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The blue economy and food security

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Abstract

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Shifting focus from agriculture to the sustainable use of marine resources is regarded as critical for addressing global food security amid growing demand and agricultural land degradation. Initially regarded as a conservation project, the blue economy has since transformed into a medium for innovation, especially in mariculture – the farming of marine organisms and seaweed. This study explores both the growth potential and the sustainability challenges the sector faces. The main conclusion is that blue economy activities can fulfil their promise as a pillar of global food security, but this requires the internalisation of a variety of externalities. This can be achieved through a framework for the use of mariculture in global food systems. To that end, marine activities related to food security must align with the core principles of the blue economy: integration and interconnectedness, innovation and diversification, equity and inclusivity, science-based management, and circular economy practices.

Keywords: blue economy; food security; mariculture; sustainable development

Introduction

Interest in the blue economy as an alternative to traditional land-based economic activities has increased in recent years, as policymakers, researchers, and environmental advocates have begun to explore more vigorously the complex relationship between economic development and environmental sustainability. The potential of marine resources to promote economic growth and improve livelihoods has been recognised, yet the challenge of ensuring the long-term health of marine ecosystems remains. This study aims to review the concept of the blue economy in the context of food security and to identify its potential for integration into global food systems. To accomplish this, we need to identify its shortfalls and suggest ways to overcome them.

The term "blue economy" was widely popularised at the Rio+20 United Nations Conference on Sustainable Development in 2012, where it was formally defined as a more sustainable and equitable approach to the exploitation of marine resources (Bennett et al., 2019). It represented the idea that the wellbeing of people in coastal regions and small island developing countries depends much more on the state and sustainable use of marine resources than on the state and sustainable use of their land resources. On a global scale, this is increasingly significant: as agricultural land becomes both scarce and degraded, while the world population and its demand for food grow, the ocean presents ample opportunities for food production through marine aquaculture, seaweed farming, and integrated coastal agricultural systems (Greene et al., 2022).

In this context, the term first appeared in the 2012 "Green Economy in a Blue World" report, produced by several UN and UN-affiliated institutions (UNEP et al., 2012). Prior to that, the resolutions following the regularly held UN Conference on Sustainable Development hardly noted the existence and state of marine ecosystems. Some of them did not even mention the words "ocean" or "marine." This was especially problematic with regard to food security, as it showed that the UN Conference failed to recognise the ocean's role in the global food system and the potential for marine agri-

culture to complement and supplement terrestrial farming. Meanwhile, more than 3.3 billion people presently depend on marine sources for almost 20% of their intake of animal protein (FAO, 2020).

The report voiced the growing concern about the deterioration of the world's ocean resources caused by pollution, climate change, and overuse, such as overfishing. It led to the A/RES/66/288 Resolution of 27 July 2012 of the UN General Assembly. Since 2012, the UN General Assembly has systematically focused on the state of the world's oceans because of concerns about the sustainable future of humanity. Today, it is well established that efforts to sustainably exploit land resources are contributing to the destruction of marine ecosystems and the overuse of sea-based resources, since the commonly applied solution to preserve land-based ecosystems was to transfer the problem from land to sea. The demand for marine-derived inputs, such as fishmeal and fish oil for animal feed, has been increasing exponentially, putting pressure on wild fish stocks. Meanwhile, agricultural runoff and refuse containing fertilisers and pesticides often find their way into coastal waters, contributing to dead zones and harmful algal blooms that threaten both wild fisheries and aquaculture operations.

Presently, the UN Conference on Sustainable Development brings the state of the world's oceans and the sustainable use of their resources more clearly into view. In 2016, the UN Environment Programme issued the "Blue Economy Concept Paper" (UNEP, 2016), which establishes a few essential but often overlooked facts about the role of oceans in the future of humankind. One is that the world's oceans constitute 95% of the planet's biosphere and support all life by generating oxygen, regulating temperature, and recycling waste (DOSI, 2022). Another is that they are crucial for global trade, as most goods are transported by sea. This includes the vast majority of agricultural commodities traded internationally, from grains and soybeans to fruits and livestock. The third is that oceans play a crucial role in regulating precipitation patterns and climate systems that determine the productivity of terrestrial agriculture. Additionally, millions of people rely on the oceans for their everyday protein intake, which makes sustainable marine aquaculture an essential component of global food security strategies.

The global attitude toward the blue economy has evolved accordingly. Given the wording of the "Green Economy in a Blue World" report, the initial understanding was that it is a mere extension of the green economy, following the recognition that agricultural practices on land directly impact marine ecosystems and that marine resources can be sustainably harnessed to support food production. This view of the blue economy adopts a passive approach, where the emphasis is on conservation, in line with the 14th UN Sustainable Development Goal: "Conserve and sustainably use the oceans, seas and marine resources for sustainable development" (General Assembly of the United Nations, 2015).

However, since then, the blue economy concept has changed significantly, and today it is regarded as a medium for innovation – an opportunity to develop technologies, including new forms of sustainable food production, advanced aquaculture systems, seaweed cultivation for food and agricultural inputs, and integrated multi-trophic aquaculture that mimics natural marine ecosystems. From an economic point of view, this makes the field of study very broad, encompassing diverse economic activities, including marine transportation, fisheries, energy, tourism, and biotechnology (Youssef, 2023). In 2017, the World Bank (2017) stated that blue economy activities are essential for achieving sustainable economic growth and social inclusion and for preserving or improving livelihoods while maintaining the environmental sustainability of oceans and coastal areas (OECD, 2016).

Core principles of blue economy regarding food security

Currently, the World Bank and the United Nations Department of Economic and Social Affairs define the blue economy as the "…range of economic sectors and related policies that together determine whether the use of oceanic resources is sustainable (World Bank & UN DESA, 2017, p. vi). The World Bank later elaborated it to the "…*sustainable use of ocean resources for economic growth, improved livelihoods, and jobs, and ocean ecosystem health*." (World Bank, 2017). This definition is particularly relevant to food production, as it emphasises the dual goals of economic activity and ecosystem sustainability. These goals have three practical dimensions:

1. Economic growth and livelihood improvement – The blue economy can, and should generate economic value by creating employment opportunities. This is particularly evident in the fact that mariculture, which includes marine aquaculture and seaweed farming, is one of the fastest-growing food production sectors globally, with the potential to provide protein and nutrients to a growing population while also creating jobs.
2. Sustainability – The blue economy-related economic activities must be conducted in ways that do not deplete resources or degrade land or marine ecosystems. In terms of food production, this means developing marine aquaculture practices that prevent excessive capture of wild fish, implementing integrated coastal zone management that protects both agricultural land and marine habitats, and adopting

circular economy principles under which agricultural practices benefit marine systems and vice versa.

3. Ecosystem health – The maintenance of the economic potential of marine ecosystems is a prerequisite for long-term prosperity. Healthy ecosystems provide essential services to agriculture, including coastal protection from storms, nutrient cycling, water filtration, and habitat for species that support both wild fisheries and aquaculture. Conversely, sustainable agricultural practices can reduce pollution and nutrient runoff that threaten marine ecosystems.

The European Commission offers a complementary perspective in its EU Blue Economy Report series, consistently describing the blue economy as encompassing all economic activities related to oceans, seas, and coasts. This includes a broad range of coastal, marine, and ocean-related activities, with complex socioeconomic benefits and environmental impacts due to the sizable direct and indirect upstream and downstream effects on a variety of economic sectors and activities. Rather than seeking a comprehensive definition, its approach is to group blue economy activities into sectors and sub-sectors based on common characteristics. Among other things, this approach allows new and emergent activities, such as blue biotechnology (Daniotti and Re, 2021; Reen et al., 2015), to be identified and regulated in a timely manner. Currently, according to the European Commission, the blue economy consists of several interlinked established and emerging sectors (Table 1).

Given all this, and following the characteristics of a sustainable blue economy identified by the World Bank/UN DESA, and the Food and Agriculture Organization of the United Nations (FAO) Blue Growth Initiative (2018) principles, for the purposes of this study, we identify five core blue economy principles, each with important implications for the development of sustainable food production:

1. Integration and interconnectedness – The blue economy recognises that marine and coastal systems are interconnected with land ecosystems and human societies. For food production, this principle emphasises the need for farming practices that minimise negative impacts on downstream aquatic systems; while living marine resources such as fishmeal and seaweed are used to provide fertilisers and bio-stimulants, thereby simultaneously reducing nutrient pollution originating from agriculture.
2. Innovation and diversification – The blue economy must encourage the development of new technologies, business models, and economic activities. In mariculture, this has led to innovations such as closed-loop recirculating aquaculture systems (RAS) and the cultivation of new species such as sea cucumbers and sea urchins that can help restore degraded ecosystems while providing human food, animal feed, or other sources of income, like a methane-reducing additive for livestock.
3. Equity and inclusivity – The blue economy should benefit all members of society, particularly vulnerable coastal communities and small island developing states. In food production, this means securing access to resources, technology, and markets for small-scale fishers and small marine resource farmers.
4. Knowledge and science-based management – Effective governance of marine resources is scientifically intensive and requires data-driven decision-making. For example, successful management of coastal ecosystems requires an understanding of the carrying capacity of

Table 1. Sectors of the EU blue economy

Category	Sector	Short description
Traditional sector	Marine living resources	Capture fisheries, aquaculture, and related processing activities.
Traditional sector	Marine non-living resources	Extraction of offshore and deep-sea oil, gas, and marine minerals.
Traditional sector	Marine renewable energy	Offshore wind and other ocean-based renewable energy technologies.
Traditional sector	Port activities	Cargo and passenger operations, port services, and related logistics.
Traditional sector	Shipbuilding & repair	Construction, maintenance, and repair of vessels and maritime structures.
Traditional sector	Maritime transport	Transport of goods and passengers by sea and inland waterways.
Traditional sector	Coastal tourism	Tourism activities in coastal areas, including accommodation and related services.
Emerging sector	Blue biotechnology	Use of marine organisms and bioresources for pharmaceuticals, cosmetics, and industrial uses.
Emerging sector	Ocean monitoring & surveillance	Technologies and services for observing, measuring, and monitoring the marine environment.
Emerging sector	Other emerging activities	New and emerging ocean-related activities, identified as part of the EU blue economy.

Source: Adapted from Borriello et al. (2025), The EU Blue Economy Report 2025, p. 10

coastal waters for aquaculture, monitoring the impacts of agricultural runoff on marine ecosystems, developing breeding programs for marine aquaculture species, and using precision agriculture techniques to optimise feeding and reduce waste in fish farming operations.

5. Circular economy principles – The blue economy promotes resource efficiency, waste reduction, and the reuse of materials. Implementing such principles can help design and develop new ecosystems in which agriculture and mariculture are complements, resulting in complete self-reliance without the need for additional external inputs or outputs that create negative externalities.

These core principles provide a framework for understanding how the blue economy can contribute to the food security imperative while reshaping humans' relationship with the sea. Rather than regarding agriculture and mariculture as separate, competing sectors, they can be viewed as opportunities for integration, innovation, equity, science-based management, and circularity. In the remainder of the article, these principles will serve as a reference point for evaluating existing practices and for proposing measures that can improve sustainability and complement food security.

The sustainability challenges

Mariculture typically includes two major industries: the production of animal protein and seaweed farming. The production of aquatic animals has grown from a marginal activity in 1950 to a significant industry today, registering an average annual growth rate in tonnage of 3.2 percent. This growth is mostly attributable to marine organism farming, while production from capture fisheries has remained relatively constant (FAO, 2024). This is unsurprising, given that biological and management limits constrain capture fisheries production; in fact, it increased by only 18 percent between 1990 and 2018 (FAO, 2020). In contrast, over the same period, global marine aquaculture production of animal protein grew by 527 percent (Ritchie, 2019).

In other words, aquaculture has become an essential source of animal protein. It is evident that the production of animal protein for food security is growing, which is due to a combination of factors:

– Protein production efficiency: Farmed fish are highly efficient converters of feed into protein, with feed conversion ratios (FCR) often better than those of livestock. The study by Fry et al. (2018) reports that typical commercial FCR ranges of 6.0–10.0 for beef cattle, 2.7–5.0 for pigs, 1.7–2.0 for chickens, and 1.0–2.4 for farmed fish and shrimp.
– Nutritional value: Fish and shellfish provide high-quality protein, essential omega-3 fatty acids (EPA and DHA), vitamins (particularly vitamin D and B12), and minerals (including iodine, selenium, and zinc) that are rarely found in agricultural products. This makes aquaculture particularly valuable for addressing malnutrition and micronutrient deficiencies (HLPE, 2014).
– Agricultural land size limitation: Marine aquaculture utilises space that is unsuitable for agriculture, essentially providing an alternative for arable land or grazing grounds.
– Climate resilience: As climate change impacts agriculture through droughts, floods, and changing temperature patterns, marine aquaculture offers a complementary production system that may be less vulnerable to some of these impacts, particularly in coastal and marine environments.
– Innovations aligned with circular economy principles: The rise in importance of the production of animal protein has led to the development of innovative production systems, such as the Integrated Multi-Trophic Aquaculture (IMTA), a farming approach combining growing species from different trophic levels (e.g., fish, shellfish, and seaweed) in a way that the waste from one species is a nutrient for another.
– The product of the other major industry in mariculture – seaweed farming – has also grown dramatically. In 2021, the live weight of the globally farmed seaweed reached 35.2 million tons (UNCTAD, 2024). The explanation is that the product has applications in many sectors of the economy, varying from agriculture to industry and environmental management.
– Seaweed farming has several benefits to offer for food security and sustainability, mostly due to its positive externalities:
– No feed or fertilizer required: Seaweeds obtain their nutrients directly from the water, effectively removing excess nitrogen and phosphorus. Beyond the obvious advantage of reducing input costs, seaweed farming represents a potential solution to mitigate agricultural nutrient pollution and coastal eutrophication and can serve as an integral component of the circular economy.
– Long-term carbon storage: Seaweeds absorb CO2 during photosynthesis, contributing to climate change mitigation. Some estimates suggest that large-scale seaweed farming could sequester significant amounts of carbon, though the permanence of

this sequestration depends on the fate of the harvested biomass (Fujita et al., 2022).
- Habitat creation: Seaweed farms create habitats for marine life and enhance biodiversity by providing nursery grounds for fish and invertebrates (Theuerkauf et al., 2021).
- Minimal environmental footprint: Seaweed farms are generally associated with low negative environmental impacts and can even enhance local water quality by removing excess nutrients and buffering ocean acidification (Duarte et al., 2017).

Despite these multiple positive effects, mariculture is yet to be integrated into the circular economy in order to provide for food security. Rapid growth in fish farming as an economic activity raises sustainability questions that need to be addressed. For example, farming carnivorous fish such as salmon and tuna requires fishmeal and fish oil from wild fisheries and cannot readily be replaced with cheaper, more manageable sources, such as insects, microbial proteins, and plant-based sources (Dhar et al., 2024). Intensive fish farming can cause water pollution from uneaten feed and waste, spread diseases to wild fish, alter wild gene pools through escapees, and damage habitats if the carrying capacity is exceeded. In addition, there is the risk of disease outbreaks in crowded farms.

Seaweed farming is often presented as a business model for sustainable resource use, but in practice, it remains far from fully embedded in a truly circular economy. First and foremost, seaweed farms need to be well-placed and sized to achieve the right combination of temperature, nutrients, and water movement, and second, integration in value chains requires the availability of upstream processing plants to capture the entire potential value and make the use of the resource efficient.

Mariculture in the context of the food security paradigm

It is increasingly clear that mariculture can become a strategic component of global food systems, offering a way to produce high-quality protein and micronutrient-rich foods without adding further pressure on terrestrial agriculture. As coastal populations grow and climate change undermines the reliability of land-based production and wild fisheries, mariculture presents a promising opportunity to improve food availability and diversify livelihoods. At the same time, integrating mariculture into the food security paradigm requires balancing its contribution to nutrition and income with the management of environmental risks. Additionally, instances of rent-seeking behaviour regarding the allocation of marine space and resources have been observed (Falconer at al., 2023).

Challenges related to the blue economy, such as climate change, ocean pollution, and overuse of marine resources, are inherently global. A notable example is the growing pressure on coastal areas from agglomeration, as increasing populations demand temporary or permanent accommodation. Without sustainable urban planning that balances economic growth with environmental protection, this can lead to the overuse of costytal resources. In the context of sustainable mariculture, careful planning is required to account for multiple stakeholders' interests and to prevent political or institutional rent-seeking.

In other words, the successful development of blue economy activities aimed at food security faces two main obstacles.

First, the tragedy of the commons problem: Coastal waters and marine ecosystems are often treated as unlimited, free resources, so individually rational decisions accumulate into collective overuse and degradation (Bell, 1986). This manifests in two forms:

- Land to sea: Runoff from terrestrial activities – including pesticides, herbicides, fertilisers, nutrients, soil particles, and microplastics – enters oceans through the natural hydrologic cycle. Extensive use of coastal areas for tourism and construction causes habitat destruction for marine organisms. Pollution that harms marine ecosystems is often not reflected in market prices, creating an oversupply of goods at the expense of biodiversity.
- Sea to sea: Intensive mariculture can spread parasites and pathogens through shared waters to wild stocks and other farms (Bouwmeester et al., 2021). Escapees from farms interbreed with wild populations, altering gene pools, fitness, and disease resilience (Bolstad et al., 2021). Shared space around mariculture sites requires collective management, posing risks of free riding and underinvestment in environmental safeguards.

Second, the generation of externalities: Mariculture activities create environmental and social externalities that must be internalised. Environmental externalities arise from uneaten feed and fish waste, which add nitrogen, phosphorus, and organic matter to the water, leading to algal blooms and oxygen depletion. Social externalities include conflicts with other sea users – interference with navigation, recreation, public health risks, odours, noise, and litter. These market failures incentivize overexploitation because individual actors lack motivation to conserve resources for future use.

These issues carry an economic dimension, demonstrating that sustainable mariculture faces multiple market challenges:

- Capital requirements: Establishing mariculture operations aligned with circular economy principles requires significant upfront investment in infrastructure, equipment, and working capital, posing a barrier for small-scale farmers and coastal communities.
- Market access: Limited access to markets, cold storage, processing facilities, and logistics restricts producers' ability to capture value.
- Price volatility: Seafood prices fluctuate due to supply variations, disease outbreaks, and competition with wild-caught products, generating economic risk.
- Regulatory costs: Compliance with environmental, food safety, and certification standards (e.g., organic, sustainable) imposes significant costs.
- Insurance and risk management: Marine aquaculture faces disease, extreme weather, equipment failure, and market fluctuations. Insurance options are less developed than for terrestrial agriculture, leaving producers vulnerable.

These challenges underscore that achieving food security through mariculture cannot rely solely on market mechanisms. While the sector offers substantial opportunities due to efficient protein conversion, high nutritional value, and reduced pressure on terrestrial systems, integration into the global food security paradigm requires addressing fundamental market failures and governance gaps. The tragedy of the commons necessitates coordinated management beyond individual operations. Similarly, environmental and social externalities must be internalised through regulatory mechanisms, economic incentives, and technological innovation. Without adequate access to capital, market infrastructure, insurance products, and regulatory support tailored to marine farming risks, the sector will remain vulnerable and unable to fully realise its food security potential.

Conclusions

The concept of the Blue Economy represents a paradigm shift from the need to preserve marine resources to recognising them as dynamic systems capable of sustainable innovation and food production. Despite this potential, mariculture faces sustainability challenges that prevent its full integration into a circular economy. Market failures, including high capital requirements, limited market access, price volatility, regulatory costs, and inadequate insurance mechanisms compound these challenges.

Successful integration of mariculture into the food security paradigm requires more than technological advancement or production scaling. It demands addressing the identified market failures by internalisation of environmental and social externalities and development of management structures for mariculture activities that balance economic viability, environmental sustainability, and social equity. Without these in place, the current development of economic activities remains insufficient to realise the sector's full potential for addressing global food security needs.

One important consideration is the interdependence between land-based and sea-based food systems. Agricultural practices directly impact marine ecosystems through nutrient runoff and pollution, while marine resources provide essential inputs for terrestrial activities, agriculture in particular. This interconnection requires an integrated approach to food security that recognises the ocean not as a separate domain, but as an integral component of the global food system. A properly developed framework offers a way to achieve this integration in a sustainable way.

Such a framework that establishes mariculture as a sustainable pillar of global food security must abide by the Blue Economy core principles in its policy objectives. Here we can outline the most significant ones:

Integration and interconnectedness: Achieve integration of terrestrial and marine food systems through coordinated management that recognises the ecological, economic, and social linkages between land and sea.

Innovation and diversification: Influence technological innovation and the diversification of food production systems to improve economic efficiency, reduce environmental impacts, and expand the contribution to food security.

Equity and inclusivity: Ensure that the benefits of mariculture development are shared, with particular attention to small-scale producers, coastal communities, and vulnerable populations, while protecting property rights, promoting fair labour practices, and preventing exclusion or marginalisation.

Knowledge- and science-based management: Establish comprehensive monitoring systems and analytical apparatus that enables evidence-based decision-making for improvements in environmental, economic, and social performance.

Circular economy philosophy: Shift from a linear "take-make-waste" mariculture production model to circular systems that maximise resource efficiency, minimise waste, create value from byproducts, and establish symbiotic relationships with other economic sectors.

Currently, the Blue Economy holds only a promise for global food security by offering a sustainable source of nutrition for current and future generations. However, realising this potential requires addressing the market failures that currently constrain the sector's economic development. Implementation of the policy objectives proposed in this study could enable advancing and scaling mariculture activities.

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