2021; Campbell et al., 2019). In addition to confirming most of these risks, KIIs with seaweed practitioners also revealed a risk of effluent run-offs and water pollution.

Seaweed farming offers extraordinary potential for engaging women, youth and vulnerable groups in coastal communities, providing them with opportunities for economic empowerment and improved livelihoods. However, it also carries a significant risk of human rights abuses. Recent UNCTAD research shows that the basic rights of small-scale seaweed farmers can be violated in several ways. In the informal economy, women have limited protection against harassment and verbal, physical or sexual violence, which can occur within or outside of working relationships. Sanitation and health problems, such as those resulting from excessive working hours, are also relatively common. In some cases, indigenous peoples reported that even the creation of protected areas acted as a barrier to basic access and tenure rights to water and land (UNCTAD, 2024b). In this context, the sector´s growth and the integration into global supply chains presents an opportunity to advance formalization, which demands the development and enforcement of environmental and social safeguards.

Box 3
Improving traceability in Indonesia´s seaweed supply chain

The seaweed sector is characterised by a growing awareness of the importance of traceability. On the one hand, this is driven by a growing interest in responsible business practices, as consumers demand transparency about the origin and production methods in all sectors including seaweed products ranging from food to clothing. At the same time, regulations are becoming more stringent, requiring robust traceability systems to meet requirements such as those recently imposed by the European Union and other high-end markets. However, setting up robust traceability systems comes with its own challenges and compliance costs.

Indonesia is home to some of the world´s largest seaweed production hubs such as South Sulawesi, which accounts for 11 per cent of the global seaweed supply (Permani et al., 2023). Seaweed farming is largely carried out by smallholder farmers in remote areas. The product travels through a complex network of intermediaries to processing plants, which are mainly located near urban areas on the Java Island (Soethoudt, Axmann and Kok, 2022). This not only increases transport costs and direct emissions but also makes it difficult to track the movement of seaweed through all stages. In addition, carrageenan producers often mix seaweed from different sources and regions to meet buyers' requirements (e.g., gel content). This blending creates challenges in tracing the origin of individual seaweed species in the final product.

Whether it is used as a barrier film or film in packaging or as a gelling agent in cosmetics, seaweed is usually only a small part of the final product. Given its relatively small contribution to final products, buyers may be less keen to implement traceability systems or certifications that are expensive and technically challenging in nature. At the same time, farmers often lack clear economic benefits and incentives to participate in traceability programmes. Certification costs can be high and the value proposition for farmers isn't always readily apparent.

Source: UNCTAD (2024) compilation based on KIIs with seaweed businesses and company websites.

Private sector-led approaches are becoming increasingly important in mitigating environmental and social sustainability risks. For instance, social sustainability and product traceability are emerging as new requirements for market access in key trading blocs such as the European Union, where supply chain regulations are becoming increasingly stringent, including on due diligence and other requirements in the sourcing of raw materials.[13] To meet evolving standards and secure access to sustainable markets, seaweed farming cooperatives in Indonesia are working with the World Wildlife Fund (WWF) Indonesia to obtain ecolabelling certifications in support of product traceability (Box 3).

The overall importance of sustainability as a key driver to market development is also confirmed by KIIs. Respondents unanimously pointed to buyers being ready to pay a price premium for sustainably harvested seaweed. One respondent indicated traceability as an invaluable means of shedding light on the upstream part of the supply chain as buyers have typically low visibility on where the seaweed comes from, how much producers get paid etc. The same respondent attributed an important role to voluntary sustainability standards (VSS) such as

13 An example of emerging legislation on supply chain due diligence is the European Union Directive on Corporate Sustainability Due Diligence (CSDD) (link). Conversely, traceability is a core element of the European Union Deforestation Regulation (EUDR) (link). While currently focused on terrestrial commodity sectors such as wood fibre, the requirements underlying these regulations may soon be extended to marine commodity chains such as seaweed.

Aquaculture Stewardship Council (ASC) and Marine Stewardship Council (MSC), with regulations not yet keeping pace.

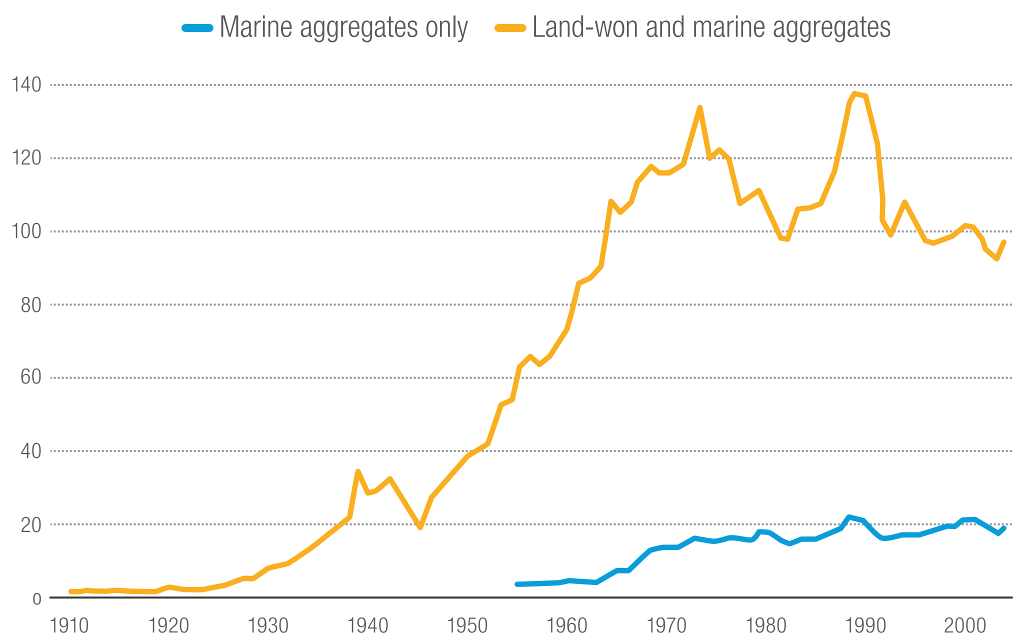
Deep-sea mining is under scrutiny by the international community due to the high risk of environmental degradation associated with the exploitation of deposits (drilling, dredging, etc.). However, deep-sea mining is at an early stage of development and commercial exploration has not yet begun. For this reason, scientific evidence is limited to small-scale trials, and the lack of data on seabed biodiversity makes thorough risk assessment difficult.

While its risks are not fully understood, environmental impacts commonly attributed to deep-sea mining include ecosystem damage and loss of biodiversity associated with seabed disturbance (e.g., noise, light, sediment), increased seawater temperature and the potential release of toxic elements (Miller et al., 2018; Ecorys, 2014). However, the landscape is changing rapidly. For instance, recent research has found that seabed polymetallic nodules produce oxygen (Sweetman, 2024) – a significant discovery which implies that deep-sea ecosystems may not be as dependent on sunlight as previously thought. This could have significant implications for future mining operations as mining would not only threaten marine ecosystems directly but also disrupt the oxygen-producing process.

A more nuanced consideration can be given to the extraction of aggregates, including sand and gravel, which has been taking place in marine environments since the 1950s as shown for example in the case of the United Kingdom (Figure 3). Despite the strategic importance of sand, its extraction and sourcing, remain largely unregulated, causing environmental and social damage in many regions. Land loss through erosion, noise disturbance and ecological imbalances in fish habitats are well-documented impacts in shallow waters and on continental shelves (UNEP, 2022). Fortunately, these impacts have been found to affect only relatively small areas in the vicinity of operations and take a relatively short time

Figure 3

Sand and gravel production of aggregates in the United Kingdom between 1900 and 2004



Source: Garel, E. et al. 2019.

to reverse once dredging ceases (Maribus, 2014). On the social side, sand mining in developing countries is often associated with child labour, a vulnerable workforce and inequalities between social and racial groups (UNEP, 2022; Bendixen et al, 2021).

Against this background, discussions on the overall feasibility of marine mining cannot be divorced from environmental and social considerations. It is crucial to acknowledge that the potential of marine mining to provide a viable solution to the plastics crisis remains highly uncertain due to the limited understanding of its long-term environmental impacts. Its externalities must be also compared with those of land-based mining, the main alternative source of these materials (Löf, A., Ericsson, M. and Löf, O., 2022). Offshore oil and gas production also offers valuable insights, as it has similar operational complexities to deep-sea mining, but in a more established setting where environmental and social impacts are well documented (Albeldawi, 2023; Cordes et al., 2016; Akakpo, 2015). The role of governance frameworks, such as those established by the United Nations Convention on the Law of the Sea (UNCLOS) and the International Seabed Authority (ISA), is also essential in ensuring that marine mining operations adhere to international environmental, social and regulatory standards.

The global coral reef population declined by 14% between 2009 and 2018

Sustainability motives, primarily the conservation of marine ecosystems and the sustainable use of ocean resources, should also be key determinants of choice relating to the harvesting of certain marine species with potential for material applications. These species, which include marine invertebrates and plants such as corals, sponges and mangroves, contribute in various ways to healthy marine and coastal ecosystems and are increasingly being studied as nature-based solutions to climate change. While corals cover only 0,2 per cent of the seafloor, they support at least 25 per cent of marine species by providing shelter, spawning grounds, and food sources, and are estimated to provide ecosystem services worth $2.7 trillion (ICRI, GCRMN, Australia Institute of Marine Science and UNEP, 2022). Sponges act as natural water filters, constantly sucking in water and filtering out plankton, bacteria, and other tiny particles, thus contributing to cleaner water (NOAA, 2024; Folkers and Rombouts, 2020). Mangroves are champions of shoreline protection because their dense root systems stabilize the soil, preventing erosion and storm damage (Sunkur et al., 2023).

Unfortunately, many of these species are highly sensitive to environmental changes and are under pressure from human activities and the effects of a changing climate. These include rising temperatures, water pollution and illegal, unreported and unregulated (IUU) fishing. For instance, reef building corals have been found to be threatened by localized stresses resulting from destructive fishing, declining water quality and degraded coastal habitats (Carpenter K.E, et al., 2008). The global coral reef population was found to have declined by 14 per cent between 2009 and 2018, highlighting the urgent need for conservation measures to avoid ecological imbalances in many ecosystems (ICRI, GCRMN, Australia Institute of Marine Science and UNEP, 2022). Similar considerations can be made for sponges and mangroves.

While not all species are currently threatened, the harvesting of marine species for human applications needs to be carefully managed to avoid creating new environmental externalities in the process of mitigating existing ones. This situation is complex and requires detailed consideration of both species-specific and geographic factors. For example, certain species might be resilient to environmental changes, while geographic variations can influence the sustainability of harvesting practices. Fortunately, there are well established legal frameworks to manage these challenges. Among them, the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), stem from inter-governmental processes and is legally binding on the 184 countries that are Parties to the Convention. Additionally, voluntary frameworks such as UNCTAD´s BioTrade Principles and Criteria (UNCTAD, 2020b), are endorsed on a voluntary basis by supply chain actors (Box 4).[14]

Legal frameworks and safeguards, including multilateral environmental agreements (MEAs), provide a legal basis for improving the sustainability of economic activities and trade that affect biological diversity. While UNCTAD's BioTrade P&C and

Box 4
Life Cycle Assessment (LCA)

UNCTAD defines BioTrade as "the activities of collection/production, transformation and commercialization of goods and services derived from native biodiversity under the criteria of environmental, social and economic sustainability". These criteria, called the BioTrade Principles and Criteria (P&C), cover a growing range of goods and services, including personal care products, natural and phytopharmaceuticals, nature-based fashion, horticultural products, handicrafts and textiles, among others. The BioTrade P&C were established and implemented since 2007 and had been revised in 2020 to address new challenges, and evolving legal and policy frameworks as they are experienced by practitioners on the ground. The P&C are now being implemented in about 100 countries.

In this context, the emerging concept of Blue BioTrade - focused on marine-based products and services – builds on the P&C to promote sustainability and equity and the responsible use of marine biodiversity. It applies the P&C to selected ocean industries, focusing the seven criteria on marine and coastal resources: Biodiversity conservation, sustainable use of biodiversity, equitable benefit-sharing, socio-economic sustainability, legal compliance, respect for stakeholders' rights, and clearly defined tenure and access to resources. Blue BioTrade draws upon international agreements (e.g., the Convention on Biological Diversity [CBD], UNCLOS and CITES) and is a spinoff of UNCTAD's Oceans Economy and Fisheries Programme and the BioTrade Initiative.

The P&C can be applied by endorsing bodies and practitioners in governments, the private sector and civil society (e.g., government organizations, IGOs, industry associations, companies, community organizations) at different levels of the supply chain to develop sustainable livelihoods, adopt an ecosystem-based management approach, and promote rapid adaptation to dynamic markets and changing environmental conditions. The P&C also support access and benefit-sharing (ABS) in line with the Nagoya Protocol, ensuring that the benefits derived from biodiversity are shared fairly with the communities that provide access to these resources. They define a sustainable sourcing model that is primarily applied on a business-to-business basis, but business-to-consumer applications have also proven successful.

In 2020, UNCTAD, the Organisation of Eastern Caribbean States (OECS) and CITES joined forces to design a pilot project to test the application of the revised P&C to the queen conch (Strombus gigas) value chain (a CITES Appendix II listed species). The project designed a regional action plan to enable small-scale coastal producers from OECS member states to sustainably produce and trade queen conch products in domestic, regional and international markets. This included addressing certain supply-side constraints, such as the lack of traceability systems and limited understanding and use of CITES procedures and permits.

Source: UNCTAD (2022b, 2020a, 2020b, 2018).

14 While BioTrade Principles and Criteria are primarily a voluntary framework promoting the sustainable trade of biodiversity-based products, their implementation is also shaped by various sectoral laws and regulations. In particular, access and benefit-sharing (ABS) measures, often mandated by national and regional legislation, make certain aspects of BioTrade compliance legally required.

VSS, such as the ASC and the MSC, are typically not legally binding, they are designed to complement and reinforce the objectives of MEAs. Both encourage the adoption of sustainable practices that align with international obligations, thereby supporting broader efforts to conserve and sustainably use biodiversity.

Black corals (Antipatharia), which are being explored as a source of chitin, are an interesting case in point. They are not currently listed as threatened on the International Union for Conservation of Nature (IUCN) Red List of Threatened Species, although reef corals account for 36 per cent of the threatened species on the list.[15] However, Antipatharia are listed in Appendix II of the CITES.[16] This means that they "are not necessarily now threatened with extinction but may become so unless trade is closely controlled". Appendix II controls include an export permit or re-export certificate issued by the Management Authority of the state of export or re-export. For Antipatharia, a specimen introduced from the sea, a certificate must be issued by the Management Authority of the state where the specimen is imported.[17] Issuance of these documents are dependent on evidence that the trade will not adversely affect the survival of the wild population. Against this backdrop, supply chain actors may choose to adhere to and implement relevant VSS for Antipatharia, provided that the VSS reinforce compliance and do not conflict with the provisions of CITES and other biodiversity-related MEAs.

The extraction of minerals and polymers from aquaculture and seafood processing waste represents, at least in theory, a viable way of extracting value from otherwise discarded by-products (e.g., shells, skins). As by-products account for 50 to 75 per cent of the weight of the catch, this would not only generate economic gains but also help to address a key environmental externality of the industry, waste (Lionetto and Esposito Corcione, 2021). Indeed, the societal costs of solid waste management are not always reflected in market prices and can be substantial. They range from oxygen depletion in water bodies to ecological imbalances in ecosystems and habitats caused by air, water and soil pollution.

Despite the high potential for resource efficiency and circularity, these approaches are not free from sustainability challenges. First and foremost, polymer recovery requires, inter-alia, collection systems and sorting facilities to collect fish waste and produce polymer rich biomass. It can be hampered in contexts where robust waste management frameworks and infrastructure are lacking, as is the case in many developing countries. Creating the right conditions to preserve marine waste prior to extraction can also be challenging, especially on a large-scale. Indeed, storage in a sterile environment is necessary to maintain the integrity of the biomaterial and to prevent contamination (Kang et al., 2023).

In addition, the degradation of fish waste in uncontrolled environments such as landfills generates emissions. It is converted in GHGs, particularly methane, which is a top contributor to global warming and climate change (World Economic Forum, 2024). From a social sustainability perspective, the lack of collection systems can drive vulnerable groups such as children into informal recycling of by-products for resale in secondary markets (e.g., waste picking), posing serious ethical and health concerns.

15 The full list can be accessed here: https://www.iucnredlist.org/.

16 CITES uses three Appendices (I, II, and III) to categorize species based on the level of protection they need from over-exploitation. Appendix I includes species facing the highest risk of extinction, i.e., endangered, due to trade. These species are subject to the most stringent controls. Appendix II includes species that are not currently endangered but that may become so if trade is not carefully controlled. Appendix III lists species included at the request of a Party where that Party already regulates trade in the species and needs the cooperation of other countries to prevent unsustainable or illegal exploitation. More information on the specific trade regulations for each Appendix can be found on the CITES website: https://cites.org/eng/app/index.php.

17 For more details, see: https://cites.org/eng/disc/how.php.

3.3. Environmental impact through LCA

3.3.1. The conventional wisdom and life cycle thinking

MBSAs have characteristics that make them substantially different from each other. As the analysis in chapter 2 and 3 suggests, these relate not only to production, market and socio-economic factors but also to environmental performance (e.g., biodegradability) and functionality. This can be seen, for example, when comparing synthetic plastic polymers with bio-based alternatives such as marine-based.

While the conventional wisdom would suggest that bio-based materials are better for the environment than synthetic ones, this is not true in all contexts. Consider, for example, a situation where a government incentivizes the development of biodegradable alternatives for synthetic plastic coatings in packaging. Grants or tax breaks could be offered to packaging companies that invest in research and development efforts. From an environmental perspective, replacing synthetic coatings with biodegradable materials, such as marine-based, may only make sense if the country has access to surplus polymer-rich biomass (e.g., fishery waste, algae) that can be used as feedstock, or to marine environments where seaweed farming systems can be established at minimal environmental cost. Conversely, the establishment of land-based crop systems dedicated to the production of feedstocks may have high environmental costs (e.g., land use, runoffs) that can at least partly offset the environmental benefits of mainstreaming biodegradable plastics.

The same considerations apply to end-of-life scenarios. Indeed, industrial composting facilities for biomaterials, a favourable regulatory environment and a critical mass of environmentally-conscious consumers would be needed to make the promotion of biomaterials environmentally sound. In the absence of these conditions, bioplastic waste would end up in landfill, where the layering and limited air circulation may make it difficult to find the right conditions for rapid decomposition, including oxygen, moisture and microbial activity. This can make biodegradation much slower than in environments with controlled conditions such as industrial composting facilities. In addition, the anaerobic breakdown of bioplastics can produce GHGs such as methane, a major contributor to global warming and climate change.

From this perspective, it is fair to assume that no material is environmentally superior to another without careful consideration of the context in which it is produced, marketed, consumed and disposed of. This example helps to illustrate that in the absence of certain framework conditions, business and policy decisions that are theoretically greener may at least partially, if not completely, negate their own environmental benefits. It is therefore important that these issues are not overlooked and that they are carefully assessed based on their opportunity costs in any decision to phase out or replace plastics.

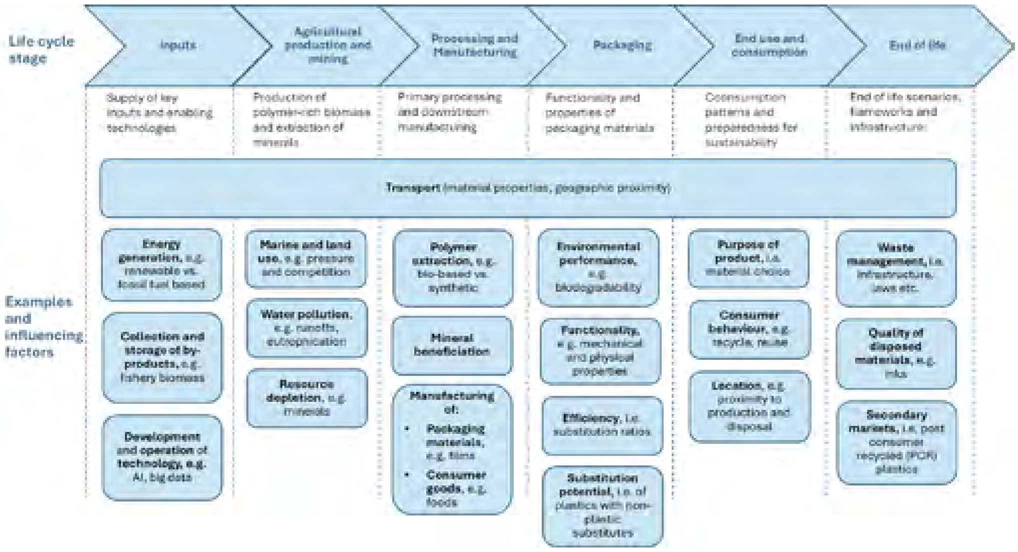
No material is environmentally superior to another without considering its production, consumption, and disposal context

One tool that is becoming increasingly popular with decision-makers, both in business and government, as it can help to properly assess situations such as the one just described is the LCA (Life Cycle Assessment). LCA is a comprehensive method designed to quantify the environmental impacts of a product, process, or service throughout its life cycle, from raw material extraction to disposal or recycling. LCA consists of four main steps: 1) Goal and scope definition; 2) Life cycle inventory; 3) Life cycle impact assessment; and 4) Life cycle interpretation.[18] The accuracy, quality and usefulness of a LCA is dependent on the criteria applied and the quality of data available. However,

18 For a detailed discussion of the methodological steps, caveats and applications of LCA to trade in non-plastic substitutes and alternatives, see UNCTAD (2024a).

Figure 4

Examples and influencing factors of environmental impact across the life cycle of MBSAs



Source: UNCTAD analysis based on ISO (2006a, 2006b) and UNCTAD (2024a).

Note: The diagram is not exhaustive as it only shows selected examples and influencing factors of environmental impact. The "Inputs" and "Packaging" stages are added for illustrative purpose and are not part of the standard life cycle process chain (cfr. ISO 2006a, 2006b).

even in the absence of high-quality data applying some degree of life-cycle thinking can provide certain direction and help to manage complex decisions.

3.3.2. Key substitution trade offs

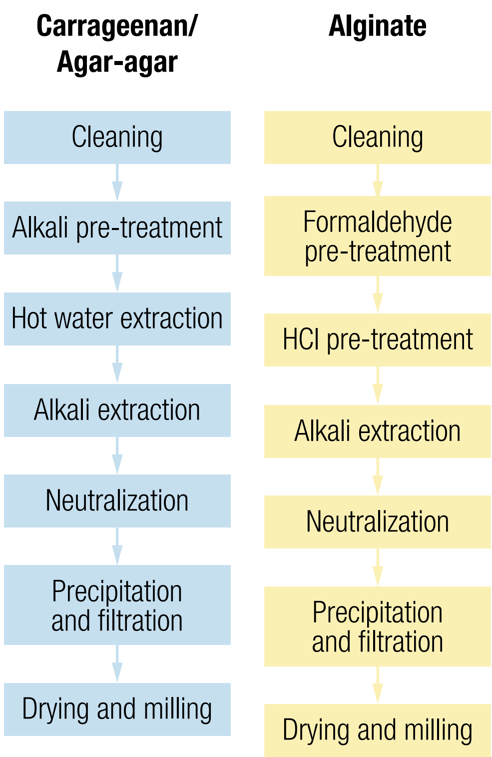
MBSAs generate various environmental externalities throughout their production, marketing, consumption, and disposal phases. These impacts, along with the key influencing factors, encompass the entire life cycle, presenting intricate trade-offs and potential constraints for business strategies and policy development (Figure 4). This framework can serve as a basis for preliminary evaluations when navigating the complex choices between conventional plastics and their MBSAs.

Some of the strategic inputs required for well-functioning MBSA industries, such as energy, embed emissions or have lifecycle impacts on the environment. For example, power generation still relies heavily on fossil fuels such as coal, oil and gas. These are the dominant sources of greenhouse gases, accounting for over 75 per cent of global emissions. From this perspective, the production of bioplastics with a fossil fuel-dominated energy matrix could reduce their GHG reduction potential compared to conventional plastics (UNCTAD, 2023a). This is particularly the case for algae, where cultivation processes such as pumping and mixing can be energy intensive. Further downstream, the extraction of agar-agar, carrageenan and alginates is a technologically complex business involving multiple steps, some of whom are known to be energy-, water- and chemical-intensive (Lomartire, Marques, and Gonçalves, 2022) (Figure 5). Similarly, a wide range of technologies that could revolutionise marine mining, such as artificial intelligence, have been identified as significant carbon emitters due to their high energy consumption (Crawford, 2024; UNCTAD, 2024c; Dhar, 2020). While they can help reducing plastic pollution by mainstreaming MBSAs globally, they can also embed invisible externalities that need to be factored into decisions.

Moving downstream, the production of agricultural and mineral commodities is known to have a high environmental footprint due to emissions to soil, water and air (e.g., from fertilisers and pesticides), high freshwater consumption and pressures on arable land. Under the right conditions, the establishment of marine-based commodity chains has the potential to save resources and reduce emissions from agriculture. For example, without needing land or freshwater, pesticides or fertilizers, seaweed farming systems can be established at relatively low environmental cost and can counteract demand for terrestrial feedstock crops such as maize (WWF, 2024).

Interestingly, as well as having a low carbon footprint, algae can achieve conversion efficiencies from raw biomass to bioplastics that make it a competitive alternative to

Figure 5
The extraction process of carrageenan and agar-agar (a) and alginate (b)



Source: UNCTAD calculations, based on World Bank International Debt Statistics.

land crops. Around 10 kg of raw algae is needed to produce 1 kg of PHAs, and conversion rates are higher for hydrocolloid-based materials such as PLAs.[19] Similarly, the exploration of deep-sea mineral deposits could reduce pressure on land-based resources in high demand for the green transition, such as rare hearts.

Nevertheless, the lifecycle GHG reduction potential of marine-based commodity chains can be affected by externalities that do not arise directly from raw materials production. This is the case of biopolymer extraction from algal biomass in cases when the processing facilities (e.g., fermentation, purification) are located far from the farming sites, e.g., inland. In such a scenario, if fossil fuel-based transport is used, transportation can cause GHG emissions to soar and add significantly to the carbon footprint of the product.

For materials that have undergone primary processing, functionality entails the specific characteristics and capabilities a material has that make it suitable for a particular application, i.e., packaging. These include mechanical properties (e.g., strength, elasticity), physical properties (e.g., density, thermal properties), chemical properties (e.g., corrosion resistance, reactivity) and other functional attributes (e.g., barrier, biodegradability, recyclability).

While research tends to agree on biodegradability (or compostability under certain conditions) as a distinctive property of MBSAs, the evidence on other properties of MBSAs compared to synthetic polymers is mixed. Recent contributions, such as Mogany, Bhola and Bux (2024) and Pipuni et al. (2023), tend to ascribe identical or at least similar physical and mechanical performance to algal bioplastics. While acknowledging similar material performance, others such as Adetunji and Erasmus, 2024 and Perera et al. (2021), take a more cautious approach and identify properties such as barrier, tensile strength and water solubility where synthetic polymers

19 Insights gathered from KIIs with producers of PHAs.

perform better. Interestingly, blending of bioplastics with other proteins, polymers and plasticizers is a common practice to enhance mechanical and physical properties and overcome certain challenges, such as low permeability in food packaging (Lionetto and Esposito Corcione, 2021).

Material properties are at the heart of the debate over MBSAs versus conventional plastics as they determine the overall efficiency of materials (e.g., substitution ratios). It is well known that using less of a material to achieve the same performance can save on emissions, both direct from production and indirect from ancillary activities such as transport. In some cases, algae-based bioplastics might require a 1:1 substitution ratio with conventional plastics to achieve the same functionality. This would be a significant advantage in terms of material efficiency. However, depending on the specific application and the property trade-offs discussed, a slightly higher amount of bioplastic might be needed to achieve the same performance as traditional plastics adding to the overall carbon footprint.

In this view, when evaluating MBSA vs. conventional plastics, it is crucial to assess their suitability for the product's intended purpose. This includes analysing how much of the substitute material is required to achieve the same performance as plastic, considering its functionality and the product´s ultimate purpose. For example, replacing plastic carrier bags with baskets made of mangrove fronds might not be an environmentally friendly solution if these alternatives are primarily used for carrying light items and are disposed of quickly without reuse.

Geographical factors, particularly the distance between production and consumption points, significantly influence a product's environmental impact. Transportation of raw materials to processing facilities, packaging materials to manufacturing sites, and waste to recycling centres all contribute to GHG emissions. Essentially, the farther goods travel, the greater the emissions generated. A meticulous examination and mapping of the supply chain can aid decision-makers understand how these factors influence material selection. For instance, packaging manufacturers situated near seaweed farms could explore producing biodegradable, algae-based food containers instead of relying on imported polymers for polypropylene production.

End-of-life management is also an important aspect of the LCA of bioplastics and includes various techniques for the effective management and disposal of materials, including recycling, landfilling, incineration, anaerobic digestion and composting (Adetunji and Erasmus, 2024). In this context, the defining characteristic of MBSA, excluding some minerals, is biodegradability (or compostability under certain conditions). This is well documented by research for most of the materials included in this study (Adetunji and Erasmus, 2024; Kang et al., 2023; Wang et al., 2023, to name a few) and is reflected in the proliferation of public and private standards for biodegradability and compostability.[20]

However, as the introductory case of this section shows, the environmental benefits of using biodegradable materials are not obvious and certain conditions need to be met for them to fully unlock their emission reduction potential (e.g., enabling framework for composting, consumer willingness).[21] Where such conditions are not met, it may be more appropriate to rely on alternatives that best fit the framework. These include conventional plastics, which can be adequately disposed of by incineration, or other non-plastic substitutes such as glass, which is non-biodegradable but highly recyclable.[22]

20 A list of relevant standards applicable within the European Union can be found on the European Bioplastics website: https://www.european-bioplastics.org/bioplastics/standards/.
21 For a discussion of the same aspects in relation to paper, see UNCTAD (2024a).
22 It must be noted, however, that materials are rarely used in isolation in packaging solutions. They are usually combined to achieve the best functionality (e.g., barrier, strength) while reducing economic and

Packaging design also requires careful consideration of producer and consumer responsibility, as these largely determine the quality of disposed materials, their potential to close loops and their marketability in secondary markets. Despite increasing environmental awareness, there is often a gap between what consumers know and how they act, known as the intention-action gap. This knowledge-behaviour gap is critical to the success of circular strategies, and integrating behavioural insights into LCA can help bridge it (Corona, Tunn and van den Broek, 2024).

environmental costs.

Chapter IV

Pursuing MBSAs through a trade lens

4. Pursuing MBSAs through a trade lens

In the absence of official statistics on the economic transactions within MBSA markets, data on cross-border movements of goods recorded by customs authorities serve as a valuable proxy for assessing the size of the global MBSA market and understanding the key supply chain relationships that underpin it. This chapter assesses trade in MBSAs using the Harmonized Commodity Description and Coding System (HS) as a reference for material mapping and trade flow analysis. It also examines tariffs and non-tariff measures applied to MBSAs that can potentially affect their trade.

4.1 The Harmonized System (HS) as a framework for measuring trade in MBSAs

The HS is the global standard that forms the basis of international import and export classification systems and is accepted by more than 200 nations worldwide. Developed and maintained by the WCO, it is regularly updated and comprises over 5,000 commodity groups.[23] In this context, an HS code is a six-digit identifier that categorizes imported (or exported) goods.

The classification seeks to balance several factors: the level of detail in market sectors or industries, the practical usability of the classifications by customs authorities and the necessity for a logical framework with clear rules to ensure consistent classification (UNCTAD, 2023a).[24] A unified HS code system could significantly increase the efficiency of international trade by allowing customs officials to verify products without lengthy searches and providing a basis for international regulations, such as those concerning endangered species.

However, there are limitations to using HS codes in this analysis. First and foremost, HS codes may not reflect the latest market developments, such as emerging and innovative products.[25] For example, this report relies on the 2022 edition of the HS codes, which may not accurately represent the market in 2024. Moreover, the six-digit HS codes may not be sufficient to capture all details of a product, prompting many countries to extend them with additional digits for more precise classification. For instance, major trading nations such as China, the European Union and the United States, use nine-digit or ten-digit codes/tariff lines for tracking cross-border trade flows.[26]

23 For more information about the HS and its applications, as well as the HS nomenclature (2022 edition) used in this report, please refer to the WCO website: https://www.wcoomd.org/en/topics/nomenclature/overview/what-is-the-harmonized-system.aspx
https://www.wcoomd.org/en/topics/nomenclature/instrument-and-tools/hs-nomenclature-2022-edition/hs-nomenclature-2022-edition.aspx.

24 For detailed information, please refer to the WCO website: https://www.wcoomd.org/en/topics/nomenclature/instrument-and-tools/hs_convention.aspx.

25 For detailed information, please refer to the WCO website: https://www.wcoomd.org/en/topics/nomenclature/overview/what-is-the-harmonized-system.aspx.

26 National tariff lines developed by the main trading nations based on the six-digit HS codes can be found here: China (see https://www.singlewindow.cn/#/parameterDetail?pqcode=CusComplex), European Union (see https://ec.europa.eu/taxation_customs/dds2/taric/taric_consultation.jsp?Lang=en), United States (see https://hts.usitc.gov/).

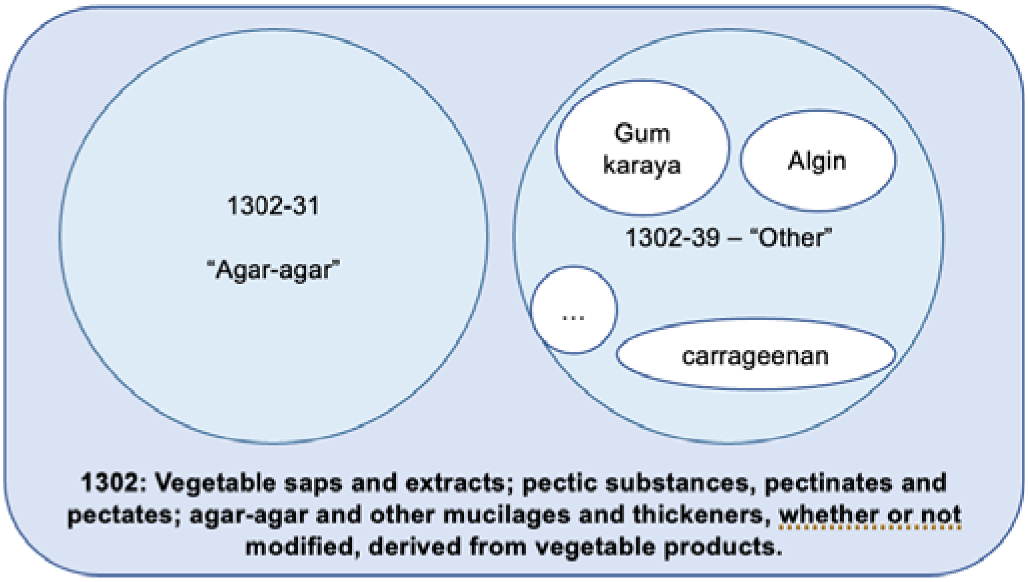
This report's trade analysis of MBSAs using six-digit HS codes thus has three limitations. First, the current HS codes do not adequately cover materials emerging in the market that are not yet widely traded. Many MBSAs, identified through recent scientific breakthroughs, fall into this category. This is the case of fungi, which can grow and create compounds for compostable packaging if combined with organic waste (Waldeck, 2023), or microorganisms that can help plastic degradation (Omura, T. et al., 2024).

The second reason is that six-digit HS codes may be too broad and encompass products other than MBSAs. Consequently, international trade data and legal analysis, which primarily relies on these six-digit codes, may not fully reflect trade patterns of MBSAs. As pointed out in a WTO report, "while there were millions of products, there was limited capacity in a usable customs nomenclature with a six-digit limit." (WTO, 2022). For example, the HS code for agar-agar captures its detailed characteristics accurately. In contrast, the HS code for carrageenan is too broad, encompassing too many products and failing to represent accurate trade data (Figure 6).

Third, the six-digit HS codes do not account for the diverse applications of materials, leading to potential inaccuracies in trade analysis, particularly concerning efforts to address plastic pollution. For example, seaweed has numerous food and non-food uses[27], yet all non-edible uses of seaweed may fall under the relevant HS code: 121229. Consequently, the trade analysis on seaweed may not entirely capture its trade as a plastic substitute.

Figure 3

Sand and gravel production of aggregates in the United Kingdom between 1900 and 2004



Source: UNCTAD analysis based on the HS nomenclature (2022 edition) and national tariff lines of China and the United States.

Note: The six-digit HS codes indicate the class of the products (i.e., "chapter" (first two digits), the category (middle two digits), and groups of products with similar characteristics (last two digits).

27 For a detailed list of food and non-food uses of commonly used and traded seaweed species, see table 1, UNCTAD (2024b) (see https://unctad.org/publication/ocean-opportunities-potential-seaweed-advance-food-environmental-and-gender-dimensions).

The gaps identified can be used as a basis for further development of the HS system to better reflect trade at the time of sustainability transitions. Options for further development include, but are not limited to, the creation of new HS codes for emerging products with sustainable trade potential (e.g., fungi and other micro-organisms) and further disaggregation of HS codes covering a broad range of products. Similarly, HS codes covering materials with multiple applications such as seaweed can be further disaggregated to reflect their use as MBSAs. In this respect, the application of the HS standard in the national tariff schedules of the largest trading nations provides precise guidance on how the system can be developed to capture the transition to a new plastics economy (Table 6).

Table 6

Examples of national tariff lines associated to HS codes covering targeted MBSAs

Targeted MBSA	Best proxy HS code at six digits level	China	European Union
Polyhydroxy-alkanoates (PHAs)	**390799** Polyacetals, other polyesters and epoxide resins, in primary forms; polycarbonates, alkyd resins, polyallelic esters and other polyesters, in primary forms - Other polyesters -- Other	Unreinforced or unmodified primary shape PBT resin (390799 10 01) Other polybutylene terephthalate (PBT) resins (390799 10 90)	Thermoplastic liquid crystal aromatic polyester copolymers (HS: 390799 05)
		—	Poly (ethylene naphthalene-2,6-dicarboxylate) (HS: 390799 10)
		Primary shape of thermoplastic liquid crystal poly (p-phenylene terephthalate)-hexanedioate-butanediol ester (390799 91 10) Other primary shapes of poly (p-phenylene terephthalate)-hexanedioate-butanediol ester (390799 91 90)	Other (HS: 390799 80), broken down in 7 materials (390799 80 10 to 90), including: Poly(hydroxyalkanoate), predominantly consisting of poly(3-hydroxybutyrate) (390799 80 30)
		Primary shape of other thermoplastic liquid crystal polyesters (390799 99 10) Primary shape of other polyesters (390799 99 90)	—
Shells, claws, cuttlebone	**050800** Coral and similar materials, unworked or simply prepared but not otherwise worked; shells of molluscs, crustaceans or echinoderms and cuttle-bone, unworked or simply prepared but not cut to shape, powder and waste thereof.	Powder and waste of endangered corals and endangered aquatic products (050800 10 10) Other powder and waste of shells and bones of aquatic products (050800 10 90)	Red coral (Corallium rubrum) (050800 10)
		Shells and bones of endangered corals and endangered aquatic products (050800 90 10) Other shells and bones of aquatic products (050800 90 90)	Other (050800 90), of which: Empty shells for food use and use as raw material for glucosamine (HS: (050800 90 10) Shells, including cuttle-bones, containing soft tissue and flesh, as referred to in Article 10, point (k)(i), of Regulation (EC) No 1069/2009 (050800 90 20) “Other” (050800 90 90)

Source: UNCTAD analysis based on the HS Nomenclature (2022 edition) and national tariff lines of China and the European Union.

Note: Chinese tariff lines are only available in Chinese and were subject to unofficial translation.

To better reflect MBSA trade, alternative approaches that go beyond the HS system's focused on the nature and composition of goods can also be considered. For instance, process and production methods (PPMs) refer to the specific techniques used to manufacture a product, which widely differ in the case of conventional vs. marine-based bioplastics. Since the key difference between MBSAs and conventional plastics lies more in their production methods than in their composition, thorough PPMs analysis can support the identification of more granular and MBSA-conscious HS codes.

Methodological considerations regarding the application of HS codes for calculating the value of global trade in MBSAs are discussed in Annex 1.

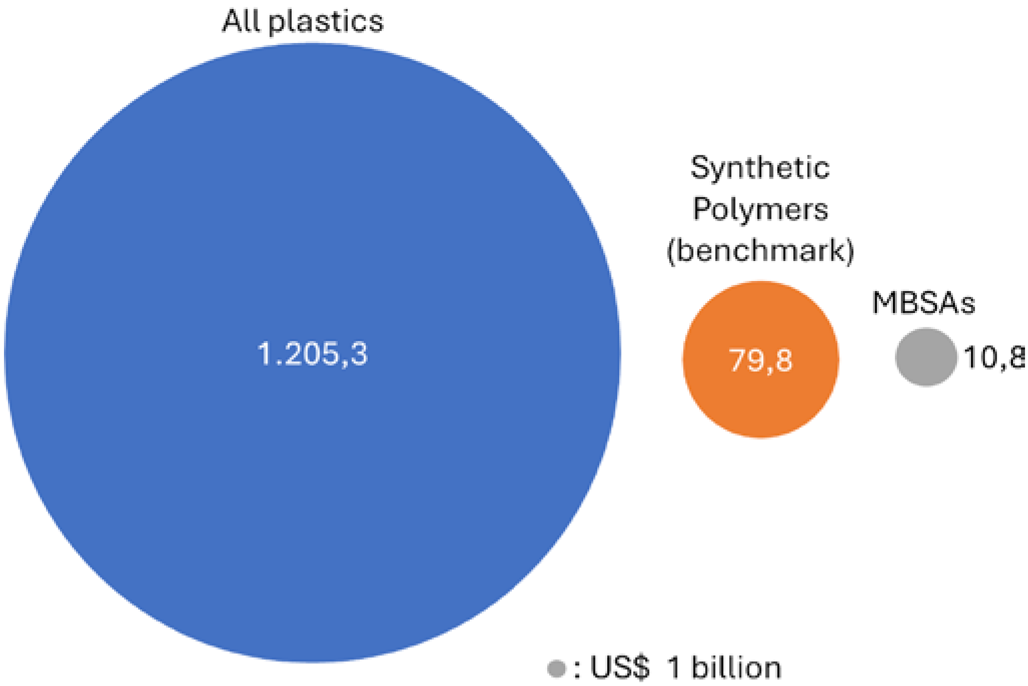
4.2. Trends and prospects in global MBSA trade

4.2.1. Global trade trends

The global export market for MBSAs is still relatively small compared to the global plastics market. In 2022, global MBSA exports amounted to US$ 10.8 billion, representing 1 per cent of global plastics exports and 14 per cent of synthetic polymer exports (Figure 7). The latter, which are chain-like materials derived from fossil fuels (e.g., PP, PET), can be considered the main competing alternatives and a reliable benchmark for MBSAs.

Despite its relatively small size, the MBSA market covers a wide rang e of materials and products with applications in alternative plastics or non-plastic substitutes (Figure 8). Some, such as minerals, are mainly derived from land-based deposits but

Figure 7
The extraction process of carrageenan and agar-agar (a) and alginate (b)



Source: UNCTAD analysis on data UN Comtrade and UNCTADStat (2024). Accessed: July 2024.

Note: Data for "All plastics" are UN Comtrade data aggregated by UNCTADStat and cover trade across the entire life cycle of plastics, from primary forms to waste (more information here). "All plastics" include "Synthetic polymers". MBSAs include all materials/products identified in this study for which a suitable proxy HS code could be found (see Annex 2, items marked "Yes").

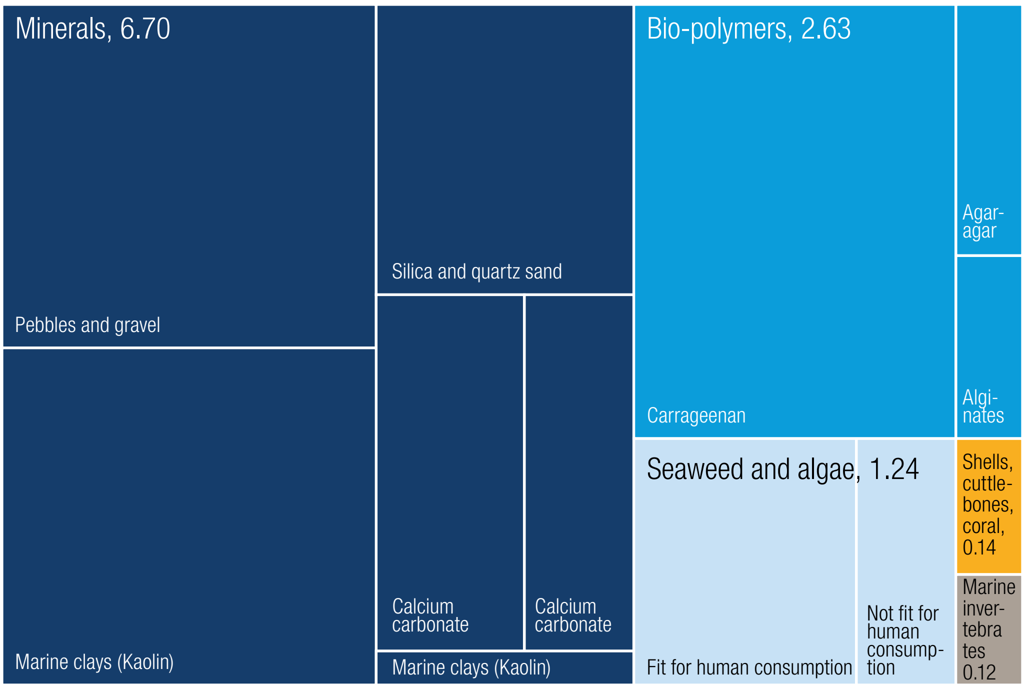
can potentially be sourced from the sea. Others, such as algae-based biopolymers, are purely marine in origin. At $6.7 billion in 2022, minerals account for the majority of MBSA exports (62 per cent). Although small, certain segments such as seaweed and algae, as well as shells, cuttlebones and coral, are equally important to the healthy functioning of the MBSA industries as they provide the raw materials needed to extract bio-based components with industrial applications. This is the case for red and brown algae biomass, from which agar-agar and alginates can be extracted, or jellyfish, which are rich in collagen.

MBSA markets are relatively concentrated and split between developed and developing countries. In 2022, the top 10 MBSA exporters made up 61 per cent of global MBSA exports. China ($1.48 billion), the United States ($1.47 billion) and Indonesia ($0.7 billion) were the largest exporters. Out of the 10 top exporters, three are developing economies (China, Indonesia and the Philippines) while 7 are developed economies (United States, United Kingdom, Germany, France, Belgium, Netherlands and the Republic of Korea).[28] While overall the minerals segment reflects these characteristics, remarkable differences appear in other material groups where developing economies play a key role (cfr. Figure 11).

The MBSA market is cyclical in nature. Over the period 2012-22, MBSA exports grew at an average annual rate of 2.6 per cent, compared with growth of 2.7 per cent and 3.1 per cent for all merchandise and all plastics exports respectively.[29] A closer look at the data suggests that MBSA exports are strongly and positively correlated with all merchandise exports (Pearson correlation

Figure 8

Global exports of MBSAs by material group ($ billion, 2022)



Source: UNCTAD analysis on data UN Comtrade (2024). Accessed: July 2024.

Note: The proxy HS codes assigned to each material/product part of these groups are listed in Annex 2. Due to the lack of suitable proxy HS codes, only selected materials/products part of the MBSA mapping were included in the analysis. For this reason, "Marine invertebrates" includes only jellyfish.

28 UNCTAD analysis on data UN Comtrade (2024). Accessed: July 2024.
29 UNCTAD analysis on data UN Comtrade (2024). Accessed: July 2024.

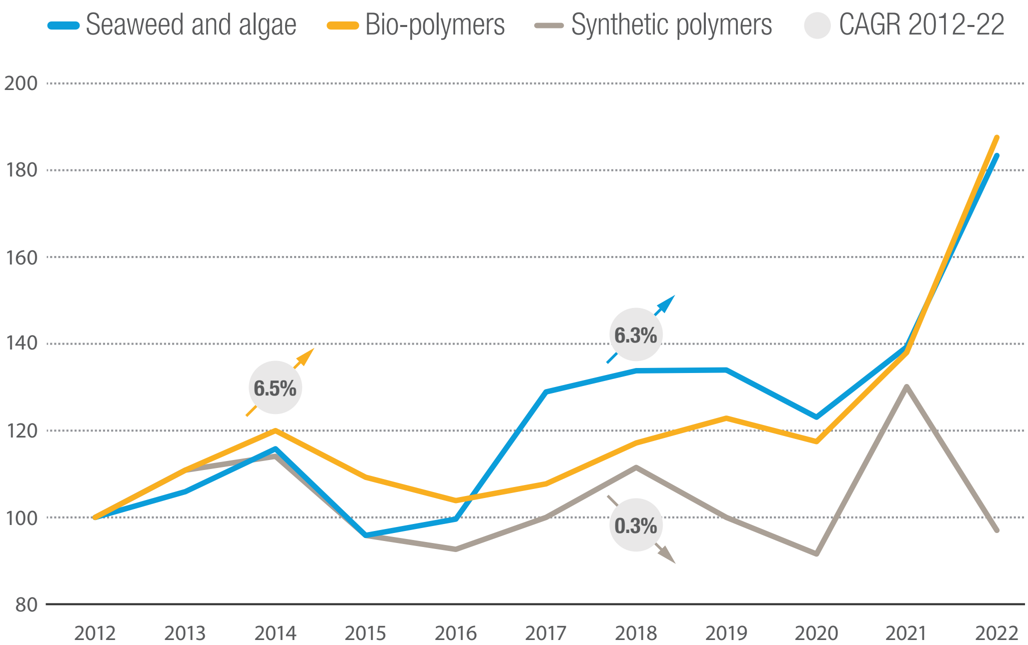
coefficient = 0.95), the latter being a proxy for the global market.[30] This suggests that MBSA industries are closely linked to the market, with market determinants such as supply shocks and consumption patterns likely affecting MBSAs.

The steady growth of the MBSA market is driven by selected segments, the fastest growing of which are those related to the supply of marine bioplastics and the raw materials needed to produce them. Between 2012 and 2022, the seaweed and algae and marine biopolymers segments both grew by an average of more than 6 per cent per year - 6.3 per cent and 6.5 per cent respectively, measured as their compound annual growth rate (CAGR). In 2022, their market size, measured in terms of FOB export value, was more than 80 per cent larger than 10 years earlier. Conversely, benchmark exports of synthetic polymers declined by 0.3 per cent per year over the reference period (Figure 9).[31] Among other things, this may be due to a shift in consumer preferences towards sustainable alternatives.

The overall participation of developing countries in MBSA trade has increased significantly over the last decade. In 2022, developed countries account for the majority of MBSA exports, as more than half of

Figure 9

Global exports of marine biopolymers and seaweed v synthetic polymers (Base year: 2012 = 100)



Source: UNCTAD analysis on data UN Comtrade (2024). Accessed: July 2024.

Note: The proxy HS codes assigned to each material/product part of these groups are listed in Annex 2. Due to the lack of suitable proxy HS codes, only selected materials/products part of the MBSA mapping were included in the analysis. For this reason, "Marine invertebrates" includes only jellyfish. CAGR means "compound annual growth rate".

30 The Pearson correlation coefficient (PCC) is a correlation coefficient that measures linear correlation between two variables, i.e., how strongly two variables move together. It is the ratio between the covariance of two variables and the product of their standard deviations. A positive correlation (PCC>0) means that as one variable increases, the other also increases. A negative correlation (PCC<0) means that as one variable increases, the other decreases. A zero correlation (PCC=0) means that there is no linear relationship between the variables.

31 Detailed summary statistics such as export values and ten-year growth rates at material/product level are presented in Annex 3.

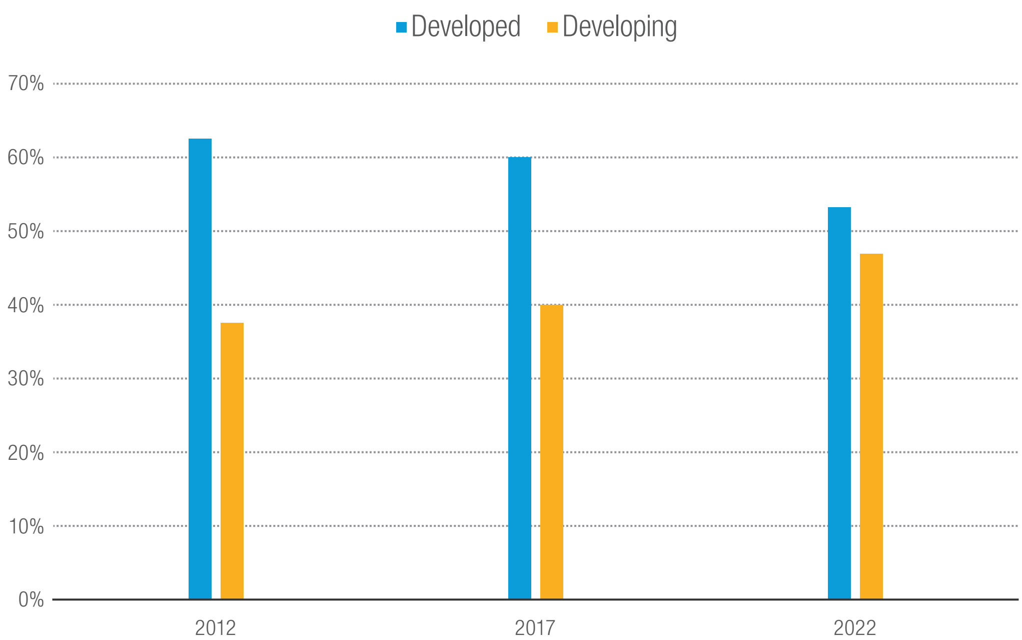
global MBSA exports originate from their territories (53 per cent). However, the overall weight of developing countries in MBSA exports has increased significantly (Figure 10). Indeed, the share of MBSA exports originating in developing countries was 9 percentage points higher in 2022 than in 2012, rising from 38 per cent to 47 per cent of the total. This suggests a shift in the geography of MBSA production, with the main export hubs increasingly located in the developing world.

While the majority of MBSA exports originate in developed countries (53 per cent), this is not the case for all segments/material groups that make up the MBSA basket. In fact, the weight of developed and developing countries in MBSA exports varies considerably between material groups. As in the benchmark segment of synthetic polymers, developed countries account for the lion's share of mineral exports (64 per cent). Conversely, developing countries dominate the marine biopolymers market, accounting for 67 per cent of its exports (Figure 11). Interestingly, developing country participation is higher in segments that include materials and compounds of purely marine origin, such as jellyfish, seaweed and algae. This suggests untapped opportunities for developing economies with a strong connection to the ocean, such as SIDS, whose contribution to MBSA exports is still low (0.05 per cent in 2022).

However, there are already success stories from developing economies in some MBSA segments. The Philippines, for example, dominates the marine biopolymers market. The country is second only to China, with more than 12 per cent of marine biopolymer exports in 2022 coming from its territory. Notably, seven of the top ten exporters of jellyfish are developing countries, with some Southeast Asian economies (Thailand,

Figure 10

Global exports of MBSAs by development status of exporting country (%, 2012-22)



Source: UNCTAD analysis on data UN Comtrade and UNCTADStat (2024). Accessed: July 2024.

Note: Data for "All plastics" are UN Comtrade data aggregated by UNCTADStat and cover trade across the entire life cycle of plastics, from primary forms to waste (more information here). "All plastics" include "Synthetic polymers". MBSAs include all materials/products identified in this study for which a suitable proxy HS code could be found (see Annex 2, items marked "Yes").

Malaysia, Indonesia and Myanmar) featuring the list and accounting for over 30 per cent of trade. Indonesia is the world's largest exporter of seaweed and algae, with exports worth $0.4 billion in 2022, followed by the Republic of Korea, Chile and Peru.[32]

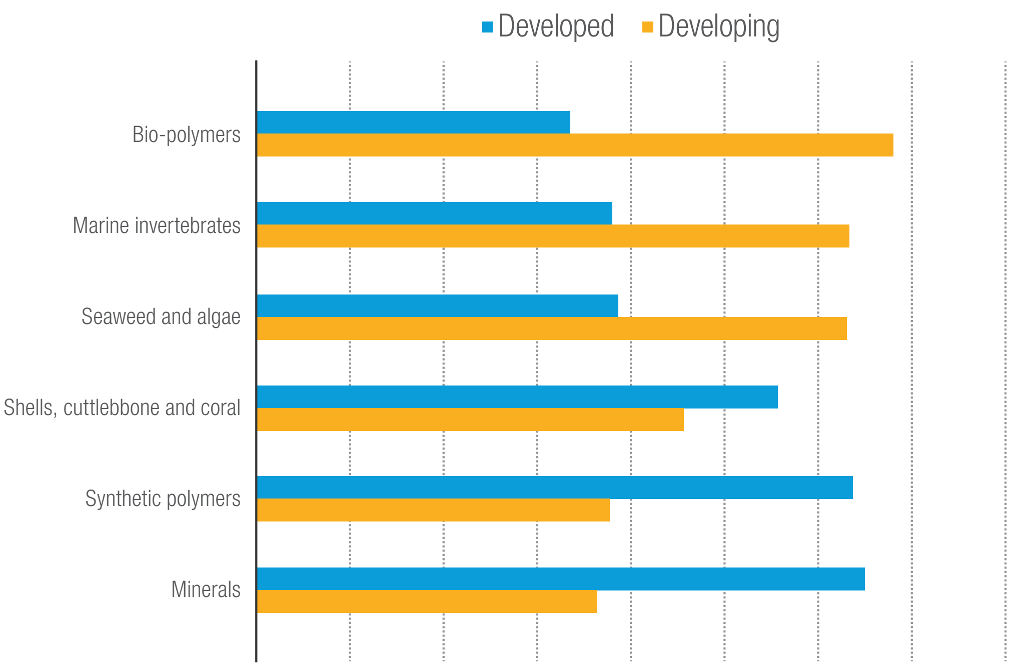
4.3. Market access policies applied to MBSAs

4.3.1. Import tariffs applied to MBSAs

This section examines the import tariffs applied to MBSAs and conventional plastics among WTO members, identifying key patterns based on product type, geographic region, and level of economic development. The analysis assesses the most-favoured-nation (MFN) tariffs notified by WTO members for the latest available year, using HS codes from both the 2017 and 2022 editions. The dataset includes tariff data across approximately 110 WTO members for each product, though the notifying members may vary by product.

Figure 11

Participation of developed and developing countries in global exports of MBSAs by material group (%, 2022)



Source: UNCTAD analysis on data UN Comtrade (2024). Accessed: July 2024.

Note: Developed and developing economies are defined according to the UNCTAD country classification (link). The proxy HS codes assigned to each material/product part of these groups are listed in Annex 2. Due to the lack of suitable proxy HS codes, only selected materials/products part of the MBSA mapping were included in the analysis. For this reason, "Marine invertebrates" includes only jellyfish.

32 UNCTAD analysis on data UN Comtrade (2024). Accessed: July 2024.

Tariffs applied to categories of MBSAs vary considerably as market access conditions differ according to the type or origin of the materials. Marine biopolymers such as carrageenan, agar-agar, and alginates enjoy quite favourable conditions, with relatively low average MFN import tariffs of 4.1 per cent. This is only slightly higher than the average tariff of 4.0 per cent for synthetic polymers (Figure 12). Conversely, marine invertebrates (jellyfish), shells, and coral face relatively high tariffs at 12.8 per cent and 8.1 per cent, respectively. Seaweed is subject to higher-than-average but moderate tariffs of around 6 per cent. This is in line with a global trend in which products of plant or animal origin are typically subject to higher tariffs, while mining and metal ores are subject to lower tariffs (UNCTAD, 2024d).

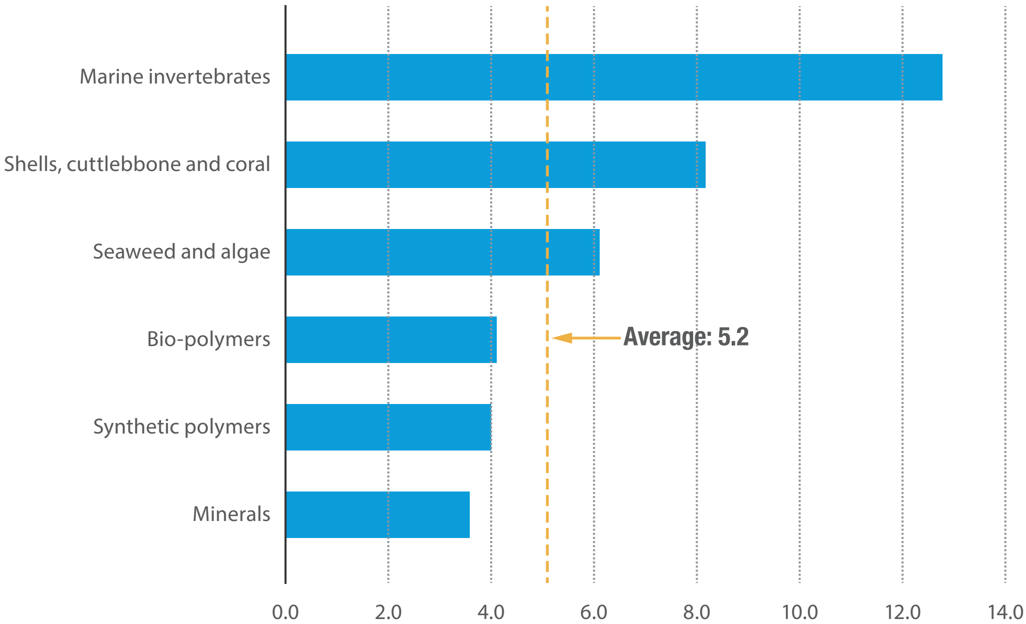
Interestingly, lower applied MFN tariffs on biopolymers as opposed to the raw materials from which they are extracted can be viewed as an opportunity for developing countries with significant marine resources, such as SIDS, to add domestic value before export.

Average tariffs applied to MBSAs are higher than those applied to synthetic polymers across all regions. However, the difference is generally not significant, except in Africa, where the average tariff for MBSAs is about 60 per cent higher than that for plastics (Figure 13). In Asia, the largest importer of seaweed in 2022,[33] the tariffs are relatively similar, at 5.2 per cent for MBSAs and 4.9 per cent for plastics. Europe, an emerging market for plastic substitutes and the region applying the lowest average tariffs, applies a 2.5 per cent rate for MBSAs and a 2.1 per cent rate for plastics (European Environment Agency, 2023).

Figure 12

Average MFN tariffs applied to MBSAs vs. synthetic polymers, by material category

a. MBSAs



Source: UNCTAD analysis on data WTO Tariff Download Facility. Last accessed: July 2024.

Note: MFN Tariff is one that WTO member countries promise to apply to all their trading partners who are also WTO members, unless the country is part of a preferential trade agreement. Therefore, this analysis may not reflect preferences foreseen in certain Free Trade Agreements (FTAs). Data are 2023 or most recent available year.

33 Data according to "Major Importers HS Code 121229 in 2022" in OECWorld. Last accessed, July 2024.

A similar pattern is observed when comparing average tariffs applied by developed versus developing economies. Remarkable differences can be observed across the country groups. In fact, tariffs applied to MBSAs by developing countries are on average more than twice as high as those applied by developed countries (5.7 versus 2.4, respectively). While developed countries offer more favourable market access conditions, under the right circumstances, the higher import tariffs applied by developing countries can create opportunities for South-South trade.

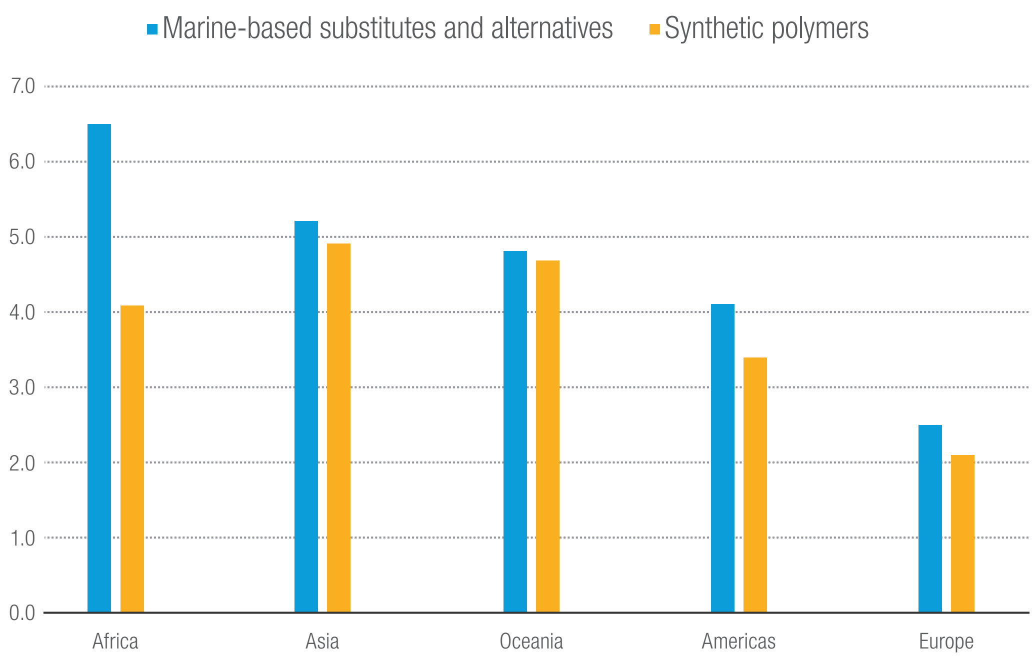
In developing countries, average tariffs on MBSAs are significantly higher than those on synthetic polymers (5.7 per cent vs. 4.3 per cent), while they are roughly the same in developed countries (2.35 vs. 2.39 per cent) (Figure 14). Like developed countries, SIDS show a relatively small tariff gap between MBSAs and synthetic polymers, indicating a more welcoming stance towards importing MBSAs than non-SIDS developing countries.

4.3.2. Non-tariff measures applied to MBSAs

4.3.2.1. What are NTMs and why they matter for MBSA trade

Non-tariff measures can be defined as "policy measures other than ordinary customs tariffs that can potentially have an economic effect on international trade in goods, changing quantities traded, or prices or both (UNCTAD, 2010). NTMs can be adopted to pursue a wide range of policy objectives such as consumer protection, public health, protection of the environment or economic development purposes. More specifically, UNCTAD's research has shown that NTMs can be closely linked to the pursuit of SDGs (UNCTAD and ESCAP, 2019a and 2019b)

Figure 13
Average MFN tariffs applied to MBSAs vs. synthetic polymers, by region



Source: UNCTAD analysis based on data from the WTO Tariff Download Facility Last accessed: July 2024.

Note: MFN tariff is one that WTO member countries promise to apply to all their trading partners who are also WTO members, unless the country is part of a preferential trade agreement. Therefore, this analysis may not reflect preferences foreseen in certain Free Trade Agreements (FTAs). Data are 2023 or most recent available year.

and that they constitute a major trade policy tool to address climate change (UNCTAD 2023a, 2023b and 2022c). NTMs are also used to tackle plastic pollution through the adoption of import bans on certain plastic products for environmental protection purposes in over 50 countries globally.[34]

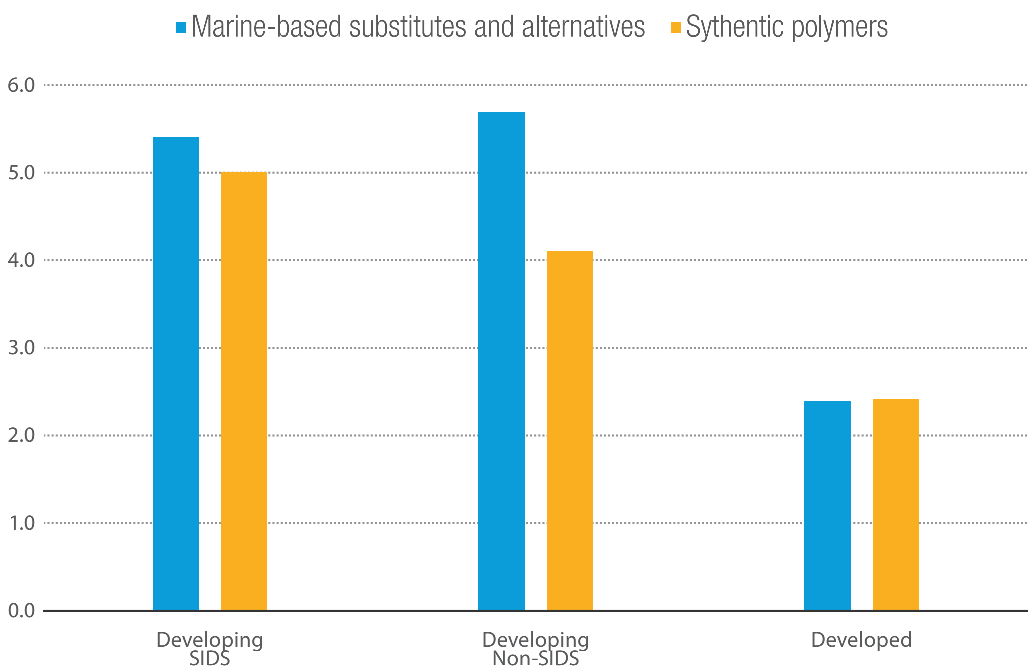
NTMs have been found to have a larger impact on international trade than tariffs (UNCTAD and World Bank, 2018). However, they tend to disproportionately affect exports from low-income countries and smaller producers (UNCTAD and World Bank 2018).

According to UNCTAD calculations, global average ad-valorem equivalents (AVEs) for all NTM types combined range between 5 and 27 per cent across sectors (UNCTAD, 2015).

Based on recent UNCTAD´s research, the most prevalent types of NTMs include technical barriers to trade (TBT), sanitary and phytosanitary (SPS), export, price control, quantity control and finance measures (UNCTAD, 2024d).[35] NTMs are often grouped into technical measures and non-technical measures. Technical measures are in principle primarily adopted

Figure 14

Average MFN tariffs applied to MBSAs vs. synthetic polymers, by development status of the importing country



Source: UNCTAD analysis based on data from the WTO Tariff Download Facility Last accessed: July 2024.

Note: Developed and developing economies are defined according to the UNCTAD country classification (link). Developing economies include China. MFN Tariff is one that WTO member countries promise to apply to all their trading partners who are also WTO members, unless the country is part of a preferential trade agreement. Therefore, this analysis may not reflect preferences foreseen in certain Free Trade Agreements (FTAs). Data are 2023 or most recent available year.

34 Authors' calculation using TRAINS data for NTM code E323 – European Union countries counted as 27 single countries. TRAINS is UNCTAD's global NTM database. It is available at: https://trainsonline.unctad.org/home.

35 SPS measures are measures that are applied to protect human or animal life from risks arising from additives, contaminants, toxins or disease-causing organisms in their food; to protect human life from plant or animal-borne diseases; to protect animal or plant life from pests, diseases, or disease-causing organisms; to prevent or limit other damage to a country from the entry, establishment or spread of pests; and to protect biodiversity. These include measures taken to protect the health of fish, wild fauna, forests and wild flora (UNCTAD, 2019a).

for non-trade related objectives and equally apply to importers and domestic producers. SPS and TBT measures are the two major types of technical measures.

The International classification of NTMs developed by UNCTAD and partner organizations forming the Multi-Agency Support Team provides basis for the identification of NTMs across countries and for reporting on internationally comparable data on non-tariff measures (UNCTAD, 2019a).

4.3.2.2. NTMs applied to MBSAs

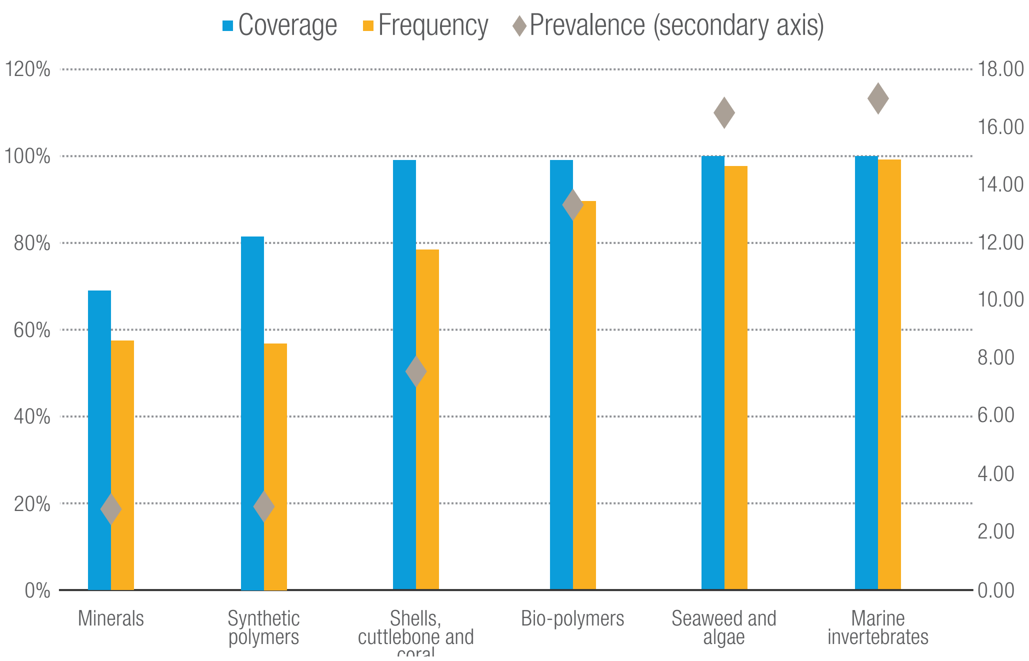
As for a previous UNCTAD´s study on plastics substitutes (UNCTAD, 2023a), the following three standard indicators were calculated to assess the use of NTMs in the regulation of trade in MBSAs:

- Frequency Index, which captures the percentage of products (at the 6-digit HS code) affected by one or more NTMs.
- Coverage ratio, which captures the share of trade subject to NTMs – unlike the frequency index, this uses trade values. It is weighted by import values rather than number of traded products.
- Prevalence score, which indicates the average number of distinct NTMs applied in a country to regulated products, thereby measuring the diversity and intensity of NTMs (UNCTAD, 2019b).

All three indicators were calculated using UNCTAD's TRAINS database which compiles NTM data from more than 100 countries covering over 90 per cent of global trade.

Except for mineral-based products, all considered MBSAs are significantly more impacted by NTMs than synthetic plastic polymers (Figure 15). On average at the global level, MBSAs face up to five times more NTMs than plastics and almost all the trade in products associated with MBSAs derived from shells, cuttlebones and coral, biopolymers, seaweed and algae, and marine invertebrates is covered by NTMs. On average, both frequency and coverage ratios of synthetic polymers by NTM are between 18 per cent and 34 per

Figure 15
Overall NTMs impact on MBSAs vs. synthetic polymers



Source: UNCTAD analysis on data UNCTAD Trains. Accessed: July 2024.

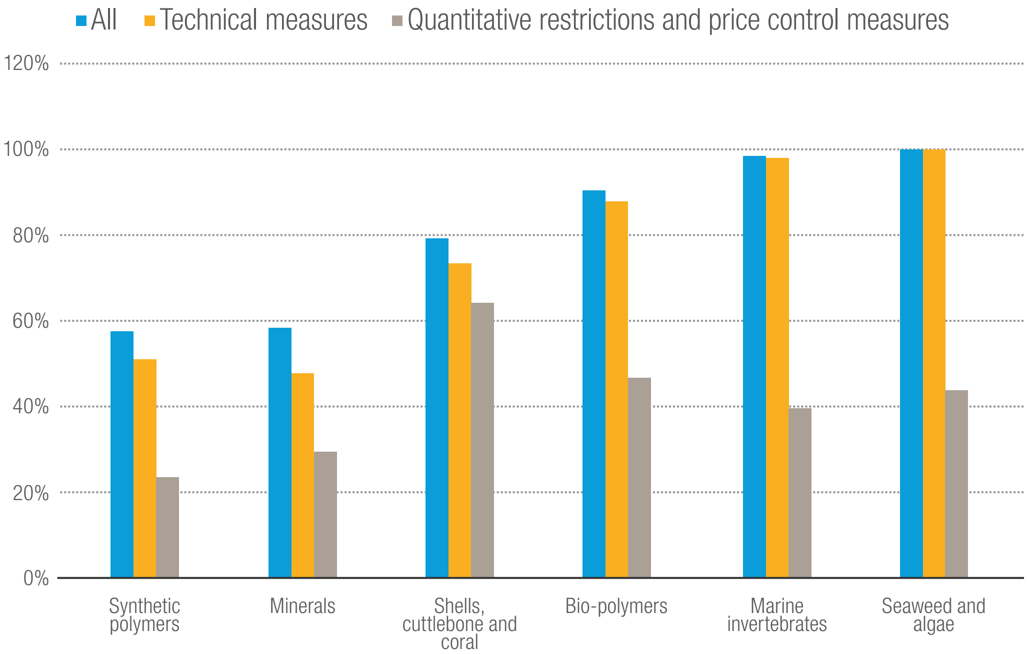
cent lower than those of substitutes and alternatives derived from marine animal and vegetable products. This means that a greater share of global trade in MBSAs is impacted by NTMs, and that the effect of NTMs on internationally traded MBSAs is significantly higher than on their plastic equivalents. Consequently, MBSAs are likely to face a competitive disadvantage and encounter higher market access barriers compared to synthetic polymers.

When looking into the major types of NTMs applied to MBSAs and their synthetic plastic equivalents, the analysis confirms that synthetic polymers and mineral-based MBSAs are less affected by NTMs than MBSAs derived from animal or vegetable raw materials, irrespective of the type of considered NTM. MBSAs from animal or vegetable raw materials are more subject to both technical measures (SPS measures and TBT) than their synthetic equivalents. They are also more subject to quantitative restrictions and price control measures (Figures 16 and 17).

The analysis also shows that technical measures are the category of NTMs which most affect global trade in MBSAs. The frequency index of technical NTMs targeting marine invertebrates, seaweed and algae is close to 100 per cent, meaning that all traded products from these two groups are subject to at least one NTM. In contrast, the NTM frequency index is only 57 per cent for synthetic polymers and 58 per cent for minerals (Figure 16). Similarly, the coverage ratio by technical NTMs of plastic substitutes derived from shells, cuttlebones and coral, biopolymers, seaweed and algae, and marine invertebrates is close to 100 per cent while that of synthetic polymers and minerals respectively amount to 77 per cent and 56 per cent (Figure 17).

The prevalence score, which provides a clearer picture of the regulatory burden faced by traded products, reveals that technical measures, particularly SPS measures, constitute the bulk of the NTMs imposed on MBSAs (Figure 18). On average, each material/product from

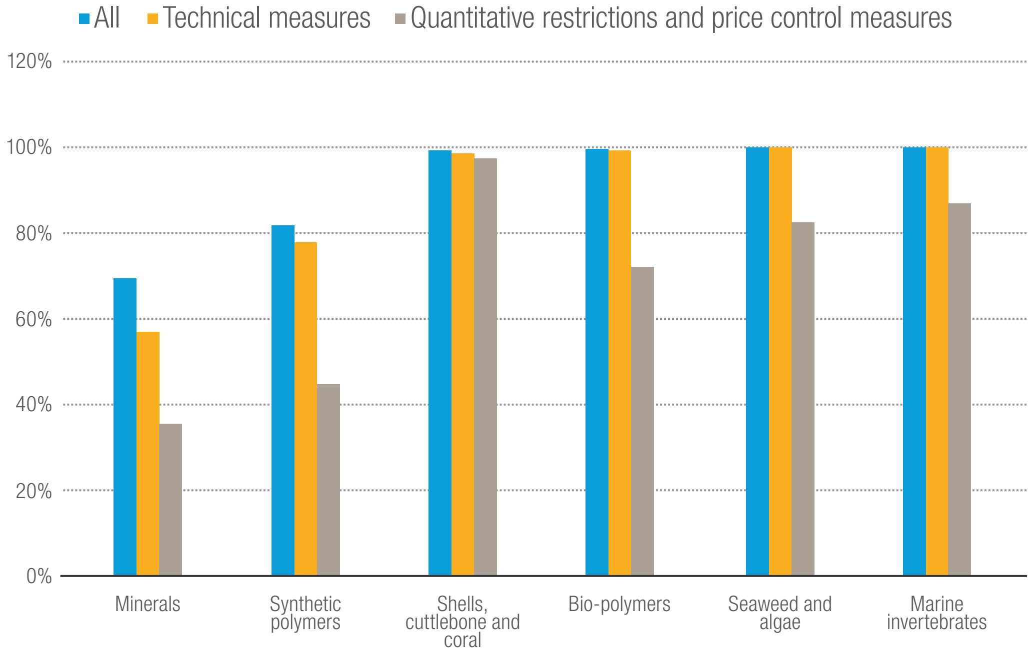
Figure 16
Frequency index by types of NTMs applied to MBSAs vs. synthetic polymers



Source: UNCTAD analysis on data UNCTAD Trains. Accessed: July 2024.

Figure 17

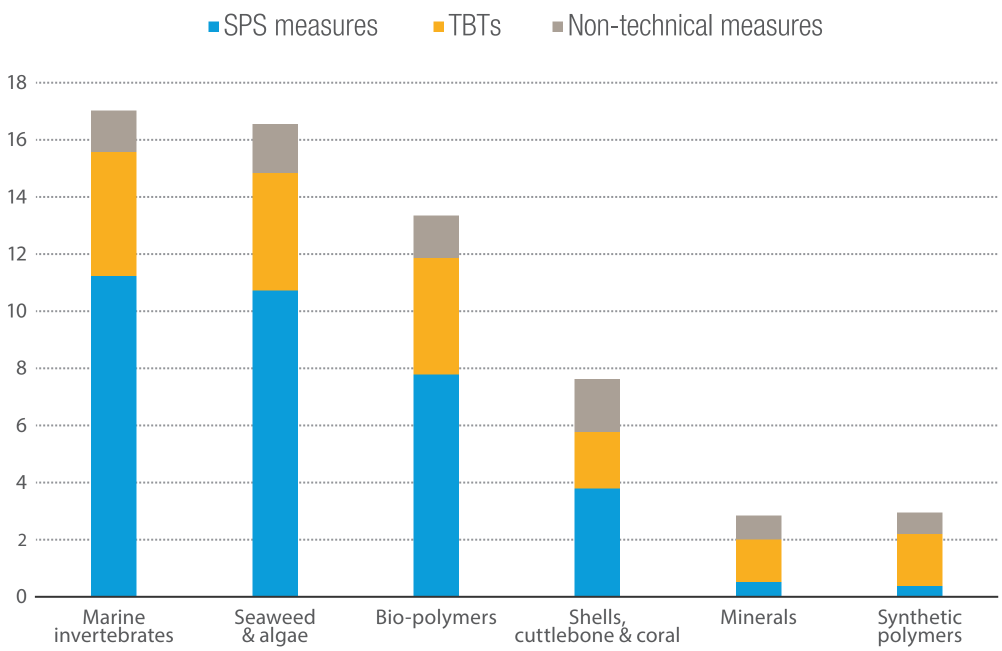
Coverage ratio by types of NTMs applied to MBSAs vs. synthetic polymers



Source: UNCTAD analysis on data UNCTAD Trains. Accessed: July 2024.

Figure 18

Average number of NTMs applied to MBSAs categories vs. synthetic polymers, by type (prevalence score)



Source: UNCTAD analysis on data UNCTAD Trains. Accessed: July 2024.

the marine invertebrate and seaweed and algae groups is faced with more than 10 SPS measures and each product from the biopolymers group is faced with close to 8 SPS measures. By comparison, products from the minerals and synthetic polymer groups face fewer than 1 SPS measure each, and fewer than 3 NTMs in total when considering all key types of NTMs.

The gap between the regulatory intensity faced by conventional plastic polymers and its most regulated substitutes narrows down in the case of TBTs, with synthetic polymers facing on average 1.8 TBT and plastic substitute products derived from marine invertebrates facing on average 4.4 TBTs. For their part, non-technical measures are much less numerous for all considered product groups.

Notably, the use of the prevalence score also confirms that trade in MBSAs is regulated in very different ways depending on the origin of the raw material. On one hand, mineral-based MBSAs face fewer NTMs per traded product than synthetic polymers. On the opposite end of the spectrum, marine invertebrates, seaweed or biopolymers are confronted with more than four times more NTMs than conventional plastic polymers. This difference in treatment can be explained by perceived potential health hazards, for human beings, flora, and fauna, associated with the use of animal- and plant-based raw materials. It is likely to result in significantly different costs of compliance and market access challenges for small producers.

Trends observed at the MBSA level in terms of NTM coverage and impact are in line with global observations on the impact of NTMs on animal and plant-based products. NTMs significantly impact animal and vegetable products, particularly through SPS and TBT measures. The cost of NTMs on these products is substantial, often exceeding the impact of tariffs (UNCTAD, 2024d).

To sum up, MBSAs are significantly more impacted by NTMs than their plastic competing alternatives. They are more frequently targeted by NTMs, face a greater number of measures, and incur higher compliance costs. This disparity in treatment largely stems from the nature of the raw materials used to produce the substitutes. Animal and plant-based MBSAs are the most affected by NTMs, while mineral-based MBSAs and synthetic polymers are among the least impacted.[36] This may involve a competitive disadvantage for the most heavily regulated categories of MBSAs, such as seaweed and algae. To complement this analysis, quantitative analysis and business insight into regulations and standards covering seaweed are presented in Annex 4.

A more in-depth analysis is needed to determine the feasibility of specific regimes to reduce the regulatory burden on MBSAs while ensuring optimal human, animal and plant health. The creation of an international legal regime for plastic substitutes through, for instance, the adoption of the United Nations Global Plastics Treaty, hold the potential to standardize regulations, lower compliance costs and create a level-playing field for MBSAs in international markets.

36 Health considerations appear as the primary justification for this situation. In fact, SPS measures constitute the majority of NTMs on MBSAs.

Chapter V

Conclusion and the way forward

This study elaborates on the need for stakeholders to move beyond the goal of a plastic-free world, and to instead collaborate to pursue a new plastics economy - one in which plastics are phased out where possible and used where useful after careful assessment of life-cycle trade-offs. By facilitating the development and diffusion of bio-based substitutes and alternatives to plastics, trade can be a powerful driver of this transition.

Building on the findings of this study, this section identifies avenues for future policy, business, advocacy and research action to effectively address plastic pollution through MBSAs. These actions for consideration are tailored to specific stakeholder groups: Governments, IGOs, business, civil society, and academia.

For intergovernmental organisations and their Member States

Intergovernmental organizations and their Member States can play a crucial role in promoting the emergence, development, and regulation of MBSAs as part of strategies to achieve a plastic pollution-free international materials system. The ongoing United Nations negotiations for an ILBI on plastic pollution, including in the marine environment under the International Negotiations Committee (INC) are at an advanced stage and may conclude by 2025. INC drafts issued in 2024 draft include references to fostering innovation, development, and regulatory controls for safe and environmentally sound non-plastic substitutes. Maintaining and expanding these references in a future treaty could help level the playing field for MBSAs compared to primary polymers and plastic products in national regulatory systems.

The ILBI could also call for the development of standards for safe and environmentally sound MBSAs, enabling harmonization and mutual recognition of standards and conformity assessments, thereby reducing compliance costs.

To improve the accuracy and understanding of trade flows and applicable NTMs for MBSAs, Members of the WCO could discuss creating more detailed codes for different types of MBSAs, especially for non-food uses. This is important as safety and environmental regulations differ significantly between food and non-food products and are managed by different regulatory agencies.

For developing countries, the Global System of Trade Preferences among Developing Countries (GSTP) could facilitate cooperation to address tariff and non-tariff measures for MBSAs through horizontal or sectoral agreements, promoting market creation and the widespread use of sustainable materials in the transition away from plastics.

UNCTAD has proposed creating a United Nations Task Force on seaweed to support R&D and supply-side capacities for diverse non-plastic applications and low-pollution product designs based on MBSAs. This task force could act as a broker of scientific knowledge, supporting discussions to address regulatory or standards gaps in production, processing, safety, and environmental sustainability along the value chain.

For Governments

Governments can play a critical role in creating an enabling environment for the development and trade of MBSAs, through multilateral processes, cooperation, and national policymaking. Overall, the establishment of comprehensive regulatory frameworks that support the production and marketing of MBSAs should be prioritised. This includes harmonising standards and regulations through intergovernmental processes (e.g., the future United Nations Global Plastics Treaty, Harmonized System reform), establishing tariff regimes that prioritise MBSAs over conventional plastics, and removing unnecessary non-tariff barriers (e.g., stringent SPS measures for non-food applications). Standards that do not directly affect trade in MBSAs but are fundamental to their accounting and understanding, e.g., through tariff determination and trade statistics, should also be considered.

The HS system and its implementation at the national level, where new codes and tariff lines may be created for emerging products, or further disaggregated for materials with both substitute and non-substitute uses, is an illustrative case.

Government actions can also help provide economic incentives where the market does not and address any market inefficiencies through direct support mechanisms. Examples of such interventions in this sense include, but are not limited to, guaranteed purchase, procurement policies, tax breaks for R&D, price controls to make MBSAs cost-competitive in early market phases (e.g., marine bioplastics) and financial support to companies for the uptake of MBSA-related technologies (e.g., bioreactors). By the same token, policy instruments that support conventional plastics production, marketing and use, such as subsidies to fossil fuels, could be phased out or diminished. This will place MBSAs on a more competitive price footing compared to conventional plastics and help create an enabling environment for MBSA industries development.

Governments also have a role to play in improving the skills base and absorptive capacity of companies to ensure they can tap into new OBEEs and compete in global MBSA markets. Investment in infrastructure (e.g., mineral transport) and capacity-building initiatives and curriculum (e.g., training on non-food applications of algae) is crucial to support local communities, particularly in coastal regions and SIDS, in the sustainable harvesting and processing of marine resources.

Promoting public-private partnerships in high-impact areas, such as strategy development, can leverage resources and expertise to ensure that emerging MBSA industries develop in a sustainable and inclusive manner. For example, the environmental impacts of marine mineral extraction can be minimised through effective and impartial impact assessment, a precautionary approach, low-intrusive technologies, risk mitigation measures, and life cycle assessments jointly commissioned by public and private actors.

For Businesses

Companies have a significant opportunity to lead the transition to a new plastics economy by integrating MBSAs into their production processes and product portfolios. To do this, companies should invest in R&D to improve the performance and competitiveness of MBSAs. In doing so, they will not only respond to the business case for sustainability but also contribute to the expansion of global MBSA markets, such as packaging, textiles and construction materials.

The private sector also plays a key role in ensuring that MBSA supply chains develop sustainably and inclusively. Large companies are at the forefront of the sustainability transition. Driven by market and regulatory trends, they are driving innovative business models and setting new and higher standards (e.g., product specifications, traceability, and due diligence) that encourage all supply chain participants to change and move towards responsible business practices. This is the case for social and environmental entrepreneurs, cooperatives and associations – often led by women – who may not operate in an enabling environment. Policies facilitating the registration of companies with broader missions than profit maximization, along with improved access to finance and fiscal incentives for their additional social and environmental contributions, would be crucial in many countries. Integrating these enterprises into the broader supply chains of larger firms can also advance social sustainability and women's empowerment.

Adopting responsible business practices and transparent reporting can build consumer trust and demand for eco-friendly products, contributing to stronger and more predictable MBSA markets. Companies can also support advocacy efforts favouring industry standards that promote sustainability.

For Civil Society

Civil society organisations (CSOs) are key advocates for putting people and planet first and can play a vital role in raising awareness of the benefits of MBSAs. CSOs could engage in public education campaigns to inform policymakers and consumers about the environmental and social impacts of plastic pollution and the benefits of adopting MBSAs. In doing so, they would ensure that the environmental benefits of MBSAs are not offset by negative impacts at other stages of their life cycle, as is the case with marine bioplastic packaging in the absence of robust industrial composting facilities.

As the WWF case study shows (Box 3), CSOs can also facilitate community-based projects that promote sustainable livelihoods through local production and use of MBSAs. By doing so, they can act as knowledge catalysts between private and public actors in strategic areas such as product traceability.

In addition, CSOs can hold governments and companies accountable for their environmental commitments by advocating for stronger regulations and enforcement mechanisms at the national level. Under the right conditions, these actions can lead to better legal frameworks and environmental safeguards, such as those for biodiversity conservation. Similarly, by building networks and coalitions, civil society can amplify its voice and influence policy-making processes at both national and international levels.

For Academia

Academic institutions and research think tanks are essential for advancing scientific understanding, technological development, and impact assessment of MBSAs. Researchers can conduct comprehensive life cycle assessments to evaluate the environmental impacts of MBSAs from production to disposal and ensure that the trade-offs of MBSA substitution are well understood (see section 3.3). In this regard, assessments should be carried out in a comparative manner, focusing on emerging products (e.g., marine vs. land-based mineral fillers). This includes identifying potential areas for improvement to ensure that MBSAs offer a net environmental benefit.

Further research is also needed to explore marine resources and develop innovative materials that are both functional and economically viable. Interdisciplinary collaboration is essential, bringing together experts in marine biology, materials science, economics and policy to address the complex challenges associated with MBSAs and to develop solutions that minimise societal (social, environmental) impacts while maximising socio-economic benefits.

In this regard, it is important that academia works closely with industry and policymakers to translate research findings into practical solutions and recommendations that can be incorporated into business and policy decisions. Communicating scientific findings to a wider, non-technical audience is also essential to raise awareness of the benefits of MBSAs and promote sustainable consumer preferences.

For consumers

Consumers play a crucial role in driving the uptake of MBSAs. Currently, the higher cost of many MBSA, particularly bioplastics such as PHAs, is a significant barrier to adoption. Consumer willingness to pay a premium for sustainable alternatives is essential to stimulate demand and create economies of scale that drive prices down. This underscores the importance of raising consumer awareness of the environmental impact of conventional plastics and the benefits of MBSAs. As the case of seaweed shows, transparency about the origin and production methods of these new materials, including certifications that verify responsible sourcing, is also essential to build consumer trust and drive market growth.

Beyond price, consumer behaviour also plays a role. While environmental awareness is growing, bridging the intention-action gap is crucial. This requires accessible information, clear labelling, and convenient access to these products. Supporting infrastructure, such as industrial composting facilities, is also needed to ensure that the environmental benefits of bioplastics are not lost at the end of their life cycle.

In conclusion, advancing MBSAs offers a promising approach to reducing plastic pollution and promoting sustainable development across its three dimensions: economic, social and environmental. By fostering collaboration between governments, businesses, civil society and academia, a supportive ecosystem can be created to enable the growth of MBSA industries through trade. This multi-faceted approach will help unlock the full potential of marine resources, drive innovation, and strengthen supply chains, making MBSAs well accepted and scalable alternatives to conventional plastics. It will also provide economic and trade diversification opportunities for local communities in coastal areas and developing countries rich in these resources.

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Annex 1. Methodological considerations

This study was conducted using a mixed-method, combining original data analysis of the world's main trade databases (e.g., UN-Comtrade, TRAINS), desk research and key informant interviews (KIIs). KIIs, also used to develop case studies, were conducted with practitioners from the private sector, civil society and academia, to explore issues that could not be adequately addressed through data analysis or for which data was not available. The full list of interviewees can be found in the Acknowledgements section.

Despite limitations discussed in section 4.1, the HS system provides a workable framework for calculating the value of global trade in MBSAs, i.e., minerals, bio-based components and materials with applications in replacing conventional plastics or producing non-plastic substitutes (e.g., glass, ceramics) that can potentially be sourced from the sea. Similarly, average applied tariff rates can be calculated and the main NTMs affecting their trade can be mapped to gain a better understanding of market access conditions in MBSA markets.

Based on Table 6, UNCTAD assigned the best proxy six-digit HS code to each material part of its global mapping of MBSAs. The association was made by combining a thorough review of over 5000 codes with desk research to better understand the nature, origin and end-use of each identified MBSA. The final list of HS codes was used to develop coherent material categories for comparative analysis (e.g., minerals, biopolymers) and to compile trade statistics (Annex 2). These categories were then used to calculate summary statistics on global trade flows, average applied tariffs and non-tariff measures affecting MBSAs, which are presented in sections 4.2.1, 4.3.1, and 4.3.2, respectively. In all analyses, MBSA categories were compared to a benchmark category of "synthetic polymers", including fossil fuel-based polymers that are commonly used as building blocks of conventional plastics (PP, PS, HDPE, LDPE, PET).

While all identified proxy HS codes were included in the list, only materials/components for which a one-to-one matching HS code could be found were included in the analyses of trade flows, tariffs and NTMs (e.g., agar-agar in Figure 6 above). In exceptional cases, relevant materials/components with proxy HS codes covering a broader group of materials/products (e.g., carrageenan in Figure 6 above) were included if the targeted product/material accounted for the majority of the trade covered by the proxy code. These cases were evaluated and included on the basis of ad-hoc analysis or reasonable assumptions. Additional information on the assumptions and caveats behind the analyses is provided in the notes to the graphs and tables.

In the absence of comprehensive statistics on the production and sale of MBSAs, international trade data can serve as a proxy for estimating the size of the global MBSA market. Exports, which in this study are measured using FOB (Free on Board) prices, represent a substantial part of the global market for many products. Countries producing more than they consume will likely export the excess, making export data a reflection of global demand. At the same time, the UN Comtrade database is a comprehensive source for international trade statistics, covering a wide range of products and includes data from many countries, and providing a strong foundation for estimation.

Annex 2. Proxy six-digit HS 2022 codes assigned to MBSAs

Code	Description	Group	Category	Abbreviation	Targeted MBSA	Included in chapter 4 analysis
130239	Mucilages and thickeners; whether or not modified, derived from vegetable products, n.e.c. in item no. 1302.3	Marine-based substitutes and alternatives	Biopolymers, of animal, plant and microbial origin	Biopolymers	Carrageenan	Yes
130231	Mucilages and thickeners; agar-agar, whether or not modified, derived from vegetable products	Marine-based substitutes and alternatives	Biopolymers, of animal, plant and microbial origin	Biopolymers	Agar-agar	Yes
391310	Polymers, natural; alginic acid, its salts and esters, in primary forms	Marine-based substitutes and alternatives	Biopolymers, of animal, plant and microbial origin	Biopolymers	Alginates	Yes
390799	Polymers, natural; alginic acid, its salts and esters, in primary forms	Marine-based substitutes and alternatives	Biopolymers, of animal, plant and microbial origin	Biopolymers	Polyhydroxy-alkanoates (PHAs)	No
391390	Polymers, natural and modified natural; in primary forms (excluding alginic acid, its salts and esters)	Marine-based substitutes and alternatives	Biopolymers, of animal, plant and microbial origin	Biopolymers	Other polymers, i.e., Chitin and Chitosan, Xylan, Mannan, Pullulan, Galactans, Fucoidan, Ulvan	No
391290	Cellulose and its chemical derivatives; n.e.c. in item no. 3912, in primary forms	Marine-based substitutes and alternatives	Biopolymers, of animal, plant and microbial origin	Biopolymers	Cellulose	No
110819	Starch; n.e.c. in item no. 1108.11 to 1108.14	Marine-based substitutes and alternatives	Biopolymers, of animal, plant and microbial origin	Biopolymers	Starch	No
050800	Animal products; coral and similar materials, shells of molluscs, crustaceans, echinoderms, cuttle-bone, unworked or simply prepared but not cut to shape, powder and waste thereof	Marine-based substitutes and alternatives	Crustacean and mollusc shells, cuttlebone and coral	Shells, cuttlebone and coral	Shells, cuttlebone and coral	Yes
051191	Animal products; of fish or crustaceans, molluscs or other aquatic invertebrates; dead animals of chapter 03, unfit for human consumption	Marine-based substitutes and alternatives	Fish waste, for purpose other than food, feed or fertilizer	Fish waste	Fish skins and leather	No

Code	Description	Group	Category	Abbreviation	Targeted MBSA	Included in chapter 4 analysis
030830	Aquatic invertebrates; jellyfish (Rhopilema spp.), live, fresh, chilled, frozen, dried, salted or in brine, smoked, whether or not cooked before or during smoking	Marine-based substitutes and alternatives	Marine invertebrates	Marine invertebrates	Jellyfish	Yes
051199	Animal products; n.e.c. in chapter 5	Marine-based substitutes and alternatives	Marine invertebrates	Marine invertebrates	Sponge	No
250700	Kaolin and other kaolinic clays; whether or not calcined	Marine-based substitutes and alternatives	Minerals, from the seabed or continental shelf	Minerals	Marine clays (Kaolin)	Yes
251710	Pebbles, gravel, broken or crushed stone; of a kind commonly used for concrete aggregates, for road metalling or for railway or other ballast, shingle and flint, whether or not heat-treated	Marine-based substitutes and alternatives	Minerals, from the seabed or continental shelf	Minerals	Pebbles and gravel	Yes
250510	Sands; natural, silica and quartz sands, whether or not coloured	Marine-based substitutes and alternatives	Minerals, from the seabed or continental shelf	Minerals	Silica and quartz sand	Yes
283650	Carbonates; calcium carbonate	Marine-based substitutes and alternatives	Minerals, from the seabed or continental shelf	Minerals	Calcium carbonate	Yes
250590	Sands; natural, (other than silica and quartz sands), whether or not coloured, (other than metal-bearing sands of chapter 26)	Marine-based substitutes and alternatives	Minerals, from the seabed or continental shelf	Minerals	Sands, other than silica and quartz	Yes
251200	Siliceous fossil meals (e.g., kieselguhr, tripolite and diatomite) and similar siliceous earths; whether or not calcined, of an apparent specific gravity of 1 or less	Marine-based substitutes and alternatives	Minerals, from the seabed or continental shelf	Minerals	Diatomite, marine biosilica	Yes
251010	Natural calcium phosphates, natural aluminium calcium phosphates and phosphatic chalk; unground	Marine-based substitutes and alternatives	Minerals, from the seabed or continental shelf	Minerals	Calcium phosphates, unground	No
261510	Zirconium ores and concentrates	Marine-based substitutes and alternatives	Minerals, from the seabed or continental shelf	Minerals	Zirconium	No

Code	Description	Group	Category	Abbreviation	Targeted MBSA	Included in chapter 4 analysis
250810	Clays (excluding expanded clays of heading no. 6806); bentonite, whether or not calcined	Marine-based substitutes and alternatives	Minerals, from the seabed or continental shelf	Minerals	Marine clays (Bentonite)	No
251110	Barium sulphate (barytes); natural	Marine-based substitutes and alternatives	Minerals, from the seabed or continental shelf	Minerals	Barium carbonate	No
252910	Feldspar	Marine-based substitutes and alternatives	Minerals, from the seabed or continental shelf	Minerals	Feldspar	No
250840	Clays (excluding expanded clays of heading no. 6806); n.e.c. in heading no. 2508, whether or not calcined	Marine-based substitutes and alternatives	Minerals, from the seabed or continental shelf	Minerals	Marine clays (Smectite, Illite, other...)	No
251020	Natural calcium phosphates, natural aluminium calcium phosphates and phosphatic chalk; ground	Marine-based substitutes and alternatives	Minerals, from the seabed or continental shelf	Minerals	Calcium phosphates, ground	No
250830	Clays (excluding expanded clays of heading no. 6806); fireclay, whether or not calcined	Marine-based substitutes and alternatives	Minerals, from the seabed or continental shelf	Minerals	Fire clay	No
251120	Barium carbonate (witherite); natural, whether or not calcined, other than barium oxide of heading no. 2816	Marine-based substitutes and alternatives	Minerals, from the seabed or continental shelf	Minerals	Barium carbonate	No
121221	Seaweeds and other algae; fit for human consumption, fresh, chilled, frozen or dried, whether or not ground	Marine-based substitutes and alternatives	Seaweed and algae	Seaweed and algae	Seaweed, fit for human consumption	Yes
121229	Seaweeds and other algae; not fit for human consumption, fresh, chilled, frozen or dried, whether or not ground	Marine-based substitutes and alternatives	Seaweed and algae	Seaweed and algae	Seaweed, unfit for human consumption	Yes
262190	Slag and ash n.e.c. in chapter 26; including seaweed ash (kelp) but excluding ash and residues from the incineration of municipal waste	Marine-based substitutes and alternatives	Seaweed, ash	Seaweed, ash	Seaweed ash (kelp)	No
560811	Twine, cordage or rope; fishing nets, made up, of man-made textile materials	Conventional plastics (benchmark)	Fishing nets	Fishing nets	Fishing nets	No
392330	Plastics; carboys, bottles, flasks and similar articles, for the conveyance or packing of goods	Conventional plastics (benchmark)	Plastic bottles	Plastic bottles	Plastic bottles	No

Code	Description	Group	Category	Abbreviation	Targeted MBSA	Included in chapter 4 analysis
392310	Plastics; boxes, cases, crates and similar articles for the conveyance or packing of goods	Conventional plastics (benchmark)	Plastic boxes and cases	Plastic boxes	Plastic boxes	No
392010	Plastics; plates, sheets, film, foil and strip (not self-adhesive), of polymers of ethylene, non-cellular and not reinforced, laminated, supported or similarly combined with other materials	Conventional plastics (benchmark)	Synthetic plastic plates, sheets, foil and film	Synthetic plastics	Plastic plates, sheets, foil and film of Polyethylene (LDPE, HDPE)	No
392020	Plastics; of polymers of propylene, plates, sheets, film, foil and strip (not self-adhesive), non-cellular and not reinforced, laminated, supported or similarly combined with other materials	Conventional plastics (benchmark)	Synthetic plastic plates, sheets, foil and film	Synthetic plastics	Plastic plates, sheets, foil and film of Polypropyl-ene (PP)	No
392030	Plastics; of polymers of styrene, plates, sheets, film, foil and strip (not self-adhesive), non-cellular and not reinforced, laminated, supported or similarly combined with other materials	Conventional plastics (benchmark)	Synthetic plastic plates, sheets, foil and film	Synthetic plastics	Plastic plates, sheets, foil and film of Polystyrene (PS)	No
392062	Plastics; plates, sheets, film, foil and strip (not self-adhesive), of poly (ethylene terephthalate), non-cellular and not reinforced, laminated, supported or similarly combined with other materials	Conventional plastics (benchmark)	Synthetic plastic plates, sheets, foil and film	Synthetic plastics	Plastic plates, sheets, foil and film of poly (ethylene terephthal-ate) (PET)	No
390110	Ethylene polymers; in primary forms, polyethylene having a specific gravity of less than 0.94	Conventional plastics (benchmark)	Synthetic polymers	Synthetic polymers	Ethylene polymers, Polyethylene (LDPE)	Yes
390120	Ethylene polymers; in primary forms, polyethylene having a specific gravity of less than 0.94	Conventional plastics (benchmark)	Synthetic polymers	Synthetic polymers	Ethylene polymers, Polyethylene (HDPE)	Yes
390210	Propylene, other olefin polymers; polypropylene in primary forms	Conventional plastics (benchmark)	Synthetic polymers	Synthetic polymers	Propylene polymers, Polypropyl-ene (PP)	Yes
390311	Styrene polymers; expansible polystyrene, in primary forms	Conventional plastics (benchmark)	Synthetic polymers	Synthetic polymers	Styrene polymers, expansible Polystyrene (PS)	Yes
390319	Styrene polymers; (other than expansible polystyrene), in primary forms	Conventional plastics (benchmark)	Synthetic polymers	Synthetic polymers	Styrene polymers, other than expansible Polystyrene (PS)	Yes

Annex 3. Global exports of MBSAs, by material group ($ million and CAGR, 2012-22)

Material	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	CAGR 2012–2022
Conventional plastics (benchmark)	**82,102**	**91,164**	**93,748**	**78,463**	**76,099**	**82,153**	**91,546**	**82,225**	**75,091**	**106,827**	**79,833**	**-0.3%**
Synthetic polymers	**82,102**	**91,164**	**93,748**	**78,463**	**76,099**	**82,153**	**91,546**	**82,225**	**75,091**	**106,827**	**79,833**	**-0.3%**
Ethylene polymers, Polyethylene (HDPE)	25,538	28,478	29,930	25,970	26,216	27,317	29,821	27,466	24,767	32,537	25,032	-0.2%
Ethylene polymers, Polyethylene (LDPE)	22,749	26,211	27,174	23,593	23,187	24,434	27,390	23,525	21,420	31,697	23,245	0.2%
Propylene polymers, Polypropyl-ene (PP)	24,148	26,106	27,367	22,224	20,342	22,982	26,254	24,452	23,107	33,573	23,208	-0.4%
Styrene polymers, expansible Polystyrene (PS)	3,383	3,897	3,507	2,646	2,396	3,011	3,227	2,482	2,092	3,722	3,789	1.1%
Styrene polymers, other than expansible Polystyrene (PS)	6,284	6,471	5,770	4,029	3,959	4,410	4,854	4,298	3,705	5,299	4,559	-3.2%
Marine-based substitutes and alternatives	**8,287**	**8,608**	**9,106**	**8,324**	**7,923**	**8,529**	**9,219**	**9,203**	**8,581**	**9,874**	**10,831**	**2.7%**
Biopolymers	**1,400**	**1,552**	**1,682**	**1,529**	**1,455**	**1,508**	**1,641**	**1,721**	**1,647**	**1,936**	**2,625**	**6.5%**
Agar-agar	217	251	293	271	258	267	268	256	241	260	272	2.3%
Alginates	180	187	184	156	155	161	152	166	156	161	194	0.7%
Carrageenan	1,002	1,114	1,205	1,102	1,043	1,080	1,221	1,300	1,250	1,514	2,159	8.0%
Marine invertebrates	**68**	**102**	**79**	**89**	**119**	**98**	**112**	**110**	**88**	**145**	**118**	**5.8%**
Jellyfish	68	102	79	89	119	98	112	110	88	145	118	5.8%
Minerals	**5,971**	**6,056**	**6,377**	**5,868**	**5,503**	**5,891**	**6,401**	**6,301**	**5,867**	**6,690**	**6,698**	**1.2%**
Calcium carbonate	858	892	815	649	607	623	656	685	745	834	819	-0.5%
Diatomite, marine biosilica	152	160	149	123	136	147	150	136	133	150	146	-0.4%
Marine clays (Kaolin)	1,566	1,590	1,754	1,674	1,614	1,676	1,765	1,667	1,467	1,825	1,965	2.3%
Pebbles and gravel	2,003	2,049	2,097	2,056	1,856	1,901	2,129	2,187	2,019	2,183	2,002	0.0%

Material	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	CAGR 2012–2022
Sands, other than silica and quartz	456	504	568	447	446	484	501	516	522	600	598	2.7%
Silica and quartz sand	936	860	994	918	844	1,060	1,200	1,110	981	1,098	1,168	2.2%
Seaweed and algae	**678**	**719**	**786**	**650**	**677**	**876**	**907**	**908**	**836**	**944**	**1,244**	**6.3%**
Seaweed, fit for human consumption	445	402	454	423	416	570	625	675	611	673	859	6.8%
Seaweed, unfit for human consumption	233	316	332	227	261	305	282	233	225	272	386	5.2%
Shells, cuttlebone and coral	**171**	**179**	**182**	**188**	**169**	**156**	**158**	**162**	**143**	**160**	**144**	**-1.7%**
Shells, cuttlebone and coral	**171**	179	182	188	169	156	158	162	143	160	144	-1.7%

Annex 4. Focus on seaweed: Qualitative analysis and business insights into regulations and standards

As shown in Figure 18, SPS measures are the most actively regulated areas for MBSAs. These measures protect humans and animals from harmful additives, contaminants, and diseases in food. They also guard against diseases from plants and animals, protect plants and animals from pests, prevent pest spread, and help preserve biodiversity. In general, states impose these measures to ensure MBSAs do not pose health or environmental risks.

While their material applications are becoming more widespread, qualitative analysis shows that seaweed and algae are still typically regulated as food commodities to ensure they are safe for consumption. In the European Union, exporters must comply with at least three key legislations: the "General Food Law," which sets requirements for traceability, hygiene, and control to ensure seaweed and algae are safe to eat and meet legal limits for contaminants; Regulation (EC) 1333/2008, which defines rules on food additives, including their definitions, conditions of use, labelling, and procedures; and European Union Regulation 2012/231/EU, which provides E-numbers and specifications for approved food additives, including for processed Eucheuma seaweed (E407a) (CBI Ministry of Foreign Affairs, 2023). Similarly, the United States regulates food, including seaweed, to ensure safety for human consumption through the Food, Drug, and Cosmetic Act, which provides the legal foundation for the Food and Drug Administration to oversee the safety, sanitation, and proper labelling of products, and the «Food Safety Modernization Act,» which focuses on the prevention of contamination and regulatory enforcement (Catherine M. Janasie, 2022). China has also promulgated the Food Safety Law to regulate food's production, distribution, and labelling. Four government departments, including the General Administration of Customs, the Ministry of Agriculture and Rural Affairs and the National Health Commission, and State Administration of Market regulation coordinate and ensure food safety (Junshi Chen and Chunzhu Wu, 2022).43

While seaweed and algae are heavily regulated as foods, there are limited regulations and standards governing their material use, e.g., in packaging, both domestically and internationally. For example, KIIs with officials involved in standards setting revealed that the International Organization for Standardization (ISO) does not have specific standards for algae-based packaging. Instead, seaweed is only included in a horizontal standard providing general requirements for "Packaging and the Environment" (ISO, 2013). Similarly, the American Society for Testing and Materials (ASTM) applies to seaweed general packaging standards, such as those governing the biodegradation of plastic materials (ASTM D6691-17). Interviews suggest that members of ASTM Committee D20 on Plastics and Subcommittee D20.96 are involved in developing and marketing biodegradable plastic materials that might incorporate seaweed as a feedstock.

As a result, producers in the seaweed packaging market, or those aspiring to enter it, may find themselves in an uncertain situation, overwhelmed by ambiguous regulatory requirements that are only partially relevant to the use of seaweed as material.44 Regulatory uncertainty is confirmed by KIIs with business executives, who reported they were discouraged to engage in international trade of seaweed due to broad regulatory requirements, unharmonized standards and unfavourable tariff structures (Box 5). This regulatory gap underscores the need for harmonized, seaweed-specific standards to support producers innovating to provide substitutes that generate socio-economic, environmental, and equity benefits.

Box 5

The impact of seaweed regulations and standards on business: Insight from members of the Global Seaweed Coalition

During KIIs, members of the Global Seaweed Coalition45 were asked specific questions about the regulatory requirements they need to meet in order to export seaweed-based packaging materials to the European Union and United Kingdom. The questions explore what standards apply, whether these standards are the same as those for biodegradable packaging (e.g., made from PHA/PLA), whether any SPS (e.g., food safety standards) apply, and whether foreign jurisdictions have or are developing standards for seaweed as a non-food material. The companies interviewed provided valuable insights and confirmed that they face both regulatory challenges and trade barriers (e.g., high tariffs).

In particular, companies face significant hurdles due to the lack of specific standards tailored to seaweed as a non-food material. While there are general standards for packaging and food contact materials, these are primarily designed for traditional non-plastic substitutes such as plastic, glass and cardboard (e.g., European Union Regulation (EC) No 1935/2004, REACH Regulation). This mismatch often results in burdensome compliance efforts for individual companies and may ultimately stifle innovation in the sector. Similarly, while biodegradability standards exist such as the Technischer Überwachungsverein (TÜV) OK Compost Industrial, they are reportedly not effective in identifying environmentally sound solutions as they do not assess turnkey issues such as the release of microplastics.

The lack of harmonisation and high regulatory fragmentation across jurisdictions is also an issue, as it increases compliance costs and creates barriers for companies seeking to enter foreign markets. Confirming the findings of the analysis presented in Chapter 4, companies also report that unfavourable tariff structures, which often favour petrochemical-based plastics over natural materials, add to the burden by increasing the monetary cost of exporting seaweed-based alternatives.

Source: UNCTAD compilation based on KIIs with Coalition officials and business executives

While businesses cope with the lack of regulations and standards for seaweed as a non-food material, more and more jurisdictions recognize its importance. The European Commission released a report titled “Towards a Strong and Sustainable European Union Algae Sector,” recognizing the diverse applications of seaweed and algae, as well as other new marine resources (biomass), in pharmaceuticals, nutraceuticals, plant biostimulants, bio-based packaging, and cosmetics. The European Commission also outlined an action plan, including “improving the governance framework and legislation,” to enhance the potential of seaweed and algae in Europe (European Commission, 2022). In May 2024, China and France issued a joint statement on preserving multilateralism and improving global governance. The joint statement recognizes the potential of seaweed and algae in the fertilizer, medicine, and cosmetics industries, and expresses the willingness for bilateral and multilateral cooperation (PRC Ministry of Foreign Affairs, 2024).

At the same time, the lack of international standards on seaweed and harmonization for seaweed regulations have also drawn the attention of intergovernmental organizations. For example, the 4th United Nations Ocean Forum and members of the Global Seaweed

Coalition (GSC) highlighted the absence of uniform regulations and standards for seaweed production and processing throughout its various applications as a significant issue (UNCTAD, 2022a; GSC, 2021). The lack of these standards poses a barrier to scaling up the sector effectively, intensifying existing challenges encountered by all producers, including women, and stakeholders along the value chain (UNCTAD 2024b). There is a pressing need for international efforts to establish and harmonize global regulations and standards.