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Towards a sustainable and circular blue bioeconomy: A scoping review

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ABSTRACT

This study explores biotechnological innovations based on marine resources in the burgeoning blue bioeconomy, aiming to unlock their potential for valorization for sustainable and circular business models. Using a scoping review to identify key trends in scientific knowledge, we specify four clusters of blue biotechnological innovations: (1) bioenergy, (2) feedstock and fertilizers, (3) biomass for food, and (4) industrial applications. These four clusters offer promising energy, food, and materials alternatives while aligning with sustainability and circular economy principles. This study thus fills a gap in extant management research by integrating ocean biodiversity into considerations of sustainable entrepreneurship and investigating valorization options in the blue bioeconomy for the development of novel business models. The findings pave the way for designing feedstock and regenerative business models that harness the blue bioeconomy's economic, environmental, and social benefits.

1. Introduction

The blue bioeconomy highlights economic motives for the intelligent use of marine biomass and promotes material circularity, a reduced need for virgin materials, waste reduction, and extended product lifecycles (Ghosh et al., 2023; Stephenson and Damerell, 2022). It is an emerging sector within the Blue Economy, a wider concept that denotes a sustainable version of the marine (or ocean) economy (Mulazzani and Malorgio, 2017). In the blue bioeconomy, biotechnological innovations drawing on groups of marine organisms, such as microorganisms (e.g., microalgae, bacteria, and fungi), algae, and invertebrates (e.g., starfish, sea cucumbers, and sea urchins) trace pathways for the commercial exploitation of marine biomass as alternative sources of energy, food, and feed (Priefer et al., 2017; Vieira et al., 2020).

The bioeconomy is crucial to achieving several of the 17 UN Sustainable Development Goals (SDGs). It is mainly associated with SDG 14 Life Below Water. Apart from that, blue biotechnological innovations help mitigate climate change (SDG 13), nurture innovation (SDG 9) and economic growth (SDG 8), and contribute to human well-being (SDG 3) by, for instance, enabling new technologies to clean wastewater (SDG 6) and providing new sources of food and protein (SDG 2) for a growing world population. The blue bioeconomy may also create novel employment opportunities (SDG 8) in, for example, seaweed farming or aquaculture, to the benefit of coastal communities, thus contributing to SDG 15 Life on Land (Vieira et al., 2020). It is sometimes denoted as the fourth industrial revolution because of its disruptive potential in science (e.g., novel nutraceutical, pharmaceutical, and medical applications derived from and inspired by aquatic resources), production (e.g., new and sustainable production methods on aquafarms), and consumption (e.g., new protein sources, foods, and products from marine-derived bioresources) (Stephenson and Damerell, 2022; Vieira et al., 2020).

The notions of bioeconomy, circular economy, and sustainability are linked (Asada et al., 2020; Ghosh et al., 2023; Stephenson and Damerell, 2022). The circular economy promotes the minimization of material input, waste, emissions, and energy use during the lifecycle of products. Adopting circular economy principles supports innovations fostering social and environmental sustainability in production and consumption (Crecente et al., 2021; Donner and de Vries, 2021; Lüdeke-Freund et al., 2019). Biotechnological innovations help reduce the reliance on non-renewable and unsustainable resources and bear potential for regional economic development. They require business models addressing economic, environmental, and social issues (Asada et al., 2020; Donner and de Vries, 2021; Lüdeke-Freund, 2020; Salvador et al., 2021). While the concept of the blue (bio)economy aims to harmonize economic development with marine conservation (Martínez-Vázquez et al., 2021), participation in Blue Economy activities does not inherently align with

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the adoption of sustainable business models (Niner et al., 2022). This scoping review aims to contribute to the advancement of the blue bioeconomy by addressing these issues. It bridges blue biotechnology with management research, especially innovation management and business models, requiring interdisciplinary collaboration and networks across science, industry, and policymaking (e.g., Thompson et al., 2018. Unlike existing reviews that primarily focus on marine biotechnology (e.g., Rotter et al., 2021; Vieira et al., 2020), this scoping review integrates management research and explores the potential of blue biotechnology innovations for sustainable and circular business models.

The growing research interest in blue biotechnology has led to a vast number of scientific findings (Befort, 2020). Industry reports and academic research covering different sectors and geographies suggest that the blue bioeconomy is rising. For example, the global market value of microalgae is estimated to be approximately 6.5 billion US dollars. Microalgae allow for various biotechnological applications, among them biorefining processes that often apply circularity principles, where waste from one process is used as a resource for another, creating a closed-loop system. Nonetheless, the microalgal biorefinery industry is still in its infancy (Chandrasekhar et al., 2022). There are also variations across geographies. For instance, in Europe, the aquaculture industry is expected to grow. Likewise, the demand for fishmeal and fish oil may increase. Conversely, methods to establish a European macroalgae industry that can compete with Asian counterparts still need to be developed (EUMOFA, 2018a; Vincent et al., 2020). The blue bioeconomy bears considerable potential for developing countries. For example, Brazil has heavily invested in marine biotechnology for the last three decades, leading to a position among the top 15-world aquaculture producers (Thompson et al., 2018).

The existing scientific knowledge may be valorized for sustainable and circular business models (Crecente et al., 2021; Konietzko et al., 2023). These are often described as sub-categories of the general business model concept (e.g., Antikainen and Valkokari, 2016; Donner and de Vries, 2021). A sustainable business model does not purely concentrate on the creation of economic value but includes environmental and social aspects, thus enhancing an organization's purpose and the range of stakeholders addressed (Antikainen and Valkokari, 2016; Donner and de Vries, 2021; Lüdeke-Freund, 2020, Lüdeke-Freund et al., 2024). A circular business model entails principles, such as the minimization of waste in product design, transparent product life cycles, flexible design to ease repair and facilitate recycling, the use of renewable energy, and the maximization of energy efficiency (Ahmad et al., 2023; Hossain et al., 2024). It aims to "maintain resource value at its maximum wherever and whenever possible, and reduce or eliminate resource leakage by slowing, narrowing, or closing resource loops" (Salvador et al., 2021, p. 3). Briefly, while a sustainable business model emphasizes value creation and delivery for and with diverse stakeholders, a circular business model additionally stresses resource efficiency and the design and execution of production and consumption processes with and within closed loops. These aspects are discussed by proponents of feedstock and regenerative business models. Feedstock business models promote the processing and recovery of waste materials and by-products as production inputs or their safe disposal into the biosphere. Going further, regenerative business models aim to enhance resource efficiency and effectiveness by replacing or restoring cells, organisms, or ecosystems to promote planetary health and societal well-being (Donner and de Vries, 2021; Konietzko et al., 2023; Lüdeke-Freund et al., 2019; Salvador et al., 2021). The combination of scientific findings referring to blue biotechnological innovations with product innovations targeting mainstream markets and creating economic, environmental, and social value may enrich the extant research on sustainable and circular business models. To explore and map the field, we draw on a scoping review (e.g., Aguinis et al., 2023; Levac et al., 2010) and answer the following questions: *First, what are key innovations in the blue bioeconomy? Second, in what ways can current scientific findings about blue biotechnological innovations inspire the development of novel business models that address sustainability and circularity?*

Answering these questions, we make two contributions: first, this study follows recent calls to investigate the use of the oceans for economic purposes (e.g., European Commission, 2017; Jouffray et al., 2020; OECD, 2016) as addressed by, for example, SDG 14 from a management perspective. To date, management studies focusing on SDG 14 and with an emphasis on marine resources do not exist. For instance, Berrone et al. (2023), providing a comprehensive review of the management literature on the SDGs, could not identify any study focusing on SDG 14. Salvador et al. (2021), studying business models for a circular bioeconomy, highlighted a lack of research on ocean-related activities. This study fills this gap by specifying valorization options in the blue bioeconomy. Second, the findings reveal four clusters of innovations: first, bioenergy from marine biomass, second, feedstock and fertilizers, third, biomass for food, and fourth, industrial applications. These innovations are at different stages of development, illustrating that the blue bioeconomy is an emerging sector within the Blue Economy (e.g., Cisneros-Montemayor et al., 2019; Spalding, 2016) and pointing to potential difficulties in marketability and scalability (e.g., Vincent et al., 2020). The development of blue biotechnology products faces challenges including lengthy development times, high costs, seasonal biomass fluctuations, and a lack of established technologies and methods ensuring sustainability and circularity, such as those used in biorefining processes (Rotter et al., 2021). Nonetheless, this scoping review reveals how blue biotechnological innovations may inspire feedstock and regenerative business models, that connect them to potential markets and redefine how enterprises create and capture economic, environmental, and social value in the future (Asada et al., 2020; Lüdeke-Freund, 2020).

2. Methodology

We opted for a scoping review as the blue bioeconomy has not been extensively and systematically reviewed because of its heterogeneity (e.g., Befort, 2020; Ligtvoet et al., 2019) and novelty (e.g., Vieira et al., 2020), especially in the context of business and management. To date, this type of review research has rarely been used in management studies (Aguinis et al., 2023). Scoping reviews, originally suggested by Arksey and O'Malley (2005) and further refined by Levac et al. (2010), "aim to map the literature on a particular topic or research area and provide an opportunity to identify key concepts; gaps in the research; and types and sources of evidence to inform practice, policymaking, and research" (Daudt et al., 2013, p. 8). This aim is in line with our objectives to explore the range of blue biotechnological innovations that were addressed in previous scientific research, synthesize the existing evidence, and present a comprehensive overview. In contrast to systematic literature reviews which draw on narrow research questions and a limited number of studies, scoping reviews examine the breadth of coverage rather than its depth (Daudt et al., 2013; Levac et al., 2010). We opted against a bibliometric analysis. This decision may have limited the scope of our findings, and the scoping review may lack a comprehensive understanding of the field's evolution and its key players. Bibliometric indicators, such as citation counts, may have highlighted differences in the significance and impact of the studies eventually included in the scoping review. However, blue biotechnological innovations do not yet have a long research trajectory, which is essential to discern the intellectual structure of a research field or trace changes in research foci or methodologies over time (Donthu et al., 2021).

Our analysis followed the steps suggested by Arksey and O'Malley (2005), Levac et al. (2010), and Daudt et al. (2013). First, we specified two research questions. Second, we identified relevant studies. Given the interdisciplinarity of research focusing on blue biotechnological innovations, studies were collected from Google Scholar, Scopus, Web of Science, and AgEcon Search electronic databases. Google Scholar was used because of its vast coverage of scientific research from diverse sources. Being particularly strong in the life sciences, Scopus was an adequate choice for the search for literature on blue biotechnological innovations. Because it covers research across scientific disciplines relevant to the blue bioeconomy, such as chemistry, physics, and environmental science, the Web of Science database was included. Although AgEcon Search predominantly focuses on agricultural economics, this database was adequate because biotechnology has applications in agriculture (e.g., marine aquaculture), and it included research highlighting aspects of blue biotechnology related to economics, such as the economic and social impacts of new biotechnological innovations. Several search terms were combined into the following search string: ("blue bioeconomy" OR "marine biomass" OR "ocean-originated resources") AND ("circular economy" OR "valorization" OR "innovation"). These terms were inspired by previous publications on (blue) bioeconomy (e.g., Priefer et al., 2017; Vieira et al., 2020) and the Blue Economy (e.g., Mulazzani and Malorgio, 2017). As circularity is often used in conjunction with or even encompasses sustainability (e.g., Asada et al., 2020; Ghosh et al., 2023; Hossain et al., 2024; Lüdeke-Freund et al., 2019; Stephenson and Damerell, 2022), the search string does not explicitly include this concept. The search string was discussed with colleagues knowledgeable about the methodology and the chosen topical area and deemed appropriate by these experts. The results from the search were screened for relevance based on titles and abstracts. Third, full-text articles were retrieved for further evaluation and review for inclusion or exclusion according to the criteria outlined and justified in Table 1.

Scientific knowledge about blue biotechnological innovations represents a time-sensitive topic. Scientific, medical, or technology-related findings are easily outdated. Hence, we opted for articles on blue biotechnological innovations published from 2017 to 2023 (March) to ensure currency. An initial screening of 3212 titles and abstracts was carried out, duplicates ($N = 342$) and studies not related to biotechnology innovations in the blue bioeconomy ($N = 1504$) were discarded.

Table 1
Inclusion and Exclusion Criteria.

Inclusion criteria	Justification
• Studies presenting the original results of the empirical blue bioeconomic research field	• current advancements in this field, based on solid evidence
• Focus on blue bioeconomy (i.e. marine-based biomass) and circular processes	• marine-based biomass and its potential applications, sustainability and changes in production and consumption
• Discussion of valorization options: monetization, commercialization, and marketing	• the economic and commercial aspects of the blue bioeconomy
• Research must be available online through the library databases	• wide access, quality control, and standardization
• Full-text papers published in a peer-reviewed journal	• quality and credibility, full access to findings
• Full-text papers written in English	• wide access, comparability of findings
Exclusion criteria	**Justification**
• Sources that do not discuss valorization options	• economic viability and sustainability of marine-based biomass utilization
• Non-empirical papers (e.g., conceptual papers, editorials) and grey literature	• solid empirical evidence, which is accessible and verifiable
• Conference proceedings, book chapters, unpublished theses, and white papers	• high standards of quality and accessibility, wide availability
• Papers that do not focus on the development of innovative products, services, or processes related to the blue bioeconomy	• current advancements and their potential for economic benefits, environmental sustainability, and policy implications
• Papers published in journals with an impact factor lower than 2	• influence within the academic community

(Source: Authors' own work)

A further 32 papers were excluded, comprising non-peer-reviewed and conference papers. To ensure a thorough in-depth review of blue biotechnological innovations, we decided to reduce the breadth of scientific findings. Therefore, from the remaining 1334 papers, we selected a random sample of 100 articles for a full-text review. Moreover, we aimed to include studies that were influential in the blue bioeconomy field, as indicated by an objective external criterion, such as a journal impact factor. Thus, we only considered articles published in journals with a citation impact factor exceeding 2 as eligible (i.e., articles had been cited more than two times during the last two years). By focusing on journals with an impact factor above 2, we prioritized research that has demonstrably influenced the broader scholarly community, as evidenced by frequent citations. Journals with higher impact factors tend to have more stringent peer-review processes, leading to the publication of rigorous research and robust methodology, thus enhancing the quality and credibility of this scoping review. Our final sample comprised 74 articles. Fig. 1 depicts the study selection procedure (Haddaway et al., 2022). Any discrepancies between authors' data extractions were resolved using a consensus-based approach, ensuring that all data was accurately and uniformly interpreted.

Fourth, we charted the data and entered them into a data-charting form for further analysis. This helped us identify themes and recurring aspects. We content-analyzed the studies regarding the innovation type and clustered them based on the sector of the blue bioeconomy that was addressed. We categorized the findings into four thematic clusters (see Table 2): (1) harnessing bioenergy from marine biomass; (2) the valorization of waste and by-products for producing feed and fertilizers; (3) biomass for food; and (4) industrial applications.

Fifth, the charted data were synthesized and collated into a narrative summary. In contrast to Levac et al. (2010) and Arksey and O'Malley (2005), we did not engage in an optional consultation with stakeholders as a sixth step. The reasons for this omission are that this scoping review aims to highlight the potential for future research on how the valorization of blue biotechnological innovations could be valorized for sustainable entrepreneurship. We thus juxtaposed our findings with the literature on sustainable and circular business models (e.g., Ahmad et al., 2023; Lüdeke-Freund et al., 2019, 2024) and discussed the entrepreneurial potential of the valorization options. Briefly, we considered the opportunities and risks of the blue biotechnological innovations emerging from our scoping review for being transformed into products aimed at the mainstream market.

3. Results

3.1. Bioenergy from marine biomass

Marine-based biomass has increasingly been investigated for bioenergy production including aquatic microorganisms and wasted biomass (Morales et al., 2021; Onyeaka et al., 2021). Ethanol, biodiesel, methanol, and reformulated gasoline components are examples of biofuels made from biomass (Klassen et al., 2017). While bioenergy has an important role in decarbonizing and boosting energy security (Lund et al., 2022), it can provide other economic advantages (Acosta-Michlik et al., 2011; Zabaniotou, 2018). For instance, biofuel production generates value-added economic activity that raises demand for local feedstocks with higher commodity prices, which ultimately increases income from farming and rural welfare (Schnepf, 2007). In addition, the integration of waste materials from bioenergy production into bioprocesses for producing valuable products and metabolites drives a sustainable circular bioeconomy (Leong et al., 2021).

3.1.1. Biofuel from marine biomass

The two most prevalent forms of biofuels in use are bioethanol and biodiesel (Mizik and Gyarmati, 2021). The renewable biomass used for generating ethanol can be categorized into sugars, starch, lignocellulosic, and algae biomass (Khan et al., 2021). Ethanol obtained from

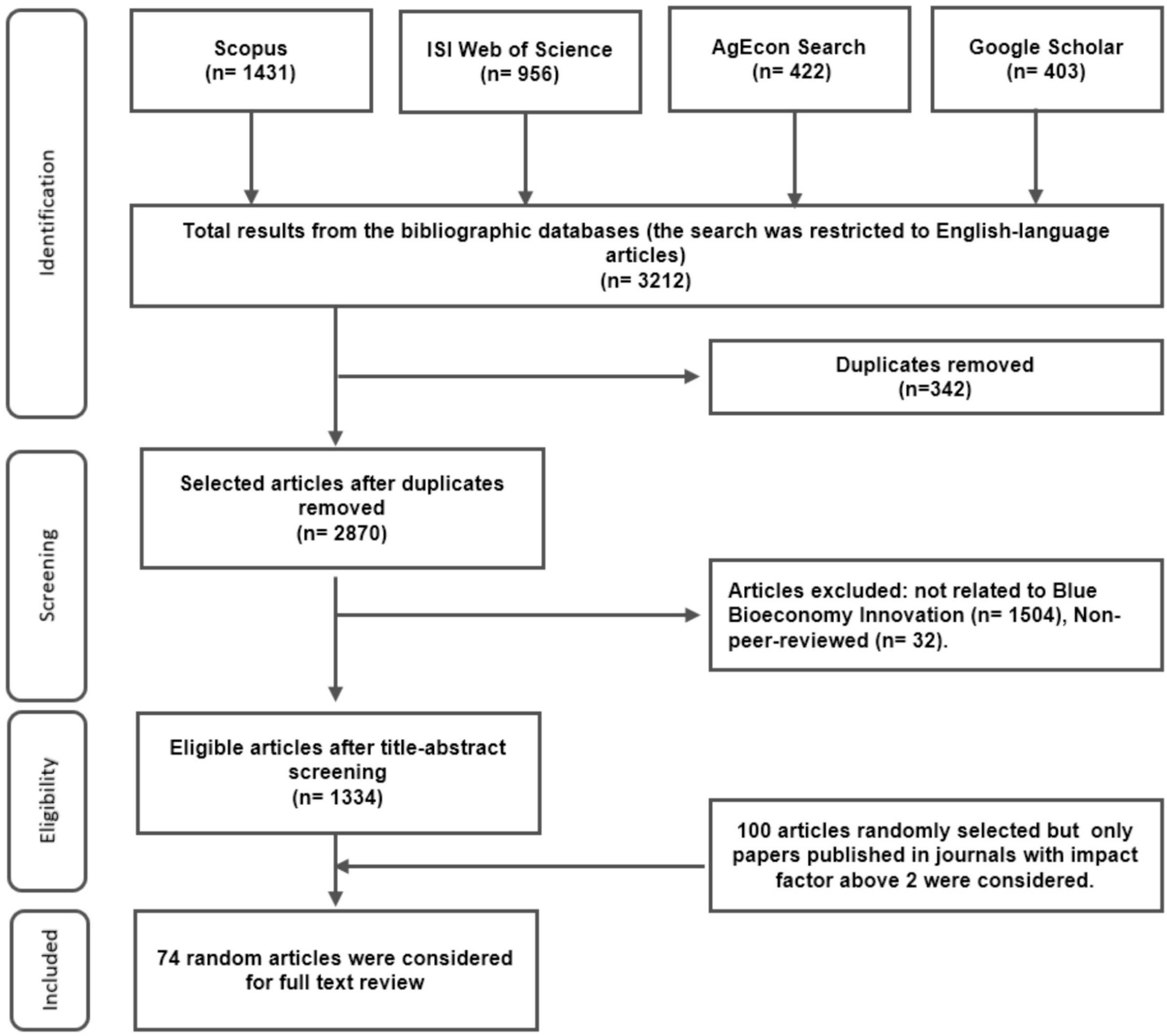

Fig. 1. Study Selection
(Source: Authors' own work).

algae is still in its infancy and is confined to laboratory experimentations, whereas other forms of biomass (e.g., marine yeast) have demonstrated commercial-scale potential as bioethanol feedstocks (Efroymson et al., 2021; Jacob et al., 2021; Koley et al., 2019; Zaky et al., 2020). The current challenges associated with large-scale algae ethanol include the relatively low concentration of ethanol produced by fermentation, the identification of species for extensive algal farming, and the need for low-energy input refining techniques (Bux and Chisti, 2016; Klassen et al., 2017). The production of ethanol from algae bears the advantage that algae can be grown in water areas that do not compete with arable lands (and freshwater) with a relatively high biomass productivity rate (Aswathy et al., 2010; Kumar et al., 2009). For instance, algae and bacteria consortia can be used for wastewater decontamination and assimilated into biodiesel, bioethanol, biohydrogen, biofertilizers, and animal feed (Anand et al., 2023).

Microalgae-based biofuels are also considered a promising source of biodiesel (Mahata et al., 2022; Morales et al., 2021; Onyeaka et al., 2021). Microalgal biomass such as *Spirulina* and *Chlorella* has demonstrated good potential as a carbon source to produce biodiesel and bioethanol (Maia et al., 2020). However, the present costs of large-scale biomass production and downstream processing make it economically unviable (Bux and Chisti, 2016; Klassen et al., 2017). Biogas methane is typically obtained through the degradation of energy crops and other organic matter by bacteria under anaerobic conditions. Microalgae biomass was not previously considered a substrate for biogas generation via anaerobic digestion (Klassen et al., 2016) because of its high resistance towards microbial decomposition and the unfavorable low carbon-to-nitrogen ratio of the biomass (Maia et al., 2020). Recent findings, however, suggest that microalgae biomass (e.g., *Chlamydomonas*, *Chlorella* and *Scenedesmus*) is suitable for methane production (Bhushan et al., 2021; de Oliveira et al., 2022; Klassen et al., 2017).

3.1.2. Biohydrogen from microorganisms

Biohydrogen production from microalgae has recently emerged as a potential alternative method for marine-based energy production (Ahmed et al., 2021). By unit weight, hydrogen's exothermic energy is three times higher than that of petroleum (Tashie-Lewis and Nnabuife, 2021). In addition, it does not exhibit a high risk of polluting the atmosphere from its combustion. This, along with the potential for conversion to electrical power both as a solid and a liquid fuel, has gained attention as a key future fuel source (Foong et al., 2021; Kim, 2019). Microalgal biomass (green algae) is used as a fermentation substrate by microbes (e.g., *Cyanobacteria*, *Fermentative* bacteria) to generate biohydrogen (Ahmed et al., 2021). Different metabolic methods for producing microalgae-based biohydrogen (including fermentation, biophotolysis, and electrochemical processes) offer diverse advantages, yet none are presently viable for large-scale application (Ahmed et al., 2021).

Table 2
Innovation Clusters and Valorization Options.

Innovation Clusters	Utilization	Valorization Options	Studies
Bioenergy from marine biomass	Biofuel from marine biomass	Bioethanol and biodiesel from algae and microorganisms	Anand et al. (2023); Efroymson et al. (2021); Jacob et al. (2021); Koley et al. (2019); Maia et al. (2020); Zabed et al. (2017); Zaky et al. (2020)
		Methane based on anaerobic fermentation	de Oliveira et al. (2022); González-González et al. (2018); Klassen et al. (2017)
PMV: moderate CoD: low to medium	Biohydrogen from microorganisms	Biohydrogen from microalgae	Ahmed et al. (2021)
		Biohydrogen from photosynthetic bacteria	Sagir and Alipour (2021)
Animal feed and biofertilizers	Fishmeal and oil for animal feed	Fish oil extracts from waste fishery	Hilmarsdóttir et al. (2022); Ivanovs and Blumberga (2017)
		Fish feed substitutes from algae and marine microalgae	Allen et al. (2019); Nagappan et al. (2021); Sarker et al. (2020); Simtoe et al. (2022); Stuart et al. (2021); Zheng et al. (2023);
PMV: medium to high CoD: low to medium	Fish protein hydrolysates for animal nutrition	Hydrolysate extracts from fishery discards	Moya Moreira et al. (2023); Siddik et al. (2021); Vázquez et al. (2017); Vázquez et al. (2020)
	Agrochemicals and fertilizers	Soil nutrients from fish waste	Ahuja et al. (2020); Dróżdż et al. (2020); Radziemska et al. (2019)
		Organic fertilizers from aquatic biomass	Emadodin et al. (2020); Madejón et al. (2022)
Biomass for food	New or additional resources	Novel species	Aakre et al. (2021); Bito et al. (2020); Broch et al. (2019); Buck et al. (2018); Tzachor et al. (2021); Thomas et al. (2022)
		Large-scale production of in-use species	Nielsen et al. (2019); Olin et al. (2022)
PMV: medium to high CoD: low to medium	Food-grade extracts from waste biomass	Utilizing at-sea discards (e.g., bycatch)	Chan et al. (2019); Coppola et al. (2020); Silva et al. (2020); Tigchelaar et al. (2022)
		Utilization of fishery by-products	Borges et al. (2023); Mao et al. (2023); Šimat (2021); Venugopal (2022); Venugopalan et al. (2021); Wang et al. (2021)
		Enzymes for food processing	Birolli et al. (2020)
	Biocomponents for nutraceuticals and functional foods	Biocomponent extracts from aquatic biomass	Chakraborty and Joy (2020); Ganesan et al. (2020); Jester et al. (2022); Mohamed and Ibrahim (2021)
		Biomolecules from wasted marine biomass	Amin et al. (2020); Monsiváis-Alonso et al. (2020); Mutalipassi et al. (2021); Venugopalan et al. (2021)
		Hydrolyzed edible extracts	Cunha and Pintado (2022)
		Nutraceuticals from marine microorganisms	Stincone and Brandelli (2020); Dhakal et al. (2017); Zhang et al. (2017)
Industrial applications	Industrial bioprocesses	Bioactive compounds with moisturizing, anti-aging, and anti-inflammatory effects	Bhattacharya and Goswami (2020); Veríssimo et al. (2021); Wang et al. (2021)
		Pulp and paper	Birolli et al. (2020); Mohamed and Ibrahim (2021)
PMV: very high CoD: very high	Biomaterials and bioplastics	Marine-based bioplastics	Abdallah et al. (2020); He et al. (2017); Jeong et al. (2021); Mostafa et al. (2020); Zhang et al., 2019b
		Natural chemicals	Dhakal et al. (2017); Ghosh et al. (2022); Marsol-Vall et al. (2022); Veríssimo et al. (2021); Zhang et al. (2017)
		Processed fish oils	Välimaa et al. (2019)
	Bioremediation	Water treatment	Dell'Anno et al. (2021); Zhang et al. (2021)

Notes: PMV: Potential Market Value; CoD: Cost of Development (Ligtvoet et al., 2019).

(Source: Authors' own work)

As summarized in Table 2, marine biomass bioenergy production presents a moderate potential market value with relatively low to medium development costs (Ligtvoet et al., 2019). Our analysis indicates that biofuel production from marine biomass, such as algae, has achieved relatively higher technology readiness, with several cases reaching pilot-scale and demonstration stages, particularly for biodiesel and bioethanol. In contrast, biohydrogen production from microorganisms, including microbial electrolysis and fermentation, remains at a lower technology readiness level, with most advancements limited to lab-scale studies.

3.2. Feedstock and fertilizers

According to the Food and Agriculture Organization (FAO), in 2018, about 88 % of 179 million tons of total fish production were exploited for direct human consumption, while the remaining 12 % of non-food uses mainly included feed production (FAO, 2020). By-products and wasted marine biomass could potentially be used to produce imperative dietary nutrient inputs, such as fishmeal and fish oil (FAO, 2020). By-products constitute about 75 % of all raw materials growing through seafood processing (Rustad et al., 2011). A substantial amount of marine biomass is wasted throughout the supply chain or even discarded before entering the value chain (Blanco et al., 2015; Wang et al., 2017). Fishery waste includes inedible fish tissues, such as fins, heads, skin and viscera, but also by-catch species having low or no commercial value, and commercial species that are undersized, insufficient in amount (that warrant sales), or damaged (Caruso, 2015). Other aquatic organisms, such as shellfish, seaweed, and aquatic plants, have increasingly become the research focus to produce feed and other biomaterials (Barbot et al., 2016; Nisticò, 2017; Poblete-Castro et al., 2020).

3.2.1. Fishmeal and oil for animal feed

Fishmeal has long been used as animal feed, such as shrimp, farmed fish, and other livestock. A high concentration of digestible protein and a balanced ratio of essential amino acids and minerals make fishmeal an excellent feed source (Tacon et al., 2009). The rapid expansion of the global aquaculture industry has led to a substantial increase in demand for processed fishmeal and its constituent components and raised concerns about the depletion of harvested species and the future availability of fishmeal (Sarker et al., 2020). Currently, about 90 % of the world's fishmeal production comes from oily fish like sardines, anchovies, capelin, and menhaden, while less than 10 % comes from white fish offal like cod and haddock (Barlow, 2003). Lately, there have been numerous efforts to increase the share of fish offal in producing fishmeal (El-Sayed, 2020; Hilmarsdóttir et al., 2022; Ivanovs and Blumberga, 2017).

Marine micro/macroalgae showed high potential for the replacement of fish oil and fishmeal (Allen et al., 2019; Stuart et al., 2021; Zheng et al., 2023). Sarker et al. (2020) studied the potential of two types of marine microalgae, *Nannochloropsis* sp. and *Isochrysis* sp., to replace fishmeal and fish oil in rainbow trout diet and found that the latter has a better performance. Similarly, Stuart et al. (2021) suggested oil-rich alga *Schizochytrium* sp. as a dietary source for replacing fish oil in the juvenile California yellowtail diet. Simtoe et al. (2023) reported that the green algae *Chaetomorpha* sp. can be regarded as a suitable alternative for a 20 %-replacement of fishmeal in the giant tiger prawn diet.

A growing body of research emphasizes the role of microalgae cultivation (e.g., *Chlorella*, *Scenedesmus*, and *Arthrospira*) in producing biocomponents, such as lutein, beta carotene, chlorophyll, phycobiliprotein, and the utilization of these biomolecules in animal feed (particularly shrimp farming) (e.g., Nagappan et al., 2021; Saadaoui et al., 2021). The production of microalgae-based biomolecules and their subsequent application in animal feed have raised interest in microalgae culturing both at small and industrial scales (Nagappan et al., 2021). Unlike land-based feed production systems, large-scale production of microalgae has the advantages of high net biomass productivity with the right blend of protein, lipid, and carbohydrate whilst using non-arable land and non-potable water (Hodar et al., 2020; Nagappan and Nakkeeran, 2020). Moreover, biomolecules can be extracted as a by-product of biorefinery or procuring biofuel from microalgae (Nagappan et al., 2021). Nevertheless, large-scale microalgae-based feed involves other economic trade-offs, such as the selection of strains with the desired nutritional characteristics, cultivation methods, and strategies for downstream processing (Saadaoui et al., 2021).

3.2.2. Hydrolysates for animal nutrition

Fishmeal is obtained through a thermal process that separates the oil and coagulates the protein from fish byproducts. This complex process yields low-quality products with relatively high environmental impacts because waste biomass must be transferred from fishing ports to processing plants (Vázquez et al., 2020). Thus, alternative valorization processes for the best use of biomass are focused on enzymatic hydrolysis to harvest fish protein hydrolysates (FPHs) including the retrieval of essential nutrients (Blanco et al., 2015; Martínez-Alvarez et al., 2015) and bioactive compounds (Halim et al., 2016; Shahidi and Ambigaipalan, 2015). Extensive studies on the characterization of FPHs have demonstrated excellent functional possessions such as antioxidants (Batista et al., 2010; Nasri et al., 2013) and antimicrobial properties (Jiang et al., 2014; Wang et al., 2018). Vázquez et al. (2020) developed a pilot integral process based on enzyme proteolysis applied to fish discards (i.e., species subjected to catch quotas and undersized species) and obtained FPHs, oils, bioactive peptides, and fish peptones. Lab-scale trials in comparison with conventional fishmeal confirmed the industrial viability of the proposed method (Vázquez et al., 2020). A wide range of alternative technologies exist for producing protein hydrolysates (Iñarra et al., 2019; Mangi and Catchpole, 2014) using different species (Chalamaiah et al., 2012), enzymes (Halim et al., 2016), or hydrolysis conditions (Vázquez et al., 2017), yet not all of them are equally practical (Vázquez et al., 2020).

3.2.3. Agrochemicals and fertilizers

Marine biomass is increasingly discussed as a source for bio-refinery in the production of fertilizers (Ahuja et al., 2020; Dróżdż et al., 2020; Radziemska et al., 2019). The European Commission aims to reduce 30 % of non-renewable fertilizer production and encourages the implementation of waste valorization (Chojnacka et al., 2020). Fish waste is suitable for producing fertilizer due to its high nutrient nitrogen, phosphorus, and calcium content (Dróżdż et al., 2020). Other aquatic biomass has increasingly been investigated as sources of marine-derived organic fertilizers (Emadodin et al., 2020; Madejón et al., 2022).

Emadodin et al. (2020) reviewed novel methods for the utilization of seagrass and jellyfish biomass and their implications for coastal management and soil restoration. Seagrass and jellyfish have immense potential as substitute fertilizers due to their high content of essential macro- and microelements that are vital for soil and plants. Seaweed is especially rich in potassium and micronutrients as well as growth activators such as auxins, cytokines, and alginates, which improve the soil structure (Papenfus et al., 2013). These marine-based fertilizers increase the soil's water-holding capacity while stimulating seed germination and seedling establishment (Emadodin et al., 2020). However, efficient utilization of biological resources must be incentivized and requires the installation of small waste solubilization or fertilizer plants near the location of waste creation (Chojnacka et al., 2020).

Marine biomass for animal feed and biofertilizer production offers a relatively high potential market value and low to medium development costs (see Table 2). Our results indicate that fishmeal and fish oil production for animal feed demonstrate high technology readiness, being well-established and commercially implemented. In contrast, fish protein hydrolysates for animal nutrition and agrochemicals or biofertilizers derived from marine biomass exhibit moderate technological readiness, with advancements largely confined to research and limited pilot-scale applications.

3.3. Biomass for food

The simultaneous increase in marine biomass resulting from improvements in fishing and aquaculture and the need to reduce wastage create challenges (European Commission et al., 2017). The extra biomass could be produced by exploiting new or untapped resources or in-use species on a large scale (EUMOFA, 2018b).

3.3.1. Novel sources

Wild marine biomasses (e.g., Kelp, Ascidian, Baltic mussel mariculture, and Pacific oyster harvesting) are explored for their potential for food production (Thomas et al., 2022). Seaweed or macroalgae are increasingly recognized as novel sustainable food sources (Barba, 2017; Hasselström et al., 2020; Wang et al., 2019). Kelp is among the most promising macroalgae in aquaculture with food and non-food applications (Aakre et al., 2021; Buck et al., 2018; Hasselström et al., 2020). It bears environmental and health benefits that have attracted interest as a nutritious and sustainable alternative to conventional animal-based protein resources (Tzachor et al., 2021). For example, the inclusion of macroalgae and mussels in an Integrated Multi-Trophic Aquaculture system provides unique opportunities for farming aquatic products because it adds feedstock to the system and recycles aquaculture waste (Buck et al., 2018; Tzachor et al., 2021). Currently, the majority of Kelps are produced in Asia (Araújo et al., 2021; Thomas et al., 2022; Thomas et al., 2020), but the interest among European countries for marine macroalgal cultivation is rising (Broch et al., 2019; FAO, 2018).

Microalgae such as chlorella (*Chlorella vulgaris*) and spirulina (*Arthrospira platensis*) are also promising future food sources due to their rapid rate of development as unicellular organisms (Bito et al., 2020; Tzachor et al., 2021). Another recently emerging mariculture is wild Pacific oyster harvesting with high nutrient extraction potential (Mortensen et al., 2019; Thomas et al., 2020). Another example is ascidians (*Ciona intestinalis*, commonly known as sea squirts) with considerable biomass potential for food production (Thomas et al., 2022). Over the past few years, trial farming for food production has been successful, and recent initiatives explore other utilization possibilities such as fish feed (Hackl et al., 2018; Hrůzová et al., 2020). Similarly, commercial-scale harvesting of fish species, such as roach, stickleback, and bream, can be considered as new biological resources for food (Iho et al., 2016; Nielsen et al., 2019).

3.3.2. Food grade extracts from marine biomass

Discarded marine biomass can make a valuable contribution to food production. Food-grade components (e.g., enzymes and amino acids) can be extracted from at-sea discards, fishery by-products, and other components to be used in food processing industries. Approx. 10 million tons of commercial fisheries harvests are discarded annually (Mavuru et al., 2022). Discards include species of low market value, damaged harvest, and bycatches. It is one of the most pervasive threats to marine sustainability and constitutes a significant loss of marine biological resources. Some of these bycatches (e.g., small pelagic fish such as sardines, scads, and croakers) are often minimally processed and locally marketed as a low-cost source of protein (Chan et al., 2019; Tigchelaar et al., 2022). Another example of utilizing onboard discards is the conversion of bycatch into minced fish meat (Silva et al., 2020).

Fishery discards and effluents can also be utilized for the extraction of enzymes, amino acids, carotenoids, and minerals (Borges et al., 2023; Mao et al., 2023; Venugopal, 2022; Venugopalan et al., 2021). Enzymes derived from fish and other marine biomass possess a myriad of advantages over traditional enzymes used in food processing owing to their functionality at temperature and pH extremes (Rasmussen and Morrissey, 2007). Gelatin-derived fish proteins, such as collagens, function at relatively low temperatures and are hence applicable to heat-sensitive processes, such as stabilizing and gelling (Coppola et al., 2020). Enzymes can be extracted from fungal species such as *Cladosporium* and *Aspergilus* with many food processing applications (Birolli et al., 2020). Despite recent attempts to utilize discarded biomass, a considerable share of bycatch is still used in animal and aquaculture feeds (Ghosh et al., 2022; Mutalipassi et al., 2021).

3.3.3. Biocomponents for nutraceuticals and functional foods

Marine biomass can be used as food additives or for functional food (Amin et al., 2020; Jester et al., 2022; Monsiváis-Alonso et al., 2020; Mutalipassi et al., 2021; Šimat, 2021; Venugopalan et al., 2021). Numerous marine-based compounds, including omega-3 fatty acids and photosynthetic pigments, are essential in nutraceutical developments (Mohamed and Ibrahim, 2021). These metabolites offer versatile bioactivities in the food and feed industry, such as antimicrobial, insecticidal, anticancer, antifouling, anti-malarial, anti-hyperlipidemic, and α-glucosidase (Amin et al., 2020; Pan et al., 2020; Rischer et al., 2019; Zhang et al., 2019a).

Post-harvest processing of fish and seafood is being explored as an alleged source of marine-derived food components such as fish oil (primarily omega-3 polyunsaturated fatty acids, PUFA), peptides, and protein hydrolysates (Šimat, 2021). PUFAs lower the incidence of cardiovascular diseases and prostate cancer (Manlusoc et al., 2019). Protein hydrolysis peptides isolated from crustaceans, algae, and fish species exhibit for example, antioxidant, antihypertensive, and antibacterial functions with wide applications in functional foods (Cunha and Pintado, 2022). Seaweed and shrimp are the source of disaccharides called trehalose, with an anti-aging characteristic (Wang et al., 2021). Polysaccharide extracts from algae such as algins, carrageenans, and agar, are extensively used as thickeners and stabilizers in various foods (Rasmussen and Morrissey, 2007).

Biopolymers extracted from marine invertebrates, such as molluscs (Cephalopoda, Bivalvia, and Gastropoda), Annelida (marine worms), Porifera (sponges), Cnidaria (corals, jellyfish), have a wide range of nutraceutical applications (Chakraborty and Joy, 2020; Ganesan et al., 2020). They can be used as animal feed and biomedical treatments (Ganesan et al., 2020).

Marine microorganisms, such as fungi, bacteria, and microalgae, are also rich in bioactive chemicals with biotechnological and functional food applications (Mohamed and Ibrahim, 2021). Cladosporium (*Cladosporiaceae*) is one of the largest marine-derived fungi species that have attracted substantial interest due to their capability to yield a wide range of metabolites, including alkaloids, macrolides, diketopiperazines, pyrones, tetralones, sterols, phenolics, terpenes, lactones, and tetramic acid derivatives (Mohamed and Ibrahim, 2021).

Recent studies also indicate that unique marine microbes and their biologically active metabolites have the potential to serve as new sources of sustainable food and pharmaceutical applications (Dhakal et al., 2017; Stincone and Brandelli, 2020). *Archaea* and *Eubacteria* are increasingly examined as potential sources of novel bioactive chemicals (Dhakal et al., 2017). Research interest also emerged towards other forms of marine-bacteria such as *Proteobacteria* and *Cyanobacteria* due to their quick generation period and great potential in producing bioactive chemicals (Stincone and Brandelli, 2020; Zhang et al., 2017). Wang et al. (2022) have reviewed recent developments in producing novel inhibitors from marine bacteria taxa, such as inhibitors of glycosidases (α-glucosidase and α-amylase) used as anti-diabetic medication and dietary supplements (Trang et al., 2021).

Overall, marine biomass for food production has high market potential with low to medium development costs (see Table 2). Among its applications, new or additional resources, such as seaweed cultivation, exhibit high technology readiness with established commercial practices, while food-grade extracts from waste biomass and biocomponents for nutraceuticals and functional foods demonstrate moderate readiness, with advancements primarily in research and pilot applications.

3.4. Industrial applications

Apart from its use as food, feed, and biofuel, marine biomass can find diverse uses across various other sectors of the industry.

3.4.1. Industrial bioprocesses

Marine biomass provides a supply of bioactive compounds for haircare and cosmetic products. Extracts from seaweed are widely recognized for their moisturizing, anti-aging, and anti-inflammatory properties (Bhattacharya and Goswami, 2020; Veríssimo et al., 2021). Seaweeds produce compounds, such as tyrosinase inhibitors, superoxide dismutase, and Ultraviolet (UV) absorption components that are used in cosmetic products (Bhattacharya & Goswami, 2020; Veríssimo et al., 2021). Fish and invertebrates waste are utilized to extract biomaterials, such as peptones and oils, for industrial applications (Marsol-Vall et al., 2022; Välimaa et al., 2019; Veríssimo et al., 2021; Wang et al., 2021). Marine biomass also offers a rich source of biomaterials with applications in textile and pulp/paper. Fungal species such as *Cladosporium* and *Aspergilus* are rich in enzymes (e.g., agarases, carrageenans, laccases, peroxidases, tannases, pectinases, invertases, cellulases, and xylanases) (Birolli et al., 2020). Biotechnological applications include food processing, eco-friendly pulp and paper solutions, liquid fuels, and bioremediation for contaminants (Mohamed and Ibrahim, 2021).

3.4.2. Biomaterials and bioplastics

Marine-based bioplastics are becoming a promising and cost-effective alternative to synthetic plastics. In contrast to terrestrial crop-based plastics, marine-derived bioplastics do not compete with edible food crops for arable lands (Tennakoon et al., 2023). Marine-derived sources for bioplastics include algae (e.g., *Ulva lactuca*, *Sargassum*, and *Gelidium*), microorganisms (e.g., red macroalgae such as *Sargassum* and *Ulva lactuca*, and microalgae, such as *Chlorella vulgaris* and *Micractinium* sp.), and fishery wastes (e.g., fish skin and crab) (Abdallah et al., 2020; Tennakoon et al., 2023). Seaweeds (e.g., *Shewanella marisflavi* and *Ralstonia eutropha*) are rich in polyhydroxyalkanoate which can be used to produce bioplastics under minimum nutrient requirements (Jeong et al., 2021; Mostafa et al., 2020). Chitin, chitosan, and collagen extracted from marine waste biomass also bear the potential to be used for producing bioplastics with antimicrobial properties (He et al., 2017; Zhang et al., 2019b).

In the last decade, marine microbes have been increasingly investigated as potential sources of novel chemicals (Dhakal et al., 2017; Ghosh et al., 2022; Zhang et al., 2017). *Archaea* and *Eubacteria* are two forms of marine bacteria that have recently gained interest for their potential in the synthesis of natural chemicals (Dhakal et al., 2017). *Actinobacteria*, a source of stable enzymes, can grow in harsh environments, such as low temperatures and salinity (Ghosh et al., 2022). *Gram-negative* bacteria are another source of many bioactive chemicals (e.g., bryostatins, pentabromo-pseudilin, ectoine, vibriobactin, solonamide, violacein, thiomarinol, bromoaltero-chromide), but they received less attention in research (Zhang et al., 2017).

3.4.3. Bioremediation

Certain types of marine microorganisms have the potential to mitigate water contaminants vital to bioremediation, i.e., the removal of contaminants, pollutants, and toxins from water, and wastewater treatment processes. Marine microbes are highly suitable candidates for bioremediation processes due to their wide range of catalytic properties and resilience in harsh environments (Dell'Anno et al., 2021; Zhang et al., 2021).

Industrial applications based on marine biomass exhibit a very high market potential; however, they are associated with very high development costs (see Table 2). Among these, industrial bioprocesses, such as enzyme production, and biomaterials or bioplastics demonstrate moderate technology readiness with advancements in research and early commercialization, while bioremediation remains at lower readiness, primarily limited to lab-scale studies.

4. Integrating innovation clusters into business model patterns

The four identified innovation clusters may allow for business models for sustainability, circularity, and regeneration (Ahmad et al., 2023; Antikainen and Valkokari, 2016; Donner and de Vries, 2021; Ghosh et al., 2023; Konietzko et al., 2023; Lüdeke-Freund et al., 2019, 2024; Stephenson and Damerell, 2022). Conventional business models mainly focus on economic value (Beltramello et al., 2013; Lüdeke-Freund et al., 2024), whereas sustainable business models embrace the triple bottom line, chiefly, environmental, social, and economic value (Konietzko et al., 2023; Lüdeke-Freund et al., 2024). Although the concepts of sustainability and circular economy overlap (e.g., Hossain et al., 2024), circular business models are viewed as “a subcategory of sustainable business models with a primary focus on environmental and economic outcomes creating value by slowing, intensifying and closing material loops” (Ahmad et al., 2023, p. 5). Regenerative business models may be viewed as another, less frequently discussed subcategory emphasizing environmental and social aspects in terms of planetary health and societal well-being (Hossain et al., 2024; Konietzko et al., 2023).

Lüdeke-Freund et al. (2024, p. 209) argue that “the differences between sustainability-oriented and conventional business models lie not so much in their respective activities only, but in how far the activities follow particular design themes”, or how value is maintained (preserving and restoring the functionality of the natural environment and materials, goods, and infrastructures), unlocked (creating awareness for sustainability among stakeholders), and shared (involving, engaging, and supporting stakeholders). In the blue bioeconomy, the question is how biotechnological innovations can lead to products, materials, and applications that contribute to a reduction of the usage of natural resources and have positive economic, environmental, and societal impacts (Antikainen and Valkokari, 2016). To answer this question, the four innovation clusters summarized in Table 2 are connected with feedstock and regenerative business models.

4.1. Feedstock business models

Feedstock business models are aligned with the “closing the loop” concept (Bocken et al., 2014), which focuses on creating value from waste in various forms. First, *resource recovery business models* build on activities that “seek to recover the value of resources, thus maintaining them cycling for as long as possible, constantly developing and improving ways to create value from co-products and byproducts, facilitating reuse and recycling of bioresources” (Salvador et al., 2021, p. 9). In the blue bioeconomy, these activities include opportunities to recover and repurpose waste (and by-product) marine resources for new value-added applications. In the innovation cluster “Animal feed and biofertilizers”, fishmeal, fish oil, and hydrolysate extracts are valorization options promising the creation of economic and environmental value. Waste and by-products are turned into marketable products, whilst reducing waste quantities to be collected. These activities contribute to maintaining the value of materials and resources by avoiding or at least reducing waste and extending life cycles (Lüdeke-Freund et al., 2024). The seafood industry is a case in point. Waste includes discarded fish, seafood processing by-products, and seaweed waste, which could be used to create high-value products like fish oil, collagen, and chitin. However, a significant challenge for efficient processing is the short shelf-life of by-products (Rotter et al., 2021).

Second, *bio-refinery models* draw on biological processes to convert feedstock into different products, like biofuels, chemicals, materials, or food. This allows for efficient and sustainable utilization of feedstock (Donner and de Vries, 2021; Salvador et al., 2021). In the blue bioeconomy, innovations categorized as “Biomass for food” is a case in point. Activities to produce “blue foods” include, for example, the utilization of fishery by-products and by-catch for food-grade extracts (e.g., Tigchelaar et al., 2022) or the generation of biomolecules from wasted marine biomass (e.g., Amin et al., 2020; Mutalipassi et al., 2021). These “blue foods are more accessible and affordable than other animal-source foods and offer benefits beyond health alone” (Tigchelaar et al. (2022), p. 3). They may ensure livelihoods in many vulnerable communities that depend on small-scale fisheries and aquaculture. Bio-refinery models drawing on marine biomass for food are hence promising, but products that could target mainstream markets are still in different stages of development. For instance, while fish oil for nutraceutical products is produced all over the world, many other compounds are still the subject of clinical trials (Mutalipassi et al., 2021).

The cluster “Bioenergy from marine biomass” also includes activities constituting bio-refinery business models, such as the production of bioethanol, biodiesel, and biohydrogen based on algae, microorganisms, or bacteria (e.g., Anand et al., 2023). These activities contribute to, first, maintaining the value of materials and aquatic resources by reducing waste and, second, unlocking value by enabling alternative product offerings that promote sustainability and circularity (Lüdeke-Freund et al., 2024). However, “the environmental benefits are not always clear cut, as one might argue that biorefineries based on creating value from waste might sustain existing waste streams rather than tackling the source of the issue (i.e., the sources of waste streams)” (Lüdeke-Freund et al., 2019, p. 53). Furthermore, technologies for bio-refining processes to produce, for example, fuel based on microalgae are still relatively immature and not yet economically viable. Although biofuels offer a promising alternative to fossil fuels, their current production methods are not energy-efficient enough to make them truly cost-competitive (Chandrasekhar et al., 2022).

Third, *cascading* is a nested recovery business model in which the side streams from one production process are used as feedstock for the next, ensuring maximum resource utilization and higher income. It involves using feedstock first for its highest-value applications and then cascading it down to lower-value uses as it degrades (Lüdeke-Freund et al., 2019). For example, in the blue bioeconomy, in the cluster “Animal feed and biofertilizers”, the extraction of omega-3 fatty acids from fish processing by-products is followed by the conversion of final residuals for fishmeal production, and any remaining waste is repurposed as biofertilizer or biogas feedstock (e.g., Hilmarsdóttir et al., 2022). These activities help extend the lifespan of the feedstock, minimize waste, and “retain the material value by closing resource loops” (Lüdeke-Freund et al., 2019, p. 55). Despite their potential to maintain and unlock value (Lüdeke-Freund et al., 2024), such as using marine biomass as a promising alternative to conventional fertilizers, potentially boosting agricultural sustainability, some issues remain unresolved. For example, the release of nutrients is slower compared to conventional fertilizers, composting processes can lead to increased emissions of greenhouse gases like nitrous oxide and ammonia, and marine biomass can accumulate pollutants that might exceed legal limits for agricultural applications. More research into these challenges is needed to ensure the safe and effective use of marine biomass as a sustainable fertilizer for agriculture (Rotter et al., 2021). Furthermore, as indicated by Cicculllo et al. (2022), emerging digital solutions such as big data, while not yet fully exploited, have significant potential to reduce waste at both the early stages (aiming to maximize material efficiency) and post-consumption (closing the loop) phases of the marine supply chain.

4.2. Regenerative business models

Regenerative business models focus on closed production cycles, where resources are reprocessed and reused within the same production system (Konietzko et al., 2023; Lüdeke-Freund et al., 2019). Integrated Multi-Trophic Aquaculture (IMTA), which is discussed in the cluster "Biomass for food" is a case in point. Fed species (e.g., finfish or shrimp) are co-cultivated with extractive species (e.g., mussels or sea-urchins) to reduce the organic and inorganic effluents generated by the fed species. This approach aims to reduce the potentially harmful effects of aquaculture on coastal ecosystems whilst ensuring an increase in the availability of aquatic resources to feed a growing world population (European Commission et al., 2017). It thus contributes to, first, maintaining value by avoiding waste and harmful substances, second, unlocking value by making sustainable product offerings accessible and influencing consumption, and third, sharing value by enhancing coastal ecosystems (Lüdeke-Freund et al., 2024). A challenge of regenerative business models is that "to be economically viable, each of the individual components must be marketable (Chopin et al., 2008), or adding value through accounting for the ecosystem services that extractive species provide" (Buck et al., 2018, p. 2). To enhance the marketability of IMTA products, national governments could provide support for the development of value chains, connecting producers with processors, distributors, and retailers. Regional or national marketing campaigns to promote the benefits of IMTA products may create awareness of the benefits of IMTA and encourage innovators and entrepreneurs in agriculture to invest in it. Given the ecosystem services that IMTA farmers provide, such as water quality improvement and carbon sequestration, national governments could introduce financial compensation for the costs of producing less marketable species. Unfortunately, however, in many countries, most notably in Europe, IMTA is still "being treated as an experimental 'add-on' to existing mono-culture sites" (Alexander et al., 2015, p. 22), and the existing legal and regulatory frameworks are not conducive to its implementation.

5. Discussion

5.1. Future research

Like other studies, ours has limitations that can trace promising avenues for future research. First, scoping reviews prioritize mapping the extent and range of scientific knowledge in an emerging field, sacrificing the in-depth analysis of individual studies (Aguinis et al., 2023). They provide a less in-depth analysis than literature reviews and may thus include studies that do not meet the same level of methodological rigor (Pham et al., 2014). Future research could provide systematic literature reviews for each of the four clusters, comparing and contrasting theoretical frameworks, methodologies, and key findings and evaluating the entrepreneurial opportunities and risks of the specified innovations. Most notably, using the broad overview generated by this scoping review as a starting point, future studies could delve deeper into the hierarchy prevalent in the blue bioeconomy (e.g., Vieira et al., 2020).

Second, our decision to randomly select 100 articles for further analysis may have limited the completeness and representativeness of the described scientific findings. To refine and create a focused subset of articles, future research using scoping reviews could employ multiple query formulations instead.

Third, unlike Levac et al. (2010) and Arksey and O'Malley (2005), we did not engage in a consultation with stakeholders, but we juxtaposed our findings with the literature on sustainable, circular, and regenerative business models (e.g., Donner and de Vries, 2021; Konietzko et al., 2023; Lüdeke-Freund et al., 2019; Salvador et al., 2021). Our findings are open for further exploration in a large-scale empirical setting including stakeholders, such as consumer surveys examining how demand for sustainable offerings and responsible consumption can be stimulated (e.g., Aakre et al., 2021; Bito et al., 2020).

5.2. Implications for managerial practice

Sustainable and circular business models such as feedstock and regenerative business models aim to create and capture multiple dimensions of value for and with multiple levels and groups whose goals need to be aligned (Konietzko et al., 2023). For example, Vincent et al. (2020) highlight a market mismatch in the seaweed industry: farmers desire to scale production for cost-effectiveness, requiring long-term purchase commitments from buyers. Potential buyers, among them food, cosmetics, and feed companies, seek high-quality European seaweed but struggle to find consistent, affordable supplies. This leads them to rely on cheaper, often lower-quality imports from Asia, despite concerns about sustainability and ethical sourcing. To commercialize seaweed-based products, supply and demand must be aligned. This can be achieved through strategic partnerships between buyers and suppliers.

The juxtaposition of the four clusters of blue biotechnological innovations and the literature on sustainable and circular business models shows that a focus on activities (the issue of *what* valorization options are discernible) is not enough. As Lüdeke-Freund et al. (2024) point out, the issue of *how* value for and with stakeholders is maintained, unlocked, and shared, is vital to distinguish sustainability-oriented business models from conventional business models. Managers and entrepreneurs must develop instruments that assess and monitor the economic, environmental, and social impacts of their activities on stakeholders. Marine aquaculture is a case in point. Economic impact assessment could include, for instance, the number of direct and indirect jobs created by aquaculture operations (e.g., farming, processing, and transportation) in coastal areas. Potential environmental factors may be, for example, water quality (e.g., pollutants) and biodiversity (e.g., the potential for habitat loss, competition with wild species, and the introduction of invasive species). Social impact assessment may include the social and cultural impacts of aquaculture on local communities, such as on traditional livelihoods and cultural practices, and potential conflicts between aquaculture and other coastal uses such as tourism and fishing.

5.3. Implications for policymakers

Oceans and seas are globally spanning areas. Thus, policymakers may consider the development of international standards and guidelines for sustainable and circular business models in the blue bioeconomy. Policymakers on national and transnational levels should collaborate with stakeholders in the blue bioeconomy and develop comprehensive tools for impact measurement. For example, recent research on a biorefinery project suggests that the consideration of social group criteria complements the assessment of economic and environmental costs and leads to more sustainable and socially responsible biofuel production (Kostidi and Lyridis, 2024).

Despite their entrepreneurial potential (e.g., Ligtvoet et al., 2019), the valorization of the identified blue biotechnological innovations for sustainability-oriented business models that address mainstream markets is costly and requires access to dedicated funding schemes (Rotter et al., 2021). Policymakers could encourage governments to collaborate with businesses and investors to fund joint research projects and accelerate the commercialization of new technologies. For example, the Brazilian government plays a key role in supporting marine biotechnology research through various ministries and agencies. In particular, they established BiotecMar, a research network that focuses on various aspects of marine research, production, and commercialization and aims to position Brazil as a strong player in the global blue bioeconomy (Thompson et al., 2018).

Finally, if mainstream markets are to be targeted, policymakers should engage in awareness campaigns to educate consumers. For example, businesses that benefitted from dedicated funding schemes and governmental support could be used as case studies in those campaigns to illustrate sustainable and circular activities and how these activities create and deliver value.

6. Conclusion

This scoping review aimed to explore biotechnological innovations based on marine resources and their potential for valorization for new business models in the emerging blue bioeconomy. Addressing the first research question, the scoping review adds to the growing management literature on how the SDGs can be achieved (Berrone et al., 2023). It extends this literature by focusing on the use of the oceans for economic purposes, highlighting social and environmental implications and the potential for sustainability and circularity. For instance, the findings illustrate how blue biotechnological innovations can reduce hunger by utilizing novel species, fishery by-products, and bycatch (SDG 2), decrease water pollution (SDG 6), contribute to human health and well-being based on bioactive compounds with moisturizing, anti-aging, and anti-inflammatory effects (SDG 3), and support decarbonization and energy security with bioenergy from marine biomass and microorganisms (SDG7).

Second, addressing the second research question, we discussed how the four clusters of innovations emerging from the scoping review can enable sustainable, circular, and regenerative business model patterns and how they contribute to maintaining, unlocking, and sharing value (Konietzko et al., 2023; Lüdeke-Freund et al., 2019, 2024). However, complexities and challenges associated with integrating sustainability into blue economy business initiatives call for supportive policies as the mere involvement in ocean-based economic activities does not guarantee environmental or social sustainability (Niner et al., 2022). The suggested business model patterns may trace promising avenues for future research and inspire discussion among scientists, managers, entrepreneurs, and policymakers.

CRediT authorship contribution statement

Ashkan Pakseresht: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Methodology, Formal analysis, Data curation, Conceptualization. **Alireza Kermani:** Visualization, Methodology, Investigation, Formal analysis, Data curation. **Carolin Decker-Lange:** Writing – review & editing, Writing – original draft, Project administration, Methodology, Conceptualization.

Data availability

Data will be made available on request.

References

Aakre, I., Solli, D.D., Markhus, M.W., Mæhre, H.K., Dahl, L., Henjum, S., Alexander, J., Korneliussen, P.A., Madsen, L., Kjellevold, M., 2021. Commercially available kelp and seaweed products - valuable iodine source or risk of excess intake? Food Nutr. Res. 65, 7584. https://doi.org/10.29219/fnr.v65.7584.

Abdallah, M.M., Fernández, N., Matias, A.A., Bronze, M.D.R., 2020. Hyaluronic acid and chondroitin sulfate from marine and terrestrial sources: extraction and purification methods. Carbohydr. Polym. 243, 116441. https://doi.org/10.1016/j.carbpol.2020.116441.

Acosta-Michlik, L., Lucht, W., Bondeau, A., Beringer, T., 2011. Integrated assessment of sustainability trade-offs and pathways for global bioenergy production: Framing a novel hybrid approach. Renew. Sustain. Energy Rev. 15 (6), 2791–2809. https://doi.org/10.1016/j.rser.2011.02.011.

Aguinis, H., Ramani, R.S., Alabduljader, N., 2023. Best-practice recommendations for producers, evaluators, and users of methodological literature reviews. Organ. Res. Methods 26 (1), 46–76. https://doi.org/10.1177/1094428120943281.

Ahmad, F., Bask, A., Laari, S., Robinson, C.V., 2023. Business management perspectives on the circular economy: present state and future directions. Technological Forecasting & Social Change 187, 122182.

Ahmed, S.F., Rafa, N., Mofijur, M., Badruddin, I.A., Inayat, A., Ali, M.S., Farrok, O., Yunus Khan, T.M., 2021. Biohydrogen production from biomass sources: metabolic pathways and economic analysis. Frontiers in Energy Research 9, 753878. https://doi.org/10.3389/fenrg.2021.753878.

Ahuja, I., Dauksas, E., Remme, J.F., Richardsen, R., Løes, A.-K., 2020. Fish and fish waste-based fertilizers in organic farming – with status in Norway: A review. Waste Manag. 115, 95–112. https://doi.org/10.1016/j.wasman.2020.07.025.

Alexander, K.A., Potts, T.P., Freeman, S., Israel, D., Johansen, J., Kletou, D., Meland, M., Pecorino, D., Rebours, C., Shorten, M., Angel, D.L., 2015. The implications of aquaculture policy and regulation for the development of integrated multi-trophic aquaculture in Europe. Aquaculture 443, 16–23. https://doi.org/10.1016/j.aquaculture.2015.03.005.

Allen, K.M., Habte-Tsion, H.M., Thompson, K.R., Filer, K., Tidwell, J.H., Kumar, V., 2019. Freshwater microalgae (Schizochytrium sp.) as a substitute to fish oil for shrimp feed. Sci. Rep. 9 (1), 6178. https://doi.org/10.1038/s41598-019-41020-8.

Amin, M., Zhang, X.Y., Xu, X.Y., Qi, S.H., 2020. New citrinin derivatives from the deep-sea-derived fungus Cladosporium sp. SCSIO z015. Nat. Prod. Res. 34 (9), 1219–1226. https://doi.org/10.1080/14786419.2018.1556266.

Anand, U., Dey, S., Parial, D., Federici, S., Ducoli, S., Bolan, N.S., Dey, A., Bontempi, E., 2023. Algae and bacteria consortia for wastewater decontamination and transformation into biodiesel, bioethanol, biohydrogen, biofertilizers and animal feed: A review. Environ. Chem. Lett. 21 (3), 1585–1609. https://doi.org/10.1007/s10311-023-01562-w.

Antikainen, M., Valkokari, K., 2016. A framework for sustainable circular business model innovation. Technol. Innov. Manag. Rev. 6 (7), 5–12. https://doi.org/10.22215/timreview1000.

Araújo, R., Vázquez Calderón, F., Sánchez López, J., Azevedo, I.C., Bruhn, A., Fluch, S., Garcia Tasende, M., Ghaderiardakani, F., Ilmjärv, T., Laurans, M., Mac Monagail, M., Mangini, S., Peteiro, C., Rebours, C., Stefansson, T., Ullmann, J., 2021. Current status of the algae production industry in Europe: an emerging sector of the blue bioeconomy. Front. Mar. Sci. 7, 626389. https://doi.org/10.3389/fmars.2020.626389.

Arksey, H., O'Malley, L., 2005. Scoping studies: towards a methodological framework. Int. J. Soc. Res. Methodol. 8 (1), 19–32. https://doi.org/10.1080/1364557032000119616.

Asada, R., Cardellini, G., Mair-Bauernfeind, C., Wenger, J., Haas, V., Holzer, D., Stern, T., 2020. Effective bioeconomy? A MRIO-based socioeconomic and environmental impact assessment of generic sectoral innovations. Technological Forecasting & Social Change 153, 119946. https://doi.org/10.1016/j.techfore.2020.119946.

Aswathy, U.S., Sukumaran, R.K., Devi, G.L., Rajasree, K.P., Singhania, R.R., Pandey, A., 2010. Bio-ethanol from water hyacinth biomass: an evaluation of enzymatic saccharification strategy. Bioresour. Technol. 101 (3), 925–930. https://doi.org/10.1016/j.biortech.2009.08.019.

Barba, F.J., 2017. Microalgae and seaweeds for food applications: challenges and perspectives. Food Res. Int. 99 (Part 3), 969–970. https://doi.org/10.1016/j.foodres.2016.12.022.

Barbot, Y.N., Al-Ghaili, H., Benz, R., 2016. A review on the valorization of macroalgal wastes for biomethane production. Mar. Drugs 14 (6), 120. https://doi.org/10.3390/md14060120.

Barlow, S.M., 2003. Fish meal. In: Caballero, B. (Ed.), Encyclopedia of Food Sciences and Nutrition, 2nd ed. Academic Press, pp. 2486–2491. https://doi.org/10.1016/B0-12-227055-X/00479-X.

Batista, I., Ramos, C., Coutinho, J., Bandarra, N.M., Nunes, M.L., 2010. Characterization of protein hydrolysates and lipids obtained from black scabbardfish (Aphanopus carbo) by-products and antioxidative activity of the hydrolysates produced. Process Biochem. 45 (1), 18–24. https://doi.org/10.1016/j.procbio.2009.07.019.

Befort, N., 2020. Going beyond definitions to understand tensions within the bioeconomy: the contribution of sociotechnical regimes to contested fields. Technological Forecasting & Social Change 153, 119923. https://doi.org/10.1016/j.techfore.2020.119923.

Beltramello, A., Haie-Fayle, L., Pilat, D., 2013. Why new business models matter for green growth. OECD Green Growth Papers 2013-01. https://doi.org/10.1787/5k97gk40v3ln-en.

Berrone, P., Rousseau, H.E., Ricart, J.E., Brito, E., Giuliodori, A., 2023. How can research contribute to the implementation of sustainable development goals? An interpretive review of SDG literature in management. Int. J. Manag. Rev. 25, 318–339. https://doi.org/10.1111/ijmr.12331.

Bhattacharya, M., Goswami, S., 2020. Microalgae – A green multi-product biorefinery for future industrial prospects. Biocatal. Agric. Biotechnol. 25, 101580. https://doi.org/10.1016/j.bcab.2020.101580.

Bhushan, S., Rana, M.S., Bhandari, M., Sharma, A.K., Simsek, H., Prajapati, S.K., 2021. Enzymatic pretreatment of algal biomass has different optimal conditions for biogas and bioethanol routes. Chemosphere 284, 131264. https://doi.org/10.1016/j.chemosphere.2021.131264.

Birolli, W.G., Zanin, L.L., Jimenez, D.E.Q., Porto, A.L.M., 2020. Synthesis of Knoevenagel adducts under microwave irradiation and biocatalytic ene-reduction by the marine-derived fungus Cladosporium sp. CBMAI 1237 for the production of 2-cyano-3-phenylpropanamide derivatives. Mar. Biotechnol. 22, 317–330. https://doi.org/10.1007/s10126-020-09953-8.

Bito, T., Okumura, E., Fujishima, M., Watanabe, F., 2020. Potential of Chlorella as a dietary supplement to promote human health. Nutrients 12 (9), 2524. https://doi.org/10.3390/nu12092524.

Blanco, M., Sotelo, C.G., Pérez-Martín, R.I., 2015. Hydrolysis as a valorization strategy for unused marine food biomass: boarfish and small-spotted catshark discards and by-products. J. Food Biochem. 39 (4), 368–376. https://doi.org/10.1111/jfbc.12141.

Bocken, N.M.P., Short, S.W., Rana, P., Evans, S., 2014. A literature and practice review to develop sustainable business model archetypes. J. Clean. Prod. 65, 42–56. https://doi.org/10.1016/j.jclepro.2013.11.039.

Borges, S., Odila, J., Voss, G., Martins, R., Rosa, A., Couto, J.A., Almeida, A., Pintado, M., 2023. Fish by-products: A source of enzymes to generate circular bioactive hydrolysates. Molecules 28 (3), 1155. https://doi.org/10.3390/molecules28031155.

Broch, O.J., Alver, M.O., Bekkby, T., Gundersen, H., Forbord, S., Handå, A., Skjermo, J., Hancke, K., 2019. The kelp cultivation potential in coastal and offshore regions of Norway. Front. Mar. Sci. 5, 00529. https://doi.org/10.3389/fmars.2018.00529.

Buck, B.H., Troell, M.F., Krause, G., Angel, D.L., Grote, B., Chopin, T., 2018. State of the art and challenges for offshore integrated multi-trophic aquaculture (IMTA). Front. Mar. Sci. 5, 00165. https://doi.org/10.3389/fmars.2018.00165.

Bux, F., Chisti, Y., 2016. Algae biotechnology: products and processes. Springer. https://doi.org/10.1007/978-3-319-12334-9.

Caruso, G., 2015. Fishery wastes and by-products: A resource to be valorised. Journal of FisheriesSciences.com 9, 80–83.

Chakraborty, K., Joy, M., 2020. High-value compounds from the molluscs of marine and estuarine ecosystems as prospective functional food ingredients: an overview. Food Res. Int. 137, 109637. https://doi.org/10.1016/j.foodres.2020.109637.

Chalamaiah, M., Dinesh Kumar, B., Hemalatha, R., Jyothirmayi, T., 2012. Fish protein hydrolysates: proximate composition, amino acid composition, antioxidant activities and applications: a review. Food Chem. 135 (4), 3020–3038. https://doi.org/10.1016/j.foodchem.2012.06.100.

Chan, C.Y., Tran, N., Pethiyagoda, S., Crissman, C.C., Sulser, T.B., Phillips, M.J., 2019. Prospects and challenges of fish for food security in Africa. Glob. Food Sec. 20, 17–25. https://doi.org/10.1016/j.gfs.2018.12.002.

Chandrasekhar, K., Raj, T., Ramanaiah, S.V., Kumar, G., Banu, J.R., Varjani, S., Sharma, P., Pandey, A., Kumar, S., Kim, S.-H., 2022. Algae biorefinery: A promising approach to promote microalgae industry and waste utilization. J. Biotechnol. 345, 1–16. https://doi.org/10.1016/j.jbiotec.2021.12.008.

Chojnacka, K., Moustakas, K., Witek-Krowiak, A., 2020. Bio-based fertilizers: A practical approach towards circular economy. Bioresour. Technol. 295, 122223. https://doi.org/10.1016/j.biortech.2019.122223.

Ciccullo, F., Fabbri, M., Abdelkafi, N., Pero, M., 2022. Exploring the potential of business models for sustainability and big data for food waste reduction. J. Clean. Prod. 340, 130673. https://doi.org/10.1016/j.jclepro.2022.130673.

Cisneros-Montemayor, A.M., Moreno-Báez, M., Voyer, M., Allison, E.H., Cheung, W.W.L., Hessing-Lewis, M., Oyinlola, M.A., Singh, G.G., Swartz, W., Ota, Y., 2019. Social equity and benefits as the nexus of a transformative blue economy: A sectoral review of implications. Mar. Policy 109, 103702. https://doi.org/10.1016/j.marpol.2019.103702.

Coppola, D., Oliviero, M., Vitale, G.A., Lauritano, C., D'Ambra, I., Iannace, S., de Pascale, D., 2020. Marine collagen from alternative and sustainable sources: extraction, processing and applications. Mar. Drugs 18 (4), 214. https://doi.org/10.3390/md18040214.

Crecente, F., Sarabia, M., Teresa del Val, M., 2021. Climate change policy and entrepreneurial opportunities. Technological Forecasting & Social Change 163, 120446. https://doi.org/10.1016/j.techfore.2020.120446.

Cunha, S.A., Pintado, M.E., 2022. Bioactive peptides derived from marine sources: biological and functional properties. Trends Food Sci. Technol. 119, 348–370. https://doi.org/10.1016/j.tifs.2021.08.017.

Daudt, H.M.L., van Mossel, C., Scott, S.J., 2013. Enhancing the scoping study methodology: A large, inter-professional team's experience with Arksey and O'Malley's framework. BMC Med. Res. Methodol. 13, 48. https://doi.org/10.1186/1471-2288-13-48.

Dell'Anno, F., Rastelli, E., Sansone, C., Brunet, C., Ianora, A., Dell'Anno, A., 2021. Bacteria, fungi and microalgae for the bioremediation of marine sediments contaminated by petroleum hydrocarbons in the omics era. Microorganisms 9 (8), 1695. https://doi.org/10.3390/microorganisms9081695.

Dhakal, D., Pokhrel, A.R., Shrestha, B., Sohng, J.K., 2017. Marine rare actinobacteria: isolation, characterization, and strategies for harnessing bioactive compounds. Front. Microbiol. 8, 01106. https://doi.org/10.3389/fmicb.2017.01106.

Donner, M., de Vries, H., 2021. How to innovate business models for a circular bio-economy? Bus. Strateg. Environ. 30, 1932–1947. https://doi.org/10.1002/bse.2725.

Donthu, N., Kumar, S., Mukherjee, D., Pandey, N., Lim, W.M., 2021. How to conduct a bibliometric analysis: an overview and guidelines. J. Bus. Res. 133, 285–296. https://doi.org/10.1016/j.jbusres.2021.04.070.

Dróżdż, D., Malińska, K., Kacprzak, M., Mrowiec, M., Szczypiór, A., Postawa, P., Stachowiak, T., 2020. Potential of fish pond sediments composts as organic fertilizers. Waste and Biomass Valorization 11 (10), 5151–5163. https://doi.org/10.1007/s12649-020-01074-6.

Efroymson, R.A., Jager, H.I., Mandal, S., Parish, E.S., Mathews, T.J., 2021. Better management practices for environmentally sustainable production of microalgae and algal biofuels. J. Clean. Prod. 289, 125150. https://doi.org/10.1016/j.jclepro.2020.125150.

El-Sayed, A.-F.M., 2020. Chapter 7 - nutrition and feeding. In: El-Sayed, A.-F.M. (Ed.), *Tilapia culture* (2nd ed., pp. 135–172). Academic Press. https://doi.org/10.1016/B978-0-12-816509-6.00007-0.

Emadodin, I., Reinsch, T., Rotter, A., Orlando-Bonaca, M., Taube, F., Javidpour, J., 2020. A perspective on the potential of using marine organic fertilizers for the sustainable management of coastal ecosystem services. Environ. Sustain. 3 (1), 105–115. https://doi.org/10.1007/s42398-020-00097-y.

EUMOFA, 2018a. Blue Bio-Economy: Situation Report and Perspectives. Publications Office of the European Union. https://doi.org/10.2771/053734.

EUMOFA, 2018b. The EU fish market. 2018 edition. https://eumofa.eu/documents/20124/46866/EN_The+EU+fish+market+2018.pdf/5ee42f4f-6bf6-431e-afa3-d3023545a35e?t=1542391778508.

European Commission, 2017. Report on the blue growth strategy: Towards more sustainable growth and jobs in the Blue Economy. https://ec.europa.eu/maritimeaffairs/sites/maritimeaffairs/files/swd-2017-128_en.pdf.

European Commission, Directorate-General for Research and Innovation, Group of Chief Scientific Advisors, 2017. Food from the oceans: How can more food and biomass be obtained from the oceans in a way that does not deprive future generations of their benefits? Publications Office. https://doi.org/10.2777/66235.

FAO, 2018. The global status of seaweed production, trade and utilization. Globefish Research Programme 124, I.

FAO, 2020. FAO Fisheries and aquaculture - Fishery statistical collections - Global aquaculture production. https://www.fao.org/fishery/en/collection/aquaculture.

Foong, S.Y., Chan, Y.H., Cheah, W.Y., Kamaludin, N.H., Tengku Ibrahim, T.N.B., Sonne, C., Peng, W., Show, P.L., Lam, S.S., 2021. Progress in waste valorization using advanced pyrolysis techniques for hydrogen and gaseous fuel production. Bioresour. Technol. 320 (Part A), 124299. https://doi.org/10.1016/j.biortech.2020.124299.

Ganesan, A.R., Saravana Guru, M., Balasubramanian, B., Mohan, K., Chao Liu, W., Valan Arasu, M., Abdullah Al-Dhabi, N., Duraipandiyan, V., Ignacimuthu, S., Sudhakar, M. P., Seedevi, P., 2020. Biopolymer from edible marine invertebrates: A potential functional food. Journal of King Saud University - Science 32 (2), 1772–1777. https://doi.org/10.1016/j.jksus.2020.01.015.

Ghosh, S., Sarkar, T., Pati, S., Kari, Z.A., Edinur, H.A., Chakraborty, R., 2022. Novel bioactive compounds from marine sources as a tool for functional food development. Front. Mar. Sci. 9, 832957. https://doi.org/10.3389/fmars.2022.832957.

Ghosh, S., Raut, R.D., Cheikhrouhou, N., Sinha, S., Ray, A., 2023. Attaining sustainable development goals through embedding circular economy principles: evidence from food processing small- and medium-sized enterprises in India. Bus. Strateg. Environ. https://doi.org/10.1002/bse.3591.

González-González, L.M., Correa, D.F., Ryan, S., Jensen, P.D., Pratt, S., Schenk, P.M., 2018. Integrated biodiesel and biogas production from microalgae: towards a sustainable closed loop through nutrient recycling. Renew. Sust. Energ. Rev. 82, 1137–1148. https://doi.org/10.1016/j.rser.2017.09.091.

Hackl, R., Hansson, J., Norén, F., Stenberg, O., Olshammar, M., 2018. Cultivating ciona intestinalis to counteract marine eutrophication: environmental assessment of a marine biomass based bioenergy and biofertilizer production system. Renew. Energy 124, 103–113. https://doi.org/10.1016/j.renene.2017.07.053.

Haddaway, N.R., Page, M.J., Pritchard, C.C., McGuinness, L.A., 2022. PRISMA2020: an R package and shiny app for producing PRISMA 2020-compliant flow diagrams, with interactivity for optimised digital transparency and open synthesis. Campbell Syst. Rev. 18 (2), e1230. https://doi.org/10.1002/cl2.1230.

Halim, N.R.A., Yusof, H.M., Sarbon, N.M., 2016. Functional and bioactive properties of fish protein hydolysates and peptides: A comprehensive review. Trends Food Sci. Technol. 51, 24–33. https://doi.org/10.1016/j.tifs.2016.02.007.

Hasselström, L., Thomas, J.-B., Nordström, J., Cervin, G., Nylund, G.M., Pavia, H., Gröndahl, F., 2020. Socioeconomic prospects of a seaweed bioeconomy in Sweden. Sci. Rep. 10 (1), 1610. https://doi.org/10.1038/s41598-020-58389-6.

He, M., Wang, X., Wang, Z., Chen, L., Lu, Y., Zhang, X., Li, M., Liu, Z., Zhang, Y., Xia, H., Zhang, L., 2017. Biocompatible and biodegradable bioplastics constructed from chitin via a "green" pathway for bone repair. ACS Sustain. Chem. Eng. 5 (10), 9126–9135. https://doi.org/10.1021/acssuschemeng.7b02051.

Hilmarsdóttir, G.S., Ögmundarson, Ó., Arason, S., Gudjónsdóttir, M., 2022. Identification of environmental hotspots in fishmeal and fish oil production towards the optimization of energy-related processes. J. Clean. Prod. 343, 130880. https://doi.org/10.1016/j.jclepro.2022.130880.

Hodar, A., Vasava, R., Mahavadiya, D., Joshi, N., 2020. Fish meal and fish oil replacement for aqua feed formulation by using alternative sources: A review. Journal of Experimental Zoology India 23 (1).

Hossain, M., Park, S., Suchek, N., Pansera, M., 2024. Circular economy: A review of review articles. Bus. Strateg. Environ. https://doi.org/10.1002/bse.3867.

Hrůzová, K., Matsakas, L., Karnaouri, A., Norén, F., Rova, U., Christakopoulos, P., 2020. Second-generation biofuel production from the marine filter feeder ciona intestinalis. ACS Sustain. Chem. Eng. 8 (22), 8373–8380. https://doi.org/10.1021/acssuschemeng.0c02417.

Iho, A., Ahtiainen, H., Artell, J., Heikinheimo, O., Kauppila, P., Kosenius, A.-K., Laukkanen, M., Lindroos, M., Oinonen, S., Ollikka, K., Parkkila, K., Pavlova, Y., Peltonen, H., Pouta, E., Uusitalo, L., 2016. The role of fisheries in optimal eutrophication management. Water Economics and Policy 3 (2), 1650031. https://doi.org/10.1142/S2382624X16500314.

Iñarra, B., Bald, C., Cebrián, M., Antelo, L.T., Franco-Uría, A., Vázquez, J.A., Pérez-Martín, R.I., Zufía, J., 2019. What to do with unwanted catches: Valorisation options and selection strategies. In: Uhlmann, S.S., Ulrich, C., Kennelly, S.J. (Eds.), The European Landing Obligation: Reducing Discards in Complex, Multi-Species and Multi-Jurisdictional Fisheries. Springer, pp. 333–359. https://doi.org/10.1007/978-3-030-03308-8_17.

Ivanovs, K., Blumberga, D., 2017. Extraction of fish oil using green extraction methods: A short review. Energy Procedia 128, 477–483. https://doi.org/10.1016/j.egypro.2017.09.033.

Jacob, A., Ashok, B., Alagumalai, A., Chyuan, O.H., Le, P.T.K., 2021. Critical review on third generation micro algae biodiesel production and its feasibility as future bioenergy for IC engine applications. Energy Convers. Manag. 228, 113655. https://doi.org/10.1016/j.enconman.2020.113655.

Jeong, D.W., Hyeon, J.E., Lee, M.E., Ko, Y.J., Kim, M., Han, S.O., 2021. Efficient utilization of brown algae for the production of Polyhydroxybutyrate (PHB) by using

an enzyme complex immobilized on Ralstonia eutropha. Int. J. Biol. Macromol. 189, 819–825. https://doi.org/10.1016/j.ijbiomac.2021.08.149.
Jester, B.W., Zhao, H., Gewe, M., Adame, T., Perruzza, L., Bolick, D.T., Agosti, J., Khuong, N., Kuestner, R., Gamble, C., Cruickshank, K., Ferrara, J., Lim, R., Paddock, T., Brady, C., Ertel, S., Zhang, M., Pollock, A., Lee, J., Xiong, J., Tasch, M., Saveria, T., Doughty, D., Marshall, J., Carrieri, D., Goetsch, L., Dang, J., Sanjaya, N., Fletcher, D., Martinez, A., Kadis, B., Sigmar, K., Afreen, E., Nguyen, T., Randolph, A., Taber, A., Krzeszowski, A., Robinett, B., Volkin, D.B., Grassi, F., Guerrant, R., Takeuchi, R., Finrow, B., Behnke, C., Roberts, J., 2022. Development of spirulina for the manufacture and oral delivery of protein therapeutics. Nat. Biotechnol. 40 (6), 956–964. https://doi.org/10.1038/s41587-022-01249-7.
Jiang, L., Wang, B., Li, B., Wang, C., Luo, Y., 2014. Preparation and identification of peptides and their zinc complexes with antimicrobial activities from silver carp (Hypophthalmichthys molitrix) protein hydrolysates. Food Res. Int. 64, 91–98. https://doi.org/10.1016/j.foodres.2014.06.008.
Jouffray, J.B., Blasiak, R., Norström, A.V., Österblom, H., Nyström, M., 2020. The blue acceleration: the trajectory of human expansion into the ocean. One Earth 2, 43–54. https://doi.org/10.1016/j.oneear.2019.12.016.
Khan, N., Sudhakar, K., Mamat, R., 2021. Role of biofuels in energy transition, green economy and carbon neutrality. Sustainability 13 (22), 12374. https://doi.org/10.3390/su132212374.
Kim, S.-K., 2019. Essentials of marine biotechnology. Springer. https://doi.org/10.1007/978-3-030-20944-5.
Klassen, V., Blifernez-Klassen, O., Wobbe, L., Schlüter, A., Kruse, O., Mussgnug, J.H., 2016. Efficiency and biotechnological aspects of biogas production from microalgal substrates. J. Biotechnol. 234, 7–26. https://doi.org/10.1016/j.jbiotec.2016.07.015.
Klassen, V., Blifernez-Klassen, O., Wibberg, D., Winkler, A., Kalinowski, J., Posten, C., Kruse, O., 2017. Highly efficient methane generation from untreated microalgae biomass. Biotechnol. Biofuels 10 (1), 186. https://doi.org/10.1186/s13068-017-0871-4.
Koley, S., Mathimani, T., Bagchi, S.K., Sonkar, S., Mallick, N., 2019. Microalgal biodiesel production at outdoor open and polyhouse raceway pond cultivations: A case study with Scenedesmus accuminatus using low-cost farm fertilizer medium. Biomass Bioenergy 120, 156–165. https://doi.org/10.1016/j.biombioe.2018.11.002.
Konietzko, J., Das, A., Bocken, N., 2023. Towards regenerative business models: A necessary shift? Sustainable Production and Consumption 38, 372–388. https://doi.org/10.1016/j.spc.2023.04.014.
Kostidi, E., Lyridis, D., 2024. Social impact assessment of biofuel production for maritime and aviation sectors: a case study of a pilot biorefinery project. Frontiers in Energy Research 12. https://doi.org/10.3389/fenrg.2024.1454862.
Kumar, A., Singh, L.K., Ghosh, S., 2009. Bioconversion of lignocellulosic fraction of water-hyacinth (Eichhornia crassipes) hemicellulose acid hydrolysate to ethanol by Pichia stipitis. Bioresour. Technol. 100 (13), 3293–3297. https://doi.org/10.1016/j.biortech.2009.02.023.
Leong, H.Y., Chang, C.-K., Khoo, K.S., Chew, K.W., Chia, S.R., Lim, J.W., Chang, J.-S., Show, P.L., 2021. Waste biorefinery towards a sustainable circular bioeconomy: A solution to global issues. Biotechnol. Biofuels 14 (1), 87. https://doi.org/10.1186/s13068-021-01939-5.
Levac, D., Colquhoun, H., O'Brien, K.K., 2010. Scoping studies: advancing the methodology. Implement. Sci. 5, 1–9.
Ligtvoet, A., Maier, F., Doranova, A., Eaton, D.J.F., Guznajeva, T., Gallou, M.L., Saes, L., Sijtsma, L., Broek, B.v.d., Kals, J., Poelman, M.P., Zhechkov, R., 2019. Blue bioeconomy forum: roadmap for the blue bioeconomy. European Commission. https://doi.org/10.2826/613128.
Lüdeke-Freund, F., 2020. Sustainable entrepreneurship, innovation, and business models: integrative framework and propositions for future research. Bus. Strateg. Environ. 29, 665–681. https://doi.org/10.1002/bse.2396.
Lüdeke-Freund, F., Gold, S., Bocken, N., 2019. A review and typology of circular economy business model patterns. J. Ind. Ecol. 23 (1), 36–61. https://doi.org/10.1111/jiec.12763.
Lüdeke-Freund, F., Froese, T., Dembek, K., Rosati, F., Massa, L., 2024. What makes a business model sustainable? Activities, design themes, and value functions. Organ. Environ. 37 (2), 194–220. https://doi.org/10.1177/10860266241235212.
Lund, H., Skov, I.R., Thellufsen, J.Z., Sorknæs, P., Korberg, A.D., Chang, M., Mathiesen, B.V., Kany, M.S., 2022. The role of sustainable bioenergy in a fully decarbonised society. Renew. Energy 196, 195–203. https://doi.org/10.1016/j.renene.2022.06.026.
Madejón, E., Panettieri, M., Madejón, P., Pérez-de-Mora, A., 2022. Composting as sustainable managing option for seaweed blooms on recreational beaches. Waste and Biomass Valorization 13 (2), 863–875. https://doi.org/10.1007/s12649-021-01548-1.
Mahata, C., Das, P., Khan, S., Thaher, M.I.A., Abdul Quadir, M., Annamalai, S.N., Al Jabri, H., 2022. The potential of marine microalgae for the production of food, feed, and fuel (3F). Fermentation 8 (7), 316. https://doi.org/10.3390/fermentation8070316.
Maia, J.L.D., Cardoso, J.S., Mastrantonio, D., Bierhals, C.K., Moreira, J.B., Costa, J.A.V., Morais, M.G., 2020. Microalgae starch: A promising raw material for the bioethanol production. Int. J. Biol. Macromol. 165 (Part B), 2739–2749. https://doi.org/10.1016/j.ijbiomac.2020.10.159.
Mangi, S.C., Catchpole, T.L., 2014. Using discards not destined for human consumption. Environ. Conserv. 41 (3), 290–301. https://doi.org/10.1017/S0376892913000532.
Manlusoc, J.K., Hsieh, C.-L., Hsieh, C.-Y., Salac, E.S., Lee, Y.-T., Tsai, P.-W., 2019. Pharmacologic application potentials of sulfated polysaccharide from marine algae. Polymers 11 (7), 1163. https://doi.org/10.3390/polym11071163.
Mao, J., Fu, J., Zhu, Z., Cao, Z., Zhang, M., Yuan, Y., Chai, T., Chen, Y., 2023. Flavor characteristics of semi-dried yellow croaker (Pseudosciaena crocea) with KCl and ultrasound under sodium-reduced conditions before and after low temperature vacuum heating. Food Chem. 426, 136574. https://doi.org/10.1016/j.foodchem.2023.136574.
Marsol-Vall, A., Aitta, E., Guo, Z., Yang, B., 2022. Green technologies for production of oils rich in n-3 polyunsaturated fatty acids from aquatic sources. Crit. Rev. Food Sci. Nutr. 62 (11), 2942–2962. https://doi.org/10.1080/10408398.2020.1861426.
Martínez-Alvarez, O., Chamorro, S., Brenes, A., 2015. Protein hydrolysates from animal processing by-products as a source of bioactive molecules with interest in animal feeding: A review. Food Res. Int. 73, 204–212. https://doi.org/10.1016/j.foodres.2015.04.005.
Martínez-Vázquez, R.M., Milán-García, J., de Pablo Valenciano, J., 2021. Challenges of the blue economy: evidence and research trends. Environ. Sci. Eur. 33 (1). https://doi.org/10.1186/s12302-021-00502-1.
Mavuru, A., Mhlanga, L., Nhiwatiwa, T., 2022. An assessment of post-harvest fish losses (PHFLs) in the artisanal fishery of Lake Kariba, Zimbabwe. Scientific African 16, e01124. https://doi.org/10.1016/j.sciaf.2022.e01124.
Mizik, T., Gyarmati, G., 2021. Economic and sustainability of biodiesel production—a systematic literature review. Clean Technologies 3 (1), 19–36. https://doi.org/10.3390/cleantechnol3010002.
Mohamed, G.A., Ibrahim, S.R.M., 2021. Untapped potential of marine-associated cladosporium species: an overview on secondary metabolites, biotechnological relevance, and biological activities. Mar. Drugs 19 (11), 645. https://doi.org/10.3390/md19110645.
Monsiváis-Alonso, R., Mansouri, S.S., Román-Martínez, A., 2020. Life cycle assessment of intensified processes towards circular economy: Omega-3 production from waste fish oil. Chem. Eng. Process. Process Intensif. 158, 108171. https://doi.org/10.1016/j.cep.2020.108171.
Morales, M., Aflalo, C., Bernard, O., 2021. Microalgal lipids: A review of lipids potential and quantification for 95 phytoplankton species. Biomass Bioenergy 150, 106108. https://doi.org/10.1016/j.biombioe.2021.106108.
Mortensen, S., Dolmer, P., Strand, Å., Naustvoll, L.-J., Laugen, A.T., 2019. Policy brief: the Pacific oyster – a new Nordic food resource and a basis for tourism. Nordisk Ministerråd. https://doi.org/10.6027/Nord2019-015.
Mostafa, Y.S., Alrumman, S.A., Alamri, S.A., Otaif, K.A., Mostafa, M.S., Alfaify, A.M., 2020. Bioplastic (poly-3-hydroxybutyrate) production by the marine bacterium Pseudodonghicola xiamenensis through date syrup valorization and structural assessment of the biopolymer. Sci. Rep. 10 (1), 8815. https://doi.org/10.1038/s41598-020-65858-5.
Moya Moreira, T.F., Gonçalves, O.H., Leimann, F.V., Ribeiro, R.P., 2023. Fish Protein Hydrolysates: Bioactive Properties, Encapsulation and New Technologies for Enhancing Peptides Bioavailability. Curr. Pharm. Des. 29 (11), 824–836. https://doi.org/10.2174/1381612829666230110141811.
Mulazzani, L., Malorgio, G., 2017. Blue growth and ecosystem services. Mar. Policy 85, 17–24. https://doi.org/10.1016/j.marpol.2017.08.006.
Mutalipassi, M., Esposito, R., Ruocco, N., Viel, T., Costantini, M., Zupo, V., 2021. Bioactive compounds of nutraceutical value from fishery and aquaculture discards. Foods 10 (7), 1495. https://doi.org/10.3390/foods10071495.
Nagappan, S., Nakkeeran, E., 2020. Biorefinery: A concept for co-producing biofuel with value-added products. In: Gothandam, K., Ranjan, S., Dasgupta, N., Lichtfouse, E. (Eds.), *Environmental Biotechnology, Vol. 2. Environmental Chemistry for a Sustainable World* (Vol. 45, Pp. 23–52). Springer. https://doi.org/10.1007/978-3-030-38196-7_2.
Nagappan, S., Das, P., Abdul Quadir, M., Thaher, M., Khan, S., Mahata, C., Al-Jabri, H., Vatland, A.K., Kumar, G., 2021. Potential of microalgae as a sustainable feed ingredient for aquaculture. J. Biotechnol. 341, 1–20. https://doi.org/10.1016/j.jbiotec.2021.09.003.
Nasri, R., Younes, I., Jridi, M., Trigui, M., Bougatef, A., Nedjar-Arroume, N., Dhulster, P., Nasri, M., Karra-Châabouni, M., 2013. ACE inhibitory and antioxidative activities of goby (Zosterissessor ophiocephalus) fish protein hydrolysates: effect on meat lipid oxidation. Food Res. Int. 54 (1), 552–561. https://doi.org/10.1016/j.foodres.2013.07.001.
Nielsen, R., Hoff, A., Waldo, S., Hammarlund, C., Virtanen, J., 2019. Fishing for nutrients – economic effects of fisheries management targeting eutrophication in the Baltic Sea. Ecol. Econ. 160, 156–167. https://doi.org/10.1016/j.ecolecon.2019.02.013.
Niner, H.J., Barut, N.C., Baum, T., Diz, D., Laínez del Pozo, D., Laing, S., Lancaster, A.M.S.N., McQuaid, K.A., Mendo, T., Morgera, E., Maharaj, P.N., Okafor-Yarwood, I., Ortega-Cisneros, K., Warikandwa, T.V., Rees, S., 2022. Issues of context, capacity and scale: essential conditions and missing links for a sustainable blue economy. Environ. Sci. Pol. 130, 25–35. https://doi.org/10.1016/j.envsci.2022.01.001.
Nisticò, R., 2017. Aquatic-derived biomaterials for a sustainable future: A European opportunity. Resources 6 (4), 65. https://doi.org/10.3390/resources6040065.
OECD, 2016. The ocean economy in 2030. OECD Publishing. https://doi.org/10.1787/9789264251724-en.
Olin, A.B., Olsson, J., Eklöf, J.S., Eriksson, B.K., Kaljuste, O., Briekmane, L., Bergström, U., 2022. Increases of opportunistic species in response to ecosystem change: the case of the Baltic Sea three-spined stickleback. ICES J. Mar. Sci. 79 (5), 1419–1434. https://doi.org/10.1093/icesjms/fsac073.
de Oliveira, M.C., Bassin, I.D., Cammarota, M.C., 2022. Microalgae and cyanobacteria biomass pretreatment methods: A comparative analysis of chemical and thermochemical pretreatment methods aimed at methane production. Fermentation 8 (10), 497. https://doi.org/10.3390/fermentation8100497.
Onyeaka, H., Miri, T., Obileke, K., Hart, A., Anumudu, C., Al-Sharify, Z.T., 2021. Minimizing carbon footprint via microalgae as a biological capture. Carbon Capture Science & Technology 1, 100007. https://doi.org/10.1016/j.ccst.2021.100007.
Pan, F., El-Kashef, D.H., Kalscheuer, R., Mueller, W.E., Lee, J., Feldbruegge, M., Mandi, A., Kurtan, T., Liu, Z., Wu, W., 2020. Cladosins LO, new hybrid polyketides

from the endophytic fungus Cladosporium sphaerospermum WBS017. Eur. J. Med. Chem. 191, 112159. https://doi.org/10.1016/j.ejmech.2020.112159.

Papenfus, H.B., Kulkarni, M.G., Stirk, W.A., Finnie, J.F., Van Staden, J., 2013. Effect of a commercial seaweed extract (Kelpak®) and polyamines on nutrient-deprived (N, P and K) okra seedlings. Sci. Hortic. 151, 142–146. https://doi.org/10.1016/j.scienta.2012.12.022.

Pham, M.T., Rajić, A., Greig, J.D., Sargeant, J.M., Papadopoulos, A., McEwen, S.A., 2014. A scoping review of scoping reviews: advancing the approach and enhancing the consistency. Res. Synth. Methods 5 (4), 371–385. https://doi.org/10.1002/jrsm.1123.

Poblete-Castro, I., Hoffmann, S.-L., Becker, J., Wittmann, C., 2020. Cascaded valorization of seaweed using microbial cell factories. Curr. Opin. Biotechnol. 65, 102–113. https://doi.org/10.1016/j.copbio.2020.02.008.

Priefer, C., Jörissen, J., Frör, O., 2017. Pathways to shape the bioeconomy. Resources 6, 10. https://doi.org/10.3390/resources6010010.

Radziemska, M., Vaverková, M.D., Adamcová, D., Brtnický, M., Mazur, Z., 2019. Valorization of fish waste compost as a fertilizer for agricultural use. Waste Biomass Valoriz. 10 (9), 2537–2545. https://doi.org/10.1007/s12649-018-0288-8.

Rasmussen, R.S., Morrissey, M.T., 2007. Marine biotechnology for production of food ingredients. Adv. Food Nutr. Res. 52, 237–292. https://doi.org/10.1016/s1043-4526(06)52005-4.

Rischer, M., Lee, S.R., Eom, H.J., Park, H.B., Vollmers, J., Kaster, A.-K., Shin, Y.-H., Oh, D.-C., Kim, K.H., Beemelmanns, C., 2019. Spirocyclic cladosporicin A and cladosporiumins I and J from a Hydractinia-associated Cladosporium sphaerospermum SW67. Organic Chemistry Frontiers 6 (8), 1084–1093. https://doi.org/10.1039/c8qo01104d.

Rotter, A., Barbier, M., Bertoni, F., Bones, A.M., Cancela, M.L., Carlsson, J., Carvalho, M. F., Cegłowska, M., Chirivella-Martorell, J., Conk Dalay, M., Cueto, M., Dailianis, T., Deniz, I., Díaz-Marrero, A.R., Drakulovic, D., Dubnika, A., Edwards, C., Einarsson, H., Erdoğan, A., Vasquez, M.I., 2021. The essentials of marine biotechnology. Front. Mar. Sci. 8. https://doi.org/10.3389/fmars.2021.629629.

Rustad, T., Storrø, I., Slizyte, R., 2011. Possibilities for the utilisation of marine by-products. Int. J. Food Sci. Technol. 46 (10), 2001–2014. https://doi.org/10.1111/j.1365-2621.2011.02736.x.

Saadaoui, I., Rasheed, R., Aguilar, A., Cherif, M., Al Jabri, H., Sayadi, S., Manning, S.R., 2021. Microalgal-based feed: promising alternative feedstocks for livestock and poultry production. Journal of Animal Science and Biotechnology 12 (1), 76. https://doi.org/10.1186/s40104-021-00593-z.

Sagir, E., Alipour, S., 2021. Photofermentative hydrogen production by immobilized photosynthetic bacteria: Current perspectives and challenges. Renew. Sustain. Energy Rev. 141, 110796. https://doi.org/10.1016/j.rser.2021.110796.

Salvador, R., Puglieri, F.N., Halog, A., de Andrade, F.G., Piekarski, C.M., De Francisco, A. C., 2021. Key aspects for designing business models for a circular bioeconomy. J. Clean. Prod. 278, 124341. https://doi.org/10.1016/j.jclepro.2020.124341.

Sarker, P.K., Kapuscinski, A.R., Vandenberg, G.W., Proulx, E., Sitek, A.J., 2020. Towards sustainable and ocean-friendly aquafeeds: evaluating a fish-free feed for rainbow trout (Oncorhynchus mykiss) using three marine microalgae species. Elementa: Science of the Anthropocene 8, 5. https://doi.org/10.1525/elementa.404.

Schnepf, R., 2007. Agriculture-Based Renewable Energy Production, Report, October 16, 2007. Washington D.C. https://digital.library.unt.edu/ark:/67531/metadc811562/.

Shahidi, F., Ambigaipalan, P., 2015. Novel functional food ingredients from marine sources. Curr. Opin. Food Sci. 2, 123–129. https://doi.org/10.1016/j.cofs.2014.12.009.

Siddik, M.A.B., Howieson, J., Fotedar, R., Partridge, G.J., 2021. Enzymatic fish protein hydrolysates in finfish aquaculture: a review. Rev. Aquacult. 13 (1), 406–430. https://doi.org/10.1111/raq.12481.

Silva, F., Duarte, A.M., Mendes, S., Borges, P., Magalhães, E., Pinto, F.R., Barroso, S., Neves, A., Sequeira, V., Vieira, A.R., Magalhães, M.F., Rebelo, R., Assis, C., Gordo, L. S., Gil, M.M., 2020. Adding value to bycatch fish species captured in the Portuguese coast-development of new food products. Foods 10 (1), 68. https://doi.org/10.3390/foods10010068.

Šimat, V., 2021. Nutraceuticals and pharmaceuticals from marine fish and invertebrates. Mar. Drugs 19 (7), 401. https://doi.org/10.3390/md19070401.

Simtoe, A.P., Luvanga, S.A., Lugendo, B.R., 2022. Partial replacement of fishmeal with Chaetomorpha algae improves feed utilization, survival, biochemical composition, and fatty acids profile of farmed shrimp Penaeus monodon post larvae. Aquac. Int. https://doi.org/10.1007/s10499-022-01029-9.

Simtoe, A.P., Luvanga, S.A., Lugendo, B.R., 2023. Partial replacement of fishmeal with Chaetomorpha algae improves feed utilization, survival, biochemical composition, and fatty acids profile of farmed shrimp Penaeus monodon post larvae. Aquac. Int. 31, 1375–1388. https://doi.org/10.1007/s10499-022-01029-9.

Spalding, M.J., 2016. The new blue economy: the future of sustainability. Journal of ocean and coastal Economics 2 (2), 8. https://doi.org/10.15351/2373-8456.1052.

Stephenson, P.J., Damerell, A., 2022. Bioeconomy and circular economy approaches need to enhance the focus on biodiversity to achieve sustainability. Sustainability 14, 10643. https://doi.org/10.3390/su141710643.

Stincone, P., Brandelli, A., 2020. Marine bacteria as source of antimicrobial compounds. Crit. Rev. Biotechnol. 40 (3), 306–319. https://doi.org/10.1080/07388551.2019.1710457.

Stuart, K.R., Barrows, F.T., Silbernagel, C., Alfrey, K., Rotstein, D., Drawbridge, M.A., 2021. Complete replacement of fish oil and fish meal in the diet of juvenile California yellowtail Seriola dorsalis. Aquac. Res. 52 (2), 655–665. https://doi.org/10.1111/are.14923.

Tacon, A.G.J., Metian, M., Hasan, M.R., 2009. Feed ingredients and fertilizers for farmed aquatic animals: sources and composition. FAO Fisheries and Aquaculture Technical Paper. No. 540. Rome, FAO. 2009 209. https://www.fao.org/4/i1142e/i1142e.pdf.

Tashie-Lewis, B.C., Nnabuife, S.G., 2021. Hydrogen production, distribution, storage and power conversion in a hydrogen economy - A technology review. Chemical Engineering Journal Advances 8, 100172. https://doi.org/10.1016/j.ceja.2021.100172.

Tennakoon, P., Chandika, P., Yi, M., Jung, W.-K., 2023. Marine-derived biopolymers as potential bioplastics, an eco-friendly alternative. iScience 26 (4), 106404. https://doi.org/10.1016/j.isci.2023.106404.

Thomas, J.-B.E., Sodré Ribeiro, M., Potting, J., Cervin, G., Nylund, G.M., Olsson, J., Albers, E., Undeland, I., Pavia, H., Gröndahl, F., 2020. A comparative. Environmental life cycle assessment of hatchery, cultivation, and preservation of the kelp Saccharina latissima. ICES J. Mar. Sci. 78 (1), 451–467. https://doi.org/10.1093/icesjms/fsaa112.

Thomas, J.-B.E., Sinha, R., Strand, Å., Söderqvist, T., Stadmark, J., Franzén, F., Ingmansson, I., Gröndahl, F., Hasselström, L., 2022. Marine biomass for a circular blue-green bioeconomy?: A life cycle perspective on closing nitrogen and phosphorus land-marine loops. J. Ind. Ecol. 26 (6), 2136–2153. https://doi.org/10.1111/jiec.13177.

Thompson, F., Krüger, R., Thompson, C.C., Berlinck, R.G.S., Coutinho, R., Landell, M.F., Pavão, M., Mourão, P.A.S., Salles, A., Negri, N., Lopes, F.A.C., Freire, V., Macedo, A. J., Maraschin, M., Pérez, C.D., Pereira, R.C., Radis-Baptista, G., Rezende, R.P., Valenti, W.C., Abreu, P.C., 2018. Marine biotechnology in Brazil: recent developments and its potential for innovation. Front. Mar. Sci. 5. https://doi.org/10.3389/fmars.2018.00236.

Tigchelaar, M., Leape, J., Micheli, F., Allison, E.H., Basurto, X., Bennett, A., Bush, S.R., Cao, L., Cheung, W.W.L., Crona, B., DeClerck, F., Fanzo, J., Gelcich, S., Gephart, J.A., Golden, C.D., Halpern, B.S., Hicks, C.C., Jonell, M., Kishore, A., Koehn, J.Z., Little, D. C., Naylor, R.L., Phillips, M.J., Selig, E.R., Short, R.E., Sumaila, U.R., Thilsted, S.H., Troell, M., Wabnitz, C.C.C., 2022. The vital roles of blue foods in the global food system. Glob. Food Sec. 33, 100637. https://doi.org/10.1016/j.gfs.2022.100637.

Trang, N.T.H., Tang, D.Y.Y., Chew, K.W., Linh, N.T., Hoang, L.T., Cuong, N.T., Yen, H.T., Thao, N.T., Trung, N.T., Show, P.L., Tuyen, D.T., 2021. Discovery of α-glucosidase inhibitors from marine microorganisms: optimization of culture conditions and medium composition. Mol. Biotechnol. 63 (11), 1004–1015. https://doi.org/10.1007/s12033-021-00362-3.

Tzachor, A., Richards, C.E., Holt, L., 2021. Future foods for risk-resilient diets. Nature Food 2 (5), 326–329. https://doi.org/10.1038/s43016-021-00269-x.

Välimaa, A.-L., Mäkinen, S., Mattila, P., Marnila, P., Pihlanto, A., Mäki, M., Hiidenhovi, J., 2019. Fish and fish side streams are valuable sources of high-value components. Food Quality and Safety 3 (4), 209–226. https://doi.org/10.1093/fqsafe/fyz024.

Vázquez, J.A., Blanco, M., Massa, A.E., Amado, I.R., Pérez-Martín, R.I., 2017. Production of fish protein hydrolysates from scyliorhinus canicula discards with antihypertensive and antioxidant activities by enzymatic hydrolysis and mathematical optimization using response surface methodology. Mar. Drugs 15 (10), 306. https://doi.org/10.3390/md15100306.

Vázquez, J.A., Fraguas, J., Mirón, J., Valcárcel, J., Pérez-Martín, R.I., Antelo, L.T., 2020. Valorisation of fish discards assisted by enzymatic hydrolysis and microbial bioconversion: lab and pilot plant studies and preliminary sustainability evaluation. J. Clean. Prod. 246, 119027. https://doi.org/10.1016/j.jclepro.2019.119027.

Venugopal, V., 2022. Green processing of seafood waste biomass towards blue economy. Current Research in Environmental Sustainability 4, 100164. https://doi.org/10.1016/j.crsust.2022.100164.

Venugopalan, V.K., Gopakumar, L.R., Kumaran, A.K., Chatterjee, N.S., Soman, V., Peeralil, S., Mathew, S., McClements, D.J., Nagarajarao, R.C., 2021. Encapsulation and protection of Omega-3-rich fish oils using food-grade delivery systems. Foods 10 (7), 1566. https://doi.org/10.3390/foods10071566.

Veríssimo, N.V., Mussagy, C.U., Oshiro, A.A., Mendonça, C.M.N., Santos-Ebinuma, V.d. C., Pessoa, A., Oliveira, R.P.d.S., Pereira, J.F.B., 2021. From green to blue economy: marine biorefineries for a sustainable ocean-based economy. Green Chem. 23 (23), 9377–9400. https://doi.org/10.1039/D1GC03191K.

Vieira, H., Leal, M.C., Calado, R., 2020. Fifty shades of blue: how blue biotechnology is shaping the bioeconomy. Trends Biotechnol. 38 (9), 940–943. https://doi.org/10.1016/j.tibtech.2020.03.011.

Vincent, A., Stanley, A., Ring, J., 2020. Hidden champion of the ocean: Seaweed as a growth engine for a sustainable European future. https://www.seaweedeurope.com/wp-content/uploads/2020/10/Seaweed_for_Europe-Hidden_Champion_of_the_ocean-Report.pdf.

Wang, J., Qian, W., He, Y., Xiong, Y., Song, P., Wang, R.M., 2017. Reutilization of discarded biomass for preparing functional polymer materials. Waste Manag. 65, 11–21. https://doi.org/10.1016/j.wasman.2017.04.025.

Wang, J., Zhang, M., Fang, Z., 2019. Recent development in efficient processing technology for edible algae: A review. Trends Food Sci. Technol. 88, 251–259. https://doi.org/10.1016/j.tifs.2019.03.032.

Wang, L., Sun, J., Ding, S., Qi, B., 2018. Isolation and identification of novel antioxidant and antimicrobial oligopeptides from enzymatically hydrolyzed anchovy fish meal. Process Biochem. 74, 148–155. https://doi.org/10.1016/j.procbio.2018.08.021.

Wang, X., Zhang, Z., Zhang, S., Yang, F., Yang, M., Zhou, J., Hu, Z., Xu, X., Mao, G., Chen, G., Xiang, W., Sun, X., Xu, N., 2021. Antiaging compounds from marine organisms. Food Res. Int. 143, 110313. https://doi.org/10.1016/j.foodres.2021.110313.

Wang, X., Li, J., Shang, J., Bai, J., Wu, K., Liu, J., Yang, Z., Ou, H., Shao, L., 2022. Metabolites extracted from microorganisms as potential inhibitors of glycosidases (α-glucosidase and α-amylase): A review. Front. Microbiol. 13, 1050869. https://doi.org/10.3389/fmicb.2022.1050869.

Zabaniotou, A., 2018. Redesigning a bioenergy sector in EU in the transition to circular waste-based Bioeconomy-A multidisciplinary review. J. Clean. Prod. 177, 197–206. https://doi.org/10.1016/j.jclepro.2017.12.172.

Zabed, H., Sahu, J.N., Suely, A., Boyce, A.N., Faruq, G., 2017. Bioethanol production from renewable sources: Current perspectives and technological progress. Renew. Sustain. Energy Rev. 71, 475–501. https://doi.org/10.1016/j.rser.2016.12.076.

Zaky, A., French, C., Tucker, G., Du, C., 2020. Improving the productivity of bioethanol production using marine yeast and seawater-based media. Biomass Bioenergy 139, 105615. https://doi.org/10.1016/j.biombioe.2020.105615.

Zhang, F.-Z., Li, X.-M., Li, X., Yang, S.-Q., Meng, L.-H., Wang, B.-G., 2019a. Polyketides from the mangrove-derived endophytic fungus Cladosporium cladosporioides. Mar. Drugs 17 (5), 296. https://doi.org/10.3390/md17050296.

Zhang, J.J., Tang, X., Zhang, M., Nguyen, D., Moore, B.S., 2017. Broad-host-range expression reveals native and host regulatory elements that influence heterologous antibiotic production in gram-negative bacteria. mBio 8 (5). https://doi.org/10.1128/mBio.01291-17 e01291–01217.

Zhang, W., Yin, B., Xin, Y., Li, L., Ye, G., Wang, J., Shen, J., Cui, X., Yang, Q., 2019b. Preparation, mechanical properties, and biocompatibility of graphene oxide-reinforced chitin monofilament absorbable surgical sutures. Mar. Drugs 17 (4), 210. https://doi.org/10.3390/md17040210.

Zhang, X., Das, S., Li, A., Ma, Q., Tan, L., 2021. Editorial: marine microbes for contaminant bioremediation. Front. Microbiol. 12, 762968. https://doi.org/10.3389/fmicb.2021.762968.

Zheng, X., Juan, M., Kou, X., Gao, X., Liu, J., Li, S., Zheng, B., Liu, Y., Xue, Z., 2023. Investigation on the emulsification mechanism in aqueous enzymatic extraction of edible oil from Schizochytrium sp. J. Sci. Food Agric. 103 (6), 2904–2913. https://doi.org/10.1002/jsfa.12471.

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