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Review

Empowering blue economy: From underrated ecosystem to sustainable industry

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ABSTRACT

With increasing demand for resources to achieve global food-water-energy nexus and rapid decline in land-based sources, oceans represent both solution and boost to sustainable environment and economy. In addition to fundamental part of earth's ecosystem for uncatalogued diversity of life, oceans are undervalued economy powerhouse with gross marine product value. With sustainable management of existing assets including shipping, transportation, manufacturing, fisheries, tourism and exploration of new business like marine biotechnology and renewable energy, the ocean or blue economy has potential to fulfill sustainable development goals (SDG). In spite of recognition of blue economy as a new economic frontier, investments by existing industries and emergence of new ones are limited and less known, hence require more in depth attention and scientific understanding. In the present study, authors present a systematic comparative assessment of blue economy sectors with distinct challenges and strategies to be further explored and implemented for industrial deployment. The conceptualization of integrated routes of bio(economy) by the current study can act as gateway for key stakeholders, i.e. governance, bluepreneurs (scientists and industries) to prioritize technologies for sustainable applications of marine resources.

1. Introduction

The economic development based on finite resources like coal and related environmentally destructive activities is responsible for massive levels of climate change causing air pollution (greenhouse gas emissions), water pollution and loss of biodiversity. With these environmental concerns, the sustainability of this economic growth also known as "brown economy" is highly questioned and criticized (Sakhuja, 2015). To overcome these challenges, the concept "Green economy" was introduced in Rio+20 held in Rio de Janeiro, Brazil in June 2012 as low carbon, resource efficient and socially inclusive alternative (UNCSD et al., 2016). As per definition by multiple organizations like UNEP (United Nations Environmental Program), IUCN (International Union for Conservation of Nature) and UNCTAD (United Nations Conference on Trade and Development), green economy is premised on sustainable development (economic, social and environmental) which involves recycling of natural resources while reducing environmental risks and costs (Golden et al., 2017). Following this concept, many developing countries relied on expansion of agriculture to uplift the economic conditions but also remain partly successful due to increased environmental costs along with inequitable social welfare (Antikainen et al., 2016). The limitation of land-based agriculture to achieve global food production targets made researchers to look beyond green economy and realize the presence of another vast repository of natural resources, i.e. oceans (Bari, 2017; Dundas et al., 2020). In a synthesis report in 2012, UNEP initiated the consideration of "Green economy in Blue world" which stated the importance of marine environment as integral component for urgently needed paradigm shift in bioeconomy called as "blue economy" as coined by pacific Small Island Developing States (SIDS)(UNEP et al., 2012). By definition, blue economy is a systematic way of utilizing ocean resources by integration of short and long term economic activities based on principles of social inclusion, environmental sustainability and innovations on and around the sea (Smith-Godfrey, 2016; Spalding, 2016). Realizing the immense potential of

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oceans as major sink of atmospheric CO_2, rich biodiversity and energy source (wind, wave, tidal, thermal and biomass energy), the concept of blue economy is being accepted by many coastal countries to be implemented by ocean-based industries (Bennett et al., 2019). The opportunities of blue economy vary from country to country depending on whether it is terrestrial dominated or have more marine environment. The developing countries are most benefited by maritime transportation followed by coastal tourism which is one of the emerging sectors of blue economy (Wenhai et al., 2019). Another major economic sector is marine-based energy which currently fulfills the commercial energy requirement which is primarily relying on coal and petroleum and with minor input from natural gas, hydropower, and a few other sources (Hoerterer et al., 2020). However, the increasing gap between demand and supply with high CO_2 emissions of petroleum-based fuels demands supplementation of alternative sources like waves, tides and winds from coastal areas to fulfill the sustainable goal of blue economy. One of the major objectives for stepping from land to sea is to meet global food demand of a growing population by supply of sustainable food or feed, transportation/tourism facility, shipbuilding, oil and gas, seabed mining for mineral sources from the sea as it serves different sources of biological and non-biological raw materials (Costa et al., 2019; Kaşdoğan, 2020; Vigani, 2020). Despite promising blue economy potential of several marine products, the ultimate goal of industrialization is still facing challenges involving high risk investments and lack of coordination between public research and private investors (Bari, 2017).

The present review article explores the various resources available from blue economy and their potential for industrial opportunities by highlighting the market economics and challenges involved. This review charted down critical components of blue economy to be identified by researchers, industrialists and policy makers to lead the way towards an environmentally sustainable and socially equitable blue economy. Further sections of this review explains about the various opportunities involved in the new integrated conceptualizations with blue and green economies for the sustainable energy development.

2. Components of blue economy

Ocean is the natural source which covers two-third of the earth surface and support about 40% population lives near coastlines. In global history, natural resource exploitation has been proved as the foundation of economic development and trades at local, national and global scales in terms of food, energy and superhighway for global trades (recreation). Sea water and its related contributions towards global economy is significant. The estimates of the same could be as high as USD 2.5 trillion as gross marine products based on direct outputs (e.g. aquaculture, fishing), other services (tourism, education), transportations (e.g. coastal and oceanic shipping) and other related benefits (e.g. carbon sequestration, biotechnology) (Hoegh-Guldberg, 2015).

Ocean or seawater has significant role and impact on the overall health of the planet and its sustainable development. It supports all lives by generating oxygen, absorbing carbon dioxide, nutrient recycling and regulating global climate and temperature. Being the source of food and livelihood to the substantial portion of global population as well as tourism industries, oceans have potential to achieve major sustainable goals of eliminating hunger and poverty. Additionally, deep sea or seabed's are the excellent sources of hydrocarbons and mineral resources which provides 32% of the global supply (Bennett et al., 2019). The ocean also offers renewable or blue energy from wind, wave, tide and from thermal and biomass sources as well (Keen et al., 2018). There are multiple components which are contributing towards blue economy which can be categorized into biological and non-biological components (Fig. 1).

2.1. Biological components

In marine ecosystem, eukaryotic photosynthetic organisms belong to

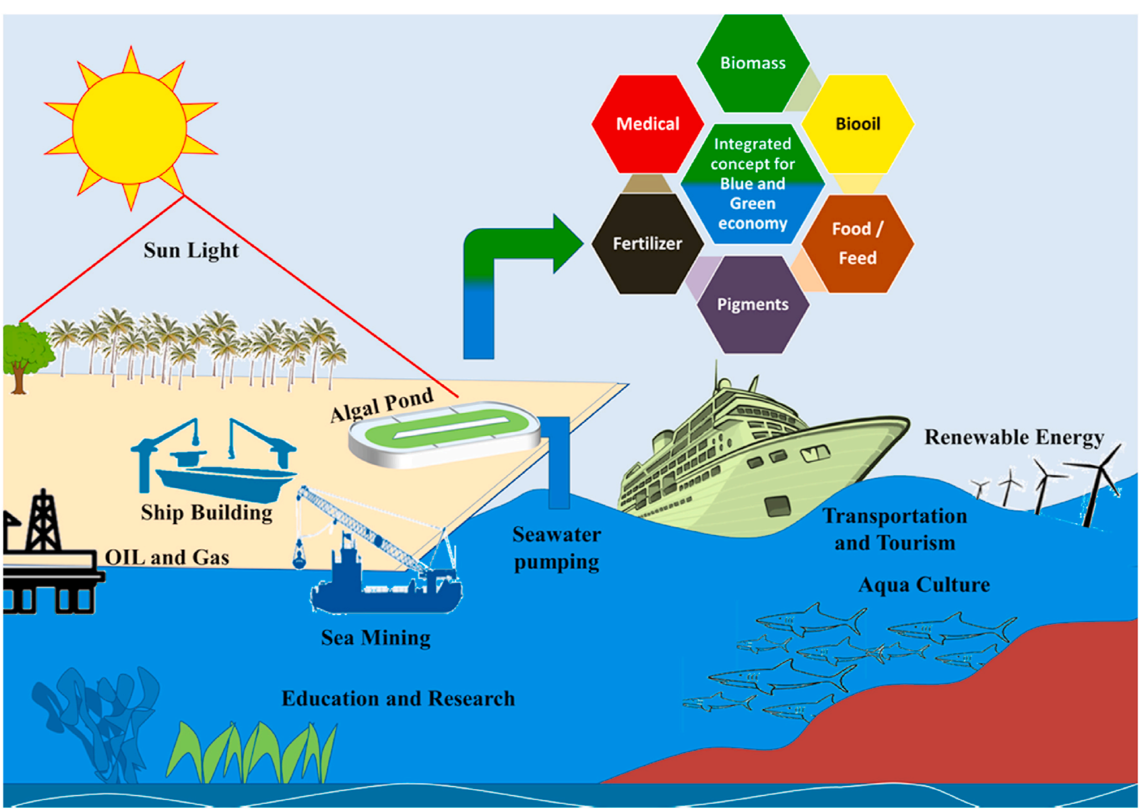

Fig. 1. Schematic of blue economy components (biological and non-biological) with potential bio-products. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

Table 1
Summary of global transdisciplinary projects of biological components of blue economy.

S.No.	Projects & Duration	Funding agency & scientific coordinators	Objectives	Reference
Microalgae				
1	FUEL4ME, FUture European League 4 Microalgal Energy (Jan 1, 2013–Dec 31, 2016)	European Union, FP7 Research Programme; Wageningen Food & Biobased Research, Wageningen University	To develop a sustainable, scalable process for biofuels from microalgae and to valorize the by-products by 2017	http://fuel4me.eu/
2	DEMA - Direct Ethanol from MicroAlgae (December 1, 2012–May 31, 2017) Grant agreement ID: 309086	FP7-ENERGY University of Limerick, Ireland,	Develop, demonstrate and licence a complete economically competitive technology for the direct production of bioethanol from microalgae with low-cost scalable photobioreactors by 2016.	https://cordis.europa.eu/project/id/309086
3	BISIGODOS November2013–April 30, 2017 Grant agreement ID: 613680	FP7-KBBE AIMPLAS - Asociacion De Investigacion DE materiales plasticos y conexas, Spain	Production of valuable algae-derived chemicals, amino acids and high added-value bio-resins, starting from algae biomass fed directly with CO2 from industrial emissions (cement, steel factory, thermal power plants, etc.) as a cost-effective and renewable raw material, a process assisted by solar radiation, nutrients and seawater microalgae	http://www.bisigodos.eu/
4	BIOFAT (Biofuels from Algae Technologies) 60 months	European Commission's Seventh Framework Program (FP7) Budget:10 M€ Department of Agriculture, Food and Environmental Sciences of the University of Florence (Italy)	Demonstration project for (i)Process optimization in two pilot scale facilities, each one-half hectare in size, located in Italy and Portugal; and (ii) Economical modeling and scale-up to a 10-ha demo facility	http://www.biofat-project.eu/
5	MED-ALGAE 36 months	European Union Alexandria University	Establishment of "The Mediterranean Regional Centre for Bioproduction" that will be established in Alexandria as a training centre, demonstration centre, workshop centre for the region and also one algae growth unit for biodiesel production will be hosted by this Centre.	https://med-algae.com/about/
Macroalgae				
1	SIMBA (Sustainable Innovation of Microbiome Applications in the Food System Nov 2018–Oct 2022	EU's Horizon 2020 programme; Natural Resources Institute Finland (Luke)	Identification of viable land and aquatic microbiomes that can assist in the sustainability of European agro- and aquaculture	https://simbaproject.eu/about/project-overview/
2	Seaweed Carbon Farming Project	Climate Works Foundation, San Francisco, CA and the Jeremy and Hannelore Grantham Environmental Trust, Boston, MA	To implement a step change in the scale up of seaweed aquaculture and set seaweed farming on track to sequester gigatons of carbon CO2, help to restore abundance to the ocean and create a new, socially just blue economy to help feed and power the world in a regenerative way	https://www.oceans2050.com/seaweed
3	Seaweed Cultivation	National Fisheries Development Board, Hyderabad, India CSIR-Central Salt Marine and Chemicals Research Institute (CSMCRI), Gujarat & Mandapam Regional Centre, Tamil Nadu	(i)Creation of livelihood opportunities for coastal populations under Blue Revolution Scheme (ii) Meet the ever increasing industrial demand for manufacture of Agar, Agarose, Carrageenan and Alginates from Seaweeds. (iii) Mass production of seed material for commercialization of the seaweed culture and conserving natural resources	https://nfdb.gov.in/NFDB-Projects
4	Macrofuels Jan 1, 2016–Dec 31, 2019 Grant agreement ID: 654010	Funded under H2020 EU.3.3.3.1 & H2020-EU.3.3.3.3. Teknologisk Institut, Denmark	To develop technology for the production of fuels from macroalgae or seaweeds which are suitable as liquid fuels or precursor thereof for the heavy transport sector as well as potentially for the aviation sector.	https://www.macrofuels.eu/
5	BAL-DuPont	DOE's Advanced Research Projects Agency-Energy (ARPA-E) Bio Architecture Lab DuPont and BAL	Development of a process to convert sugars produced by macroalgae into next-generation biofuels called isobutanol.	https://www.scientificamerican.com/article/seaweed-algae-du-pont-feedstock-biobutanol-biofuel/

micro and macroalgae (based on size) are the primary producers and provides habitat for the growth of many marine fauna (Eikeset et al., 2018). These organisms can live and perform photosynthesis from prehistoric (anoxic to oxygenic) to present carbon rich atmosphere and witnessed several climatic changes and have overcome many challenges. Marine algae and coastal ecosystems can fix the alarmingly increasing greenhouse gases (CO_2) through photosynthesis process are now termed as "blue carbon" fixation (Vigani, 2020) The stored energy can be converted into economically important products for multiple industries like food, feed, fuel and fertilizer. Table 1 summarizes few major projects undertaken for economic development of biological components.

2.1.1. Macroalgae

Macroalgae popularly known as seaweeds are multicellular and macroscopic autotrophs which are taxonomically categorized in three distinct groups based on their color of the thallus: Chlorophyta (green algae), Rhodophyta (red algae), and phaeophyta (brown algae). Like plants, macroalgae sustain several benthic animal communities as primary producers of the marine food chain and also have ecological role as bioindicators of water quality for bioremediation (Lourenço-Lopes et al., 2020).

The commercial seaweed farming involves either direct harvest of naturally available wild seaweeds or onshore and near shore cultivation. However, onshore macroalgae cultivation conflicts with other uses of coastal areas such as aquaculture, recreational activities, and other compatible activities such as wind energy production and direct harvesting leads to overexploitation of wild macroalgae varieties. In this context, offshore cultivation in sheltered areas and exposed coastal environments has been proposed and tested by researchers for biofuel and feed applications. However, the success of seaweed farming requires selection of suitable macroalgae, cultivation site, determination of physical and biological factors (light, temperature, nutrients and extreme currents) and the ability to withstand high waves in offshore waters. With global production of approximately USD 6 billion, it represents major component of ocean economy with applications ranging from molecule to whole plants as food, fuel, feed, fertilizer, pharmaceutical, nutraceuticals, cosmetics etc. (Horn, 2009). Among 200 commercially cultivated species, around 10 species are cultivated intensively for seaweed production. In terms of cultivation, *Saccharina japonica* accounts for 33%, followed by *Kappaphycus alvararezi* (17%) and remaining includes *Undaria pinnatifida, Porphyra* spp, *Sargassum fusiforme, Eucheuma, Gracilaria* spp, *Enteromorpha clathrata, Monsotroma nitidium and Caluerpa* spp.

2.1.2. Microalgae

Similar to macroalgae, the ocean is occupied with small microscopic microalgae. They are categorized into different classes (Chlorophyta (green algae), Rhodophyta (red algae), Bacillariophyta (diatoms) and prokaryotic Cyanophyta (Blue-green algae) based on their pigmentation, life cycle and cellular structure (Barra et al., 2014). Higher growth rate, use of non-agricultural land and production of different commercially important compounds are the advantages of microalgae cultivation (Bhushan et al., 2020). The composition of the microalgal biomass depends on several factors, such as nutrient concentrations, cultivation system, environmental conditions (temperature and light), agitation and pH (Mazzelli et al., 2020;(Choudhary et al., 2020a)). The microalgae industry uses two major cultivation systems viz. open raceway ponds (ORP) and closed photobioreactors (PBR) with the main microalgal species grown being *Chlorella* and *Spirulina* for health food, *Dunaliella salina* for β-carotene, *Haematococcus pluvialis* for astaxanthin and several other species for biofuels & chemicals (Khoo et al., 2019). The other commercially grown species include *Nannochloris, Nitzschia, Crypthecodinium, Schizochytrium, Tetraselmis, Skeletonema, Isochrysis* and *Chaetoceros.* ORPs are most preferred owing to its low energy consumption and cost of production over the other cultivation systems (Richardson et al., 2014). According to a study by Norsker et al. (2011), the production costs for a 100 ha facility is 4.95 and 5.96 € kg^{-1} of biomass for raceway ponds and PBRs, respectively. In spite of high costs, PBR are preferred for producing clean biomass for high value products as it offers advantage of greater control over cultivation condition and lower contamination as compared to ORP. Hence, the product of interest and its economic viability drives the selection of cultivation system for a microalgae farm. With the global market of USD 5.4 billion, around 7000t of dry algae is being produced as green feedstock for several applications like bioenergy, biofertilizers animal feed, human nutrition and bioplastics etc. (Acién et al., 2017; Kumari and Singh, 2019). With multiple use characteristics, microalgae can be used for resource recovery by coupling with wastewater treatment and CO_2 sequestration makes it suitable feedstock for a bio-based economy (Choudhary et al., 2017; Romero-Villegas et al., 2018).

2.2. Non-biological components

The non-biological components of blue economy are established sectors in comparison to biological ones. The efforts made in commercialization of these components are summarized in Table 2, including major projects sanctioned for non-biological economic sectors.

2.2.1. Minerals, metals and hydrocarbons

Deep sea oceans are the excellent sources of marine rare earth minerals including hydrocarbons, metals, oil and natural gas etc. Deep sea mining is considered as potential sector for promotion of blue economy. More than 70 minerals can be extracted from the deep oceans. Metals like sea floor massive sulphide deposits-copper, lead, zinc, gold, silver, manganese nodules, cobalt-rich ferromanganese crusts containing nickel, copper and cobalt, coupled with significant concentrations of rare-earth and other rare metals. In that case, the potential and performance of that sector remains underestimated. In addition, exploration of seabed resources requires permission of the International Seabed Authority (ISA) (Mohanty et al., 2015).

2.2.2. Marine tourism

Ocean is the primary base for beautiful landscapes and seascapes (e.g. beaches, islands, coral reefs, panoramic seascapes, marine parks, water-sports etc.) which led to bloom in tourism industries. Coastal and marine tourism is the significant share of the industry supporting more than 6.5 million employment with global growth rate of more than 3.5% (Brumbaugh and Patil, 2017). Coastal and marine tourism is expected to be the largest value-adding segment of the ocean economy (26%) by 2030 (Brumbaugh and Patil, 2017). Globally, many countries or regions like Southeast Asia, Caribbean's, Mexico, Indonesia, Australia, Maldives, and Mauritius have million-dollar reefs that generate more than one million dollars per square kilometre (Brumbaugh and Patil, 2017). Additionally, there are more than 70 such countries around the world thriving on their million-dollar industry as a contribution for the blue economy (Patil et al., 2016).

2.2.3. Shipping, port activities and marine manufacturing

Marine ports play significant role in many activities as far as marine transportation is concerned. Sea is the cost effective and more convenient mode of transportation contributing to 90% word trade (Mohanty et al., 2015). Many sophisticated technologies have improved the shipping efficiency which basically helped to sustain in the world seaborn trade (Mohanty et al., 2015). In international trade, about 50,000 merchant ships (container ships, bulk carriers, ferries and cruise ships) are engaged. As per 2013 published report, the size of the seaborne trade is about 9600 million tons (Mohanty et al., 2015). Dry cargo accounts for more than 70 %of the total volume of seaborne trade in the world. These include trade in bulk commodities such as iron ore, coal, grain, bauxite, aluminum, phosphate rock, containerized trade and general cargo (Mohanty et al., 2015). The sail making, manufacturing, maintenance, engineering, instrumentations etc. are few activities at dry docking

Table 2
Summary of global projects targeted non-biological components of blue economy.

S.No.	Projects & Duration	Site locations	Objectives	Reference
Oil and gas				
1.	Mars Oil & gas Field Project, 1996 continued to Mars B project in 2014	Gulf of Mexico, US(Shell & BP)	Mars oil field development	https://www.offshore-technology.com/projects/marshttps://www.shell.com/about-us/major-projects/mars-b
2	Block KG-D6 Integrated Development, Bay of Bengal; 2020–2022	Krishna-Godavari basin of the Bay of Bengal, India (Reliance Industries and BP)	Aim to develop Offshore gas field; Develop approximately 3 trillion cubic feet (tcf) of gas and produce 30–35 million cubic metres (1bcf) of gas per day for the domestic market.	https://www.nsenergybusiness.com/projects/kg-d6-block-integrated-development/
3	Buffalo Oil Field Redevelopment, Timor Sea, 2016	Timor-Leste (Carnarvon Petroleum)	Oil and gas field redevelopment	https://www.offshore-technology.com/projects/buffalo-oil-and-gas-field-redevelopment
Marine renewable energy production				
1.	Hornsea1; 2010 Walney Extension East Anglia ONE	Horse sea Zone, North Sea, UK; Orsted and Global Infrastructure Partners.	Generate renewable electricity	https://www.power-technology.com/projects/hornsea-project-one-north-sea/
2.	Gode Wind farms, Germany, 2017	Germany; Orsted	Offshore renewable Power generation	https://www.power-technology.com/projects/gode-wind-1-and-2-offshore-wind-farms/
3.	Dhofar Wind Power Project	Oman; Abu Dhabi-based renewable energy major Masdar and financed by the Abu Dhabi Fund for Development (ADFD)	To generate adequate electricity, eliminate 110,000 tonnes of carbon dioxide emissions, and reduce power generation on natural gas	https://masdar.ae/en/masdar-clean-energy/projects/dhofar-wind-project https://renewablesnow.com/news/
4.	Muppandal wind farms; 2007	Tamil Nadu; Tamil Nadu Energy Development Agency	Reduce India's reliance on fossil fuels, in addition to reducing emissions	https://www.power-technology.com/projects/tamilnaduwind/
Seabed mining				
1.	SPC-EU Deep Sea Minerals Project, 2011	Pacific Community (SPC) and the European Union (EU)	To improve the governance and management of their deep-sea minerals resources	https://dsm.gsd.spc.int/https://sustainabledevelopment.un.org/partnership/
2.	Solwara 1; 2005	Papua New Guinea; Nautilus Minerals	Extract high-grade Seafloor Massive Sulphide (SMS) deposits of copper, gold, zinc and silver	https://www.mining-technology.com/projects/solwara-project/
Port activities				
1	Sagarmala Project; 2015–2035	Ministry of Ports, India	Port modernization & new port development, port connectivity enhancement, port-linked industrialization and coastal community development	http://sagarmala.gov.in/
2	West Side Modernization project 2011–2022	Canada; Port Saint John, the Government of Canada and the Province of New Brunswick	Port modernization	https://www.sjport.com/port-modernization-project-well-underway/, https://atlanticbusinessmagazine.net/article/west-side-modernization-project-positions-port-saint-john-for-global-growth/
Tourism				
1	Gili Lankanfushi and the Coral Line Project, Maldives, 2014	Maldives	Strengthen the regeneration of coral reefs.	https://www.greenpearls.com/green-projects/coral-lines-project/ https://www.wanderlust.co.uk/content/costa-rica-sensational-and-sustainable/
2	Climate Projects Juist	Juist, Germany	Tourism is created for sustainability	https://www.greenpearls.com/green-projects/climate-project-juist/

centers at respective port areas which can generate blue economy (Table 2).

2.2.4. Renewable energy

The world population is expected to increase to an estimated 9 billion people in 2050, which is 1.5 times greater than the current population, resulting in an increase in global demands of fossil fuels (Mohanty et al., 2015). However, to reduce this burden on fossil fuels and to meet this huge demand in future renewable energy from natural resources is mandatory as an alternative source. Currently, there are traditional ways of trading or marine transportation where ships or cargos are depending on fuels. Moreover, there are more than 50,000 ships running on fuels around the world, which are creating many environmental problems (Mohanty et al., 2015). In this context, clean and low-carbon options in terms of renewable energy are the great opportunities. It's critical and practical need for renewable energy through natural resources (e.g. Sun or solar energy, wind, waves, tides, currents, as well as thermal and salinity gradients). Since, these are natural and abundant resources which can be utilized profusely however it requires innovations and advanced technologies for implementation (Table 2).

2.2.5. Marine research and development

Research and development and innovative approaches in any industrial sector is the fundamental pillars for the sustainable growth. Globally, there are many government and private maritime institutes, research and development centers, Innovation academies, universities, which are looking after many aspects related to oceans e.g. Centre for Maritime research and Experimentation (CMRE), Intergovernmental oceanographic commissions, International Maritime Organization (IMO), International Council for exploration of the Sea etc. Their research and advanced innovations are supporting the sustainable growth in the marine and maritime sectors which are helping for the blue economy evolutions efficiently.

3. Industrial potential of different marine resources

Developing a sustainable and equitable blue economy relies on the identification of components and their commercialization potential, based on market demand and economic state of the country. Despite numerous R & D efforts in marine biotechnology, the transfer of knowledge from fundamental research into technically realizable and cost-effective products and technologies is still limited. Hence, further sections explore comprehensive analysis of both biological and non-biological components of blue economy in context of applications in different industrial sectors and their technical challenges.

3.1. Potential of ocean bio market

3.1.1. Macroalgae

Islands and countries with coastal lines rich in marine flora and fauna (Exclusive Economic Zone) are considered as potential market for blue economy. Unlike other forms of aquaculture, seaweed farming has unique characteristics of short grow out cycles, minimum technological and capital requirements and grow without fertilizers (Leandro et al., 2020). Given these advantages, seaweed farming is considered as potential livelihood strategy with significant socio-economic benefits to marginalized coastal communities in developing countries. From ecological point of view, seaweed farming is an ecofriendly activity to conserve natural populations of concerned seaweeds which additionally provides continuous supply of uniform quality raw materials for seaweed industry (Garcia-Vaquero et al., 2017). Mariculture of macroalgae is also considered as major tool to treat coastal pollution in the sea and reduce CO_2 in global warming. However, seaweed economy was affected by many factors such as over exploitation of wild natural resources, more demand-less supply, devastating cyclones, lack of training and market awareness, lack of technology to improve processed product quality and poor cultivation practices, and limited research on novel and alternative sources of raw materials. In order to make large scale production of macroalgae (phyconomy) to be economically and environmentally sustainable, Hurtado et al. (2019) suggested responsible expansion of farming areas to improve productivity per unit area. It should be accompanied with use of improved quality and diversity of seedling and increased investment in research and innovative approaches such as multitrophic aquaculture. Kappaphycus and Eucheuma, the two related genera of red seaweeds known collectively as 'eucheumatoids', are current global phyconomy leaders which uses three major types of cultivation practices: single rope floating raft method (SRFR), fixed bottom long line method (FBLL) and integrated multi trophic aquaculture (IMTA) method (Vigani, 2020). While single rope technology is followed in wide area and greater depth, the floating raft technology is suitable for agarophyte cultivation. The investment in seaweed farming varies with area and cultivation practice for instance 2500 m^2 requires US$~500 for fixed bottom method) and US$~1000 for raft longline method. With the given investment, the net farm income varies from USD 565 crop−1 (fixed off-bottom method) to USD 739 crop−1 (raft long-line and annual 2 crops method) (Samonte, 2017) With 141–201% high rate of return on investment (ROI) and less than a year payback period, seaweed farming can be main source of household income and hence indicates major scope of expansion by both private- and public-sector value-chain players. Seaweed farming has long history of large-scale cultivation with low cost technologies and high returns helps to improve the gross domestic product (GDP) and foreign exchange as witnessed by China, Indonesia, Philippines and Zanzibar (Tanzania). In order to valorize the seaweed farming, government should frame the integrated coastal zone management policy and organize the buyer and seller sectors which can create a value chain from farm to market for sustainable production (Neish and Suryanarayan, 2017).

Global market categorizes the seaweeds mainly into three type namely edible seaweeds, dried seaweeds and hydrocolloids like agar and carrageenans. Global seaweed industry produces ~12 million tonnes of seaweeds per annum worth of US$ 6 billion (FAO, 2018). China is a major cultivator (50.1%) of seaweeds, followed by Indonesia (34.6%), Philippines (5.8%) Republic of Korea (4.2%) and remaining rest of world (5%) (Sadhukhan et al., 2019). With bio-refinery approaches, few pharmaceutical, nutraceutical and cosmetics industries have successfully valorized the seaweeds for multiple products as summarized in Table 3. Further section explores the industrial value of these seaweeds in detail.

3.1.1.1. Polysaccharides. Polysaccharides are integral part of macroalgal cell wall which helps to sustain in the harsh sea environment. Ulvans isolated from green algae, agar, carrageenans, porphyrans from red algae, and fucoidan, laminarin, ascophyllan from brown algae are the major polysaccharides obtained from seaweeds. Carrageenans and agar are the cost drivers of global phycocolloids industry owing to their diverse applications in many industries. Apart from emulsifier and stabilizing agent, carrageenan is used as food additives in dairy products (e.g. yoghurts, flavoured milkshakes, flans, jellies, ice creams, and beers) and meat products (e.g. hams) Carrageenan and semi-refined carrageenan extracted from *Kappaphycus* (170,000–200,000 MT dwt) and *Eucheuma* (40,000–45,000 MT dwt\) are majorly marketed from Indonesia and Philippines with price ranging from US$ 6 to 15/kg based on purity and demand (Campbell and Hotchkiss, 2017; Pereira, 2020). According to report by Campbell and Hotchkiss (2017), the global carrageenan market is expected to cross US$1 billion by 2024. Similar to carrageenan, agar also has gelling properties and majorly used as thickener in food products and a vegetarian substitute for gelatine. Extracted from red algal species like *Gelidium* sp., *Gracilaria* sp. and *Pterocladiella* sp., agar is gaining industrial interest as alternative sustainable and biodegradable biomaterial for packaging to replace

Table 3
Summary of biological components of blue economy including products, applications and key global industries.

Sources	Products	Companies	Applications	Reference
Macroalgae				
Ascophyllum nodosum	Seaweed extract	Acadian Seaplants Limited, Canada	Fertilizers	www.acadianplanthealth.com,)
Gigartina, Chondrus Iridaea, Eucheuma	Carrageenan	Cargill.US	Food, personal care and pharma	www.cargill.com,)
Kelp and other seaweeds	Alginic acid, food grade algin, carrageenan, agar, Seaweed plant hollow capsule, seaweed strips	Qingdao Gather Great Ocean Algae Industry Group CO., LTD, China	Food, feed, fertilizer and pharmaceuticals	https://en.judayang.com/,)(High, 2020)
Brown and red seaweeds	Protanal, Alginates Viscarin, Gelcarin, Lactarin, Lactogel Carrageenan	DuPont, US Gelymar S.A, Santiago, Chile	Food, dairy, nondairy-beverages, bakery fillings	(www.dupont.com/now/sustainable-seaweed (360 market updates, 2020)
Chondrus Crispus, Lamanaria, Digitata, Wakame	Fresh or dried	Irish seaweeds, UK	Food, High fibre Food rich in iodine, vitamins, fucoxanthin	https://irishseaweed.co.uk/,
Ascopharm, Algovert, Sea Spaghetti, Calseapowder, Dulse, Lichen, sea lettuce	Ingredients or finished product	Roullier Groupe, France	Food, Pet food, plant nutrition, Cosmetics	https://www.roullier.com/en/activities/algology, 2021)
Mixture of Red, brown and green seaweed	Dry powder	Ocean Harvest technology limited, Ireland	Pet food	OceanFeed™ Pet, 2021)
Microalgae				
Spirulina	Powder, Tablets, Capsules, Flakes, Liquid, Phycocyanin Extract	Yunnan Green A Biological Project Co., Ltd, China, Earthrise Nutritionals, Llc USA, Zhejiang Comp Spirulina Co., Ltd. China, E.I.D. – Parry Limited, India Cyanotech Corporation, USA,	Nutraceuticals, Food and Beverages, Pharmaceuticals, Cosmetic, Personal Care, Animal Feed, Agriculture,	https://meticulousblog.org/, 2020 Kunsel and Sumant (2019)
Chlorella	Powder, Tablets, Capsules, Liquid	Sun Chlorella Corporation, Japan E.I.D. Parry Limited, India Taiwan Chlorella Manufacturing Company, Taiwan Fuqing King Dnarmsa Spirulina, China Tianjin Norland Biotech Co., Ltd. China	Functional Food & Beverages, Nutraceuticals & Health Supplement, Pharmaceuticals, Personal Care, Animal Feed	(/www.marketdataforecast.com/,)
Haematococcus	Astaxanthin (Oleoresin) in the form of Capsules, Tablets, Oil, Softgel	Cyanotech Corporation, USA E.I.D. Parry Limited, India BlueBioTech International GmbH, Germany Algatechnologies Ltd. Israel AlgaeCan Biotech Ltd. Canada	Functional Food and Beverages, Nutraceuticals, Pharmaceuticals, Cosmetics	(grand view research, 2020) (Zion Market Research Report, 2020a)
Dunaliella	Powder, Extracted beta-carotene	Seagrass Tech Private Limited, India Plankton Australia Pty Ltd, Australia Hangzhou OuQi Food co., Ltd., China Monzón Biotech S.L., Spain A4F – Algafuel S.A., Portugal	Food and Beverages, Feed, Nutraceutical & Health Supplement, Pharmaceuticals, Cosmetics	(Grand view research, 2016) (Zion Market Research Report, 2020a)
Nannochloropsis	Powder, Liquid Extract, Oil (EPA & DHA)	Yantai Hairong Biology Technology Co. Ltd., China Cellana, LLC, USA Clean Algae, SL, Spain Necton, Portugal Qualitas Health, Israel	Food Feed Nutraceutical & Health Supplement, Pharmaceuticals Agriculture	(contrivedatuminsights, 2020)
Aquaculture & Fisheries				
Fish, Crustaceans (crabs, lobsters, crayfish, shrimps, prawns	Crustaceans, Trout, Tilapia, Finfish, seabass, salmon, mollu	Pentair plc.,US AKVA Group,Norway Luxsol Belgium Pioneer Group (Taiwan), FREA Aquaculture Solutions, Denmark	Equipment, Chemicals, Pharmaceuticals, Fertilizers	(The World bank, 2013) (FAO, 2020) (www.adroitmarketresearch.com, .)

plastics. Another gelling agent extracted from brown seaweeds (eg. *Laminaria* sp., *Macrocystis* sp.,*Lessonia* sp., *Ascophyllum* sp.,) is alginate which is commonly used in spherification process either with calcium lactate or calcium chloride for molecular cooking. With these attributes, the blue economy potential is expected to be USD 214.98 million for agar market, USD 923.8 million for alginate market and USD 38 million by for fucoidan market by 2025 (360 market updates, 2020; Grand view research, 2020). According to this study, over the next five years the laminarin market might register a 8.7% CAGR in terms of revenue and can escalate the global market size up to US$ 2 million by 2024 (All market Insights, 2019).

3.1.1.2. Edible seaweeds. Seaweeds are rich in macro, micro-nutrients especially iodine, vitamins and high amount of fiber, essential amino acids, proteins and low calories food. Many Asian and African countries consumes seaweeds either as staple food or as an ingredient in preparation of variety of food and coastal cuisines. China, Republic of Korea and Japan are top players in growing edible seaweeds and harvests 5 million, 0.8 million and 0.6 million wet tons per annum respectively (Table 3). Top 3 commercially successful edible seaweeds are *Porphyra* (Nori), *S. japonica* (Kombu) and *U. pinnatifida (*Wakame) available @ US $ 16000/dry tonne,US$ 2800/dry tonne, and US$ 6900/dry tonne, respectively (Ferdouse et al., 2018). Authors reported that 40% of global seaweed production is for human consumption and hence supports the food security and reduce the pressure on land based agricultural products (Ferdouse et al., 2018). Price of the edible seaweeds vary based on country of origin and quality. Additionally, seaweeds tend to accumulate heavy metals hence requires strict cultivation practices in compliances with coastal management policy and clean environmental conditional to be followed during seaweed farming (Froehlich et al., 2019; Yong et al., 2017). In addition, edible seaweeds or its extract is being used as fertilizer and also as traditional or folk medicine in many countries (Nayar and Bott, 2014).

3.1.1.3. Dried seaweeds. Dried seaweeds used as food and for extraction of phycocolloids have a shelf life of 12 months. China is the major importer of dried seaweeds and emerged as price setter in global market. In 2016, China has imported 250 ktonnes of dried seaweeds for their use and exported from countries like Indonesia, Philippines, Malaysia and Chile which generates substantial amount of revenues and foreign exchange (Table 3).

3.1.2. Microalgae

Microalgae forms the integral part of the ocean ecosystem; and its derived products contributes as pioneer building blocks of blue economy concept. With 146 companies worldwide, microalgae biorefinery is gaining global attention due to high demand of algal biomass for food and feed ingredients, nutraceuticals, cosmetics, high-value chemicals and biomaterials (Choudhary et al., 2020b; Rajak et al., 2020). Global bio-refinery product market is estimated to accrue revenue worth nearly USD 855.16 Billion by 2026 with CAGR of about 9.3% from 2020 to 2026 (Zion Market Research Report, 2020a). Under an integrated strategy in the frame of biorefineries, the market potential of microalgae as blue economy component is reviewed and sectioned in different industries are summarized in Table 3 and discussed below:

3.1.2.1. Biofuels industry. Microalgae biomass can produce carbon neutral biofuels namely biodiesel, biogas, bioethanol and bio-hydrogen through different conversion processes like gasification, pyrolysis, liquefaction, anaerobic digestion and transesterification (Vieira de Mendonça et al., 2021). Global algae biofuel market was valued at approximately USD 4.70 billion in 2017 and is expected to generate revenue of around USD 9.88 billion by end of 2024, growing at a CAGR of around 8.6% between 2017 and 2024 (Zion Market Research Report, 2018a).

3.1.2.2. Food and feed industry. Microalgae as food reported long back and recently available in the form of powder, flour, tablets, capsules and liquids (Enamala et al., 2020). Owing to their varied chemical properties, they can act as a nutritional supplement and a source of natural food colorants (Mehta et al., 2018). The microalgae food market is mainly dominated by *Spirulina, Chlorella, Nanochloropsis, Hematococcus, Dunaliella* etc (Camacho et al., 2019). Most of these algae used in human food and nutrition because of its high protein, lipid, pigment content which makes them excellent options over conventional sources (Torres-Tiji et al., 2020). Most of the algae producers sell a wide variety of nutraceuticals made from these microalgae, such pure powder, tablets, oil and liquid extract (Vigani, 2020). In addition to its use in human food, microalgae found to be used in feed for a wide variety of animals such as fish, pets, poultry and farm animals (Bleakley and Hayes, 2017). Essentially, 30% of the current world algal production and over 50% of the *Spirulina* production being used for animal feed applications (Camacho et al., 2019). The main objective of using microalgae for aquaculture is due to its high nutritional value and provide natural fresh coloring to the flesh. Also microalgae mainly required for mollusks, shrimp and fish as direct consumption (Morales et al., 2020). The most commonly used species for feed are *Spirulina, Chlorella, Tetraselmis, Isochrysis, Phaeodactylum, Chaetoceros, Nannochloropsis, Skeletonema* and *Thalassiosira*. The nutritional and toxicological evaluations has proved to be positively affecting the physiology, improve immune response, fertility and external appearance in animals fed with microalgae supplement. In poultry feed it was recorded that the algae replaced conventional protein source by 5–10% and proved to be safe for animal consumption (Wayne et al., 2017a).

3.1.2.3. Nutraceutical industry. Microalgal proteins mainly used to formulate food supplements in the form of whole biomass or and hydrolyzed to improve nutritional deficiencies in the people. The hydrolyzed protein from biomass with bioactive peptides offers higher digestibility, and these bio-peptides have demonstrated various biological activities such as antioxidant, antimicrobial, antihypertensive, antitumor and antidiabetic activities beneficial to the human body (Samarakoon and Jeon, 2012). Recently, amino acid composition of microalgal proteins engrossed the attention of the nutraceutical industry, not only due to presence of all the essential amino acids but also due to its higher bioavailability (Bleakley and Hayes, 2017). The algae protein market accounted for USD 650 Million in 2018 and is expected to reach USD 1043.8 Million by 2026, growing at a CAGR of around 6.1% between 2019 and 2026 (Kunsel and Sumant, 2019).

Microalgae lipids have huge commercial interest mainly due to presence of omega 3 and 6 polyunsaturated fatty acids (PUFAs) such as eicosapentaenoic (EPA), docosahexanoic (DHA) and gamma linolenic (GLA) (Katiyar and Arora, 2020). These PUFAs provide benefit in reduction of complications in cardiovascular effusions, arthritis, and hypertension; however, they cannot be synthesized by humans (Lupette and Benning, 2020). They are mainly used as a source of essential fatty acids in the human food supplements and for the fortification of animal feed (Pratiwy and Pratiwi, 2020). According to Zion Market Research Global report (2020a) and grand view research (2020) the algae and plant (fish-Free) Omega 3 ingredients market growing at a CAGR of around 6.1% between 2019 and 2026. The global Algae Oil market, which hit the revenue of 2.1 (USD Billion) in 2019 and is set to accrue earnings worth 5.2 (USD Billion) by 2026, is slated to register a CAGR of nearly 4% over 2020–2026.

Microalgae pigments namely chlorophylls, carotenes, phycobiliproteins (c-phycocyanin, allophycocyanin and phycoerythrin) and astaxanthin are responsible for several health benefits, such as anti-inflammatory, antihypertensive, anticancer, antioxidant, antidepressant, and antiaging (Jacob-Lopes et al., 2019); however, their other applications are in natural food colorants and cosmetics (Marino et al., 2020). Additionally, astaxanthin and β-carotene have experienced a strong and ever growing market of USD 1710.6 Million in 2019, and is expected to generate revenue of around USD 2273.9 Million by end of 2026, at a CAGR of around 4.15% from 2020 to 2026 (Grand view research, 2016; Zion Market Research Report, 2020b). The strict regulations for the application of synthetic dyes in the food industry has motivated studies aimed at the development and use of microalgal pigments as a food additive (Hosseini et al., 2020). Microalgae are also rich sources of different vitamins and several algal strains such as *Haslea ostrearia, P. cruentum, D. salina* etc. are rich source of vit E (tocopherols), vit C, vit A (β-carotene), pyridoxine, nicotinic acid, thiamine, riboflavin and biotin are researched for commercialization (Wayne et al., 2017b).

3.1.2.4. Biopolymers or Bioplastic industry. Microalgae are able to produce biopolymers also known as bioplastic, which accumulate inside cells when grown with excess carbon sources and solar energy and limited nutrients (N&P) (Özçimen et al., 2017).

Microalgae, specifically cyanobacteria synthesize PHA and accumulated inside the cell as insoluble granules (Didem et el 2017). PHB poly-(hydroxybutyrate) is type of PHA and found abundantly as homopolymer of hydroxybutyrate in several cyanobacteria such as *Spirulina* sp., *Aphanothece* sp., *Gloeothece* sp., *Synechococcus* sp. *Synechocystis* sp, *Gloeocapsa* sp, *Phormidium* sp. etc. (Balaji et al., 2013; Wu et al., 2001; Gopi et al., 2014). Microalgae derived biopolymers have many useful applications in field of medical, pharmaceutical and food industries as novel materials (Morais et al., 2016; Cavalheiro et al., 2012). Zion Market Research Report (2018b), reported that the global biopolymer market is estimated to reach up to USD 35.47 billion in 2022, at a CAGR of 12.5% from year 2017–2022.

Considering the role of blue economy in the Sustainable Development Goals of the United Nations; microalgae is and will continue to play very vital role owing to its humongous potential to produce natural and sustainable bio-products for the wellbeing of human and nature (Pant et al., 2019). However, considering the rich biodiversity of microalgae, only limited number of strains are well explored for their potential in commercial and biotechnological applications. This may be owing to fewer studies regarding growth characterization and cultivation optimization in outdoor environment, less attempts to improve algae cultivation systems, and overall no economic feasibility. To overcome these challenges, more strains need to be explored including genetic improvement of strains and need to further improve algae production systems for its more competitiveness and economic feasibility. For multiproduct biorefinery approach, extensive study on different cultivations such as heterotrophic, mixotrophic cultivation can be tried to get more productivity of the bio-products(Choudhary et al., 2020b) . In recent time, the high cost of operation is a major challenge for the industrial-scale microalgae biorefinery; which can be overcome by cultivating algae using CO_2 from refinery, seawater or wastewater from industrial effluents ((López-Pacheco et al., 2021;

3.1.3. Potential of other biological sources

3.1.3.1. Fisheries and aquaculture. Marine resources have wide coastal and marine regions with a wide variety of biodiversity including shrimps, fishes, crabs, seaweeds, molluscs, mammals, etc. Marine based aquaculture is mainly with *Penaeus monodon* (tiger shrimp) and at limited scale with *Scylla serrata* (soft shell crab) and major export is being presently dominated by frozen shrimp and live mud carb. As compared to inland capture of culture fisheries, marine capture fisheries are insufficient. But under blue economy, marine fisheries and aquaculture sector are extremely promising with the other sectors of oceangoing resources (Yates et al., 2015). The potentials and opportunities of coastal aquaculture and non-traditional marine species culture have been discussed in detail as below:

3.1.3.1.1. Marine Fisheries. Large industrial fishery (Trawl fishery) contributes 14.2%; *i.e.* 0.084 million tonnes (DoF, 2016) of total marine production. Large trawlers are used for mostly penaeid shrimps and finfish fishing within the depth of 40–100 m (Hussain and Rahman, 2010). In particular for marine capture fisheries, countries must come out of the traditional fishing practices and harness the fishing potentials (moving beyond the existing fishing grounds) to harvest large pelagic fishes from deeper zones and even up to the high seas.

For harvesting of large pelagic fish i.e. tuna and tuna like species, countries should have to adopt appropriate deep-sea fishing technologies i.e. long line and hook fishing and using supporting gears and vessels. Similarly, 50–60% of global hilsa catch takes place in the coastal and marine waters of Bangladesh 20–25% in Myanmar, 15–20% in India and the remaining 5–10% in other countries (Hossain et al., 2014). Similarly, harvesting of gravid mother shrimp, *P. monodon* by trawling at the depth of 10–40 m of inshore marine waters. This will certainly conserve the tiger shrimp brood stocks, which will ultimately be used at onshore shrimp hatcheries to support seeds for shrimp farming at the coastal farms.

3.1.3.1.2. Marine aquaculture. Tremendous success achieved in aqua cultivation of species like carps, tilapias, catfishes (*Pangasius* and Asian catfish) and climbing perch is due to innovation and development of artificial breeding techniques and various aquaculture technologies. There are many opportunities for brackish and aquaculture fish species culturing. For example, 4000–6000 kg/ha/crop of shrimp production can be achieved from 60 to 230 kg/ha/crop by adopting semi-intensive farming methods (Hossain et al., 2014). Breeding and farming of sea bass, *Lates calcarifer*, is initiated as an important high value aquaculture species. If artificial breeding and seed production techniques are evolved, then land based farming at onshore and cage culture at offshore locations can be expanded. Similarly, artificial breeding and farming technologies can be evolved and implemented for fish species (brackish and marine) viz. mullets, pomfrets, grouper, marine eel etc.

3.1.3.2. Non-traditional Marine species cultivation. The mariculture of non-traditional marine living species including seaweed, macro algae, mussel, oyster and other shellfish (edible oysters, *Crassostrea* sp. *Saccostrea* sp, pearl oyster, *Anadra* sp. green mussel, *Perna viridis*, clam, *Meretrix meretrix*, *Marcia opima*, sea snails), sea urchin, sea cucumber etc. is another less explored sector for its economic potential. Selection of suitable species and extraction of useful compounds could be performed by screening, isolation and characterization through the biotechnological tools. Similarly, mussel, Oyster, other shellfish, sea urchin, and sea cucumber etc. living habitat can also be explored in costal segments. The application of marine invertebrates is used in many developing countries to produce pharmaceuticals in cancer treatment.

3.1.3.3. Marine Biotechnology. Marine biotechnology is an application of scientific and engineering principles in marine biological agents for goods and services (novel pharmaceutical drugs, chemical products, enzymes and other industrial products and processes) from oceanic biological sources in biomaterials, health care diagnostics, fisheries and aquaculture, sea food safety, bioremediation and biofueling sectors (Thakur and Thakur, 2006; Zilinskas et al., 1995).

3.1.3.4. Carbon sequestration - mangrove forests. The process of carbon sequestration (i.e. several decades and centuries) by mangrove forests, intertidal saltmarshes and seagrass beds of the coastal habitats is owing to their ability to fix carbon and the stored carbon often referred to as blue carbon (Carr et al., 2018). These habitats can fix carbon at higher rate (four times higher than mature tropical forests) per unit area than land-based systems and are more effective in sequestration of carbon in long term. These coastal communities, the mangroves, saltmarsh and seagrass ecosystems are very operative at sequestering and storing carbon (Chowdhury et al., 2015).

3.2. Potential of non-biological components of ocean

3.2.1. Oil and gas

Within the maritime territory, there are several rich oil and gas reserves, which needs to be explored and exploited. In view of harnessing and identifying more potential oil and gas reserves, a logical plan and framework needs to be established by the concerned ministry of the government (Hodgson et al., 2019). Based on that a thorough survey needs to be conducted and international companies should be appointed to accelerate offshore exploration of future energy security (Table 4). In this public and private partnerships are to be encouraged in data and information, monitoring with best practices as well (www.oilandgasiq.com, n. d.).

Table 4
Summary of non-biological components of blue economy including products, applications and key global industries.

Sources	Products	Companies & Countries	Applications	Reference
Oil & Gas	Petrochemicals,Oil, LNG	Sinopec, China Saudi Aramco, Saudi Arabia Royal Dutch Shell, UK-Netherlands BP, UK	Exploration and Production of oil & gas for refining purposes, Refined products from fuel to chemicals through downstream processes for myriad of industries	(www.oilandgasiq.com, n.d)
Marine renewable energy production	Wind energy, Wave energy, Tidal energy, Ocean current energy, Ocean thermal energy conversion (OTEC)	Orsted, Denmark PNE AG, German Vattenfall, Sweden Next Era Energy, USA	Renewable Power generation – Electrical and Mechanical	(https://worldoceanreview.com, n.d.)
Seabed Mining	Cobalt, Gold, Diamonds, Polymetallic nodules and sulphides	Deep Green, Canada De Beers Group Beijing Pioneer Hi-Tech Development Corporation, China Neptune Minerals, USA/Australia	To generate metals from polymetallic rocks to produce high tech applications, renewable energy, Jewelry market.	Miller et al. (2018) (www.theoxygenproject.com, n.d.)
Sea salt	Salt	SaltWorks, USA INFOSA, Spain Tata Salt, India	Food & Service Industry, Agriculture, Cosmetic and Animal feed industries	(www.marketwatch.com, n.d)
Ship building & repair	Shipbuilding and repairs, commercial and military	Hyundai Heavy Industries, South Korea Samsung Heavy Industry, South Korea Fincantieri S.p.A., Italy JSC united ship Building Corporation, Russia	Production of vessels for merchant fleet and military. Offshore development facilities like, fixed platforms, TLPs, and Semi-Submersibles	Menon (2021)
Port Activities	Logistic and infrastructure activities	PSA International, Singapore Hutchison Port Holdings (HPH), China Dubai Ports World (DPW), Dubai AP Møller Terminals, Netherlands	Global Supply chain; cargo logistics, port terminal operations, maritime services and free trade zones	(Network, 2021)
Tourism	Travel and tourism	MSC cruises, Switzerland Carnival Corporation, USA Genting Hong Kong, Hong Kong Royal Caribbean, USA	Travel and Recreational activities	(www.decisiondatabases.com, 2020)

3.2.1.1. Minerals mining. Besides the exploration of oil and gas resources, there are promising potentials of deposits of marine minerals from deep sea mining at the seabed areas belonging to the categories like i) polymetallic sulphides; ii) ferromanganese crusts and nodules; and iv) rate earth elements e.g. Yttrium etc. They differ in composition, shape and location. The exploration of entire coastal have contributed in discovery of potentially valuable minerals such as rutile, zircon, leucoxene, ilmenite, garnet, kyanite, monazite and magnetite etc. (Alam, 2004; Childs and Hicks, 2019; Miller et al., 2018). This natural capital of mineral exploration could be converted into jobs, infrastructure, public service improvements and growth in the domestic private sector (Table 4). According to Kung et al. (2021) coming future has brought accelerating utilization of marine minerals resources with potential scientific and economic benefits. To accelerate the mining of mineral under blue economy, it is extremely essential to update the potential and then proceeded to way forwards for expansion even to the onshore, offshore and deep-sea minerals mining.

3.2.1.2. Marine - renewable Energy production. Marine wind, wave, solar radiation, tide, water currents etc. are the naturally available energy sources and could be utilized as renewable alternative for electric power generated from conventional sources and provides tremendous opportunities (Table 4). In this sector, necessary plans and strategies needs to be formulated with respective ministries/departments and subsequently implement at the coastal belt. Further efforts are required to install the wind turbines or any other hydro-electric infrastructures to connect the generated power lines from the transmission grids with the suitable offshore areas.

3.2.1.3. Sea salt. The production of common salt, i.e. Sodium chloride (NaCl) by evaporating marine waters is a traditional ancient practice throughout the world. The salt reserves in entire oceans have already been estimated over 50 million billion tones and these source cover over 50% of the world production (Mannar and Bradley, 1984). Most of the salt farms are small-scale, using manually operated local equipment and lease the land leading to the lesser yield in the salt production. Enhanced salt production can be achieved by community-focused land leasing systems and use of mechanical equipment (water pump, leveler, etc.) and reliable weather forecasting. Moreover, some of the countries like Europe and North America are using modern techniques in collecting and refining in salt mining.

3.2.1.4. Marine trade, shipping and tourism. Worldwide global trade is mostly handled and rotated by coastal ports and seaborne transportations. This is about 80% of global trade by volume, and over 70% by value is carried by sea and handled by ports. In the developing countries, on a national basis, these percentages are typically higher (Alam, 2014). Marine tourism could be one of the important sources of income in world and it is one of the five top export earners (Menon, 2021). There are plenty of opportunities in onshore and offshore coastal areas like capital investment in coastal tourism. In this connection, countries like Maldives, Malaysia, Myanmar and Thailand are good examples in learning the lessons in costal tourism(www.marketwatch.com, n.d.). The costal tourism at onshore and offshore coastal locations will be attractive with the medium sized luxury cruise and catamaran ships and construction of modern hotels, cottages and restaurants at the tourist spots (Table 4). The costal tourism has the scope of additional business of rich and middle-class people and jobs for hundreds and thousands of job seekers in different categories(www. decisiondatabases.com, 2020).

4. Comparison of market potential of different blue economy sources

Economic activities that directly or indirectly take place in the ocean and use outputs from the ocean, while incorporating goods and services into the ocean's economic activities corresponds to Ocean economy. Marine ecosystems and industrial activity form two support system of the whole ocean based industries (Park and Kildow, 2014). Ocean economy has customized definition and sectors in different countries around the world. Browsing through numerous activities across the globe we can broadly categorize these into different sectors as discussed in section 2 which again change depending on the country. Many have tried to redefine and give structure to these sectors (Park and Kildow, 2014). OECD has estimated an increase of value added by ocean economy from USD 1.5 trillion in 2010 to USD 3 trillion in 2030 (OECD, 2016). Adapting various scenarios may impact these values, for example sustainable scenario with high economic growth low environment degradation and developing resource efficient & climate friendly technologies resulted a value of USD 3.2 trillion. However, with unsustainable scenario it is around 2.8 million and this difference in value will also grow with technology and time (Fig. 2). Market size contribution to this $3 trillion economy from specific sectors and industries have been calculated and estimated for future prediction and trends. Fig. 2 summarizes the sectors and related activities comparing all the sectors along with estimated market size. Biological sectors contribute majorly in food industry, serving as world's largest protein source for 3 billion people along with employing directly or indirectly around 200 million people (FAO, 2011). With advancement in research, major ocean flora and fauna species are now being explored as substitute for chemicals and energy. Few of these raw materials and products exclusively can be produced by marine algae. Several macro and micro-algal species provides us with a wide range of chemicals for cosmetics, food ingredients, and fertilizers. With wide range of products and a food source as such, seaweed industry is estimated to have an annual value of USD 7 billion (FAO, 2011). Studies on algae for producing renewable energy in the form of bio-crude, electricity and hydrogen are on-going. Ocean economy as can be seen from the above market products and market size is a fast growing economy and OECD predicts that it will outpace global economic growth within 15 years (OECD, 2016). This predicted growth is at the expense of marine ecosystem and biodiversity and a great deal of effort has to be made in order to develop oceans potential without compromising these resources.

4.1. *Challenges for blue world economy*

Major research of the blue economy management is based on a sustainable development and conceptual framework to assess sustainable market. The growth blue economy requires joint efforts to achieve sustainable development in marine ecosystem which is closely linked to blue growth. The concept of growth in blue economy for sustainable development increase multidisciplinary research especially on the main challenges associated with it. There are many challenges involved in various disciplines of Blue economy.

Fisheries and aquaculture contribute enormously towards food and nutrition sector, however some forms of aquaculture add environmental pressures on already suffering, which include habitat destruction, effluent discharge, disease and escapes, and high use of fishmeal and oil in feeds (Coppa et al., 2021). Carbon emissions by the direct and indirect use of fossil fuels in production systems and the conversion of land that is high in sequestered carbon such as mangroves, sea grass or forest areas into aquaculture production is another challenge to be addressed (FAO, 2018). The main pressure on the shipping industry, from the environmental perspective, is prevention of pollution of the oceans and coastlines which can arise from different sources including: oil, chemical and liquefied gases in bulk; anti-fouling systems; dangerous goods in bulk

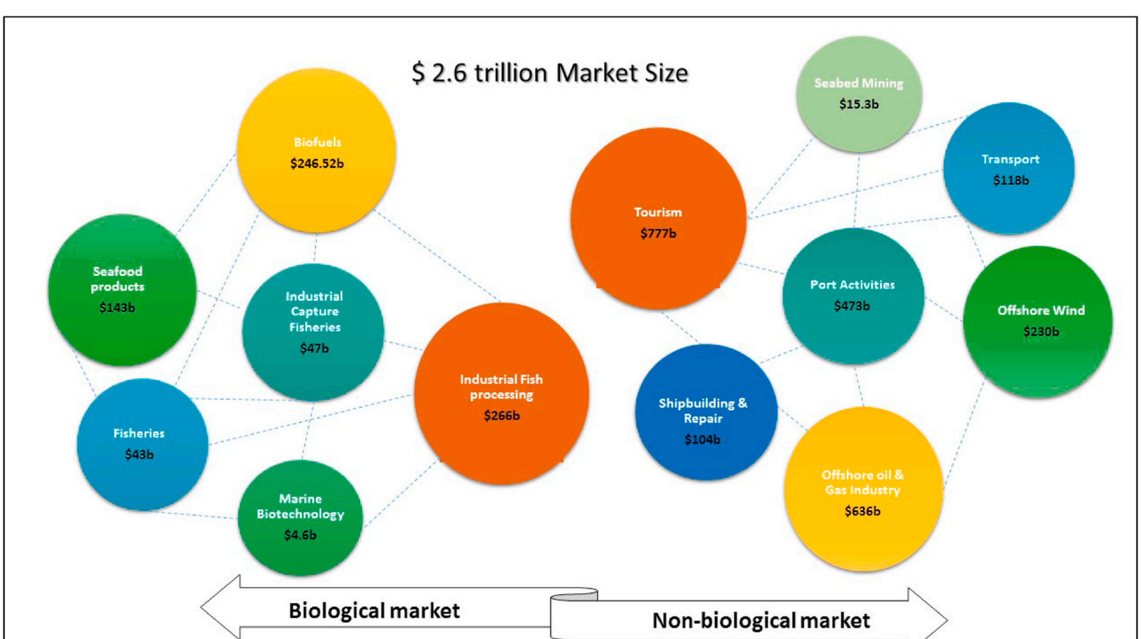

Fig. 2. Comparative representation of biological and non-biological market potential of blue economy. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

and packaged form; sewage; garbage; bio-fouling engine exhaust (including sulphur, nitrous oxides and carbon dioxide); Cargo vapour emissions; Chlorofluorocarbons (CFCs); and Noise.

Being in infancy stage and lack of maturity in wave and tidal energy technologies, there are limited information on GHG emissions or life cycle assessments from marine energy technologies leading to uncertainties for commercial deployment (Amponsah et al., 2014). Few of other uncertain threats of these energy systems include noise pollution from construction, loss of habitats for various life forms; migration barriers for birds, sea turtles and whales; changes in seabed from oil spills, sedimentation and change in estuarine water flow.

Coastal tourism is a major contributor to emissions of greenhouse gases and thus climate change. Construction and development have resulted in destruction of coastal wet lands, dune complexes, and mangroves – decreasing the biodiversity and hence decreasing carbon sequestration, pollution of land, and water from discharge from various sources. Balancing environmental aspects of blue world economy needs to be focused on to overcome consequences like extensive ecosystem destruction and thus permanent damage to livelihood. These aspects economically and industrially play a major key role for the sustainable development of the energy yields from all the types of economics including blue, green and brown. Among all the integration of the energy sources from blue and green economical regions may create good sustainable opportunities in industry and environment perspective as discussed in following section.

5. Opportunities of integrated blue economy routes

Blue economy follows circular economy approach and ensures no waste by using an ecological support, mimicking the biological ecosystem and enhancing productivity in each sector of the economy (Venkata Mohan et al., 2020). However, implementation and development of blue economy intersects land –sea ecosystem boundaries which raises urgency for revaluating marine and land environment economic relationships Fig. 1. The extensive literature study suggested that linking blue economy to the UN Sustainable development goals (SDG) is even more challenging when there are potential conflicts between industrial goals and socio-environmental sustainability. Achieving 17 goals of SDG requires global change in economic strategies by multi-stakeholder agreement among countries and government. In this context, this section is focused on selection of important drivers of blue economy growth which could lead towards integrated routes to reach SDG.

(i) Innovations towards greening blue economy

In order to achieve sustainable blue economy, one of the key driver is coastal urbanisation and conservation which requires introduction of innovative strategies to minimize pollution and loss of biodiversity Fig. 3. Enabling low impact and fuel-efficient fishing methods; to improve the efficiency of fishing industry is one of the initiatives. From improving the design of the vessel (from body to engine), to maintenance, to reducing the speed; in order to reduce consumption and pollution are few adopted actions. Along with these, attempts can be made to use biofuels, having less harmful impact on the environment. Reduction in energy use and implementing greener refrigeration technologies with improved waste management in fish handling, processing and transportation, can significantly reduce negative impacts on the biodiversity and environment due to GHG emissions (Lee et al., 2020) as per requirement of SDG 7 and 13. One such endeavour towards renewable energy by CARICOM (Caribbean community) in Bonaire where 12 wind turbines with a total of 11 MW of wind power capacity were constructed. In this case, the price of electricity in Bonaire dropped from US$0.50 per kWh to US$0.22 per kWh (Patil et al., 2016).

Design and implementation of various programs in aquaculture and fisheries to practice sustainable management of natural resources and biodiversity with the local community can create livelihood for the locals as well as boost up the national economy without loss of biodiversity fulfilling SDG goals 1, 5 and 8 Fig. 3. Many programs focus on supporting women and sustain their daily livelihood like Try Association was such program for oyster harvesting females; in Gambia (United

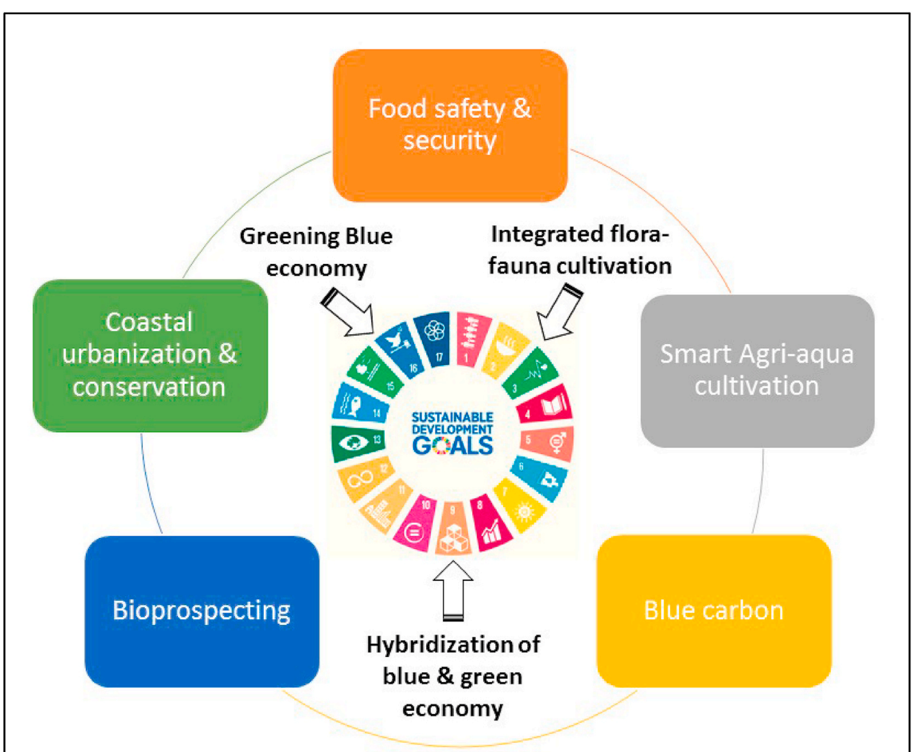

Fig. 3. Conceptualization of integrated bio-economy routes with suitable drivers of growth to achieve SDGs.

Nations Development Programme, 2013). Another program in Australia use shellfish aquaculture as a means of getting rid of excessive nutrients and at same time producing food for the growing population, can be used to counter negative environmental impact of industries nearby by hybrid economy concept (Wenhai et al., 2019).

The market potential of macro-algae is huge with its increased demand as food; component of food, cosmetic and medicine indicates bioprospecting as another important driving agent. As current packaging coatings are based on petrochemical derived waxes and polymers, the food packaging sector is dwelling into alternative reliable and sustainable coating product (European Commission, 2014). PLANTPACK project is involved in developing eco-friendly food package coating product made from seaweed extracts and starch, which will be applied to paper and cardboard in the form of a spray (European Commission, 2014). Other projects to develop medicine and flavor ingredients from seaweeds are being spawned throughout the globe. Benefits of seaweed farming are highly economical if done pertinently and serve as major carbon sinks for the coast carbon cycle indicating blue carbon as backbone of sustainable blue economy (Fig. 3).

(ii) Hybridization of green and blue economy

Introducing and hybridizing green economy measures to the ocean economy for improving the current and future economic and societal values of the oceans could be novel approach to address key ocean economy challenges. A demo project called "The Macro-algae Biorefinery" funded by Danish Strategic Research Council (Innovation fund), proposed off shore macro-algae cultivation by utilizing land-based emissions of air and surface water (Seghetta et al., 2016a). With expansion of bio-based production, the concept indicated scope to restore climate balance through circular resource management by hybrid economy. In a comparative life cycle assessment of *Saccharina latissima* for 208 km^2 area off shore cultivation with average productivity of 150 mg/km^2,researchers reported net reduction in aquatic eutrophication levels of 32.29 kg N eq. and 16.58 kg $PO4_3$−eq. per mg (dry weight) of seaweed for bio-fertilizer and bio-waste system, respectively (Seghetta et al., 2016b). With expansion of current biorefinery for extraction of multiple products like bioethanol, liquid fertilizer and protein-rich ingredient for fish feed, this sea grown crop can be potential resource on the green market in agriculture. Similar to the above project multiple-product bio-refinery technologies for production of high value specialties could be possible by coupled agriculture-aquaculture innovations Fig. 1. Implementing principles of green economy to overcome all the challenges in various ocean based sectors has further brought ocean economy towards sustainability. With further improvement in policies and increased research towards blue economy, this amalgamation of green economy with ocean economy can ensure increase in economic development along with environmental and social developments Fig. 3. Additionally, studies and projects aimed to improve the understanding of carbon sequestration in coastal and marine ecosystems are required to identify options for the incorporation of hybrid economy into policy and management for sustainable ecosystems preserved for future generations.

(iii) Integrated cultivation of marine flora and fauna: A Novel biological blue market

In sea (blue) environment, all biological organisms live together harmoniously and depends on each other for their food and habitat. Over exploitation of this natural resources affect the nature which eventually affect sustainability of market. Farming of non-competitive and economically important micro-macro algae together can increase the value of both biomass with overall reduction in cost of land, cultivation practices and processes. During downstream processing, for instance, lipid and protein rich microalgae can be extracted along with carbohydrate and mineral rich macro algae and then isolation of cell wall, liquid bio fertilizers, stimulants will be a(n) unique blend of biorefinery approach and also serve as raw material for many industries. In addition, seaweeds like *Gracilaria* and *Ulva* species were cultivated in raceway ponds with paddle wheel to support abalone (Sea snail) production in South Africa (FAO, 2018). Integrated farming of micro and macro algae in raceway ponds will support the aquaculture system year around and will valorize the blue economy. Additionally the industrialization of integrated cultivation of macroalgae and microalgae can be used to generate highly potent bioactive compounds for treatment of infectious diseases. For example, griffithsin extracted from *Griffithsia* and sulphated polysaccharides derived from *Saccharina japonica* have antiviral properties against retrovirus iodine rich *Sarconema* and *Asparagopsis taxiformis* to control goiter are few seaweed based pharmacological products which can be valorized for revenue generation (Kwon et al., 2020; Lusvarghi and Bewley, 2016). In another way, integration of microalgae or macro algae with carnivorous fishes or other aquatic animals will double the income of sea farmers and could support the SDG 15 appropriately (Ahmad Ansari et al., 2020).

6. Conclusion & recommendations

The scope for business activities including industrial expansion on and around the sea are enormous. Aquaculture, fisheries, minerals extraction, medical or pharma industry, transportation and tourism are some of the long known business endeavors on and around the sea. Moreover, biological blue economy market involving marine organisms like microalgae and macroalgae requires more attention to achieve profitable commercialization. Apart from individual development for biofuel, feed etc., productions, coupling of two or more biological components (e.g microalgae + macroalgae) can create multiple product chain which needs to be explored by coastal industries to build resilience of ocean ecosystems as a whole Exploiting blue economy reservoirs for green economy and developing green economy in the blue world economy thus will bring best of both worlds, utilizing marine resources for world economic development, without exploiting the environment. This paper highlighted challenges of green and blue economy and presented integrated routes to meet economic gap under the sustainable environment and economic equity in relation to the UN's SDGs. To achieve the sustainable targets, multi government commitment with developed financial innovations is required for integrating ocean and terrestrial solutions into a comprehensive climate change policy. The above scenario will be helpful to yield higher economic growth than traditional investments for the environment under sustainable development and due to this the greenhouse gas emissions will be fall by one third from the current levels. This study provides preliminary framework intended to explore research and economic opportunities of ocean economy. Based on enormous scope for bridging green and blue economy, the study recommend to explore (i) smart innovations in coupled terrestrial-marine cultivation (ii) realistic approach to operationalise marine renewable energy (iii) aligning socio-environmental goals with coastal urbanization (iv) efficient infrastructure for bioprospecting unexplored marine biodiversity. The review encourage the execution of transdisciplinary projects for sustainable use of ocean by industries, scientists and local communities and promote pragmatic approach to meet sustainable development goals.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

360 market updates, 2020. Fucoidan market will revenue to cross USD 38 million in 2020 to 2025 research by business opportunities, top companies report covers, globally market-specific challenges, new opportunities planning, consumption by regional data [WWW document], 360 Mark. Updat. URL. https://primefeed.in/news/3711022/fucoidan-market-will-revenue-to-cross-usd-38-million-in-2020-to-2025-research-by-business-opportunities-top-companies-report-covers-globally-market-specific-challenges-new-opportunities-planning-c/. accessed 12.23.20.

Acién, F.G., Molina, E., Fernández-Sevilla, J.M., Barbosa, M., Gouveia, L., Sepúlveda, C., Bazaes, J., Arbib, Z., 2017. Economics of microalgae production. In: Microalgae-Based Biofuels and Bioproducts: from Feedstock Cultivation to End-Products. Elsevier, pp. 485–503. https://doi.org/10.1016/B978-0-08-101023-5.00020-0.

Ahmad Ansari, F., Nasr, M., Guldhe, A., Kumar Gupta, S., Rawat, I., Bux, F., 2020. Techno-economic feasibility of algal aquaculture via fish and biodiesel production pathways: a commercial-scale application. Sci. Total Environ. 704, 135259. https://doi.org/10.1016/j.scitotenv.2019.135259.

Alam, M.K., 2004. Bangladesh's Maritime Challenges in the 21st Century. Pathak Shamabesh.

Alam, M.K., 2014. Ocean/blue economy for Bangladesh. MAU, MOFA 1–13.

All market Insights, 2019. Global Laminarin Market Growth 2019-2024 [WWW Document]. All Mark. Insights. URL. accessed 12.23.20. https://www.allmarketinsights.com/report/global-laminarin-market-growth-2019-2024.

Amponsah, N.Y., Troldborg, M., Kington, B., Aalders, I., Hough, R.L., 2014. Greenhouse gas emissions from renewable energy sources: a review of lifecycle considerations. Renew. Sustain. Energy Rev. 39, 461–475. https://doi.org/10.1016/j.rser.2014.07.087.

Antikainen, R., Droste, N., Loiseau, E., Saikku, L., Aissani, L., Hansjürgens, B., Kuikman, P.J., Leskinen, P., Thomsen, M., 2016. What can be learned from practical cases of green economy ? e studies from fi ve European countries 139, 666–676. https://doi.org/10.1016/j.jclepro.2016.08.071.

Bari, A., 2017. Our oceans and the blue economy: opportunities and challenges. Procedia Eng 194, 5–11. https://doi.org/10.1016/j.proeng.2017.08.109.

Barra, L., Chandrasekaran, R., Corato, F., Brunet, C., 2014. The challenge of ecophysiological biodiversity for biotechnological applications of marine microalgae. Mar. Drugs 12, 1641–1675. https://doi.org/10.3390/md12031641.

Bennett, N.J., Cisneros-Montemayor, A.M., Blythe, J., Silver, J.J., Singh, G., Andrews, N., Calò, A., Christie, P., Di Franco, A., Finkbeiner, E.M., Gelcich, S., Guidetti, P., Harper, S., Hotte, N., Kittinger, J.N., Le Billon, P., Lister, J., López de la Lama, R., McKinley, E., Scholtens, J., Solås, A.M., Sowman, M., Talloni-Álvarez, N., Teh, L.C.L., Voyer, M., Sumaila, U.R., 2019. Towards a sustainable and equitable blue economy. Nat. Sustain. 2, 991–993. https://doi.org/10.1038/s41893-019-0404-1.

Bhushan, S., Kalra, A., Simsek, H., Kumar, G., Prajapati, S.K., 2020. Current trends and prospects in microalgae-based bioenergy production. J. Environ. Chem. Eng. 8, 104025. https://doi.org/10.1016/j.jece.2020.104025.

Bleakley, S., Hayes, M., 2017. Algal proteins: extraction, application, and challenges concerning production. Foods 6, 33. https://doi.org/10.3390/foods6050033.

Brumbaugh, R., Patil, P., 2017. Sustainable Tourism Can Drive the Blue Economy: Investing in Ocean Health Is Synonymous with Generating. ocean wealth [WWW Document]. World Bank Blogs. URL. accessed 10.5.20. https://blogs.worldbank.org/voices/Sustainable-Tourism-Can-Drive-the-Blue-Economy.

Camacho, F., Macedo, A., Malcata, F., 2019. Potential industrial applications and commercialization of microalgae in the functional food and feed industries: a short review. Mar. Drugs 17 (312), 1–25. https://doi.org/10.3390/md17060312.

Campbell, R., Hotchkiss, S., 2017. Carrageenan industry market overview. In: Tropical Seaweed Farming Trends, Problems and Opportunities. Springer International Publishing, pp. 193–205. https://doi.org/10.1007/978-3-319-63498-2_13.

Carr, E.W., Shirazi, Y., Parsons, G.R., Hoagland, P., Sommerfield, C.K., 2018. Modeling the economic value of blue carbon in Delaware estuary wetlands: historic estimates and future projections. J. Environ. Manag. 206, 40–50. https://doi.org/10.1016/j.jenvman.2017.10.018.

Childs, J., Hicks, C.C., 2019. Securing the blue: political ecologies of the blue economy in Africa. J. Polit. Ecol. 26, 324–340. https://doi.org/10.2458/v26i1.23162.

Choudhary, P., Prajapati, S.K., Kumar, P., Malik, A., Pant, K.K., 2017. Development and performance evaluation of an algal biofilm reactor for treatment of multiple wastewaters and characterization of biomass for diverse applications. Bioresour. Technol. 224, 276–284. https://doi.org/10.1016/j.biortech.2016.10.078.

Choudhary, P., Assemany, P.P., Naaz, F., Bhattacharya, A., Castro, J. de S., Couto, E., de, A., do, C., Calijuri, M.L., Pant, K.K., Malik, A., 2020a. A review of biochemical and thermochemical energy conversion routes of wastewater grown algal biomass. Sci. Total Environ. 726, 137961. https://doi.org/10.1016/j.scitotenv.2020.137961.

Choudhary, P., Malik, A., Pant, K.K., 2020b. Exploration of a novel biorefinery based on sequential hydropyrolysis and anaerobic digestion of algal biofilm: a comprehensive characterization of products for energy and chemical production. Sustain. Energy Fuels 4 (3), 1481–1495. https://doi.org/10.1039/C9SE00939F.

Chowdhury, S.R., Hossain, M.S., Sharifuzzaman, S.M., Sarker, S., 2015. Blue carbon in the coastal ecosystems of Bangladesh. In: Proj. Doc. Support to Bangladesh Clim. Chang. Negot. Knowl. Manag. Var. Streams UNFCCC Process Proj. Funded by DFID Danida, Implemented by IUCN Bangladesh Ctry. off.

Coppa, S., Pronti, A., Massaro, G., Brundu, R., Camedda, A., Palazzo, L., Nobile, G., Pagliarino, E., de Lucia, G.A., 2021. Fishery management in a marine protected area with compliance gaps: socio-economic and biological insights as a first step on the path of sustainability. J. Environ. Manag. 280, 111754. https://doi.org/10.1016/j.jenvman.2020.111754.

Costa, J.A.V., Freitas, B.C.B. de, Lisboa, C.R., Santos, T.D., Brusch, L.R. de F., de Morais, M.G., 2019. Microalgal biorefinery from CO2 and the effects under the blue economy. Renew. Sustain. Energy Rev. 99, 58–65. https://doi.org/10.1016/j.rser.2018.08.009.

Dundas, S.J., Levine, A.S., Lewison, R.L., Doerr, A.N., White, C., Galloway, A.W.E., Garza, C., Hazen, E.L., Padilla-Gamiño, J., Samhouri, J.F., Spalding, A., Stier, A., White, J.W., 2020. Integrating oceans into climate policy: any green new deal needs a splash of blue. Conserv. Lett. 1–12 https://doi.org/10.1111/conl.12716.

Eikeset, A.M., Mazzarella, A.B., Davíðsdóttir, B., Klinger, D.H., Levin, S.A., Rovenskaya, E., Stenseth, N.C., 2018. What is blue growth? The semantics of "Sustainable Development" of marine environments. Mar. Pol. 87, 177–179. https://doi.org/10.1016/j.marpol.2017.10.019.

Enamala, M.K., Dixit, R., Tangellapally, A., Singh, M., Dinakarrao, S.M.P., Chavali, M., Pamanji, S.R., Ashokkumar, V., Kadier, A., Chandrasekhar, K., 2020. Photosynthetic microorganisms (Algae) mediated bioelectricity generation in microbial fuel cell: concise review. Environ. Technol. Innov. 19, 100959. https://doi.org/10.1016/j.eti.2020.100959.

European Commission, 2014. Blue Economy Innovation : Examples of EU.

FAO, 2011. Energy-smart food for people and climate. In: Issue Paper, vol. 66. Food Agric. Organ. United Nations.

FAO, 2018. The State of World Fisheries and Aquaculture 2018 - Meeting the Sustainable Development Goals (Rome).

Ferdouse, F., Løvstad Holdt, S., Smith, R., Murúa, P., Yang, Z., 2018. The Global Status of Seaweed Production, Trade and Utilization. FAO Globefish Research Programme.

Froehlich, H.E., Afflerbach, J.C., Frazier, M., Halpern, B.S., 2019. Blue growth potential to mitigate climate change through seaweed offsetting. Curr. Biol. 29, 3087–3093. https://doi.org/10.1016/j.cub.2019.07.041 e3.

Garcia-Vaquero, M., Rajauria, G., O'Doherty, J.V., Sweeney, T., 2017. Polysaccharides from macroalgae: recent advances, innovative technologies and challenges in extraction and purification. Food Res. Int. 99, 1011–1020. https://doi.org/10.1016/j.foodres.2016.11.016.

Golden, J.S., Virdin, J., Nowacek, D., Halpin, P., Bennear, L., Patil, P.G., 2017. Making sure the blue economy is green. Nat. Ecol. Evol. 1, 1–3. https://doi.org/10.1038/s41559-016-0017.

Grand view research, 2016. Beta-carotene market analysis by source (algae, fruits & vegetables, & synthetic), by application (food & beverages, dietary supplements, cosmetics, & animal feed) and segment forecasts to 2024. Gd. view Res 78.

grand view research, 2020. Astaxanthin market size, share | industry report, 2020-2027. Gd. view Res 76.

Grand view research, 2020. Alginate market size, share & trends analysis report by type (high M, high G), by product (sodium alginate, propylene glycol alginate), by application (industrial, pharmaceutical), and segment forecasts [WWW Document]. Gd. view Res. URL. https://www.grandviewresearch.com/press-release/global-alginate-market. accessed 12.23.20, 2020-2027.

Hodgson, E.E., Essington, T.E., Samhouri, J.F., Allison, E.H., Bennett, N.J., Bostrom, A., Cullen, A.C., Kasperski, S., Levin, P.S., Poe, M.R., 2019. Integrated risk assessment for the blue economy. Front. Mar. Sci. 6, 1–14. https://doi.org/10.3389/fmars.2019.00609.

Hoegh-Guldberg, O., 2015. Reviving the Ocean Economy: the Case for Action. World Wide Fund Univ. Queensl.

Hoerterer, C., Schupp, M.F., Benkens, A., Nickiewicz, D., Krause, G., Buck, B.H., 2020. Stakeholder perspectives on opportunities and challenges in achieving sustainable growth of the blue economy in a changing climate. Front. Mar. Sci. 6, 1–12. https://doi.org/10.3389/fmars.2019.00795.

Hossain, M.S., Chowdhury, S.R., Navera, U.K., Hossain, M.A.R., Imam, B., Sharifuzzaman, S.M., 2014. Opportunities and strategies for ocean and river resources management. Dhaka: background paper for preparation of the 7th Five Year Plan. Planning Commission, Ministry of Planning, Bangladesh 67.

Hosseini, S.F., Rezaei, M., McClements, D.J., 2020. Bioactive functional ingredients from aquatic origin: a review of recent progress in marine-derived nutraceuticals. Crit. Rev. Food Sci. Nutr. 1–28. https://doi.org/10.1080/10408398.2020.1839855.

Hurtado, A.Q., Neish, I.C., Critchley, A.T., 2019. Phyconomy: the extensive cultivation of seaweeds, their sustainability and economic value, with particular reference to important lessons to be learned and transferred from the practice of eucheumatoid farming. Phycologia 58, 472–483. https://doi.org/10.1080/00318884.2019.1625632.

Hussain, M.G., Rahman, M.J., 2010. Marine fisheries resources of Bangladesh: stock status and management issues. Sustain. Manag. Fish. Resour. Bay Bengal. In: Support to BOBLME Proj. Bangladesh Fish. Res. Institute, Bangladesh, pp. 37–51.

Jacob-Lopes, E., Maroneze, M.M., Deprá, M.C., Sartori, R.B., Dias, R.R., Zepka, L.Q., 2019. Bioactive food compounds from microalgae: an innovative framework on industrial biorefineries. Curr. Opin. Food Sci. 25, 1–7. https://doi.org/10.1016/j.cofs.2018.12.003.

Kaşdoğan, D., 2020. Designing sustainability in blues: the limits of technospatial growth imaginaries. Sustain. Sci. 15, 145–160. https://doi.org/10.1007/s11625-019-00766-w.

Katiyar, R., Arora, A., 2020. Health promoting functional lipids from microalgae pool: a review. Algal Res 46, 101800. https://doi.org/10.1016/j.algal.2020.101800.

Keen, M.R., Schwarz, A.M., Wini-Simeon, L., 2018. Towards defining the Blue Economy: practical lessons from pacific ocean governance. Mar. Pol. 88, 333–341. https://doi.org/10.1016/j.marpol.2017.03.002.

Khoo, C.G., Dasan, Y.K., Lam, M.K., Lee, K.T., 2019. Algae biorefinery: review on a broad spectrum of downstream processes and products. Bioresour. Technol. 292 https://doi.org/10.1016/j.biortech.2019.121964.

Kumari, N., Singh, R.K., 2019. Biofuel and co-products from algae solvent extraction. J. Environ. Manag. 247, 196–204. https://doi.org/10.1016/j.jenvman.2019.06.042.

Kung, A., Svobodova, K., Lèbre, E., Valenta, R., Kemp, D., Owen, J.R., 2021. Governing deep sea mining in the face of uncertainty. J. Environ. Manag. 279, 111593. https://doi.org/10.1016/j.jenvman.2020.111593.
Kunsel, T., Sumant, O., 2019. Spirulina Market Outlook - 2026. www.alliedmarketresearch.com/210.
Kwon, P.S., Oh, H., Kwon, S.J., Jin, W., Zhang, F., Fraser, K., Hong, J.J., Linhardt, R.J., Dordick, J.S., 2020. Sulfated polysaccharides effectively inhibit SARS-CoV-2 in vitro. Cell Discov 6, 4–7. https://doi.org/10.1038/s41421-020-00192-8.
Leandro, A., Pereira, L., Gonçalves, A.M.M., 2020. Diverse applications of marine macroalgae. Mar. Drugs 18, 1–15. https://doi.org/10.3390/md18010017.
Lee, K.H., Noh, J., Khim, J.S., 2020. The blue economy and the united Nations' sustainable development goals: challenges and opportunities. Environ. Int. 137, 105528. https://doi.org/10.1016/j.envint.2020.105528.
López-Pacheco, I.Y., Silva-Núñez, A., García-Perez, J.S., Carrillo-Nieves, D., Salinas-Salazar, C., Castillo-Zacarías, C., Afewerki, S., Barceló, D., Iqbal, H.N.M., Parra-Saldívar, R., 2021. Phyco-remediation of swine wastewater as a sustainable model based on circular economy. J. Environ. Manag. 278, 111534 https://doi.org/10.1016/j.jenvman.2020.111534.
Lourenço-Lopes, C., Fraga-Corral, M., Jimenez-Lopez, C., 2020. Metabolites from Macroalgae and its Applications in the Cosmetic Industry : A Circular Economy Approach. https://doi.org/10.3390/resources9090101.
Lupette, J., Benning, C., 2020. Human health benefits of very-long-chain polyunsaturated fatty acids from microalgae. Biochimie 178, 15–25. https://doi.org/10.1016/j.biochi.2020.04.022.
Lusvarghi, S., Bewley, C., 2016. Griffithsin: an antiviral lectin with outstanding therapeutic potential. Viruses 8, 296. https://doi.org/10.3390/v8100296.
Mannar, M.G.V., Bradley, H.L., 1984. Guidelines for the Establishment of Solar Salt Facilities from Seawater, Underground Brines, and Salted Lakes.
Marino, T., Casella, P., Sangiorgio, P., Verardi, A., Ferraro, A., Hristoforou, E., Molino, A., Musmarra, D., 2020. Natural beta-carotene: a microalgae derivate for nutraceutical applications. Chem. Eng. Trans. 79, 103–108. https://doi.org/10.3303/CET2079018.
Mazzelli, A., Cicci, A., Di Caprio, F., Altimari, P., Toro, L., Iaquaniello, G., Pagnanelli, F., 2020. Multivariate modeling for microalgae growth in outdoor photobioreactors. Algal Res 45, 101663. https://doi.org/10.1016/j.algal.2019.101663.
Mehta, P., Singh, D., Saxena, R., Rani, R., Gupta, R.P., Puri, S.K., Mathur, A.S., 2018. High-Value Coproducts from Algae—An Innovational Way to Deal with Advance Algal Industry. Springer, Singapore, pp. 343–363. https://doi.org/10.1007/978-981-10-7431-8_15.
Menon, A., 2021. List of Major Shipbuilding Companies Around the Globe. www.marineinsight.com.
Miller, K.A., Thompson, K.F., Johnston, P., Santillo, D., 2018. An overview of seabed mining including the current state of development, environmental impacts, and knowledge gaps. Front. Mar. Sci. 4, 418. https://doi.org/10.3389/fmars.2017.00418.
Mohanty, S.K., Dash, P., Gupta, A., Gaur, P., 2015. Prospects of blue economy in the Indian ocean. Res. Inf. Syst. Dev. Ctries. 100.
Morales, M., Bonnefond, H., Bernard, O., 2020. Rotating algal biofilm versus planktonic cultivation: LCA perspective. J. Clean. Prod. 257, 120547. https://doi.org/10.1016/j.jclepro.2020.120547.
Nayar, S., Bott, K., 2014. Current status of global cultivated seaweed production and markets. World Aquacult. 45, 32–37.
Neish, I.C., Suryanarayan, S., 2017. Development of eucheumatoid seaweed value-chains through carrageenan and beyond. Trop. Seaweed farming trends. Probl. Oppor. Dev. Appl. Phycol. 9 https://doi.org/10.1007/978-3-319-63498-2_12.
Norsker, N.H., Barbosa, M.J., Vermuë, M.H., Wijffels, R.H., 2011. Microalgal production - a close look at the economics. Biotechnol. Adv. 29 (1), 24–27. https://doi.org/10.1016/j.biotechadv.2010.08.005.
OECD, 2016. The Ocean Economy in 2030. OECD Publishing, Paris. https://doi.org/10.1787/9789264251724-en. OECD.
Özçimen, D., İnan, B., Morkoç, O., Efe, A., 2017. A review on algal biopolymers. J. Chem. Eng. Res. Updat. 4, 7–14. https://doi.org/10.15377/2409-983x.2017.04.2.
Pant, D., Misra, S., Nizami, A.S., Rehan, M., van Leeuwen, R., Tabacchioni, S., Goel, R., Sarma, P., Bakker, R., Sharma, N., Kwant, K., Diels, L., Elst, K., 2019. Towards the development of a biobased economy in Europe and India. Crit. Rev. Biotechnol. 39, 779–799. https://doi.org/10.1080/07388551.2019.1618787.
Patil, P.G., Virdin, J., Diez, S.M., Roberts, J., Singh, A., 2016. Toward a Blue Economy: A Promise for Sustainable Growth in the Caribbean. World Bank, Washington, DC.
Pereira, L., 2020. Characterization of bioactive components in edible algae. Mar. Drugs 18, 65. https://doi.org/10.3390/md18010065.
Pratiwy, F.M., Pratiwi, D.Y., 2020. The potentiality of microalgae as a source of DHA and EPA for aquaculture feed. Review 8, 39–41.
Rajak, R.C., Jacob, S., Kim, B.S., 2020. A holistic zero waste biorefinery approach for macroalgal biomass utilization: a review. Sci. Total Environ. 716, 137067. https://doi.org/10.1016/j.scitotenv.2020.137067.
Richardson, J.W., Johnson, M.D., Zhang, X., Zemke, P., Chen, W., Hu, Q., 2014. A financial assessment of two alternative cultivation systems and their contributions to algae biofuel economic viability. Algal Res 4, 96–104. https://doi.org/10.1016/j.algal.2013.12.003.
Romero-Villegas, G.I., Fiamengo, M., Acién-Fernández, F.G., Molina-Grima, E., 2018. Utilization of centrate for the outdoor production of marine microalgae at the pilot-scale in raceway photobioreactors. J. Environ. Manag. 228, 506–516. https://doi.org/10.1016/j.jenvman.2018.08.020.
Sadhukhan, J., Gadkari, S., Martinez-Hernandez, E., Ng, K.S., Shemfe, M., Torres-Garcia, E., Lynch, J., 2019. Novel macroalgae (seaweed) biorefinery systems for integrated chemical, protein, salt, nutrient and mineral extractions and environmental protection by green synthesis and life cycle sustainability assessments. Green Chem. 21, 2635–2655. https://doi.org/10.1039/c9gc00607a.
Sakhuja, V., 2015. Harnessing the blue economy. Indian Foreign Aff. J. 10, 39–49.
Samarakoon, K., Jeon, Y.J., 2012. Bio-functionalities of proteins derived from marine algae - a review. Food Res. Int. 48, 948–960. https://doi.org/10.1016/j.foodres.2012.03.013.
Samonte, G.P., 2017. Economics of Kappaphycus spp. seaweed farming with special reference to the Central Philippines. In: Tropical Seaweed Farming Trends, Problems and Opportunities, pp. 147–154.
Seghetta, M., Marchi, M., Thomsen, M., Bjerre, A.B., Bastianoni, S., 2016a. Modelling biogenic carbon flow in a macroalgal biorefinery system. Algal Res 18, 144–155. https://doi.org/10.1016/j.algal.2016.05.030.
Seghetta, M., Tørring, D., Bruhn, A., Thomsen, M., 2016b. Bioextraction potential of seaweed in Denmark - an instrument for circular nutrient management. Sci. Total Environ. 563–564, 513–529. https://doi.org/10.1016/j.scitotenv.2016.04.010.
Smith-Godfrey, S., 2016. Defining the blue economy. Marit. Aff. 12, 58–64. https://doi.org/10.1080/09733159.2016.1175131.
Spalding, M.J., 2016. The new blue economy: the future of sustainability. J. Ocean Coast. Econ. 2 https://doi.org/10.15351/2373-8456.1052.
Thakur, N.L., Thakur, A.N., 2006. Marine biotechnology: an overview. Indian J. Biotechnol. 5, 263–268.
Torres-Tiji, Y., Fields, F.J., Mayfield, S.P., 2020. Microalgae as a future food source. Biotechnol. Adv. https://doi.org/10.1016/j.biotechadv.2020.107536.
UNCSD, USAID, United Nations Economic Commission for Africa, Africana, U., , UNEP, Babb, A.C., Choi, Y.R., Rustomjee, C., Al Nsour, I.A., Bari, A., Keen, M.R., Schwarz, A.M., Wini-Simeon, L., Nations, U., 2016. Para 2. The future we want. UNCSD 2012). Mar. Policy 194, 1–15. https://doi.org/10.1057/s41301-016-0046-9.
UNEP, FAO, IMO, UNDP, IUCN, World Fish Center, G., 2012. Green Economy in a Blue World https://doi.org/978-82-7701-097-7.
United Nations Development Programme, 2013. TRY Oyster Women's Association, the Gambia. Equator Initiative Case Study Series, New York, NY.
Venkata Mohan, S., Varjani, S., Pant, D., Sauer, M., Chang, J.S., 2020. Circular bioeconomy approaches for sustainability. Bioresour. Technol. 318, 124084 https://doi.org/10.1016/j.biortech.2020.124084.
Vieira de Mendonça, H., Assemany, P., Abreu, M., Couto, E., Maciel, A.M., Duarte, R.L., Barbosa dos Santos, M.G., Reis, A., 2021. Microalgae in a global world: new solutions for old problems? Renew. Energy 165, 842–862. https://doi.org/10.1016/j.renene.2020.11.014.
Vigani, M., 2020. The Bioeconomy of Microalgae-Based Processes and Products, Handbook of Microalgae-Based Processes and Products. Elsevier Inc. https://doi.org/10.1016/b978-0-12-818536-0.00029-4.
Wayne, K., Ying, J., Loke, P., Hui, N., Ching, J., Chuan, T., Lee, D.J., Chang, J.S., Chew, K.W., Yap, J.Y., Show, P.L., Suan, N.H., Juan, J.C., Ling, T.C., Lee, D.J., Chang, J.S., 2017a. Microalgae biorefinery: high value products perspectives. Bioresour. Technol. 229, 53–62. https://doi.org/10.1016/j.biortech.2017.01.006.
Wayne, K., Ying, J., Loke, P., Hui, N., Ching, J., Chuan, T., Lee, D.J., Chang, J.S., Chew, K.W., Yap, J.Y., Show, P.L., Suan, N.H., Juan, J.C., Ling, T.C., Lee, D.J., Chang, J.S., 2017b. Microalgae biorefinery: high value products perspectives. Bioresour. Technol. 229, 53–62. https://doi.org/10.1016/j.biortech.2017.01.006.
Wenhai, L., Cusack, C., Baker, M., Tao, W., Mingbao, C., Paige, K., Xiaofan, Z., Levin, L., Escobar, E., Amon, D., Yue, Y., Reitz, A., Neves, A.A.S., O'Rourke, E., Mannarini, G., Pearlman, J., Tinker, J., Horsburgh, K.J., Lehodey, P., Pouliquen, S., Dale, T., Peng, Z., Yufeng, Y., 2019. Successful blue economy examples with an emphasis on international perspectives. Front. Mar. Sci. 6, 261. https://doi.org/10.3389/fmars.2019.00261.
www. decisiondatabases.com, 2020. Global marine tourism market trends, growth, manufacturers analysis report 2020 By type, application and forecast to 2025. www.decisiondatabases.com/.
n.d. www.marketwatch.com. Sea salt market insights 2021-2026, by share, growth, trends evaluation, global growth, recent developments, latest technology, and 2026 future forecast research report [WWW document], accessed 4.15.21. www.marketwatch.com. https://www.marketwatch.com/press-release/sea-salt-market-insights-2021-2026-by-share-growth-trends-evaluation-global-growth-recent-developments-latest-technology-and-2026-future-forecast-research-report-2021-04-15?tesla=y.
n.d www.oilandgasiq.com, 2019. The top 10 oil & gas companies in the world [WWW Document]accessed 4.15.21. www.oilandgasiq.com. https://www.oilandgasiq.com/strategy-management-and-information/articles/oil-and-gas-companies.
Yates, K.L., Schoeman, D.S., Klein, C.J., 2015. Ocean zoning for conservation, fisheries and marine renewable energy: assessing trade-offs and co-location opportunities. J. Environ. Manag. 152, 201–209. https://doi.org/10.1016/j.jenvman.2015.01.045.
Yong, W.T.L., Chin, J.Y.Y., Thien, V.Y., Yasir, S., 2017. Heavy metal accumulation in field cultured and tissue cultured Kappaphycus alvarezii and Gracilaria changii. Int. Food Res. J. 24.
Zilinskas, R.A., Colwell, R.R., Lipton, D.W., Hill, R.T., 1995. The Global Challenge of Marine Biotechnology: a Report on the United States, Japan, Australia, and Norway.
Zion Market Research Report, 2018a. Algae biofuel market by type (bioethanol, biodiesel, methane. Jet Fuel, Biobutanol, Biogasoline, Green Diesel, and Others) and for Application (Transportation, Aerospace, and Other Applications): Global Industry Perspective. Comprehensive Analysis and For [WWW Document]. Zion

Mark. Res. URL. https://www.zionmarketresearch.com/report/algae-biofuel-market . accessed 11.27.20.
Zion Market Research Report, 2018b. Global Bio-Plastics Market: Industry Overview by Size, Share, Growth and Forecast 2016 – 2022 [WWW Document]. Zion Mark. Res. URL. https://www.zionmarketresearch.com/report/bioplastics-market. accessed 11.27.20.
Zion Market Research Report, 2020a. Fish free omega 3 market: by application (Film-Food packaging, film-non food packaging, film- stretch & shrink. Automotive, Polymer Modification, Wires & Cables, Medical, and Other): Global Industry Perspective, Comprehensive Analysis and Forecast, 2016 – [WWW Document]. Zion Mark. Res. URL. https://www.zionmarketresearch.com/news/fish-free-omega-3-market. accessed 11.27.20.
Zion Market Research Report, 2020b. Carotenoids Market - by Product (Astaxanthin, Capsanthin, Lutein, Beta-Carotene, Lycopene, and Others), Source (Natural, and Synthetic), Application (Animal Feed, Human Food, Dietary Supplement, Personal Care & Cosmetic, Pharmaceuticals, and Others): Glob [WWW Document]. Zion Mark. Res. URL. https://www.zionmarketresearch.com/report/carotenoids-market. accessed 11.30.20.