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Review

# Importance of Blue Carbon in Mitigating Climate Change and Plastic/Microplastic Pollution and Promoting Circular Economy

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**Abstract:** Blue carbon has made significant contributions to climate change adaptation and mitigation while assisting in achieving co-benefits such as aquaculture development and coastal restoration, winning international recognition. Climate change mitigation and co-benefits from blue carbon ecosystems are highlighted in the recent Intergovernmental Panel on Climate Change Special Report on Ocean and Cryosphere in a Changing Climate. Its diverse nature has resulted in unprecedented collaboration across disciplines, with conservationists, academics, and politicians working together to achieve common goals such as climate change mitigation and adaptation, which need proper policy regulations, funding, and multi-prong and multi-dimensional strategies to deal with. An overview of blue carbon habitats such as seagrass beds, mangrove forests, and salt marshes, the critical role of blue carbon ecosystems in mitigating plastic/micro-plastic pollution, as well as the utilization of the above-mentioned blue carbon resources for biofuel production, are critically presented in this research. It also highlights the concerns about blue carbon habitats. Identifying and addressing these issues might help preserve and enhance the ocean's ability to store carbon and combat climate change and mitigate plastic/micro-plastic pollution. Checking out their role in carbon sequestration and how they act as the major carbon sinks of the world are integral parts of this study. In light of the global frameworks for blue carbon and the inclusion of microalgae in blue carbon, blue carbon ecosystems must be protected and restored as part of carbon stock conservation efforts and the mitigation of plastic/micro-plastic pollution. When compared to the ecosystem services offered by terrestrial ecosystems, the ecosystem services provided by coastal ecosystems, such as the sequestration of carbon, the production of biofuels, and the remediation of pollution, among other things, are enormous. The primary purpose of this research is to bring awareness to the extensive range of beneficial effects that can be traced back to ecosystems found in coastal environments.

**Keywords:** climate change; plastic/micro-plastic pollution; blue carbon ecosystems; carbon sinks; circular economy



**Citation:** Bandh, S.A.; Malla, F.A.; Qayoom, I.; Mohi-Ud-Din, H.; Butt, A.K.; Altaf, A.; Wani, S.A.; Betts, R.; Truong, T.H.; Pham, N.D.K.; et al. Importance of Blue Carbon in Mitigating Climate Change and Plastic/Microplastic Pollution and Promoting Circular Economy. *Sustainability* **2023**, *15*, 2682. https://doi.org/10.3390/su15032682

Academic Editor: Elena Cristina Rada

Received: 9 January 2023
Revised: 28 January 2023
Accepted: 29 January 2023
Published: 2 February 2023



## 1. Introduction

Blue carbon was established as a metaphor to highlight that, apart from terrestrial ecosystems, coastal ecosystems also contribute significantly to carbon sequestration [1].

Apart from being recognized as a helpful carbon sink, blue carbon ecosystems provide various other services, including shelter for different migratory birds, fishes, and crabs [2,3]. It is also vital in minimizing net carbon emissions. But various lines of evidence, including remote sensing data and other studies about land use land cover (LULC), depict the drastic reduction of mangrove ecosystems in different coastal areas environments. In 2003, the first carbon storage global budget highlighted the planetary significance of mangroves and salt marshes as carbon sinks. In 2005, it was revealed that fifty percent of all marine carbon sequestered comes from seagrasses, mangroves, and tidal marshes [2]. Threats from natural and human activities are responsible for destroying these productive ecosystems, thereby reducing their capability to absorb and store carbon [4]. A surge in the sea level, natural and human-made disasters, and large-scale coastal development are responsible for the rapid change in the blue carbon landscapes [5]. The Holocene's glacial and interglacial eras have caused the mean sea level to fluctuate by up to 120 m [6]. Therefore, urgent research is needed at the international and national levels to preserve and restore the blue carbon ecosystems and tackle climate change [2].

The critical role of "Blue Carbon" in tackling climate change has become increasingly understood in recent years. To date, initiatives have helped achieve co-benefits such as aquaculture and coastal conservation, thus gaining international prominence. Beyond the scientific community, blue carbon has captivated awareness among various stakeholder groups, including government and non-governmental bodies responsible for protecting marine environments and mitigating climate change [7]. Indeed, blue carbon not only plays an important role in mitigating climate change but also could be used as a potential biomass source for biofuel production. As depicted in Figure 1, blue carbon could play a role as a critical intermediate in the circular process of $CO_2$.

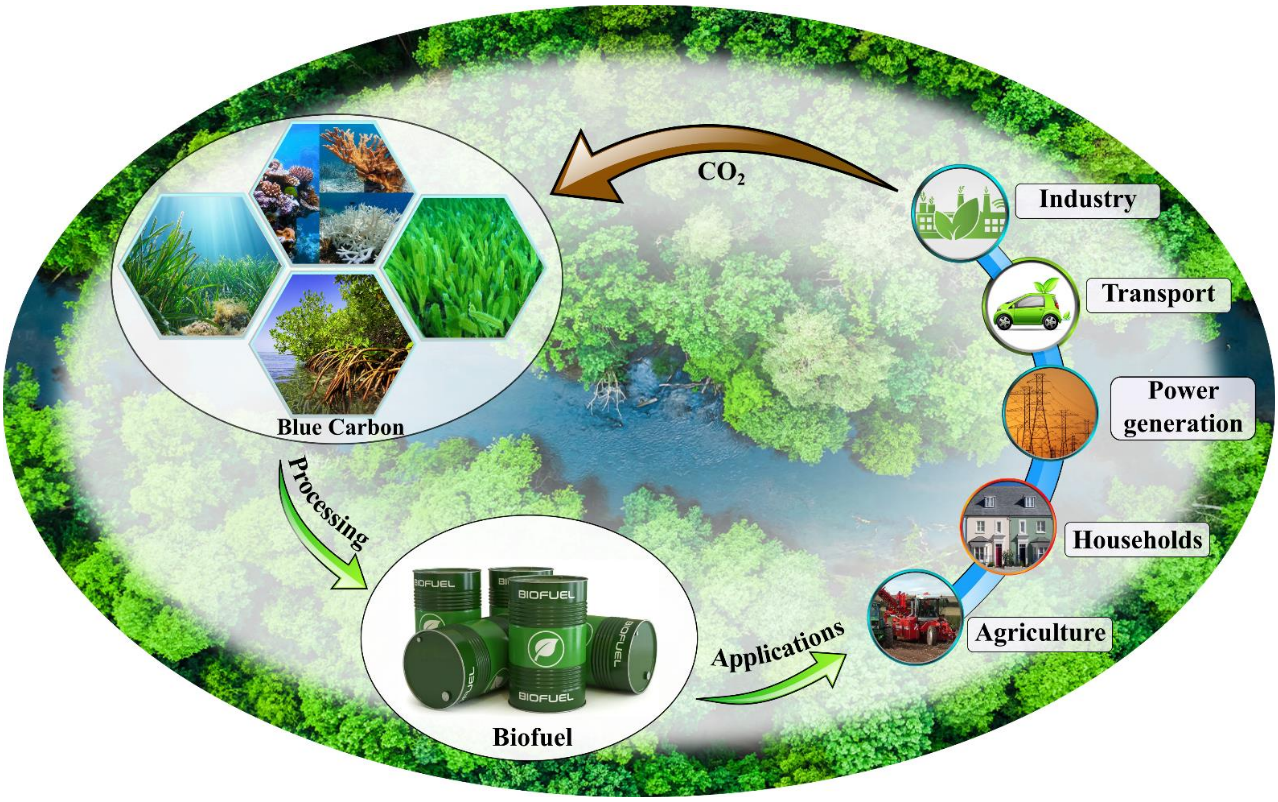


**Figure 1.** Role of blue carbon in climate change mitigation and circular economy.

The research related to blue carbon received impetus after UNEP's report 'Blue Carbon: A rapid response assessment' in 2009 which focused on the importance of marine and coastal areas [1]. Soon after the report, the blue carbon initiative was established in

2010. Blue carbon science is evolving fast, accelerated through scalable and reproducible observations, but is yet to achieve its maturity. Therefore, there should be proper policy regulations and funding options to avail the maximum possible benefits from these blue carbon ecosystems, showing that there should be multi-prong and multi-dimensional strategies for the protection and conservation of such ecosystems. In this paper, the role of blue carbon in the ecosystems, in mitigating plastic/micro-plastic pollution, as well as the utilization of blue carbon for biofuel production are scrutinized. Indeed, the blue carbon discussion has a long way to go but needs harmonious collaboration from various stakeholders to build a positive future and help reduce carbon emissions, amongst many other benefits. This review broadens the conversation on the importance of blue carbon in climate change mitigation efforts by underlining the difficulties in measuring, valuing, managing, and governing carbon in the coastal, open ocean, and deep-sea ecosystems. In the section under "Role of Blue Carbon ecosystems in mitigation of microplastic pollution," we especially report how important coastal ecosystems are in dealing with plastic pollution. We conclude with the potential of coastal ecosystems in biofuel production which is one of the pathways to developing sustainable economies. The importance of coastal ecosystems has increased as a result of the degradation of terrestrial ecosystems brought about by human activities such as land use change, deforestation, fossil fuel consumption, etc. The ecosystem services provided by coastal ecosystems, such as carbon sequestration, biofuel production, pollution remediation, and so on, are immense in comparison to those provided by terrestrial ecosystems. The primary objective of this study was to draw attention to the wide variety of positive outcomes that can be attributed to coastal ecosystems.

## 2. Spatiotemporal Distribution of Blue Carbon Ecosystems

Coastal vegetated habitats including salt marshes, seagrasses, and mangroves have long provided humans with advantages. More recently, notwithstanding data limitations, their importance as carbon reserves has been recognized in climate change mitigation [1,8]. As illustrated in Figure 2, spatiotemporal distribution and the importance of blue carbon ecosystems in controlling climate change can be seen [9].

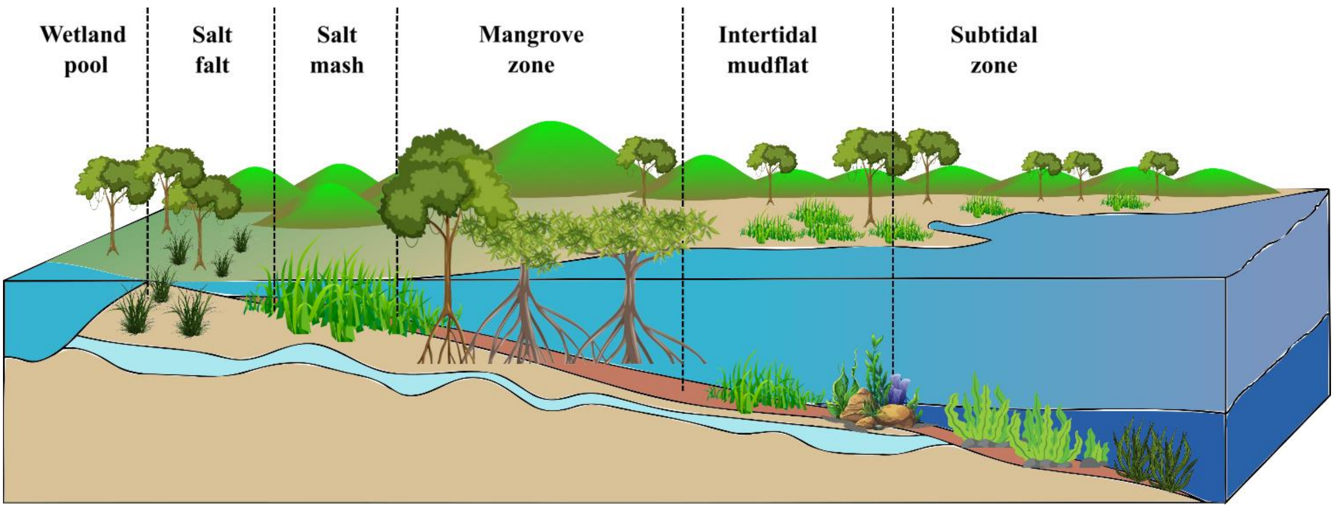


**Figure 2.** Spatiotemporal distribution and the importance of blue carbon ecosystems.

Coastal zone environments, including seagrass beds, rocky reefs and corals, intertidal marshes, sandy beaches, kelp forests, and mangrove forests [10], help combat climate change by effectively storing and sequestering $CO_2$, known as "coastal Blue Carbon" [11]. Salt marshes, seagrasses, and mangroves, for example, often form a spatially connected continuum of intertidal ecosystems. Unvegetated mudflats and sandbars are ecosystems that contain and sequester vast quantities of organic carbon [12,13]. Blue carbon soil is anaerobic, mainly in contrast to the terrestrial ground, which causes carbon stored in these soils to decay at a slow rate, and thus the carbon accumulates for hundreds to thousands of years [14,15]. The coastal wetland vegetation acts as a buffer zone between land and oceans, capable of storing surplus water during the rainy season and preventing floods [16]. They also help to protect coastlines and are considered to be more cost-effective than complicated structures such as seawalls and levees, as they are cheaper to manage and will be able to keep up with rising sea levels [17,18]. They also exhibit high burial rates leading to the seafloor's rise, acting as a barrier against rising sea levels and wave actions linked with climate change [19]. They serve as a motivator for ecosystem-based adaptation to protect humans, infrastructure, and property from the negative impacts of climate change [20].

Mangroves occur in tropical and sub-tropical regions [21]. They are found in 118 countries worldwide, with 15 countries accounting for 75% of their overall coverage. West Africa is home to nearly a quarter of the world's mangroves, containing almost 0.854 billion metric tons of carbon in below-ground and above-ground biomass [22]. Similarly, Indonesia alone accounts for 23% [23]. But a considerable loss of 0.16–0.39% per year has been recorded in the mangroves since 2000 [24]. Mangroves have an excellent ability to store carbon in the root system and act as carbon-rich forests in the tropics; hence their management and conservation need to be prioritized [25]. Geological evidence indicates the adaptation of mangroves to earlier climate and sea-level change [26,27]. They play a crucial role in promoting sedimentation in sensitive coastal regions, hence withstanding climate-induced impacts such as rising sea levels [28]. Their wide variety of aerial root structures such as pneumatophores, prop roots, plank roots, and knee roots help prevent soil erosion and differ in their efficacy to reserve sediments [29]. Moreover, mangroves speed up land development through a rise in sedimentation, lower wave exposure, and peat formation, consequently mitigating exposure to tropical storm surges and sea-level rise [30].

Seagrasses are another blue carbon ecosystem found mainly in shallow coastal margins across zero latitudes. Seagrasses use photosynthesis to take in carbon dioxide and assimilate it into their biomass. The above-ground/water vegetation traps suspended particulate matter (sedimentation) that later adds to the sedimentary storage component [31]. They have colossal mitigation potential for neutralizing $CO_2$ emissions, which leads to improvements in carbon estimates stored in seagrass sediments and incorporate seagrass ecosystems [32,33]. The total global area under seagrass ranges from 300,000–600,000 km$^2$ [34]. However, there has been a sharp decrease in recent decades, with a sevenfold decline reported from 1990 to 2009 [35]. Globally, seagrasses are declining by 2–5% each year as 30,000 Km$^2$ of seagrass have been destroyed in recent decades [36]. Every year, organic carbon oxidation in degraded seagrass meadows potentially releases 0.03–0.33 petagrams of carbon dioxide back into the atmosphere [37]. Seagrasses cover 4.8 million hectares in West Africa, holding an estimated 673 million tons of carbon [22]. In coastal waters, the restoration of seagrasses has led to increased sequestration of blue carbon [38]. However, they have a poor carbon storage capacity compared to mangroves.

Unlike seagrasses and mangroves, salt marshes differ in having low methane emissions [39,40]. Salt marshes cover 1.2 million hectares in West Africa, holding 303 million metric tons of $CO_2$ [22]. In recent studies, an area of 45,000 Km$^2$ has been reported for salt marshes [41]. Apart from carbon sinks, they are prodigious inorganic carbon sources of coastal oceans [42]. Tidal marshes, mapped only in 43 countries of the world, represent 14% of the global coastal area [43]. The minimum yearly global loss rate of tidal marshes is 1–2% [44]. Although the blue carbon ecosystems have proved their ability as ideal carbon sinks, both natural and artificial threats destroy these ecosystems. Due to the rise in sea level, marshes sink to stress and shrink with time [45]. Further, marine accidents, such as massive oil spills, are also responsible for the damage to these ecosystems [46–48]. Hence, to avail the maximum benefits of these ecosystems, proper policymaking and guiding mechanisms should be established to preserve and manage these blue carbon ecosystems.

Other coastal ecosystems such as barrier islands, dunes, and beaches made of sand, play a pivotal role in dispersing wave energy, besides having vital sediment reserves that aid in preserving coastlines, and to a certain extent, in adapting to rising sea levels [49,50]. It is debatable if coral reefs are the sinks or sources of atmospheric $CO_2$ [51]. However, they make remarkable structures, ranging from deep oceans to their surfaces and parallel to coastlines in many places extending up to several kilometres, in such a way that they form a significant part of the coastal defense. The mass flow of energy from overlying waters into the coral systems significantly reduces wave activity—a vital function of reef roughness [52,53]. However, as per Pendleton et al. [37], enormous reserves of carbon sequestered in the past are affected by the transformation of these coastal ecosystems, as blue carbon present in the sediments is released into the atmosphere when these ecosystems are degraded [37]. As a result, the value of blue carbon habitats in sequestering organic carbon has boosted conservation efforts as a means to reduce climate change and offset $CO_2$ emissions [54]. Furthermore, their contribution to strengthening coastal resilience to weather disasters and changing climate has led to their participation in many countries' nationwide defined commitments (NDCs) for climate change adaptation and mitigation [55,56].

## 3. Role of Blue Carbon Ecosystems

### *3.1. Role of Blue Carbon Ecosystems in Mitigation of Climate Change*

In recent years, the use of fossil fuels for industrial and agricultural activities and transportation means have resulted in high pollutant emissions such as $CO_2$, NOx, and PM, causing the serious consequences of environmental pollution and climate change [57–61], proof of which could be seen from the COVID-19 pandemic [62–64]. Due to this reason, seeking efficient and useful solutions relating to technology, management, and policy is very important [65–69]. Among these, shifting to renewables is considered one of the most potential approaches in mitigating environmental pollution and climate change since renewables are available, have biodegradation, and have non-toxic properties [70–73]. Indeed, the popular renewable sources are wind, solar, ocean, hydropower, biomass, and biofuels, which have all been used the most in recent years [74–83]. Besides, the development of the natural ecosystems is also considered an extremely important solution because the natural ecosystems could keep a large amount of carbon emissions [84].

Being a natural ecosystem, blue carbon has accrued global consideration for its potential role in mitigating carbon dioxide emissions, as shown in Figure 3 [85]. However, its contribution is restricted worldwide because it is limited to coastlines [86]. Coastal environments have been found to store tremendous amounts of carbon in sediments, multiple times more than numerous types of temperate and tropical forests [87]. Carbon sequestration via vegetated coastal ecosystems helps to reduce anthropogenic $CO_2$ emissions. However, their adequacy contrasts with the spatial scale of evaluating the "Blue Carbon" ecosystem provider. It is a powerful management tool for maintaining environmental wellbeing and productivity by offering enhanced assurance, protection, preservation, and services [88]. Because of the high carbon reserves and sequestration rates and the high assessment of their other ecological resources, coastal blue carbon habitats have been positioned as one of the best ocean-based solutions for climate change mitigation. Mangrove trees, seagrass meadows, and salt swamps are examples of coastal vegetated environments that have long benefited human populations and ecosystems. More recently, their role in storing large volumes of carbon and therefore contributing to tackling climate change has been well recognized [1,8]. The UN Sustainable Development Goals (SDGs) have been agreed upon as the global priorities through to 2030 by countries worldwide. Amongst the 17 SDGs are goals that are directly relevant to tackling climate change (SDG 13) and protecting and sustaining the use of coasts, oceans, and aquatic resources (SDG 14). Mangrove restoration would contribute to SDG 13 (strengthening resistance and resilient potential of all nations to climate-related threats and catastrophic events). It also contributes towards SDG 14 (sustainably maintaining and ensuring marine and seaside ecosystems to avoid crucial unfavorable effects, including enhancing their intensity and pushing toward their reclamation to accommodate climate change by 2020). [89]. Climate change threatens mangroves, causing an additional 10–15% loss by 2100 [90].

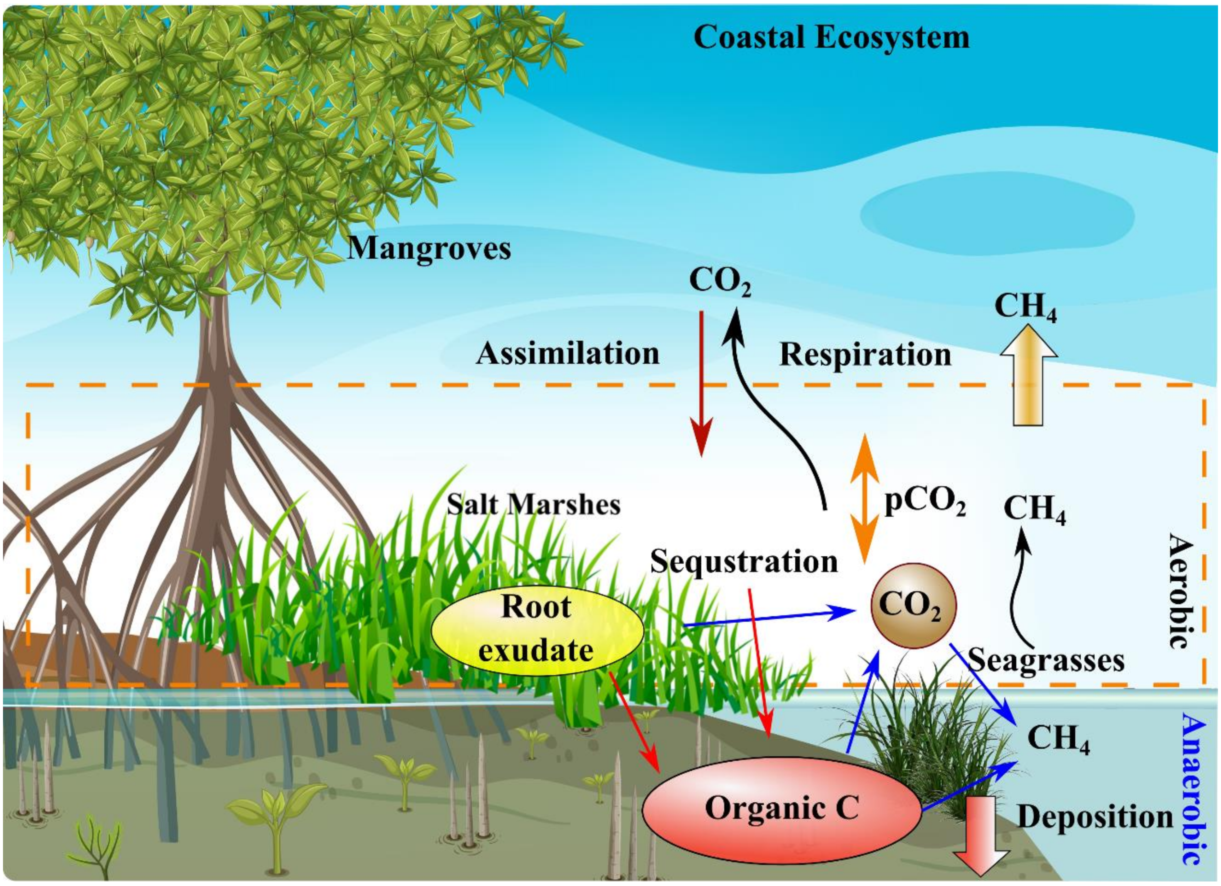


**Figure 3.** Role of blue carbon ecosystems in mitigation of climate change [85] (with permission from Elsevier using license number 5476621301963).

Blue carbon systems help tackle climate change by storing and sequestering carbon; however, these ecosystems are susceptible to global warming, resulting in uncertainty about their long-term effectiveness [56]. Sea-level rise, droughts, intensified hurricanes, changes in temperature regimes, precipitation levels, and coastal heatwaves threaten the blue carbon environment and its carbon reserves. The vulnerability of climatic stressors on the blue carbon ecosystem depends on the exposure of such systems to disturbances, which is a function of the sensitivity and resilience of these ecosystems. Moreover, it also depends on the stressor's frequency and intensity [91]. The increase in sea level has been a big challenge to coastal habitats. Still, there is regional and temporal variability in its rate [56]. For example, climate-induced storms and rising sea levels can affect mangroves by exposing previously buried organic carbon to oxidation, further increasing $CO_2$ concentrations in the atmosphere [92] and acting as a positive feedback loop contributing to global warming. Mangroves and salt marshes' ability to sequester carbon can be improved or preserved by sustaining an altitude above sea level in the wake of the sea-level rise [93]. They can, however, be eroded or submerged if there is insufficient sediment or root growth to sustain altitude [3]. Further, sea-level rise can slow the decay rate of organic matter, which may increase the carbon storage potential of intertidal sediments. Mangroves are also found to migrate landward (to adjust to climate change) where the sea-level escalation outpaces sediment deposits [94,95]. During accelerating sea-level rise, salt marsh ecosystems restructure occurs, increasing the resilience and thus carbon storage [96].

Mudd et al. [97] detected that the rate of carbon accumulation in salt marshes in South Carolina rose with a sea-level increase until it reached a critical speed, flooding the swamp vegetation and stopping carbon accumulation [3]. Increased inundation due to rising sea levels changes salt marshes and mangroves [98]. Under certain conditions, some of the salt marshes are proposed to be entirely covered by mangroves by the end of the century [99,100].

### *3.2. Blue Carbon Ecosystems as Carbon Sequestration and Sinks*

Coastal habitats are critical carbon sinks that store almost half of all organic carbon [56,101]. Sediments of blue carbon ecosystems store vast carbon stocks [102,103]. Most of the $CO_2$ from the atmosphere, taken through photosynthesis, is recompensed to the air through the respiration of microbes and plants or stored short-term in plant foliage. In contrast, the rest is stored for a prolonged period in woody biomass and soil. Depending on the vegetation type, 50–90 percent of all coastal wetland carbon is found in the ground [37,104]. The high photosynthetic strength and gradual decomposition of these ecosystems result in higher production and carbon sequestration per unit area [105,106]. Because of their tremendous productivity, they can sequester significantly more carbon than terrestrial ecosystems [3,106]. In vegetated coastal ecosystems, primary development usually is higher than respiration [2,107], enhancing their ability to produce surplus organic carbon and thus function as carbon sinks [19]. A dynamic space-time transition between carbon flows and stocks is required for blue carbon conversion, absorption, and conservation in coastal zones [106]. It includes interactions between land, sea, plants, animals, and microbes, as shown in Figure 4.

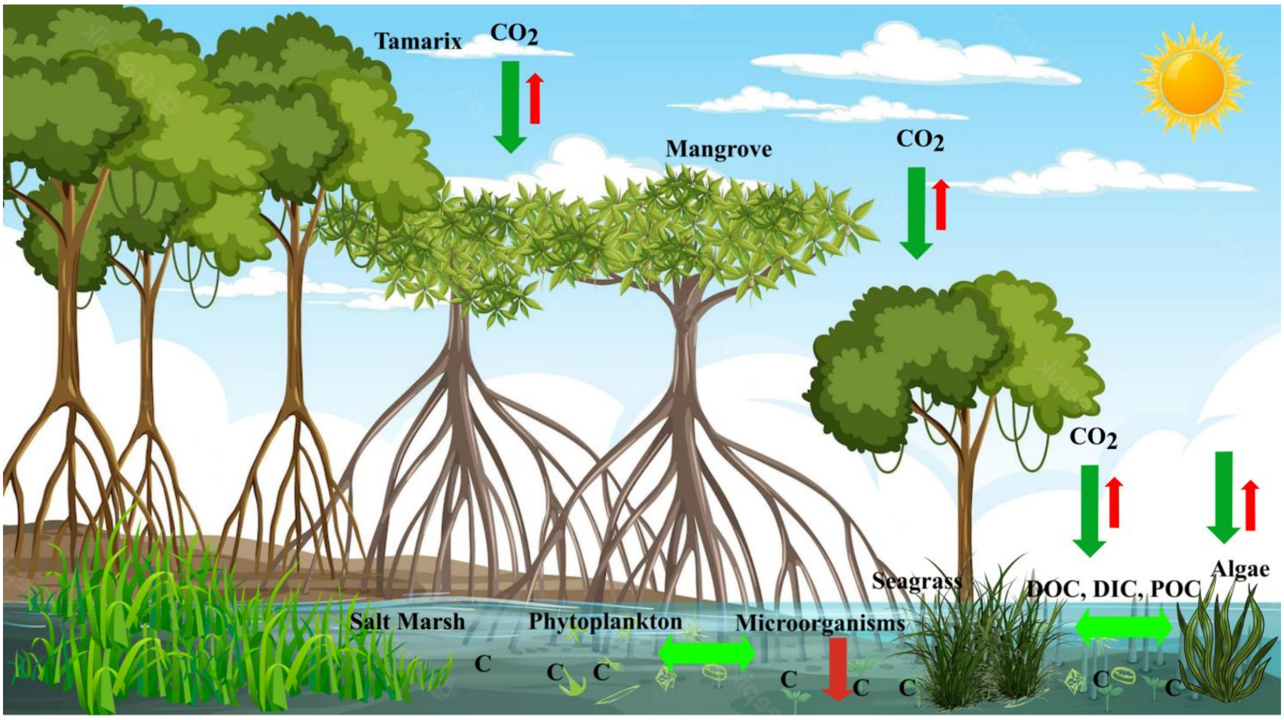


**Figure 4.** Schematic diagram of carbon exchange in blue carbon ecosystems.

Despite their importance as carbon sinks, there is concern that in some situations, they could be a source of methane emissions, which could contribute to global warming [108,109]. However, evidence shows that methane emissions from marine wetland habitats are marginal, relative to the amount of carbon sequestered [110,111]. On average, carbon stock in the uppermost meter of the soil of saltmarshes and seagrass meadows is nearly equal to that of the top 1 m soil of terrestrial forests. In comparison, the organic carbon stored by the top 1 m of mangrove forests is thrice as contained in top terrestrial soil [19]. The rate of carbon burial in the sediments of these three ecosystems is relatively large. Coastal vegetated ecosystems contribute significantly to long-term carbon sequestration, a contribution equivalent to terrestrial ecosystem carbon sinks, despite covering a smaller area than inland forests [3].

Mangrove ecosystems make up 30% of all coastal ecosystems' carbon burial and 5% of the net primary production of carbon, even though they cover just 1.9% of the tropical and subtropical coasts [26,112]. Mangroves sequester 174 $gCm^{-2}yr^{-1}$ on average, and the global mean burial amount of mangrove soil carbon is 24 $TgCyr^{-1}$ (10–15 percent of sediment carbon storage) [113]. According to a study of mangroves in desert inlets off the coast of Baja California, carbon sequestration in mangroves is most likely in the form of organic peat and soil [114,115]. It revealed nearly 2000 years of carbon storage in organic soils and below-ground carbon content of 1130 metric tonnes per hectare [115].

Salt marshes are one of the world's most active habitats (sequestering up to 3900 $gCm^{-2}yr^{-1}$). On average, salt marsh soils store around 210 $gCm^{-2}yr^{-1}$, converted to 770 g of $CO_2$ $m^{-2}yr^{-1}$ due to rapid burial rates [116,117]. The world's coastal salt marshes hold an estimated 437 to 1210 million tonnes of carbon in their trees and soil [91,115]. The top 50 cm of sediment in coastal salt marshes sequesters 430 Tg C globally. However, this is an exaggeration since most studies only look at the top meter of soil, even though organic-rich soil profiles extend several meters deep [104].

Although seagrass meadows cover less than 0.2% of the ocean's surface, annual carbon sequestration of seagrass sediments accounts for 10–15% of total ocean carbon sequestration. It is also estimated that seagrass environments sequester carbon at around 21 times the rate of tropical rainforests (43 $gCm^2yr^{-1}$) [106,118]. Seagrass meadows are expected to store 27 and 40 $TgCyr^{-1}$ in the short and long term, respectively [117,119]. Furthermore, global organic carbon accumulation in the sediments of seagrass habitats is up to 19.9 petagrams (Pg) (between 4.2 and 8.4 Pg if a more traditional approach is used) [33,102], with carbon storage lasting centuries or even millennia [33]. However, owing to the interaction of various biotic and abiotic causes, there is a significant variation in the C storage amounts fixed under seagrass beds [19,120]. Recent studies indicate that salt marshes, mangroves, and seagrasses have average carbon sink capabilities of 218 $gCm^{-2}yr^{-1}$, 226 $gCm^{-2}yr^{-1}$, and 138 $gCm^{-2}yr^{-1}$, respectively, while terrestrial forests have just 5 $gCm^{-2}yr^{-1}$ or less [3,106]. The lack of understanding about the fate of imported organic matter is to blame for the variance in estimates of coastal ecosystems' overall susceptibility to climate change [121,122].

Macroalgae (or seaweed) is an extensive and the most productive vegetated coastal ecosystem. They grow on a hard substratum where no carbon accumulation occurs because they do not have a vascular root system and stockpile a huge quantity of carbon in their above-ground living biomass [123]. They are the source of the world's highest carbon dioxide flux [124] and contribute significantly to the carbon sink of the world [107,125]. As they fail to absorb below-ground carbon relative to saltmarshes, seagrasses, and mangroves, macroalgae have been underestimated in the blue carbon domain. However, it has been stated that they play a significant role as "carbon donors", that is, they donate carbon to the receiving habitats. They export macroalgal material to the deep sea and sediments as detritus [123], thus indirectly contributing to global carbon sequestration, an assumption recently validated by the study of Ortega et al. [126] which examined the metagenomes of macroalgae. Up to 14TgC $yr^{-1}$ macroalgal carbon was found in coastal sediments and 152 TgC $yr^{-1}$ in deep-sea; so, proposed was the inclusion of macroalgae in blue carbon assessments. Another study by Queiros et al. [124] validated the entry or presence of macroalgal detritus in deep coastal sediments using bulk isotope analysis and eDNA sequencing as complementary bio-tracing techniques. They found that the study area sequesters an average of 8.75 g (0.73 mol) of macroalgal carbon per $m^2$ of deep coastal sediment every year as particulate organic carbon. The study also highlighted the role of macroalgae in helping sea-bed species during the winter months when other food supplies are scarce in contributing to carbon sequestration. Several reports have been published regarding the microalgal carbon sequestration potential being buried in marine sediments or exported to the deep sea [123,127]. Kelp forests (Ecklonia Radiata) absorb 1.3–2.8 TgC per year, according to Dexter et al. [128], accounting for almost 30% of the total blue carbon stored and sequestered over the Great Southern Reef. Studies have also shown the presence of refractive carbon compounds [129], which may be the essential organic carbon reservoir in the oceans [130]. According to some findings, organic carbon extracted from macroalgae is buried alongside organic carbon derived from seagrass [131–133]. Although macroalgae (especially kelp organisms) contribute significantly to the carbon cycle along the coast, most species and regions still lack accurate carbon fixation estimates [134,135]. More research into the methods and eventual disposal of this waste, as well as the significance of these ecosystems in the carbon cycle and as a potential source of blue carbon, is necessary [135]. Furthermore, detailed assessments of the macroalgal ecosystem's global surface area are desperately required to extend the reach of carbon sequestration research from a local to a worldwide scale [136].

Temperature affects carbon accumulation in salt marshes, seagrass meadows, and mangroves because it impacts the metabolic cycles of carbon gain via photosynthesis and carbon loss via plant and microbial respiration [3]. A slight temperature rise improves efficiency, but higher temperatures induce stress, which decreases productivity and thus carbon storage. Temperature fluctuations affect productivity and, therefore, carbon storage [137]. Increasing sea temperature also impacts seagrass habitats and their ability to retain carbon. As a case in Australia depicts, a large amount of organic carbon storage loss from seagrass has recently been recorded after a period of rising sea temperature. Ocean heatwaves have emerged as a threat to coastal ecosystems and have resulted in seagrass meadows' mortality. Arias-Ortiz et al. [138] estimated a substantial loss of seagrass carbon stocks (2–9) Tg $CO_2$ over three years, following a heatwave in Shark Bay (Western Australia).

Another climate-induced factor is rainfall [139], increasing carbon stock below-ground in tropical Mangroves, as indicated by Sanders et al. [140]. This is because most of the carbon stored in mangrove forests is contained within soils, and an increase in rainfall leads to a decline in the decomposition of organic matter [141,142]. Climate change is amplified by anthropogenic disruptions, increasing the vulnerability of coastal ecosystems. For example, the coastal squeeze and submergence of the intertidal zone's seaward edge due to rising sea levels has a big influence on coastal habitats and hence blue carbon stocks [143]. Similarly, the damming of rivers affects the sediment supply to the coastal wetlands, thus increasing the vulnerability of submergence and decreasing the tendency of sediment accretion and soil carbon accumulation [56]. Extreme weather seems to alter blue carbon supplies, but more research is needed to predict future effects. So, there is a considerable need to improve and understand how climate change affects blue carbon storage to scale up the ecological restoration, which further helps mitigate climate change.

### *3.3. Role of Blue Carbon Ecosystems in Mitigation of Microplastic Pollution*

Plastic was widely produced and employed after 1950 owing to its properties such as high water resistance, low expenses, durability, flexibility, as well as lightness [144,145]. Significantly, in 2018, plastic generation reached 359 million tons globally [146–148] and Yang et al. [149] showed that its yield is increasing by 300 million tons every year. Plastic would not entirely disappear due to the impacts of typical environmental conditions (such as temperature or salinity), ultraviolet radiation, biological activity (namely aggregation, biofilm formation, and so on), and mechanical stress that was caused by the wave as well as the current action. However, plastic would be separated into smaller pieces, weathered, corroded, etc. [150–152]. This was found especially true for coastal wetlands that received plastic waste from not only terrestrial habitats near the rivers but also the ocean via currents [153]. It was noticed that plastic debris was highly retained in low-energy environments that had weak hydrodynamics [154–156], and then plastic debris was gradually degraded to form plastic fibers, fragments, or particles with less than 5 mm in size, so-called microplastics. Microplastics were produced in the marine environment through coastal fishing activity, which was driven by currents and winds from beaches [157], and transported by rivers, sewage from industrial zones, and effluents to the coastal areas, where sewage discharges, for instance, were a necessary source of fibers from washing activity [158,159]. The accumulation of microplastics in the ecosystem could cause harm to organisms by reducing individual growth, reproduction, and adaptability [160]. Furthermore, because the size of microplastics was small and their specific surface area was large, they frequently absorbed environmental contaminants such as organic pollutants or heavy metals [161,162], which severely threatened plant and animal growth. As a result, the detrimental effects mentioned above endangered the ecosystem and primary functions of coastal wetlands including flood defense [163,164] as well as carbon sequestration [165,166]. Hence, it was critical to prevent and control microplastic contamination. The blue carbon ecosystem could highly block and intercept microplastics, which provided significant benefits [167,168].

The majority of microplastics were less than 1 mm, which included sizes of less than 0.5 mm (13.7%), in the range of 0.5–1 mm (42.9%) and 1–2 mm (24.2%). In addition, a small portion of 2–3 mm (7.8%), 4–5 mm (6.4%), and 3–4 mm (5.0%) were also observed. Thus, the small size of microplastics could be due to the fact that the smaller size made them easier to be washed to the intertidal area by the tide [169]. Noticeably, compared to in mangroves, the number of microplastics less than 1 mm in saltmarshes was found significantly greater, which was associated with the saltmarsh sediments which had larger particle sizes as plastics could be easily broken into smaller fragments via coarser sediments' abrasion during transportation [170,171]. Additionally, saltmarshes being closer to the sea in comparison with mangroves and being swept by more tidal kinetic power could also be the reason for smaller microplastics in saltmarshes [171,172]. Interestingly, coastal sediments were thought to be primary sinks of marine microplastics [155,173,174]. Besides, significant microplastic stocks were frequently observed in vegetated coastal habitats with high rates of sedimentation, including mangroves, tidal marshes, and seagrasses [160,173,175]. In addition, the abundance and features of MPs in the aforementioned habitats frequently changed between places. As reported, the range of plastic abundances in mangroves was 0 to 11,256 items kg1 sediment, in seagrass was 0 to 1466, and in a tidal marsh, sediments were 22.7 to 296. The most frequently observed forms were fragments and fibers, in which polyethene and polypropylene were the most common polymers [173].

More significantly, mangrove ecosystems were identified as important sinks for different contaminants from both marine and terrestrial activities because of the mangrove ecosystem's unique properties (such as abundant organic carbon as well as high primary productivity), [176–178]. Indeed, mangroves were important blue carbon ecosystems that were found in the subtidal and intertidal areas, where they were subjected to microplastic contamination [179]. According to previous investigations, blue carbon ecosystems were capable of capturing microplastics and POCs from surface sediments [180,181]. It was obvious that mangroves could not only clean and retain contaminants generally, but they also acted as an ecological interception system for microplastics [160]. It was noted that mangrove plants could alter hydrological conditions as well as have an effect on the microplastic separation and distribution in various tidal areas. In particular, microplastics of varying sinking rates, sizes, and shapes might exhibit distinct distribution patterns in varying mangrove intertidal zones [182–184].

It was not hard to see that seagrasses were able to reduce water flow velocity, and at the same time increase particle retention and sedimentation [185–187]. Remarkably, seagrass meadows could trap particulate matter indicating that they could also be a considerable trap for microplastics. Notably, some microplastics were integrated into the epiphytic communities that were attached to seagrass blades, so not all reached the sediment [175,188,189]. When microplastics reached the seagrass ecosystem, the seagrass blades' architectural complication as well as above-ground biomass reduced water currents, which made particulate matter, namely microplastics, get trapped among the blades and then they settled into the sediment underneath [155,190]. Besides epiphytes, known as small sessile plants including macroalgae, cyanobacteria, crustose coralline algae, diatoms that attached to seagrass blades created a rough substrate for microplastics to adhere to and be trapped. Once trapped, microplastics were overgrown with epiphytes, which kept them adhered to the blade surface, which led to an increase in the likelihood of microplastic uptake by herbivores and hence entering the food web [189]. More noticeably, with an average of approximately two items per individual, the probability of microplastics recovery in shellfish was 46.3% and in fish was 47.2% in the Mediterranean [191]. Seagrasses were not only a direct source of food for a variety of herbivores, such as sea turtles and dugongs [192], but they were also a main nursery ground for fauna living near shore [193]. Goss et al. [189] and Datu et al. [188] discovered that several microplastics on seagrass blades were included within epiphyte assemblages. Moreover, there also existed evidence showing the significant relation between microplastic abundances and epiphyte density, implying that the presence of more epiphytes on a blade and more microplastics had a direct correlation. On the other hand, several seagrass genera, such as Posidonia, were able to trap microplastics not only within their habitats but also within their exported ball-shaped wrack, implying the role of seagrasses in both trapping microplastics within their ecosystem and removing them from marine environments [194]. Furthermore, in situ research revealed a high level of plastic accumulation in seagrass ecosystems, existing both on seagrass blades and in sediment. Additionally, according to Huang et al. [179], seagrass ecosystem sediments were enriched with microplastics 1.3–17.6 times more than unvegetated sites, whereas an enrichment factor was found of up to 2.9 by Huang et al. [195]. Moreover, Goss et al. [189] discovered $4.0 \pm 2.1$ microplastics in each tropical seagrass blade. More importantly, seagrass meadows, one of the most crucial blue carbon ecosystems and wetlands, were considered important global carbon sinks that contributed to alleviating climate change around the world [196].

## 4. Blue Carbon as a Potential Source for Biofuel Production

The sustainability of the first-generation bio-based fuels (1G) was also called into doubt since their utilization threatened the traditional food supply, particularly in developing nations [197,198]. The second-generation biofuels (2G/cellulosic biofuels) which were derived from cellulosic energy crops including municipal solid wastes, lignocellulosic residues, or agro-industrial wastes, provided an alternative option because of their plentiful availability [199–204]. However, this type of fuel also coped with a lot of failures due to higher investment expenses and technical problems in down streaming. Furthermore, the generation of 1G/2G biofuels necessitated additional crop cultivation acreage, and hence they could not be viewed as a viable alternative to fossil fuels because the yield gained might not fulfil the global energy demand. In addition, the third-generation biofuels (3G/advanced biofuels) were made from aquatic biomass such as algae [205,206]. Algae gained a lot of interest among third-generation biofuels because of their low lignin concentration and high productivity, which reduced the consumption of energy throughout fuel generation [207,208]. Moreover, blue carbon sources were biomasses that were morphologically and systematically more similar to plants on the ground than seaweeds [209]. Hence, exploiting blue carbon sources appeared to be an appealing solution for renewable energy generation, avoiding the significant drawbacks related to 1G and 2G bio-derived fuels. Indeed, the biofuel production pathway from blue carbon sources could be illustrated in Figure 5.

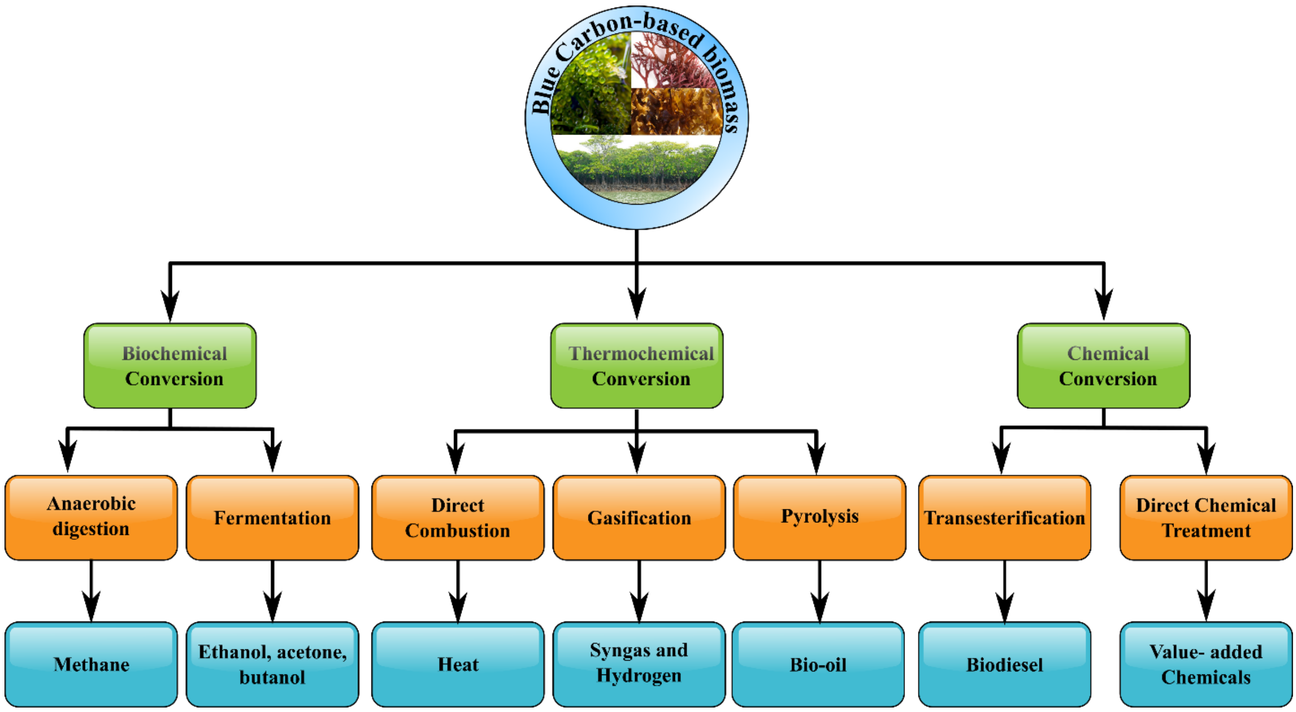


**Figure 5.** Suggested technologies for biofuel production from blue carbon sources-based biomass.

It could be seen from Figure 5 that transesterification, direct combustion, gasification, or pyrolysis were all methods for producing biofuel from dry blue carbon-based biomass [210–213]. Meanwhile, energy generation techniques from wet blue carbon-based biomass included enzyme hydrolysis, hydrothermal treatments, anaerobic digestion, and fermentation to biobutanol/bioethanol/biohydrogen [214–217]. It was noted that utilizing blue carbon-based biomass for biofuel generation was in the early stages of research and development. Besides, a lot of non-glucose-derived sugars such as cell wall polysaccharides and mannitol were accumulated in seaweed, but not so many glucose-originated polysaccharides [218]. As a result, industrial bioethanol synthesis from blue carbon-based biomass necessitated the fermentation of not only non-glucose but also glucose-based sugars [219]. For chemical compositions, the blue carbon sources and terrestrial plants differed substantially in general. For example, seaweeds have high water content (90% fresh wt), protein content (from 7 to 15% dry wt), carbohydrate content (25–50% dry wt), as well as low concentration of lipid (between 1 and 5% dry wt) in comparison with terrestrial biomass [220].

As reported, the lipid content in the blue carbon sources was low; however, their carbohydrate content was high, permitting them to be employed as a feedstock for the generation of different fermentative bio-base fuels [221]. Though fermentation facilities using macroalgae were known as relatively expensive to operate and build, they were dependable and provided large yields [222]. This is partly because of the high content of water (from 70 to 90%), the protein concentration of around 10%, and the presence of various amounts of carbohydrates [223]. Furthermore, because there was a small amount of lignin and hemicellulose in macroalgae cells, the enzymatic and chemical pretreatment stages in the production of biofuel were removed [224]. More significantly, the carbohydrate concentration of macroalgae varied greatly depending on strains, species, and cultivars. In addition, because the potential growth speed and carbohydrate concentration of the green macroalgae Ulva lactuca were high, it was thought of as a promising aquatic energy crop [225]. Regarding brown macroalgae Laminaria spp., there could be up to 55% carbohydrates in it with dry weight, principally free sugars, cellulose, hemicellulose as well as the energy storage molecules mannitol and laminarin [226]. Indeed, biohydrogen generation from blue carbon received a lot of interest because of carbohydrate-rich blue carbon. In a study by Yukesh et al. [227], they improved the generation of biohydrogen from seagrass using new ozone-linked rotor-stator homogenization. In particular, rotor-stator homogenization required 510 kJ/kg TS of specific energy to accomplish 10.45% seagrass lysis while ozone-linked rotor-stator homogenization obtained 23.7% seagrass lysis with less energy (only 212.4 kJ/kg TS) input. It was noted that the ozone-coupled rotor-stator homogenization sample's biohydrogen generation capability was evaluated and compared with using biohydrogenesis.

The generation of biogas was considered a long-time technology. Interestingly, there were multiple operational biogas systems, ranging from large-scale to small-scale and they were supplied by a variety of feedstocks such as animal wastes, agricultural products, certain residential rubbish, and sewage sludge [228,229]. Additionally, because macroalgae contained more water than terrestrial biomass (ranging between 80 and 85%), they were more suited for microbial conversion instead of thermochemical conversion [230,231]. Indeed, producing biogas from macroalgae was more technically feasible than generating biogas from other fuels because all organic components in macroalgae (such as protein, carbohydrates, and so on) could be transformed into biogas via anaerobic digestion [232,233]. Besides, a low lignocellulose concentration of macroalgae facilitated biodegradation more than that of their relative microalgae to create considerable amounts of biogas [234,235]. However, microalgae could be cultivated using pollutant water and $CO_2$ [236,237] and could be used to synthesize many types of biofuels such as bioethanol, biodiesel, and bio-oil [238–241].

Many works successfully established the practical usefulness of seaweed as a feedstock for the anaerobic digestion process. For example, the generation of biogas from marine wrack might reduce GHG emissions while also bringing economic benefits to local island people. Apart from that, Marquez et al. [242] discovered biogas generation by employing three different microbial seeds including marine sediment, marine wrack-related microflora, and manure of cow. Accordingly, the authors discovered that the average biogas generated was 1223 mL from marine wrack-related microflora, 2172 mL from marine sediment, and 551 mL from the manure of cow. Although the methane potential at 396.9 mL $CH_4$/g volatile solid was calculated using marine wrack proximate values in comparison with other feedstock, this parameter was low when the greatest methane yield of 94.33 mL $CH_4$/g volatile solid was considered. Interestingly, among the microbial seeds tested, sediment in the marine platform was found to be the most effective source of microorganisms in terms of using seawater and marine wrack biomass to produce biogas. Nonetheless, sand deposition in salinity and digesters might cause trouble in the long-term anaerobic digestion process [243,244]. As observed, several factors, including growing method, species type, harvesting time, and seaweed production per hectare all made a great contribution to the anaerobic digestion process. It was noted that the balance of material and energy, harvesting biomass cost, carbon balance, as well as expenses of creating biogas from seaweed were not evaluated [245,246]. As reported, methane yields in biogas produced from the anaerobic digestion process of blue carbon sources could be changed with biochemical composition and they were linked to ash concentration and the degree of sugars stored [234]. Therefore, to increase methane yields, Banu et al. [247] used disperser-tenside (polysorbate 80) disintegration so as to improve the biomethanation ability of seagrass (namely Syringodium isoetifolium). Indeed, dispersion-assisted tenside disintegration had a more significant influence on bio-acidification as well as biomethanation assays in terms of methane production (0.256 g/g COD) and volatile fatty acid content (1100 mg/L) when compared to dispersion disintegration, which was 0.198 g/g COD; 800 mg/L. As a result, S. isoetifolium was seen as a potential substrate for achieving third-generation biofuel targets in the foreseeable future.

Apart from that, marine algae, which contained a high concentration of hydrolyzable carbohydrates, cellulose, glucan, and galactan, might serve as a possible feedstock to produce liquid biofuels [248]. As reported, two popular liquid transportation biofuels are synthetic biodiesel, bioethanol, and biobutanol using marine macroalgae feedstock. In comparison with edible as well as lignocellulosic biomass sources, marine macroalgae biomass was gaining popularity as a renewable feedstock to produce bioethanol [234,249]. As mentioned above, macroalgae possessed a high carbohydrate concentration and low lignin [250], making them appropriate for use as a substrate in the fermentation process to generate bioethanol after hydrolysis. The current techniques for bioethanol synthesis from seaweed were separate hydrolysis and fermentation, and simultaneous saccharification and fermentation, as illustrated in Figure 6 [220,251,252]. As for separate hydrolysis and fermentation, seaweed biomass was hydrolyzed before being fermented in discrete units using yeast or bacteria [218,253]. Regarding simultaneous saccharification and fermentation, however, both fermentation and hydrolysis occurred concurrently in a single stage [254,255].

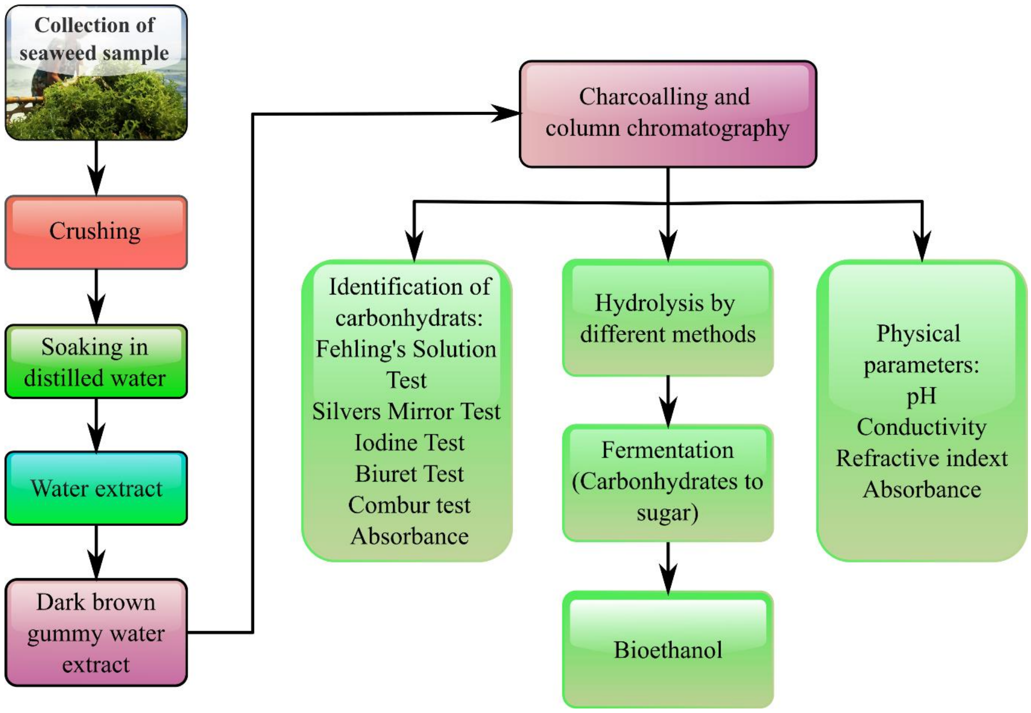


**Figure 6.** Scheme of bioethanol production from seaweed via hydrolysis and fermentation process.

Even though experiments on bioethanol generation from macroalgae were scarce, it was not hard to determine that using marine macroalgae waste for bio-derived fuel feedstock could lead to less rivalry for biofuels among food [221,256]. According to several investigations, the findings of using seagrass biowaste for bioethanol production appeared to be promising in terms of making this a reality [257–259]. In an investigation by Mahmoud et al. [260], they employed seven samples of beach-cast seagrasses (associated with *Z. marina*, *S. filiforme*, *Z. noltii*, *P. australis*, *T. testudinum*, and *P. oceanic*) gathered from maritime environments worldwide with carbohydrate concentration ranging between 73% and 81% (w/dry weight of biomass). With no pretreatment, enzymatic hydrolysis with a single step was designed to effectively extract the monomeric sugars present in biomass originating from seagrass. In shake flasks, P. oceanica hydrolysate was observed to produce higher lipid yields (at 6.8 g/L) in comparison with the synthetic minimum medium (just 5.1 g /L). Additionally, it was then used as the only fermentation medium for oleaginous yeast T. oleaginous under the technical scale with the use of a fed-batch bioreactor, yielding 224.5 g /L lipids (0.35 g /L.h). Furthermore, the proportion of sugar/lipid conversion (*w*/*w*) was seen to be 0.41. According to cumulative statistics, roughly 4 million tons of microbial oils might be created by harvesting just half of the beach-cast seagrass in the world. Besides, Ravikumar et al. [257] presented their research on manufacturing bioethanol from seagrass biowastes with the use of Saccharomyces cerevisiae. The greatest bioethanol generation (0.047 mL/g) was observed in fresh seagrass leaves under acid pretreatment. As a result, fresh seagrass leaves might be one of the appropriate substrates for bioethanol synthesis. Furthermore, an investigation by Uchida et al. [261] studied the seagrass seeds (Zostera marina) bioethanol fermentation. On a dry weight basis, there were 83.5% carbs in the seeds, which included 48.1% crude starch. This parameter was equivalent to that of cereals such as corn and wheat flour. As reported, the saccharification of seeds went smoothly with no heating pretreatment, which showed that the starch present in seagrass seeds possessed a molecular form being ready to be digested by glucoamylase. Besides, the authors proposed that it might be possible to develop alcoholic drinks and foods from seagrass seeds, resulting in the creation of a unique marine fermentation sector in the future. The treatment of *Laminaria japonica*, *Gelidium amansii*, *Ulva fasciata*, *Ulva lactuca*, and *Sargassum fulvellum* biomass with acid and hydrolytic enzymes resulted in hydrolyzates with distinct proportions of mannose, glucose, mannitol, galactose, and other sugars [262]. As reported, Laminaria japonica hydrolyzate produced 0.4 g bioethanol for each gram of carbohydrate in case hydrolytic enzymes were utilized [263]. In another study, Adams et al. [264] investigated the generation of ethanol through laminarin polysaccharide yeast fermentation from the brown macroalga *Saccharina latissimi* using a variety of pretreatments. Meanwhile, in an experiment by Wi et al. [248], fermentation pretreatments were researched for a red microalgae species (namely Ceylon moss) with a high carbohydrate concentration (normally 23% galactose and 20% glucose). Accordingly, they proved that pretreatment approaches could be utilized to broaden the range of macroalga species appropriate for bioethanol generation. Moreover, Ge et al. [265] investigated the utilization of floating residual wastes from the industry of alginate from Laminaria japonica (a brown alga) to generate bioethanol after they were pretreated with diluted sulphuric acid as well as experienced enzymatic hydrolysis. Likewise, Horn et al. [266] showed the ability of fermented extracts of *Laminaria hyporbea* to synthesize ethanol with the employment of *Pichia angophorea* (yeast), while El-Sayed et al. [267] assessed the utilization of reducing sugars from *U. lactuca* to produce bioethanol via *Saccharomyces cerevisiae*.

In the case of biobutanol, there existed just a few studies that researched the manufacture of biobutanol from macroalgae. In other words, macroalgae, especially brown algae, and their potential for biochemical transformation to butanol and other solvents by *Clostridium* spp. via acetone-butanol fermentation were not studied. However, the brown macroalgae biomass's acetone butanol fermentation feasibility via *C. acetobutylicum* was proved, and the results showed that the butanol content in the hydrolysate reached around 0.26 g butanol/g sugar while 0.29 g butanol/g sugar was obtained in the pilot investigation [268,269]. In addition, HMF was regarded as among the chemical platforms that have the most potential for the conversion of industrially important bio-originated chemical compounds. According to several researchers, a greater starch concentration was accumulated in seagrass seeds [270,271]. Moreover, several studies showed that raw biomass sources rich in non-structural carbohydrates, such as sucrose, fructose, starch, and glucose were employed as biomaterials for HMF generation [272,273]. Furthermore, by utilizing beach-cast seagrasses without feedstock expenses, seagrass feedstocks might contribute to sustainably and cost-effectively manufacturing HMF, which showed that seagrass biomasses were considered the most attractive source of bio-based feedstock to produce HMF sustainably.

Macroalgae were used to produce biogas and bioethanol instead of biodiesel since they lacked triglycerides. Typically, macroalgae were transformed into bio-derived oils such as free fatty acids and lipids, and more importantly, the lipids were separated to generate bio-based diesel. Even though free fatty acids were a precursor to biodiesel, the excessive quantity of free fatty acids in the oil might stymie the intended transformation. In an experiment, Tamilarasan [274] esterified the free fatty acids in *Enteromorpha compressa* algal oil from 6.3% to 0.34%, and subsequently, two stages for biodiesel synthesis were developed.

More notably, Xu [275] recently tried to use macroalgae as a carbon source for oleaginous yeast aiming to create bio-based diesel, and the maximal lipid concentration was observed to reach 48.30%. In contrast, the by-product-free fatty acids accompanying mannitol could be utilized to cultivate the oleaginous yeast. Also, several innovative approaches, such as ultrasonic irradiation, were employed to support transesterification through the formation of fine emulsions between alcohol and oil, and the rate of reaction was enhanced due to cavitation [274]. Furthermore, biodiesel output from wet biomass achieved was nearly 10 times lower compared to that obtained from dry biomass, suggesting that water had a detrimental influence on transesterification experiments, and hence the dehydration process was required to attain high efficiency [276]. Moreover, Saengsawang et al. [277] investigated whether Rhizoclonium sp. oil could be employed as a biodiesel alternative to optimize the reaction conditions required for the process of chemical transesterification. The biodiesel weight of $0.174 \pm 0.034$ g along with 82.2% of the whole FAME was produced during the transesterification procedure from macroalgae oil. Besides, this research indicated that biodiesel produced from Rhizoclonium might be utilized as an alternative fuel, and more research would make it appropriate for large-scale manufacturing.

Thermochemical techniques are also considered potential solutions for converting biomass sources into biofuels [278–280]. Indeed, pyrolysis was the most used technique for extracting bio-oil [230,281]. Pyrolytic cracking could quickly transform dried seaweed biomass into bio-originated oil and solid residue. Furthermore, investigations on the behaviors of pyrolysis and product properties of some macroalgae, such as brown algae, green algae, and red algae [238,282], revealed that the macroalgae's pyrolysis process to produce biofuels and that of terrestrial plants were alike [283,284], even though the macroalgae had higher activation energy than that of terrestrial biomass [285]. Importantly, pyrolysis of macroalgae operating under 500 °C was shown to be a favorable temperature for maximizing bio-oil output [254,286]. Liquefaction was seen as a process where biomass experienced complex thermochemical reactions in a solvent solution, resulting in mostly liquid products. Remarkably, hydrothermal liquefaction mostly neglected macroalgae in the role of a feedstock for bio-originated oil since microalgae were assumed to have a greater lipid concentration intrinsically [287,288]. Elliott et al. [289] reported on the hydrothermal liquefaction of Macrocystis sp. with the employment of a batch reactor that was fed with 10% kelp dry mass in water. According to the oil product's solvent separation, an oil yield of 19.2 wt% was observed. Utilizing $Na_2CO_3$ as a catalyst, Zhou et al. [290] investigated the hydrothermal liquefaction of the green marine macroalgae named *Enteromorpha prolifera* and got a maximal bio-oil output of 23.0% dw as well as an energy density of 29.89 MJ/kg. In another study, Neveux et al. [291] used hydrothermal liquefaction in a batch reactor to convert six types of freshwater and marine green macroalgae into bio-crude. The findings showed that the high ash concentration of macroalgae caused poorer bio-oil yields when compared to the results achieved from hydrothermal liquefaction of a variety of microalgae (in the range of 26–57% dw) [292]. Although the gasification of biomass on a wide scale was successfully demonstrated, it was still comparatively costly in contrast to fossil-fuel energy [293,294]. Indeed, gasification was able to generate hydrogen and syngas at a competitive price in the market. Actually, several nations had very few pilot gasification factories, more widespread industrial penetration appeared to be dependent on integration into the chain of biofuel from seaweed [295]. Table 1 compared and showed the benefits and drawbacks of several biofuel generation methods from blue carbon sources.

**Table 1.** Advantages and disadvantages of various processing techniques for converting blue carbon to biofuels [220,296–300].

| Processing Techniques | Target Products | Benefits | Drawbacks |
|---|---|---|---|
| Anaerobic digestion | Biogas | Finishing technology without drying process | High inhibition and salt |
| Fermentation | Bioethanol/biobutanol | High content of carbohydrate | Low efficiency in forming various mixed sugars |
| Transesterification | Biodiesel | No required the dewatering process | Low yield |
| Pyrolysis/Gasification/Liquefaction | Bio-oil, syngas, hydrogen, bio-char | Fast rate without required chemicals | High energy consumption |

## 5. Global Blue Carbon Framework for Climate Change Mitigation

The blue carbon systems enhance climate mitigation strategies as these ecosystems store carbon for the long term. The same is recognized in global agreements on climate change such as the "United Nations Framework Convention on Climate Change" and "Kyoto Protocol". It helps countries hit pollution reduction goals and comply with the Paris Agreement's Nationally Appropriate Contributions [301]. Clean development mechanisms are being established to finance the blue carbon initiative at the local level. It was also included in the 2017 Sixth Climate Change Assessment Report by the IPCC.

The international blue carbon initiative is the world's first coordinated global program, launched jointly by the Intergovernmental Oceanographic Commission of UNESCO, Conservation International, and the IUCN to combat climate change by protecting and restoring the ocean. The initiative is coordinating two working groups, the International Blue Carbon Scientific Working Group and the International Blue Carbon Policy Working Gropu. International standards for blue carbon monitoring and measurement, data collection and quality control, field survey guides, blue carbon preservation strategies, and management recommendations have been established by the International Blue Carbon Scientific Working Group. The International Blue Carbon Policy Working Group is committed to incorporating blue carbon projects into the UNFCCC and the CBD. It formulates financial support, and other policy programs and guides needed for research, projects, and policy priorities.

Nationally Determined Contributions (NDCs) for climate change mitigation and adaptation have included blue carbon ecosystems because of their role in increasing coastal vulnerability to climate change and weather catastrophes. The benefits of ecosystem flood management are also significant, with mangroves being anticipated to offer yearly flood protection worth US$65bn, saving 15 million people from flood risk. Mangroves, seagrasses, and saltmarsh inside the Coral Triangles are exceptionally delicate to rising sea levels and are likewise being menaced by climate change. For example, changes such as coastal ecosystem pulverization by clearing, infilling, siltation from upland catchment aggravations, and contamination from industry and metropolitan improvement, destabilize these significant ecosystems along the coast. The disruption of diverse processes at multiple geographical and temporal scales occurs as a result of climate change in blue carbon ecosystems and associated sedimentary carbon deposits. Changes in exposure, affectability and adaptation potential make blue carbon vulnerable to changing climate. Sea level rise is affecting carbon-rich silt deposits, as can be seen in the current state and growth of these stocks. Ocean level rise predictions on beachside regions are the most advanced of our insights for assessing the effects of blue carbon on climate change [56]. Changes in the environment have a direct impact on the unique blue carbon ecosystems, which are threatened by plant and soil destruction and reduced enlistment. Recently, the blue carbon initiative provided guidelines for incorporating blue carbon into NDCs. These recommendations offer technical advice for integrating these habitats into the revised

NDCs in several ways, thus assisting countries in encouraging and maintaining the climate benefits of blue carbon ecosystems.

A deltaic blue carbon frangibility, such as that seen on sea islands and atolls, may also suffer from rising sea levels and increased wave heights. When carbon in vegetation and sediments is disrupted and mineralized to carbon dioxide, the global depletion of coastal habitats causes significant carbon dioxide discharges. The potential of the surviving ecosystems to mitigate climate change and offer other environmental functions has been weakened due to their degradation. Blue carbon habitats and programs aimed at protecting them, on the other hand, are yet to be included in regulatory instruments aimed at combating climate change [302]. Owing to the dramatic changes in coastal growth and mismanagement of coastal habitats, coastal areas are being destroyed at a critical pace all over the world due to acidification, currents, anoxia, precipitation, rising sea level, storm frequency, and other changes in the environment [87].

Even though blue carbon is being more widely discussed, actual efforts and complete adoption of the actions and proposed policy proposals are still uncommon. Many nations are yet to develop and adopt climate and carbon policies specific to coastal carbon ecosystems [55]. Coastal blue carbon habitats, on the other hand, have been included in several pioneering mitigation initiatives [15,55].

## 6. Conclusions

The deterioration of coastal ecosystems can be attributed to the hazards caused by both natural events and human activities. However, it has been found that blue carbon is essential in the fight against climate change and in reducing the pollution caused by plastic and microplastics. Additionally, it helps in achieving co-benefits such as developments in aquaculture and coastal restoration, which has earned it international recognition. In addition, coastal vegetation systems such as sea grass meadows, coastal marshes, and mangroves are among the most important carbon sinks on a worldwide scale. Their ability to store organic carbon is comparable to that of forests found on land, and depending on the type of plant present, between 50 and 90% of all of the carbon in coastal wetland ecosystems is located in the soil. In addition, coastal vegetation systems have the capacity to keep and store substantial amounts of plastic and microplastic, and they also have the potential to be used as feedstock for the generation of bioenergy. According to the findings of this study, it is possible for diverse ocean ecosystems to contribute to the promotion of climate mitigation measures and the conservation of carbon stock, to the contribution of the circular economy through the use of blue carbon in the production of bioenergy, and to the mitigation of plastic and microplastic pollution. In order for conservation initiatives to be a success, local residents need to be involved in the decision-making process. Involvement in these projects provides immediate benefits, such as meaningful work and consistent income. To integrate social protection with action on climate change and economic recovery, global coalitions that result in immediate initiatives are required. This is necessary in order to rebuild and transform economies from an ecological point of view. Based on the various studies conducted on coastal ecosystems, future projects may be more focused on the potential of biofuel production from the biomass that is produced by coastal ecosystems. This will help in fighting against the increasing levels of greenhouse gases and climate change at the global level. Furthermore, there is a need for global collective efforts from various economies for the conservation and protection of coastal ecosystems so that we keep on deriving various benefits from them.

**Author Contributions:** S.A.B.: conceptualization, methodology, writing—original draft; F.A.M.: writing—reviewing and editing; I.Q.: writing—reviewing and editing; H.M.-U.-D.: writing—reviewing and editing; A.K.B.: writing—reviewing and editing; A.A.: writing—reviewing and editing; S.A.W.: writing—reviewing and editing; R.B.: writing—reviewing and editing; T.H.T.: writing—reviewing and editing; N.D.K.P.: writing—reviewing and editing; D.N.C.: writing—reviewing and editing; S.F.A.: writing-reviewing, supervision. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research received no external funding.

**Institutional Review Board Statement:** Not applicable.

**Informed Consent Statement:** Not applicable.

**Data Availability Statement:** No new data were created.

**Conflicts of Interest:** The authors declare no conflict of interest.

## References

1. Nellemann, C.; Corcoran, E.; Duarte, C.M.; Valdrés, L.; De Young, C.; Fonseca, L.; Grimsditch, G. *Blue Carbon: The Role of Healthy Oceans in Binding Carbon. A Rapid Response Assessment*; United Nations Environment Programme, GRID-Arendal: Nairobi, Kenya, 2009.
2. Duarte, C.M.; Kennedy, H.; Marbà, N.; Hendriks, I. Assessing the capacity of seagrass meadows for carbon burial: Current limitations and future strategies. *Ocean Coast. Manag.* **2013**, *83*, 32–38. [CrossRef]
3. Mcleod, E.; Chmura, G.L.; Bouillon, S.; Salm, R.; Björk, M.; Duarte, C.M. A blueprint for blue carbon: Toward an improved understanding of the role of vegetated coastal habitats in sequestering $CO_2$. *Front. Ecol. Environ.* **2011**, *9*, 552–560. [CrossRef]
4. Nguyen, H.-H.; McAlpine, C.; Pullar, D.; Johansen, K.; Duke, N.C. The relationship of spatial–temporal changes in fringe mangrove extent and adjacent land-use: Case study of Kien Giang coast, Vietnam. *Ocean Coast. Manag.* **2013**, *76*, 12–22. [CrossRef]
5. Jackson, J.B.C.; Cubit, J.D.; Keller, B.D.; Batista, V.; Burns, K.; Caffey, H.M. Ecological Effects of a Major Oil Spill on Panamanian Coastal Marine Communities. *Science* **1989**, *243*, 37–44. [CrossRef] [PubMed]
6. Mimura, N. Sea-level rise caused by climate change and its implications for society. *Proc. Jpn. Acad. Ser. B* **2013**, *89*, 281–301. [CrossRef] [PubMed]
7. Handa, I.T.; Aerts, R.; Berendse, F.; Berg, M.P.; Bruder, A.; Butenschoen, O. Consequences of biodiversity loss for litter decomposition across biomes. *Nature* **2014**, *509*, 218–221. [CrossRef]
8. Barbier, E.B.; Hacker, S.D.; Kennedy, C.; Koch, E.W.; Stier, A.C.; Silliman, B.R. The value of estuarine and coastal ecosystem services. *Ecol. Monogr.* **2011**, *81*, 169–193. [CrossRef]
9. OzCoasts. About Conceptual Diagrams 2022. Available online: https://ozcoasts.org.au/conceptual-diagrams/introduction/ (accessed on 18 March 2022).
10. Ruttenberg, B.; Granek, E. Bridging the marine–terrestrial disconnect to improve marine coastal zone science and management. *Mar. Ecol. Prog. Ser.* **2011**, *434*, 203–212. [CrossRef]
11. Wylie, L.; Sutton-Grier, A.E.; Moore, A. Keys to successful blue carbon projects: Lessons learned from global case studies. *Mar. Policy* **2016**, *65*, 76–84. [CrossRef]
12. Phang, V.X.H.; Chou, L.M.; Friess, D.A. Ecosystem carbon stocks across a tropical intertidal habitat mosaic of mangrove forest, seagrass meadow, mudflat and sandbar. *Earth Surf. Process Landf.* **2015**, *40*, 1387–1400. [CrossRef]
13. Roberts, C.M.; O'Leary, B.C.; McCauley, D.J.; Cury, P.M.; Duarte, C.M.; Lubchenco, J. Marine reserves can mitigate and promote adaptation to climate change. *Proc. Natl. Acad. Sci. USA* **2017**, *114*, 6167–6175. [CrossRef] [PubMed]
14. Hiraishi, T.; Krug, T.; Tanabe, K.; Srivastava, N.; Baasansuren, J.; Fukuda, M. *2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands*; IPCC: Geneva, Switzerland, 2014.
15. Herr, D.; Landis, E. Coastal blue carbon ecosystems. Opportunities for Nationally Determined Contributions. *Policy Brief* **2016**, 1–28.
16. Zhou, C.; Wong, K.; Zhao, J. Coastal Wetland Vegetation in Response to Global Warming and Climate Change. In *Sea Level Rise and Coastal Infrastructure*; InTech: London, UK, 2018. [CrossRef]
17. Beck, M.W.; Lange, G.M. *Guidelines for Coastal and Marine Ecosystem Accounting: Incorporating the Protective Service Values of Coral Reefs and Mangroves in National Wealth Accounts, Wealth Accounting and Valuation of Ecosystem Services*; World Bank: Washington, DC, USA, 2015; pp. 1–15.
18. Narayan, S.; Beck, M.W.; Reguero, B.G.; Losada, I.J.; van Wesenbeeck, B.; Pontee, N. The Effectiveness, Costs and Coastal Protection Benefits of Natural and Nature-Based Defences. *PLoS ONE* **2016**, *11*, e0154735. [CrossRef]
19. Duarte, C.M.; Losada, I.J.; Hendriks, I.E.; Mazarrasa, I.; Marbà, N. The role of coastal plant communities for climate change mitigation and adaptation. *Nat. Clim. Chang.* **2013**, *3*, 961–968. [CrossRef]
20. Narayan, S.; Beck, M.W.; Wilson, P.; Thomas, C.; Guerrero, A.; Shepard, C. *Coastal Wetlands and Flood Damage Reduction. Using Risk Industry-Based Models to Assess Natural Defenses in the Northeastern USA*; Loyd's Tercentenary Research Foundation: London, UK, 2012; pp. 1–23. [CrossRef]
21. Alongi, D. *The Energetics of Mangrove Forests*, 1st ed.; Springer: Dordrecht, The Netherlands, 2009. [CrossRef]
22. Bryan, T.; Virdin, J.; Vegh, T.; Kot, C.Y.; Cleary, J.; Halpin, P.N. Blue carbon conservation in West Africa: A first assessment of feasibility. *J. Coast. Conserv.* **2020**, *24*, 8. [CrossRef]
23. Giri, C.; Ochieng, E.; Tieszen, L.L.; Zhu, Z.; Singh, A.; Loveland, T. Status and distribution of mangrove forests of the world using earth observation satellite data. *Glob. Ecol. Biogeogr.* **2011**, *20*, 154–159. [CrossRef]
24. Hamilton, S.E.; Casey, D. Creation of a high spatio-temporal resolution global database of continuous mangrove forest cover for the 21st century (CGMFC-21). *Glob. Ecol. Biogeogr.* **2016**, *25*, 729–738. [CrossRef]

25. Donato, D.C.; Kauffman, J.B.; Murdiyarso, D.; Kurnianto, S.; Stidham, M.; Kanninen, M. Mangroves among the most carbon-rich forests in the tropics. *Nat. Geosci.* **2011**, *4*, 293–297. [CrossRef]
26. Alongi, D.M. The Impact of Climate Change on Mangrove Forests. *Curr. Clim. Chang. Rep.* **2015**, *1*, 30–39. [CrossRef]
27. Woodroffe, C.D.; Rogers, K.; McKee, K.L.; Lovelock, C.E.; Mendelssohn, I.A.; Saintilan, N. Mangrove Sedimentation and Response to Relative Sea-Level Rise. *Ann. Rev. Mar. Sci.* **2016**, *8*, 243–266. [CrossRef]
28. Hoque, M.M.; Abu Hena, M.K.; Ahmed, O.H.; Idris, M.H.; Hoque, A.T.M.R.; Billah, M.M. Can mangroves help combat sea level rise through sediment accretion and accumulation? *Malaysian J. Sci.* **2015**, *34*, 78–86. [CrossRef]
29. Krauss, K.W.; McKee, K.L.; Lovelock, C.E.; Cahoon, D.R.; Saintilan, N.; Reef, R. How mangrove forests adjust to rising sea level. *New Phytol.* **2014**, *202*, 19–34. [CrossRef] [PubMed]
30. Chow, J. Mangrove management for climate change adaptation and sustainable development in coastal zones. *J. Sustain. For.* **2018**, *37*, 139–156. [CrossRef]
31. Ramesh, R.; Banerjee, K.; Paneerselvam, A.; Raghuraman, R.; Purvaja, R.; Lakshmi, A. Importance of Seagrass Management for Effective Mitigation of Climate Change. *Coast. Manag.* **2019**, 283–299. [CrossRef]
32. Duarte, C.M. Reviews and syntheses: Hidden forests, the role of vegetated coastal habitats in the ocean carbon budget. *Biogeosciences* **2017**, *14*, 301–310. [CrossRef]
33. Ricart, A.M.; York, P.H.; Bryant, C.V.; Rasheed, M.A.; Ierodiaconou, D.; Macreadie, P.I. High variability of Blue Carbon storage in seagrass meadows at the estuary scale. *Sci. Rep.* **2020**, *10*, 5865. [CrossRef]
34. Charpy-Roubaud, C.; Sournia, A. The comparative estimation of phytoplanktonic, microphytobenthic and macrophytobenthic primary production in the oceans. *Mar. Microb. Food Webs* **1990**, *4*, 31–57.
35. Waycott, M.; Duarte, C.M.; Carruthers, T.J.B.; Orth, R.J.; Dennison, W.C.; Olyarnik, S. Accelerating loss of seagrasses across the globe threatens coastal ecosystems. *Proc. Natl. Acad. Sci. USA* **2009**, *106*, 12377–12381. [CrossRef]
36. Sundararaju, V. *Why We Must Conserve the World's Seagrasses*; Wildlife Biodiversity: New Delhi, India, 2020.
37. Pendleton, L.; Donato, D.C.; Murray, B.C.; Crooks, S.; Jenkins, W.A.; Sifleet, S. Estimating Global "Blue Carbon" Emissions from Conversion and Degradation of Vegetated Coastal Ecosystems. *PLoS ONE* **2012**, *7*, e43542. [CrossRef]
38. Greiner, J.T.; McGlathery, K.J.; Gunnell, J.; McKee, B.A. Seagrass restoration enhances "blue carbon" sequestration in coastal waters. *PLoS ONE* **2013**, *8*, e72469. [CrossRef]
39. Drake, K.; Halifax, H.; Adamowicz, S.C.; Craft, C. Carbon sequestration in tidal salt marshes of the Northeast United States. *Environ. Manag.* **2015**, *56*, 998–1008. [CrossRef] [PubMed]
40. Poffenbarger, H.J.; Needelman, B.A.; Megonigal, J.P. Salinity influence on methane emissions from tidal marshes. *Wetlands* **2011**, *31*, 831–842. [CrossRef]
41. Greenberg, R.; Maldonado, J.E.; Droege, S.A.M.; McDonald, M.V. Tidal marshes: A global perspective on the evolution and conservation of their terrestrial vertebrates. *Bioscience* **2006**, *56*, 675–685. [CrossRef]
42. Wang, Z.A.; Kroeger, K.D.; Ganju, N.K.; Gonneea, M.E.; Chu, S.N. Intertidal salt marshes as an important source of inorganic carbon to the coastal ocean. *Limnol. Oceanogr.* **2016**, *61*, 1916–1931. [CrossRef]
43. Mcowen, C.J.; Weatherdon, L.V.; Van Bochove, J.-W.; Sullivan, E.; Blyth, S.; Zockler, C. A global map of saltmarshes. *Biodivers. Data J.* **2017**, *5*, e11764. [CrossRef] [PubMed]
44. Duarte, C.M.; Dennison, W.C.; Orth, R.J.W.; Carruthers, T.J.B. The Charisma of Coastal Ecosystems: Addressing the Imbalance. *Estuaries Coasts* **2008**, *31*, 233–238. [CrossRef]
45. Doody, J.P. 'Coastal squeeze'—An historical perspective. *J. Coast. Conserv.* **2004**, *10*, 129–138. [CrossRef]
46. Hoang, A.T.; Nguyen, X.P.; Duong, X.Q.; Huynh, T.T. Sorbent-based devices for the removal of spilled oil from water: A review. *Environ. Sci. Pollut. Res.* **2021**, *28*, 28876–28910. [CrossRef]
47. Wang, H.; Liu, Z.; Wang, X.; Graham, T.; Wang, J. An analysis of factors affecting the severity of marine accidents. *Reliab. Eng. Syst. Saf.* **2021**, *210*, 107513. [CrossRef]
48. Ghasemi, O.; Mehrdadi, N.; Baghdadi, M.; Aminzadeh, B.; Ghaseminejad, A. Spilled oil absorption from Caspian sea water by graphene/chitosan nano composite. *Energy Sources Part A Recover. Util. Environ. Eff.* **2020**, *42*, 2856–2872. [CrossRef]
49. Defeo, O.; McLachlan, A.; Schoeman, D.S.; Schlacher, T.A.; Dugan, J.; Jones, A. Threats to sandy beach ecosystems: A review. *Estuar. Coast. Shelf Sci.* **2009**, *81*, 1–12. [CrossRef]
50. Spalding, M.D.; Ruffo, S.; Lacambra, C.; Meliane, I.; Hale, L.Z.; Shepard, C.C. The role of ecosystems in coastal protection: Adapting to climate change and coastal hazards. *Ocean Coast. Manag.* **2014**, *90*, 50–57. [CrossRef]
51. Chisholm, J.R.M.; Barnes, D.J. Anomalies in coral reef community metabolism and their potential importance in the reef $CO_2$ source-sink debate. *Proc. Natl. Acad. Sci. USA* **1998**, *95*, 6566–6569. [CrossRef] [PubMed]
52. Kench, P.S.; Brander, R.W. Wave Processes on Coral Reef Flats: Implications for Reef Geomorphology Using Australian Case Studies. *J. Coast. Res.* **2006**, *221*, 209–223. [CrossRef]
53. Monismith, S.G. Hydrodynamics of Coral Reefs. *Annu. Rev. Fluid Mech.* **2007**, *39*, 37–55. [CrossRef]
54. Geraldi, N.R.; Ortega, A.; Serrano, O.; Macreadie, P.I.; Lovelock, C.E.; Krause-Jensen, D. Fingerprinting Blue Carbon: Rationale and Tools to Determine the Source of Organic Carbon in Marine Depositional Environments. *Front. Mar. Sci.* **2019**, *6*, 263. [CrossRef]
55. Herr, D.; von Unger, M.; Laffoley, D.; McGivern, A. Pathways for implementation of blue carbon initiatives. *Aquat. Conserv. Mar. Freshw. Ecosyst.* **2017**, *27*, 116–129. [CrossRef]

56. Lovelock, C.E.; Reef, R. Variable Impacts of Climate Change on Blue Carbon. *One Earth* **2020**, *3*, 195–211. [CrossRef]
57. García-Oliver, J.M.; Novella, R.; Micó, C.; Bin-Khalid, U. A numerical investigation of the performance of oxymethylene ethers blended with fossil diesel to reduce soot emissions in compression ignition engines. *Fuel* **2022**, *324*, 124768. [CrossRef]
58. Bakır, H.; Ağbulut, Ü.; Gürel, A.E.; Yıldız, G.; Güvenç, U.; Soudagar, M.E.M. Forecasting of future greenhouse gas emissions trajectory for India using energy and economic indexes with various metaheuristic algorithms. *J. Clean Prod.* **2022**, *360*, 131946. [CrossRef]
59. Wang, X.; Yan, L. Driving factors and decoupling analysis of fossil fuel related-carbon dioxide emissions in China. *Fuel* **2022**, *314*, 122869. [CrossRef]
60. Chia, S.R.; Nomanbhay, S.; Ong, M.Y.; Bin, S.A.H.; Chew, K.W.; Show, P.L. Renewable diesel as fossil fuel substitution in Malaysia: A review. *Fuel* **2022**, *314*, 123137. [CrossRef]
61. Szeto, W.; Leung, D.Y.C. Is hydrotreated vegetable oil a superior substitute for fossil diesel? A comprehensive review on physicochemical properties, engine performance and emissions. *Fuel* **2022**, *327*, 125065. [CrossRef]
62. Sharma, S.; Zhang, M.; Anshika Gao, J.; Zhang, H.; Kota, S.H. Effect of restricted emissions during COVID-19 on air quality in India. *Sci. Total Environ.* **2020**, *728*, 138878. [CrossRef]
63. Chowdhury, S.; Gaur, A.; Mohapatra, S.; Verma, S.; Mishra, S.; Dwivedi, G. Environmental pollution analysis during the lockdown imposed due to COVID-19: A case study. *Energy Sources Part A Recover. Util. Environ. Eff.* **2022**, *44*, 4679–4692. [CrossRef]
64. Nguyen, X.P.; Hoang, A.T.; Ölçer, A.I.; Huynh, T.T. Record decline in global $CO_2$ emissions prompted by COVID-19 pandemic and its implications on future. *Energy Sources Part A Recover. Util. Environ. Eff.* 2021. [CrossRef]
65. Hampo, C.C.; Ojo, D.O.; Olatunde, D.E.; Isioma, O.J.; Oni, O.O.; Echendu, A.J. Life cycle assessment of renewable energy technologies in Northern Africa: A critical review. *Energy Sources Part A Recover. Util. Environ. Eff.* **2022**, *44*, 10248–10269. [CrossRef]
66. Akarsu, B.; Serdar Genç, M. Optimization of electricity and hydrogen production with hybrid renewable energy systems. *Fuel* **2022**, *324*, 124465. [CrossRef]
67. Huang, W.; Genaro Reivan Ortiz, G.; Kuo, Y.-L.; Maneengam, A.; Nassani, A.A.; Haffar, M. The Non-linear impact of renewable energy and trade on Consumption-based carbon emissions. *Fuel* **2022**, *324*, 124423. [CrossRef]
68. Kuo, Y.; Maneengam, A.; Phan The, C.; Binh An, N.; Nassani, A.A.; Haffar, M. Fresh evidence on environmental quality measures using natural resources, renewable energy, non-renewable energy and economic growth for 10 Asian nations from CS-ARDL technique. *Fuel* **2022**, *320*, 123914. [CrossRef]
69. Nochta, T.; Skelcher, C. Network governance in low-carbon energy transitions in European cities: A comparative analysis. *Energy Policy* **2020**, *138*, 111298. [CrossRef]
70. Ramamoorthi, P.; Ramasamy, K.; Muthusamy, S. A variable wind harvesting based induction generator using variable voltage and variable frequency converter for renewable energy applications. *Energy Sources Part A Recover. Util. Environ. Eff.* **2022**, *44*, 8427–8444. [CrossRef]
71. Shahavi, M.H.; Esfilar, R.; Golestani, B.; Sadeghi Sadeghabad, M.; Biglaryan, M. Comparative study of seven agricultural wastes for renewable heat and power generation using integrated gasification combined cycle based on energy and exergy analyses. *Fuel* **2022**, *317*, 123430. [CrossRef]
72. Hoang, A.T.; Sandro, N.i.ž.e.t.i.ć.; Olcer, A.I.; Ong, H.C.; Chen, W.-H.; Chong, C.T. Impacts of COVID-19 pandemic on the global energy system and the shift progress to renewable energy: Opportunities, challenges, and policy implications. *Energy Policy* **2021**, *154*, 112322. [CrossRef]
73. Zhang, Y.; Anoopkumar, A.N.; Aneesh, E.M.; Pugazhendhi, A.; Binod, P.; Kuddus, M. Advancements in the energy-efficient brine mining technologies as a new frontier for renewable energy. *Fuel* **2023**, *335*, 127072. [CrossRef]
74. Ayenew, E.; Berhanu, M. Application of artificial intelligent technique to maximize power yielding ability of wind turbine. *Energy Sources Part A Recover. Util. Environ. Eff.* **2022**, *44*, 2115–2132. [CrossRef]
75. Mohanan, J.N.; Kumaravel, S.; Ashok, S. Diffuser augmented wind turbines—A case study for hybrid energy system applications and comparison with horizontal axis wind turbines. *Energy Sources Part A Recover. Util. Environ. Eff.* **2022**, *44*, 6807–6822. [CrossRef]
76. Killingtveit, Å. Hydropower. In *Managing Global Warming*; Elsevier: Amsterdam, The Netherlands, 2019; pp. 265–315. [CrossRef]
77. Kumar Singh, S.; Mittal, M.K.; Sharma, D. Thermal performance enhancement of basin-type solar still coupled with mini solar pond and shallow solar pond in closed-cycle mode. *Energy Sources Part A Recover. Util. Environ. Eff.* **2022**, *44*, 7237–7251. [CrossRef]
78. Hoang, A.T. Prediction of the density and viscosity of biodiesel and the influence of biodiesel properties on a diesel engine fuel supply system. *J. Mar. Eng. Technol.* **2021**, *20*, 299–311. [CrossRef]
79. Vávrová, K.; Solcova, O.; Knápek, J.; Weger, J.; Soukup, K.; Humešová, T. Economic evaluation of Hemp's (Cannabis sativa) residual biomass for production of direct energy or biochar. *Fuel* **2022**, *329*, 125435. [CrossRef]
80. Soltani, M.M.; Ahmadi, P.; Ashjaee, M. Techno-economic optimization of a biomass gasification energy system with Supercritical $CO_2$ cycle for hydrogen fuel and electricity production. *Fuel* **2023**, *333*, 126264. [CrossRef]
81. Hai, T.; Alsharif, S.; Aziz, K.H.H.; Dhahad, H.A.; Kumar Singh, P. Deep learning optimization of a biomass and biofuel-driven energy system with energy storage option for electricity, cooling, and desalinated water. *Fuel* **2023**, *334*, 126024. [CrossRef]

82. Yang, C.; Kwon, H.; Bang, B.; Jeong, S.; Lee, U. Role of biomass as low-carbon energy source in the era of net zero emissions. *Fuel* **2022**, *328*, 125206. [CrossRef]
83. Mridha, B.; Ramana, G.V.; Pareek, S.; Sarkar, B. An efficient sustainable smart approach to biofuel production with emphasizing the environmental and energy aspects. *Fuel* **2023**, *336*, 126896. [CrossRef]
84. Escobedo, F.J.; Kroeger, T.; Wagner, J.E. Urban forests and pollution mitigation: Analyzing ecosystem services and disservices. *Environ. Pollut.* **2011**, *159*, 2078–2087. [CrossRef] [PubMed]
85. Gao, Y.; Yu, G.; Yang, T.; Jia, Y.; He, N.; Zhuang, J. New insight into global blue carbon estimation under human activity in land-sea interaction area: A case study of China. *Earth-Sci. Rev.* **2016**, *159*, 36–46. [CrossRef]
86. Taillardat, P.; Friess, D.A.; Lupascu, M. Mangrove blue carbon strategies for climate change mitigation are most effective at the national scale. *Biol. Lett.* **2018**, *14*, 20180251. [CrossRef]
87. Gurjar, U.R.; Naidu, B.C.; Deshmukhe, G.; Xavier, K.A.M.; Jaiswar, A.K.; Nayak, B.B. Microplastics in Shrimps: A Case Study of Mumbai Waters. In Proceedings of the International Conference on Blue Economy & Aquatic Resources, Kerala, India, 28–30 November 2019.
88. Sheehan, L.; Sherwood, E.T.; Moyer, R.P.; Radabaugh, K.R.; Simpson, S. Blue Carbon: An Additional Driver for Restoring and Preserving Ecological Services of Coastal Wetlands in Tampa Bay (Florida, USA). *Wetlands* **2019**, *39*, 1317–1328. [CrossRef]
89. Connor, R. *The United Nations World Water Development Report 2015: Water for a Sustainable World*; UNESCO publishing: Paris, France, 2015; Volume 1.
90. Zommers, Z.; van der Geest, K.; De Sherbinin, A.; Kienberger, S.; Roberts, E.; Harootunian, G. *Loss and Damage: The Role of Ecosystem Services*; United Nations Environment Programme: Nairobi, Kenya, 2016.
91. Siikamäki, J.; Sanchirico, J.N.; Jardine, S.; McLaughlin, D.; Morris, D.F. *Blue Carbon: Global Options for Reducing Emissions from the Degradation and Development of Coastal Ecosystems*; Resoucres for the Future: Washington, DC, USA, 2012; pp. 1–74.
92. Smoak, J.M.; Breithaupt, J.L.; Smith, T.J.; Sanders, C.J. Sediment accretion and organic carbon burial relative to sea-level rise and storm events in two mangrove forests in Everglades National Park. *CATENA* **2013**, *104*, 58–66. [CrossRef]
93. Langley, J.A.; McKee, K.L.; Cahoon, D.R.; Cherry, J.A.; Megonigal, J.P. Elevated $CO_2$ stimulates marsh elevation gain, counterbalancing sea-level rise. *Proc. Natl. Acad. Sci. USA* **2009**, *106*, 6182–6186. [CrossRef]
94. López-Medellín, X.; Ezcurra, E.; González-Abraham, C.; Hak, J.; Santiago, L.S.; Sickman, J.O. Oceanographic anomalies and sea-level rise drive mangroves inland in the Pacific coast of Mexico. *J. Veg. Sci.* **2011**, *22*, 143–151. [CrossRef]
95. Sanders, C.J.; Smoak, J.M.; Waters, M.N.; Sanders, L.M.; Brandini, N.; Patchineelam, S.R. Organic matter content and particle size modifications in mangrove sediments as responses to sea level rise. *Mar. Environ. Res.* **2012**, *77*, 150–155. [CrossRef] [PubMed]
96. Gonneea, M.E.; Maio, C.V.; Kroeger, K.D.; Hawkes, A.D.; Mora, J.; Sullivan, R. Salt marsh ecosystem restructuring enhances elevation resilience and carbon storage during accelerating relative sea-level rise. *Estuar. Coast. Shelf Sci.* **2019**, *217*, 56–68. [CrossRef]
97. Mudd, S.M.; Howell, S.M.; Morris, J.T. Impact of dynamic feedbacks between sedimentation, sea-level rise, and biomass production on near-surface marsh stratigraphy and carbon accumulation. *Estuar. Coast. Shelf Sci.* **2009**, *82*, 377–389. [CrossRef]
98. Traill, L.W.; Perhans, K.; Lovelock, C.E.; Prohaska, A.; McFallan, S.; Rhodes, J.R. Managing for change: Wetland transitions under sea-level rise and outcomes for threatened species. *Divers. Distrib.* **2011**, *17*, 1225–1233. [CrossRef]
99. Oliver, T.S.N.; Rogers, K.; Chafer, C.J.; Woodroffe, C.D. Measuring, mapping and modelling: An integrated approach to the management of mangrove and saltmarsh in the Minnamurra River estuary, southeast Australia. *Wetl. Ecol. Manag.* **2012**, *20*, 353–371. [CrossRef]
100. Ward, R.D.; Friess, D.A.; Day, R.H.; Mackenzie, R.A. Impacts of climate change on mangrove ecosystems: A region by region overview. *Ecosyst. Health Sustain.* **2016**, *2*, e01211. [CrossRef]
101. Duarte, C.M.; Middelburg, J.J.; Caraco, N. Major role of marine vegetation on the oceanic carbon cycle. *Biogeosciences* **2005**, *2*, 1–8. [CrossRef]
102. Fourqurean, J.W.; Duarte, C.M.; Kennedy, H.; Marbà, N.; Holmer, M.; Mateo, M.A. Seagrass ecosystems as a globally significant carbon stock. *Nat. Geosci.* **2012**, *5*, 505–509. [CrossRef]
103. Lovelock, C.E.; Feller, I.C.; Reef, R.; Hickey, S.; Ball, M.C. Mangrove dieback during fluctuating sea levels. *Sci. Rep.* **2017**, *7*, 1680. [CrossRef]
104. Howard, J.; Sutton-Grier, A.; Herr, D.; Kleypas, J.; Landis, E.; Mcleod, E. Clarifying the role of coastal and marine systems in climate mitigation. *Front. Ecol. Environ.* **2017**, *15*, 42–50. [CrossRef]
105. Zhang, Y.; Zhao, M.; Cui, Q.; Fan, W.; Qi, J.; Chen, Y. Processes of coastal ecosystem carbon sequestration and approaches for increasing carbon sink. *Sci. China Earth Sci.* **2017**, *60*, 809–820. [CrossRef]
106. Tang, J.; Ye, S.; Chen, X.; Yang, H.; Sun, X.; Wang, F. Coastal blue carbon: Concept, study method, and the application to ecological restoration. *Sci. China Earth Sci.* **2018**, *61*, 637–646. [CrossRef]
107. Duarte, C.M.; Cebrián, J. The fate of marine autotrophic production. *Limnol. Oceanogr.* **1996**, *41*, 1758–1766. [CrossRef]
108. Mitsch, W.J.; Bernal, B.; Nahlik, A.M.; Mander, Ü.; Zhang, L.; Anderson, C.J. Wetlands, carbon, and climate change. *Landsc. Ecol.* **2013**, *28*, 583–597. [CrossRef]
109. Quintana-Alcantara, C.E. Carbon Sequestration in Tidal Salt Marshes and Mangrove Ecosystems. Master's thesis, University of Sac Francisco, San Francisco, CA, USA, 2014.

110. Abril, G.; Borges, A.V. Carbon Dioxide and Methane Emissions from Estuaries. In *Greenhouse Gas Emissions—Fluxes and Processes—Hydroelectric Reservoirs and Natural Environments*; Tremblay, A., Varfalvy, L., Roehm, C., Garneau, M., Eds.; Springer: Berlin/Heidelberg, Germany, 2005; pp. 187–207. [CrossRef]
111. Livesley, S.J.; Andrusiak, S.M. Temperate mangrove and salt marsh sediments are a small methane and nitrous oxide source but important carbon store. *Estuar. Coast. Shelf Sci.* **2012**, *97*, 19–27. [CrossRef]
112. Thompson, K.; Miller, K.; Johnston, P.; Santillo, D. Storage of carbon by marine ecosystems and their contribution to climate change mitigation. *Greenpeace Res. Lab. Tech. Rep.* **2017**, 3–2017.
113. Alongi, D.M. Carbon Cycling and Storage in Mangrove Forests. *Ann. Rev. Mar. Sci.* **2014**, *6*, 195–219. [CrossRef]
114. Ezcurra, P.; Ezcurra, E.; Garcillán, P.P.; Costa, M.T.; Aburto-Oropeza, O. Coastal landforms and accumulation of mangrove peat increase carbon sequestration and storage. *Proc. Natl. Acad. Sci. USA* **2016**, *113*, 4404–4409. [CrossRef]
115. Fennessy, S.M.; Lei, G. Wetland restoration for climate change resilience. *Ramsar Brief. Note* **2018**, *10*, 1–11.
116. Chmura, G.L.; Anisfeld, S.C.; Cahoon, D.R.; Lynch, J.C. Global carbon sequestration in tidal, saline wetland soils. *Glob. Biogeochem. Cycles* **2003**, *17*, 1–12. [CrossRef]
117. Heckbert, S.; Costanza, R.; Poloczanska, E.S.; Richardson, A.J. Climate Regulation as a Service from Estuarine and Coastal Ecosystems. In *Treatise on Estuarine and Coastal Science*; Elsevier: Amsterdam, The Netherlands, 2011; pp. 199–216. [CrossRef]
118. Qiu, G.; Lin, H.-J.; Li, Z.-S.; Fan, H.-Q.; Zhou, H.-L.; Liu, G.-H. Seagrass ecosystems: Contributions to and mechanisms of carbon sequestration. *Yingyong Shengtai Xuebao* **2014**, *25*, 1825–1832. [PubMed]
119. Kennedy, H.; Björk, M. Seagrass meadows. In *The Management of Natural Coastal Carbon Sinks*; Laffoley, D., Grimsditch, G., Eds.; IUCN: Gland, Switzerland, 2009; pp. 23–29.
120. Hejnowicz, A.P.; Kennedy, H.; Rudd, M.A.; Huxham, M.R. Harnessing the climate mitigation, conservation and poverty alleviation potential of seagrasses: Prospects for developing blue carbon initiatives and payment for ecosystem service programmes. *Front. Mar. Sci.* **2015**, *2*, 32. [CrossRef]
121. Ciais, P.; Sabine, C.; Bala, G.; Bopp, L.; Brovkin, V.; Canadell, J. Carbon and other biogeochemical cycles. In *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*; Stocker, T.F., Qin, D., Plattner, G.-K., Tignor, M., Allen, S.K., Boschung, J., Nauels, A., Xia, Y., Bex, V., Midgley, P.M., Eds.; Cambridge University Press: Cambridge, UK, 2014; pp. 465–570.
122. Epple, C.; García Rangel, S.; Jenkins, M.; Guth, M. Managing ecosystems in the context of climate change mitigation: A review of current knowledge and recommendations to support ecosystem-based mitigation actions that look beyond terrestrial forests. *Tech. Ser.* **2016**, *55*.
123. Hill, R.; Bellgrove, A.; Macreadie, P.I.; Petrou, K.; Beardall, J.; Steven, A. Can macroalgae contribute to blue carbon? An Australian perspective. *Limnol. Oceanogr.* **2015**, *60*, 1689–1706. [CrossRef]
124. Queirós, A.M.; Stephens, N.; Widdicombe, S.; Tait, K.; McCoy, S.J.; Ingels, J. Connected macroalgal-sediment systems: Blue carbon and food webs in the deep coastal ocean. *Ecol. Monogr.* **2019**, *89*, e01366. [CrossRef]
125. Smith, S.V. Marine Macrophytes as a Global Carbon Sink. *Science* **1981**, *211*, 838–840. [CrossRef]
126. Ortega, A.; Geraldi, N.R.; Alam, I.; Kamau, A.A.; Acinas, S.G.; Logares, R. Important contribution of macroalgae to oceanic carbon sequestration. *Nat. Geosci.* **2019**, *12*, 748–754. [CrossRef]
127. Krause-Jensen, D.; Duarte, C.M. Substantial role of macroalgae in marine carbon sequestration. *Nat. Geosci.* **2016**, *9*, 737–742. [CrossRef]
128. Filbee-Dexter, K.; Wernberg, T. Substantial blue carbon in overlooked Australian kelp forests. *Sci. Rep.* **2020**, *10*, 12341. [CrossRef]
129. Trevathan-Tackett, S.M.; Kelleway, J.; Macreadie, P.I.; Beardall, J.; Ralph, P.; Bellgrove, A. Comparison of marine macrophytes for their contributions to blue carbon sequestration. *Ecology* **2015**, *96*, 3043–3057. [CrossRef] [PubMed]
130. Pessarrodona, A.; Moore, P.J.; Sayer, M.D.J.; Smale, D.A. Carbon assimilation and transfer through kelp forests in the NE Atlantic is diminished under a warmer ocean climate. *Glob. Chang. Biol.* **2018**, *24*, 4386–4398. [CrossRef] [PubMed]
131. Nur Hidayah, N.H.; Mohammad Rozaimi, M.R.; Mohd Nadzir, M.S. Sumber Penyumbang Karbon ke dalam Sedimen Dataran Rumput Laut di Muara Sungai Pulai, Johor, Malaysia. *Sains Malays.* **2019**, *48*, 2405–2413. [CrossRef]
132. Rozaimi, M.; Lavery, P.S.; Serrano, O.; Kyrwood, D. Long-term carbon storage and its recent loss in an estuarine Posidonia australis meadow (Albany, Western Australia). *Estuar. Coast. Shelf Sci.* **2016**, *171*, 58–65. [CrossRef]
133. Arina, N.; Raynusha, C.; Hidayah, N.; Zainee, N.F.A.; Prathep, A.; Rozaimi, M. Coralline macroalgae contribution to ecological services of carbon storage in a disturbed seagrass meadow. *Mar. Environ. Res.* **2020**, *162*, 105156. [CrossRef] [PubMed]
134. Reed, D.C.; Brzezinski, M.A. Kelp forests. In *The Management of Natural Coastal Carbon Sinks*; IUCN: Gland, Switzerland, 2009; p. 31.
135. King, N.G.; Moore, P.J.; Pessarrodona, A.; Burrows, M.T.; Porter, J.; Bue, M. Ecological performance differs between range centre and trailing edge populations of a cold-water kelp: Implications for estimating net primary productivity. *Mar. Biol.* **2020**, *167*, 137. [CrossRef]
136. Macreadie, P.I.; Anton, A.; Raven, J.A.; Beaumont, N.; Connolly, R.M.; Friess, D.A. The future of Blue Carbon science. *Nat. Commun.* **2019**, *10*, 3998. [CrossRef]
137. Ellison, J.C. How South Pacific Mangroves May Respond to Predicted Climate Change and Sea-level Rise. In *Climate Change in the South Pacific: Impacts and Responses in Australia, New Zealand, and Small Island States*, 1st ed.; Gillespie, A., Burns, W.C.G., Eds.; Springer: Dordrecht, The Netherlands, 2000; pp. 289–300. [CrossRef]

138. Arias-Ortiz, A.; Serrano, O.; Masqué, P.; Lavery, P.S.; Mueller, U.; Kendrick, G.A. A marine heatwave drives massive losses from the world's largest seagrass carbon stocks. *Nat. Clim. Chang.* **2018**, *8*, 338–344. [CrossRef]
139. Huang, P.; Xie, S.-P.; Hu, K.; Huang, G.; Huang, R. Patterns of the seasonal response of tropical rainfall to global warming. *Nat. Geosci.* **2013**, *6*, 357–361. [CrossRef]
140. Sanders, C.J.; Maher, D.T.; Tait, D.R.; Williams, D.; Holloway, C.; Sippo, J.Z. Are global mangrove carbon stocks driven by rainfall? *J. Geophys. Res. Biogeosciences* **2016**, *121*, 2600–2609. [CrossRef]
141. Lee, R.Y.; Porubsky, W.P.; Feller, I.C.; McKee, K.L.; Joye, S.B. Porewater biogeochemistry and soil metabolism in dwarf red mangrove habitats (Twin Cays, Belize). *Biogeochemistry* **2008**, *87*, 181–198. [CrossRef]
142. Lewis, D.B.; Brown, J.A.; Jimenez, K.L. Effects of flooding and warming on soil organic matter mineralization in Avicennia germinans mangrove forests and Juncus roemerianus salt marshes. *Estuar. Coast. Shelf Sci.* **2014**, *139*, 11–19. [CrossRef]
143. Schuerch, M.; Spencer, T.; Temmerman, S.; Kirwan, M.L.; Wolff, C.; Lincke, D. Future response of global coastal wetlands to sea-level rise. *Nature* **2018**, *561*, 231–234. [CrossRef] [PubMed]
144. Razeghi, N.; Hamidian, A.H.; Wu, C.; Zhang, Y.; Yang, M. Scientific studies on microplastics pollution in Iran: An in-depth review of the published articles. *Mar. Pollut. Bull.* **2021**, *162*, 111901. [CrossRef]
145. Chau, M.Q.; Hoang, A.T.; Truong, T.T.; Nguyen, X.P. Endless story about the alarming reality of plastic waste in Vietnam. *Energy Sources Part A Recover. Util. Environ. Eff.* **2020**, 1–9. [CrossRef]
146. Ya, H.; Jiang, B.; Xing, Y.; Zhang, T.; Lv, M.; Wang, X. Recent advances on ecological effects of microplastics on soil environment. *Sci. Total Environ.* **2021**, *798*, 149338. [CrossRef]
147. Huang, R.; Zhang, C.; Xu, X.; Jin, R.; Li, D.; Christakos, G. Underestimated PAH accumulation potential of blue carbon vegetation: Evidence from sedimentary records of saltmarsh and mangrove in Yueqing Bay, China. *Sci. Total Environ.* **2022**, *817*, 152887. [CrossRef]
148. Li, Q.; Su, L.; Ma, C.; Feng, Z.; Shi, H. Plastic debris in coastal macroalgae. *Environ. Res.* **2022**, *205*, 112464. [CrossRef]
149. Yang, S.; Zhou, M.; Chen, X.; Hu, L.; Xu, Y.; Fu, W. A comparative review of microplastics in lake systems from different countries and regions. *Chemosphere* **2022**, *286*, 131806. [CrossRef]
150. Cole, M.; Lindeque, P.; Halsband, C.; Galloway, T.S. Microplastics as contaminants in the marine environment: A review. *Mar. Pollut. Bull.* **2011**, *62*, 2588–2597. [CrossRef]
151. Rocha-Santos, T.; Duarte, A.C. A critical overview of the analytical approaches to the occurrence, the fate and the behavior of microplastics in the environment. *TrAC Trends Anal. Chem.* **2015**, *65*, 47–53. [CrossRef]
152. Auta, H.S.; Emenike, C.; Fauziah, S. Distribution and importance of microplastics in the marine environment: A review of the sources, fate, effects, and potential solutions. *Environ. Int.* **2017**, *102*, 165–176. [CrossRef] [PubMed]
153. Peng, G.; Zhu, B.; Yang, D.; Su, L.; Shi, H.; Li, D. Microplastics in sediments of the Changjiang Estuary, China. *Environ. Pollut.* **2017**, *225*, 283–290. [CrossRef] [PubMed]
154. Martin, C.; Almahasheer, H.; Duarte, C.M. Mangrove forests as traps for marine litter. *Environ. Pollut.* **2019**, *247*, 499–508. [CrossRef]
155. de Smit, J.C.; Anton, A.; Martin, C.; Rossbach, S.; Bouma, T.J.; Duarte, C.M. Habitat-forming species trap microplastics into coastal sediment sinks. *Sci. Total Environ.* **2021**, *772*, 145520. [CrossRef]
156. Al-Rumaihi, A.; Shahbaz, M.; Mckay, G.; Al-Ansari, T. Investigation of co-pyrolysis blends of camel manure, date pits and plastic waste into value added products using Aspen Plus. *Fuel* **2023**, *340*, 127474. [CrossRef]
157. Veerasingam, S.; Saha, M.; Suneel, V.; Vethamony, P.; Rodrigues, A.C.; Bhattacharyya, S. Characteristics, seasonal distribution and surface degradation features of microplastic pellets along the Goa coast, India. *Chemosphere* **2016**, *159*, 496–505. [CrossRef]
158. Browne, M.A.; Crump, P.; Niven, S.J.; Teuten, E.; Tonkin, A.; Galloway, T. Accumulation of Microplastic on Shorelines Woldwide: Sources and Sinks. *Environ. Sci. Technol.* **2011**, *45*, 9175–9179. [CrossRef]
159. Lebreton, L.C.M.; van der Zwet, J.; Damsteeg, J.-W.; Slat, B.; Andrady, A.; Reisser, J. River plastic emissions to the world's oceans. *Nat. Commun.* **2017**, *8*, 15611. [CrossRef]
160. Liu, X.; Liu, H.; Chen, L.; Wang, X. Ecological interception effect of mangroves on microplastics. *J. Hazard Mater.* **2022**, *423*, 127231. [CrossRef]
161. Holmes, L.A.; Turner, A.; Thompson, R.C. Interactions between trace metals and plastic production pellets under estuarine conditions. *Mar. Chem.* **2014**, *167*, 25–32. [CrossRef]
162. Bakir, A.; Rowland, S.J.; Thompson, R.C. Enhanced desorption of persistent organic pollutants from microplastics under simulated physiological conditions. *Environ. Pollut.* **2014**, *185*, 16–23. [CrossRef] [PubMed]
163. Zhu, Z.; Vuik, V.; Visser, P.J.; Soens, T.; van Wesenbeeck, B.; van de Koppel, J. Historic storms and the hidden value of coastal wetlands for nature-based flood defence. *Nat. Sustain.* **2020**, *3*, 853–862. [CrossRef]
164. Temmerman, S.; Meire, P.; Bouma, T.J.; Herman, P.M.J.; Ysebaert, T.; De Vriend, H.J. Ecosystem-based coastal defence in the face of global change. *Nature* **2013**, *504*, 79–83. [CrossRef] [PubMed]
165. Wang, F.; Sanders, C.J.; Santos, I.R.; Tang, J.; Schuerch, M.; Kirwan, M.L. Global blue carbon accumulation in tidal wetlands increases with climate change. *Natl. Sci. Rev.* **2021**, *8*, nwaa296. [CrossRef]
166. Temmink, R.J.M.; Lamers, L.P.M.; Angelini, C.; Bouma, T.J.; Fritz, C.; van de Koppel, J. Recovering wetland biogeomorphic feedbacks to restore the world's biotic carbon hotspots. *Science* **2022**, *376*, eabn1479. [CrossRef]

167. Zheng, Y.; Li, J.; Cao, W.; Jiang, F.; Zhao, C.; Ding, H. Vertical distribution of microplastics in bay sediment reflecting effects of sedimentation dynamics and anthropogenic activities. *Mar. Pollut. Bull.* **2020**, *152*, 110885. [CrossRef]
168. Mao, R.; Song, J.; Yan, P.; Ouyang, Z.; Wu, R.; Liu, S. Horizontal and vertical distribution of microplastics in the Wuliangsuhai Lake sediment, northern China. *Sci. Total Environ.* **2021**, *754*, 142426. [CrossRef]
169. Lin, L.; Pan, X.; Zhang, S.; Li, D.; Zhai, W.; Wang, Z. Distribution and source of microplastics in China's second largest reservoir—Danjiangkou Reservoir. *J. Environ. Sci.* **2021**, *102*, 74–84. [CrossRef]
170. Ding, L.; Mao, R.F.; Guo, X.; Yang, X.; Zhang, Q.; Yang, C. Microplastics in surface waters and sediments of the Wei River, in the northwest of China. *Sci. Total Environ.* **2019**, *667*, 427–434. [CrossRef]
171. Jiang, Y.; Yang, F.; Hassan Kazmi, S.S.U.; Zhao, Y.; Chen, M.; Wang, J. A review of microplastic pollution in seawater, sediments and organisms of the Chinese coastal and marginal seas. *Chemosphere* **2022**, *286*, 131677. [CrossRef]
172. Dubaish, F.; Liebezeit, G. Suspended Microplastics and Black Carbon Particles in the Jade System, Southern North Sea. *Water Air Soil Pollut.* **2013**, *224*, 1352. [CrossRef]
173. Ouyang, X.; Duarte, C.M.; Cheung, S.-G.; Tam, N.F.-Y.; Cannicci, S.; Martin, C. Fate and Effects of Macro- and Microplastics in Coastal Wetlands. *Environ. Sci. Technol.* **2022**, *56*, 2386–2397. [CrossRef] [PubMed]
174. Martin, C.; Baalkhuyur, F.; Valluzzi, L.; Saderne, V.; Cusack, M.; Almahasheer, H. Exponential increase of plastic burial in mangrove sediments as a major plastic sink. *Sci. Adv.* **2020**, *6*, eaaz5593. [CrossRef] [PubMed]
175. de los Santos, C.B.; Krång, A.-S.; Infantes, E. Microplastic retention by marine vegetated canopies: Simulations with seagrass meadows in a hydraulic flume. *Environ. Pollut.* **2021**, *269*, 116050. [CrossRef] [PubMed]
176. Bayen, S. Occurrence, bioavailability and toxic effects of trace metals and organic contaminants in mangrove ecosystems: A review. *Environ. Int.* **2012**, *48*, 84–101. [CrossRef] [PubMed]
177. Mohamed Nor, N.H.; Obbard, J.P. Microplastics in Singapore's coastal mangrove ecosystems. *Mar. Pollut. Bull.* **2014**, *79*, 278–283. [CrossRef] [PubMed]
178. Deng, H.; He, J.; Feng, D.; Zhao, Y.; Sun, W.; Yu, H. Microplastics pollution in mangrove ecosystems: A critical review of current knowledge and future directions. *Sci. Total Environ.* **2021**, *753*, 142041. [CrossRef]
179. Huang, Y.; Xiao, X.; Effiong, K.; Xu, C.; Su, Z.; Hu, J. New Insights into the Microplastic Enrichment in the Blue Carbon Ecosystem: Evidence from Seagrass Meadows and Mangrove Forests in Coastal South China Sea. *Environ. Sci. Technol.* **2021**, *55*, 4804–4812. [CrossRef]
180. Furukawa, K.; Wolanski, E.; Mueller, H. Currents and Sediment Transport in Mangrove Forests. *Estuar. Coast. Shelf Sci.* **1997**, *44*, 301–310. [CrossRef]
181. Kristensen, E.; Bouillon, S.; Dittmar, T.; Marchand, C. Organic carbon dynamics in mangrove ecosystems: A review. *Aquat Bot* **2008**, *89*, 201–219. [CrossRef]
182. Van Melkebeke, M.; Janssen, C.; De Meester, S. Characteristics and Sinking Behavior of Typical Microplastics Including the Potential Effect of Biofouling: Implications for Remediation. *Environ. Sci. Technol.* **2020**, *54*, 8668–8680. [CrossRef] [PubMed]
183. Waldschläger, K.; Schüttrumpf, H. Effects of Particle Properties on the Settling and Rise Velocities of Microplastics in Freshwater under Laboratory Conditions. *Environ. Sci. Technol.* **2019**, *53*, 1958–1966. [CrossRef]
184. Duan, J.; Han, J.; Cheung, S.G.; Chong, R.K.Y.; Lo, C.-M.; Lee, F.W.-F. How mangrove plants affect microplastic distribution in sediments of coastal wetlands: Case study in Shenzhen Bay, South China. *Sci. Total Environ.* **2021**, *767*, 144695. [CrossRef] [PubMed]
185. Butman, C.A.; Grassle, J.P.; Webb, C.M. Substrate choices made by marine larvae settling in still water and in a flume flow. *Nature* **1988**, *333*, 771–773. [CrossRef]
186. Boström, C.; Törnroos, A.; Bonsdorff, E. Invertebrate dispersal and habitat heterogeneity: Expression of biological traits in a seagrass landscape. *J. Exp. Mar. Bio Ecol.* **2010**, *390*, 106–117. [CrossRef]
187. Gacia, E.; Granata, T.; Duarte, C. An approach to measurement of particle flux and sediment retention within seagrass (Posidonia oceanica) meadows. *Aquat. Bot.* **1999**, *65*, 255–268. [CrossRef]
188. Datu, S.S.; Supriadi, S.; Tahir, A. Microplastic in Cymodocea rotundata Seagrass Blades. *Int. J. Environ. Agric. Biotechnol.* **2019**, *4*, 1758–1761. [CrossRef]
189. Goss, H.; Jaskiel, J.; Rotjan, R. Thalassia testudinum as a potential vector for incorporating microplastics into benthic marine food webs. *Mar. Pollut. Bull.* **2018**, *135*, 1085–1089. [CrossRef]
190. Miyajima, T.; Hori, M.; Hamaguchi, M.; Shimabukuro, H.; Adachi, H.; Yamano, H. Geographic variability in organic carbon stock and accumulation rate in sediments of East and Southeast Asian seagrass meadows. *Glob. Biogeochem. Cycles* **2015**, *29*, 397–415. [CrossRef]
191. Digka, N.; Tsangaris, C.; Torre, M.; Anastasopoulou, A.; Zeri, C. Microplastics in mussels and fish from the Northern Ionian Sea. *Mar. Pollut. Bull.* **2018**, *135*, 30–40. [CrossRef] [PubMed]
192. Short, F.T.; Polidoro, B.; Livingstone, S.R.; Carpenter, K.E.; Bandeira, S.; Bujang, J.S. Extinction risk assessment of the world's seagrass species. *Biol. Conserv.* **2011**, *144*, 1961–1971. [CrossRef]
193. Dahlgren, C.; Kellison, G.; Adams, A.; Gillanders, B.; Kendall, M.; Layman, C. Marine nurseries and effective juvenile habitats: Concepts and applications. *Mar. Ecol. Prog. Ser.* **2006**, *312*, 291–295. [CrossRef]
194. Sanchez-Vidal, A.; Canals, M.; de Haan, W.P.; Romero, J.; Veny, M. Seagrasses provide a novel ecosystem service by trapping marine plastics. *Sci. Rep.* **2021**, *11*, 254. [CrossRef]

195. Huang, Y.; Xiao, X.; Xu, C.; Perianen, Y.D.; Hu, J.; Holmer, M. Seagrass beds acting as a trap of microplastics—Emerging hotspot in the coastal region? *Environ. Pollut.* **2020**, *257*, 113450. [CrossRef]
196. Gullström, M.; Lyimo, L.D.; Dahl, M.; Samuelsson, G.S.; Eggertsen, M.; Anderberg, E. Blue Carbon Storage in Tropical Seagrass Meadows Relates to Carbonate Stock Dynamics, Plant–Sediment Processes, and Landscape Context: Insights from the Western Indian Ocean. *Ecosystems* **2018**, *21*, 551–566. [CrossRef]
197. Khan, S.; Naushad, M.; Iqbal, J.; Bathula, C.; Al-Muhtaseb, A.H. Challenges and perspectives on innovative technologies for biofuel production and sustainable environmental management. *Fuel* **2022**, *325*, 124845. [CrossRef]
198. Manikandan, S.; Subbaiya, R.; Biruntha, M.; Krishnan, R.Y.; Muthusamy, G.; Karmegam, N. Recent development patterns, utilization and prospective of biofuel production: Emerging nanotechnological intervention for environmental sustainability—A review. *Fuel* **2022**, *314*, 122757. [CrossRef]
199. Son Le, H.; Said, Z.; Tuan Pham, M.; Hieu Le, T.; Veza, I.; Nhanh Nguyen, V. Production of HMF and DMF biofuel from carbohydrates through catalytic pathways as a sustainable strategy for the future energy sector. *Fuel* **2022**, *324*, 124474. [CrossRef]
200. Karimi-Maleh, H.; Rajendran, S.; Vasseghian, Y.; Dragoi, E.-N. Advanced integrated nanocatalytic routes for converting biomass to biofuels: A comprehensive review. *Fuel* **2022**, *314*, 122762. [CrossRef]
201. Bamisaye, A.; Ige, A.R.; Adegoke, I.A.; Ogunbiyi, E.O.; Bamidele, M.O.; Adeleke, O. Eco-friendly de-lignified and raw Celosia argentea waste solid biofuel: Comparative studies and machine learning modelling. *Fuel* **2023**, *340*, 127412. [CrossRef]
202. Maaoui, A.; Ben Hassen Trabelsi, A.; Hamdi, M.; Chagtmi, R.; Jamaaoui, F.; Lopez, G. Towards local circular economy through Opuntia Ficus Indica cladodes conversion into renewable biofuels and biochars: Product distribution and kinetic modelling. *Fuel* **2023**, *332*, 126056. [CrossRef]
203. Tuan Hoang, A.; Nižetić, S.; Ölçer, A.I.; Chyuan Ong, H. Synthesis pathway and combustion mechanism of a sustainable biofuel 2,5-Dimethylfuran: Progress and prospective. *Fuel* **2021**, *286*, 119337. [CrossRef]
204. Bin, Y.; Yu, Z.; Huang, Z.; Li, M.; Zhang, Y.; Ma, X. Investigation on the co-pyrolysis of municipal solid waste and sawdust: Pyrolysis behaviors, kinetics, and thermodynamic analysis. *Energy Sources Part A Recover. Util. Environ. Eff.* **2022**, *44*, 8001–8011. [CrossRef]
205. Kowthaman, C.N.; Senthil Kumar, P.; Arul Mozhi Selvan, V.; Ganesh, D. A comprehensive insight from microalgae production process to characterization of biofuel for the sustainable energy. *Fuel* **2022**, *310*, 122320. [CrossRef]
206. Wu, Y.; Xu, X.; Jiang, X.; Lin, J.; Lin, X.; Zhao, S. Valorisation of harmful algae bloom (Enteromorpha prolifera) for polysaccharide and crude bio-oil production. *Fuel* **2022**, *324*, 124482. [CrossRef]
207. Ravichandran, S.R.; Venkatachalam, C.D.; Sengottian, M.; Sekar, S.; Kandasamy, S.; Ramasamy Subramanian, K.P. A review on hydrothermal liquefaction of algal biomass on process parameters, purification and applications. *Fuel* **2022**, *313*, 122679. [CrossRef]
208. Liu, J.; Zhou, F.; Abed, A.M.; Le, B.N.; Dai, L.; Elhosiny Ali, H. Macroalgae as a potential source of biomass for generation of biofuel: Artificial intelligence, challenges, and future insights towards a sustainable environment. *Fuel* **2023**, *336*, 126826. [CrossRef]
209. Orth, R.J.; Carruthers, T.J.B.; Dennison, W.C.; Duarte, C.M.; Fourqurean, J.W.; Heck, K.L. A global crisis for seagrass ecosystems. *Bioscience* **2006**, *56*, 987–996. [CrossRef]
210. Mumtaz, M.; Baqar, Z.; Hussain, N.; Afifa Bilal, M.; Azam, H.M.H. Application of nanomaterials for enhanced production of biodiesel, biooil, biogas, bioethanol, and biohydrogen via lignocellulosic biomass transformation. *Fuel* **2022**, *315*, 122840. [CrossRef]
211. Kota, K.B.; Shenbagaraj, S.; Sharma, P.K.; Sharma, A.K.; Ghodke, P.K.; Chen, W.-H. Biomass torrefaction: An overview of process and technology assessment based on global readiness level. *Fuel* **2022**, *324*, 124663. [CrossRef]
212. Wang, P.; Xu, P.; Wang, B.; Shen, C.; Shen, L. Green ammonia production via microalgae steam catalytic gasification process over $LaFeO_3$ perovskite. *Fuel* **2022**, *318*, 123322. [CrossRef]
213. Xu, D.; Lin, J.; Ma, R.; Hou, J.; Sun, S.; Ma, N. Fast pyrolysis of algae model compounds for bio-oil: In-depth insights into the volatile interaction mechanisms based on DFT calculations. *Fuel* **2023**, *333*, 126449. [CrossRef]
214. Agrawal, R.; Bhadana, B.; Singh Chauhan, P.; Adsul, M.; Kumar, R.; Gupta, R.P. Understanding the effects of low enzyme dosage and high solid loading on the enzyme inhibition and strategies to improve hydrolysis yields of pilot scale pretreated rice straw. *Fuel* **2022**, *327*, 125114. [CrossRef]
215. Yuan, C.; Zhao, S.; Ni, J.; He, Y.; Cao, B.; Hu, Y. Integrated route of fast hydrothermal liquefaction of microalgae and sludge by recycling the waste aqueous phase for microalgal growth. *Fuel* **2023**, *334*, 126488. [CrossRef]
216. Marín, D.; Méndez, L.; Suero, I.; Díaz, I.; Blanco, S.; Fdz-Polanco, M. Anaerobic digestion of food waste coupled with biogas upgrading in an outdoors algal-bacterial photobioreactor at pilot scale. *Fuel* **2022**, *324*, 124554. [CrossRef]
217. Germec, M.; Karhan, M.; Demirci, A.; Turhan, I. Kinetic modeling, sensitivity analysis, and techno-economic feasibility of ethanol fermentation from non-sterile carob extract-based media in Saccharomyces cerevisiae biofilm reactor under a repeated-batch fermentation process. *Fuel* **2022**, *324*, 124729. [CrossRef]
218. Murphy, F.; Devlin, G.; Deverell, R.; McDonnell, K. Biofuel production in Ireland—An approach to 2020 targets with a focus on algal biomass. *Energies* **2013**, *6*, 6391–6412. [CrossRef]
219. Mushlihah, S.; Langford, A.; Tassakka, A.C.M.A.R. Ozonolysis as an effective pretreatment strategy for bioethanol production from marine algae. *BioEnergy Res.* **2020**, *13*, 1269–1279.

220. Sudhakar, K.; Mamat, R.; Samykano, M.; Azmi, W.H.; Ishak, W.F.W.; Yusaf, T. An overview of marine macroalgae as bioresource. *Renew Sustain. Energy Rev.* **2018**, *91*, 165–179. [CrossRef]
221. El-Sheekh, M.M.; Ibrahim, H.A.H.; Barakat, K.M.; Shaltout, N.A.; Sayed, W.M.M.E.L.; Abou-Shanab, R.A.I. *Potential of Marine Biota and Bio-Waste Materials as Feedstock for Biofuel Production*; Waste Management; CRC Press: Boca Raton, FL, USA, 2022; pp. 123–139.
222. Hannon, M.; Gimpel, J.; Tran, M.; Rasala, B.; Mayfield, S. Biofuels from algae: Challenges and potential. *Biofuels* **2010**, *1*, 763–784. [CrossRef] [PubMed]
223. Quiroz-Arita, C.; Shinde, S.; Kim, S.; Monroe, E.; George, A.; Quinn, J.C. Bioproducts from high-protein algal biomass: An economic and environmental sustainability review and risk analysis. *Sustain. Energy Fuels* **2022**, *6*, 2398–2422. [CrossRef]
224. Özçimen, D.; Inan, B. An Overview of Bioethanol Production From Algae. In *Biofuels—Status and Perspective*; InTech: London, UK, 2015. [CrossRef]
225. Bruhn, A.; Dahl, J.; Nielsen, H.B.; Nikolaisen, L.; Rasmussen, M.B.; Markager, S. Bioenergy potential of Ulva lactuca: Biomass yield, methane production and combustion. *Bioresour Technol.* **2011**, *102*, 2595–2604. [CrossRef] [PubMed]
226. Chelf, P.; Brown, L.M.; Wyman, C.E. Aquatic biomass resources and carbon dioxide trapping. *Biomass Bioenergy* **1993**, *4*, 175–183. [CrossRef]
227. Kannah, R.Y.; Kavitha, S.; Gunasekaran, M.; Kumar, G.; Banu, J.R.; Zhen, G. Biohydrogen production from seagrass via novel energetically efficient ozone coupled rotor stator homogenization. *Int. J. Hydrogen Energy* **2020**, *45*, 5881–5889. [CrossRef]
228. Demirbas, A. Use of algae as biofuel sources. *Energy Convers Manag.* **2010**, *51*, 2738–2749. [CrossRef]
229. Alnaqi, A.A.; Alsarraf, J.; Al-Rashed, A.A.A.A. The waste heat of a biofuel-powered SOFC for green hydrogen production using thermochemical cycle; Economic, environmental analysis, and tri-criteria optimization. *Fuel* **2023**, *335*, 126599. [CrossRef]
230. Fakayode, O.A.; Wahia, H.; Zhang, L.; Zhou, C.; Ma, H. State-of-the-art co-pyrolysis of lignocellulosic and macroalgae biomass feedstocks for improved bio-oil production—A review. *Fuel* **2023**, *332*, 126071. [CrossRef]
231. Yameen, M.Z.; AlMohamadi, H.; Naqvi, S.R.; Noor, T.; Chen, W.-H.; Amin, N.A.S. Advances in production & activation of marine macroalgae-derived biochar catalyst for sustainable biodiesel production. *Fuel* **2023**, *337*, 127215. [CrossRef]
232. Yaashikaa, P.R.; Keerthana Devi, M.; Senthil Kumar, P. Algal biofuels: Technological perspective on cultivation, fuel extraction and engineering genetic pathway for enhancing productivity. *Fuel* **2022**, *320*, 123814. [CrossRef]
233. Nanda, M.; Jaiswal, K.K.; Negi, J.; de Farias Neves, F.; Ranjitha, J.; Vlaskin, M.S. A sustainable approach to produce yeast lipid by utilizing marine macroalgae biomass. *Fuel* **2023**, *338*, 127214. [CrossRef]
234. Chen, H.; Zhou, D.; Luo, G.; Zhang, S.; Chen, J. Macroalgae for biofuels production: Progress and perspectives. *Renew Sustain. Energy Rev.* **2015**, *47*, 427–437. [CrossRef]
235. Andrade, C.; Martins, P.L.; Duarte, L.C.; Oliveira, A.C.; Carvalheiro, F. Development of an innovative macroalgae biorefinery: Oligosaccharides as pivotal compounds. *Fuel* **2022**, *320*, 123780. [CrossRef]
236. Kim, S.; Kim, M.; Chang, Y.K.; Kim, D. Lipid production under a nutrient-sufficient condition outperforms starvation conditions due to a natural polarization of lipid content in algal biofilm. *Fuel* **2022**, 126902. [CrossRef]
237. Peter, A.P.; Chew, K.W.; Pandey, A.; Lau, S.Y.; Rajendran, S.; Ting, H.Y. Artificial intelligence model for monitoring biomass growth in semi-batch Chlorella vulgaris cultivation. *Fuel* **2023**, *333*, 126438. [CrossRef]
238. Sathya, A.B.; Thirunavukkarasu, A.; Nithya, R.; Nandan, A.; Sakthishobana, K.; Kola, A.K. Microalgal biofuel production: Potential challenges and prospective research. *Fuel* **2023**, *332*, 126199. [CrossRef]
239. Khan, S.; Naushad, M.; Iqbal, J.; Bathula, C.; Sharma, G. Production and harvesting of microalgae and an efficient operational approach to biofuel production for a sustainable environment. *Fuel* **2022**, *311*, 122543. [CrossRef]
240. Siddiki, S.Y.A.; Mofijur, M.; Kumar, P.S.; Ahmed, S.F.; Inayat, A.; Kusumo, F. Microalgae biomass as a sustainable source for biofuel, biochemical and biobased value-added products: An integrated biorefinery concept. *Fuel* **2022**, *307*, 121782. [CrossRef]
241. Thanigaivel, S.; Priya, A.K.; Dutta, K.; Rajendran, S.; Vasseghian, Y. Engineering strategies and opportunities of next generation biofuel from microalgae: A perspective review on the potential bioenergy feedstock. *Fuel* **2022**, *312*, 122827. [CrossRef]
242. Marquez, G.P.B.; Reichardt, W.T.; Azanza, R.V.; Klocke, M.; Montaño, M.N.E. Thalassic biogas production from sea wrack biomass using different microbial seeds: Cow manure, marine sediment and sea wrack-associated microflora. *Bioresour Technol.* **2013**, *133*, 612–617. [CrossRef]
243. Pechsiri, J.S.; Thomas, J.-B.E.; Risén, E.; Ribeiro, M.S.; Malmström, M.E.; Nylund, G.M. Energy performance and greenhouse gas emissions of kelp cultivation for biogas and fertilizer recovery in Sweden. *Sci. Total Environ.* **2016**, *573*, 347–355. [CrossRef] [PubMed]
244. Costa, J.C.; Gonçalves, P.R.; Nobre, A.; Alves, M.M. Biomethanation potential of macroalgae Ulva spp. and Gracilaria spp. and in co-digestion with waste activated sludge. *Bioresour Technol.* **2012**, *114*, 320–326. [CrossRef] [PubMed]
245. Peu, P.; Sassi, J.-F.; Girault, R.; Picard, S.; Saint-Cast, P.; Béline, F. Sulphur fate and anaerobic biodegradation potential during co-digestion of seaweed biomass (Ulva sp.) with pig slurry. *Bioresour Technol.* **2011**, *102*, 10794–10802. [CrossRef]
246. Thakur, N.; Salama, E.-S.; Sharma, M.; Sharma, P.; Sharma, D.; Li, X. Efficient utilization and management of seaweed biomass for biogas production. *Mater Today Sustain.* **2022**, *18*, 100120. [CrossRef]
247. Banu, J.R.; Tamilarasan, K.; Rani, R.U.; Gunasekaran, M.; Cho, S.-K.; Ala'a, H. Dispersion aided tenside disintegration of seagrass Syringodium isoetifolium: Towards biomethanation, kinetics, energy exploration and evaluation. *Bioresour Technol.* **2019**, *277*, 62–67. [CrossRef]

248. Wi, S.G.; Kim, H.J.; Mahadevan, S.A.; Yang, D.-J.; Bae, H.-J. The potential value of the seaweed Ceylon moss (Gelidium amansii) as an alternative bioenergy resource. *Bioresour Technol.* **2009**, *100*, 6658–6660. [CrossRef]
249. Alam, S.N.; Khalid, Z.; Guldhe, A.; Singh, B.; Korstad, J. Harvesting and pretreatment techniques of aquatic macrophytes and macroalgae for production of biofuels. *Environ. Sustain.* **2021**, *4*, 299–316. [CrossRef]
250. Abomohra, A.E.-F.; El-Naggar, A.H.; Baeshen, A.A. Potential of macroalgae for biodiesel production: Screening and evaluation studies. *J. Biosci Bioeng* **2018**, *125*, 231–237. [CrossRef]
251. Jambo, S.A.; Abdulla, R.; Azhar, S.H.M.; Marbawi, H.; Gansau, J.A.; Ravindra, P. A review on third generation bioethanol feedstock. *Renew Sustain. Energy Rev.* **2016**, *65*, 756–769. [CrossRef]
252. Bibi, R.; Ahmad, Z.; Imran, M.; Hussain, S.; Ditta, A.; Mahmood, S. Algal bioethanol production technology: A trend towards sustainable development. *Renew Sustain. Energy Rev.* **2017**, *71*, 976–985. [CrossRef]
253. Maceiras, R.; Rodrı, M.; Cancela, A.; Urréjola, S.; Sánchez, A. Macroalgae: Raw material for biodiesel production. *Appl. Energy* **2011**, *88*, 3318–3323. [CrossRef]
254. Li, R.; Zhong, Z.; Jin, B.; Zheng, A. Selection of temperature for bio-oil production from pyrolysis of algae from lake blooms. *Energy Fuels* **2012**, *26*, 2996–3002. [CrossRef]
255. Ye Lee, J.; Li, P.; Lee, J.; Ryu, H.J.; Oh, K.K. Ethanol production from Saccharina japonica using an optimized extremely low acid pretreatment followed by simultaneous saccharification and fermentation. *Bioresour. Technol.* **2013**, *127*, 119–125. [CrossRef] [PubMed]
256. Jeyakumar, N.; Hoang, A.T.; Nižetić, S.; Balasubramanian, D.; Kamaraj, S.; Pandian, P.L. Experimental investigation on simultaneous production of bioethanol and biodiesel from macro-algae. *Fuel* **2022**, *329*, 125362. [CrossRef]
257. Ravikumar, S.; Gokulakrishnan, R.; Kanagavel, M.; Thajuddin, N. Production of biofuel ethanol from pretreated seagrass by using Saccharomyces cerevisiae. *Indian J. Sci. Technol.* **2011**, *4*, 1087–1089. [CrossRef]
258. Viola, E.; Cardinale, M.; Santarcangelo, R.; Villone, A.; Zimbardi, F. Ethanol from eel grass via steam explosion and enzymatic hydrolysis. *Biomass Bioenergy* **2008**, *32*, 613–618. [CrossRef]
259. Harley, C.D.G.; Anderson, K.M.; Demes, K.W.; Jorve, J.P.; Kordas, R.L.; Coyle, T.A. Effects of climate change on global seaweed communities. *J. Phycol.* **2012**, *48*, 1064–1078. [CrossRef]
260. Masri, M.A.; Younes, S.; Haack, M.; Qoura, F.; Mehlmer, N.; Brück, T. A Seagrass-Based Biorefinery for Generation of Single-Cell Oils for Biofuel and Oleochemical Production. *Energy Technol.* **2018**, *6*, 1026–1038. [CrossRef]
261. Uchida, M.; Miyoshi, T.; Kaneniwa, M.; Ishihara, K.; Nakashimada, Y.; Urano, N. Production of 16.5% v/v ethanol from seagrass seeds. *J. Biosci Bioeng* **2014**, *118*, 646–650. [CrossRef]
262. Ghazal, M.A.; Ibrahim, H.A.H.; Shaltout, N.A.; Ali, A.E. Biodiesel and bioethanol production from Ulva fasciata Delie biomass via enzymatic pretreatment using marine-derived Aspergillus niger. *Int. J. Pure App. Biosci.* **2016**, *4*, 1–6. [CrossRef]
263. van der Wal, H.; Sperber, B.L.H.M.; Houweling-Tan, B.; Bakker, R.R.C.; Brandenburg, W.; López-Contreras, A.M. Production of acetone, butanol, and ethanol from biomass of the green seaweed Ulva lactuca. *Bioresour. Technol.* **2013**, *128*, 431–437. [CrossRef] [PubMed]
264. Adams, J.M.; Gallagher, J.A.; Donnison, I.S. Fermentation study on Saccharina latissima for bioethanol production considering variable pre-treatments. *J. Appl. Phycol.* **2009**, *21*, 569–574. [CrossRef]
265. Ge, L.; Wang, P.; Mou, H. Study on saccharification techniques of seaweed wastes for the transformation of ethanol. *Renew. Energy* **2011**, *36*, 84–89. [CrossRef]
266. Horn, S.J.; Aasen, I.M.; Østgaard, K. Production of ethanol from mannitol by Zymobacter palmae. *J. Ind. Microbiol. Biotechnol.* **2000**, *24*, 51–57. [CrossRef]
267. El-Sayed, W.M.M.; Ibrahim, H.A.H.; Abdul-Raouf, U.M.; El-Nagar, M.M. Evaluation of bioethanol production from Ulva lactuca by Saccharomyces cerevisiae. *J. Biotechnol. Biomater.* **2016**, *6*, 2. [CrossRef]
268. Huesemann, M.H.; Kuo, L.-J.; Urquhart, L.; Gill, G.A.; Roesijadi, G. Acetone-butanol fermentation of marine macroalgae. *Bioresour. Technol.* **2012**, *108*, 305–309. [CrossRef]
269. Potts, T.; Du, J.; Paul, M.; May, P.; Beitle, R.; Hestekin, J. The production of butanol from Jamaica bay macro algae. *Environ. Prog. Sustain. Energy* **2012**, *31*, 29–36. [CrossRef]
270. De Rosa, S.; Zavodnik, N.; De Stefano, S.; Fiaccavento, R.; Travizi, A. *Seasonal Changes of Biomass and Soluble Carbohydrates in the Seagrass Zostera noltii Hornem*; Walter de Gruyter: Berlin, Germany, 1990.
271. Syed, F.; Zakaria, M.H.; Bujang, J.S.; Ramaiya, S.D.; Hayashizaki, K. Physicochemical properties of starches from seed and rhizome of Enhalus acoroides. *Phil J. Nat. Sci.* **2019**, *24*, 27–33.
272. Heo, J.B.; Lee, Y.-S.; Chung, C.-H. Raw plant-based biorefinery: A new paradigm shift towards biotechnological approach to sustainable manufacturing of HMF. *Biotechnol. Adv.* **2019**, *37*, 107422. [CrossRef]
273. Heo, J.B.; Lee, Y.-S.; Chung, C.-H. Toward sustainable hydroxymethylfurfural production using seaweeds. *Trends Biotechnol.* **2020**, *38*, 487–496. [CrossRef]
274. Tamilarasan, S.; Sahadevan, R. Ultrasonic assisted acid base transesterification of algal oil from marine macroalgae Caulerpa peltata: Optimization and characterization studies. *Fuel* **2014**, *128*, 347–355. [CrossRef]
275. Xu, X.; Kim, J.Y.; Oh, Y.R.; Park, J.M. Production of biodiesel from carbon sources of macroalgae, Laminaria japonica. *Bioresour. Technol.* **2014**, *169*, 455–461. [CrossRef] [PubMed]

276. Daroch, M.; Geng, S.; Wang, G. Recent advances in liquid biofuel production from algal feedstocks. *Appl. Energy* **2013**, *102*, 1371–1381. [CrossRef]
277. Saengsawang, B.; Bhuyar, P.; Manmai, N.; Ponnusamy, V.K.; Ramaraj, R.; Unpaprom, Y. The optimization of oil extraction from macroalgae, Rhizoclonium sp. by chemical methods for efficient conversion into biodiesel. *Fuel* **2020**, *274*, 117841. [CrossRef]
278. Khan, M.; Raza Naqvi, S.; Ullah, Z.; Ali Ammar Taqvi, S.; Nouman Aslam Khan, M.; Farooq, W. Applications of machine learning in thermochemical conversion of biomass-A review. *Fuel* **2023**, *332*, 126055. [CrossRef]
279. Siwal, S.S.; Sheoran, K.; Saini, A.K.; Vo, D.-V.N.; Wang, Q.; Thakur, V.K. Advanced thermochemical conversion technologies used for energy generation: Advancement and prospects. *Fuel* **2022**, *321*, 124107. [CrossRef]
280. Gururani, P.; Bhatnagar, P.; Bisht, B.; Jaiswal, K.K.; Kumar, V.; Kumar, S. Recent advances and viability in sustainable thermochemical conversion of sludge to bio-fuel production. *Fuel* **2022**, *316*, 123351. [CrossRef]
281. Xu, K.; Li, J.; Zeng, K.; Zhong, D.; Peng, J.; Qiu, Y. The characteristics and evolution of nitrogen in bio-oil from microalgae pyrolysis in molten salt. *Fuel* **2023**, *331*, 125903. [CrossRef]
282. Li, D.; Chen, L.; Chen, S.; Zhang, X.; Chen, F.; Ye, N. Comparative evaluation of the pyrolytic and kinetic characteristics of a macroalga (Sargassum thunbergii) and a freshwater plant (Potamogeton crispus). *Fuel* **2012**, *96*, 185–191. [CrossRef]
283. Wang, S.; Wang, Q.; Jiang, X.; Han, X.; Ji, H. Compositional analysis of bio-oil derived from pyrolysis of seaweed. *Energy Convers. Manag.* **2013**, *68*, 273–280. [CrossRef]
284. Kan, T.; Grierson, S.; De Nys, R.; Strezov, V. Comparative assessment of the thermochemical conversion of freshwater and marine micro-and macroalgae. *Energy Fuels* **2014**, *28*, 104–114. [CrossRef]
285. Ngoc Bao Dung, T.; Lay, C.-H.; Nguyen, D.D.; Chang, S.W.; Rajesh Banu, J.; Hong, Y. Improving the biohydrogen production potential of macroalgal biomass through mild acid dispersion pretreatment. *Fuel* **2023**, *332*, 125895. [CrossRef]
286. Bae, Y.J.; Ryu, C.; Jeon, J.-K.; Park, J.; Suh, D.J.; Suh, Y.-W. The characteristics of bio-oil produced from the pyrolysis of three marine macroalgae. *Bioresour. Technol.* **2011**, *102*, 3512–3520. [CrossRef]
287. Mishra, R.K.; Kumar, V.; Kumar, P.; Mohanty, K. Hydrothermal liquefaction of biomass for bio-crude production: A review on feedstocks, chemical compositions, operating parameters, reaction kinetics, techno-economic study, and life cycle assessment. *Fuel* **2022**, *316*, 123377. [CrossRef]
288. Moazezi, M.R.; Bayat, H.; Tavakoli, O.; Hallajisani, A. Hydrothermal liquefaction of Chlorella vulgaris and catalytic upgrading of product: Effect of process parameter on bio-oil yield and thermodynamics modeling. *Fuel* **2022**, *318*, 123595. [CrossRef]
289. Elliott, D.C.; Sealock, L.J., Jr.; Butner, R.S. Product analysis from direct liquefaction of several high-moisture biomass feedstocks. In *Pyrolysis Oils from Biomass: Producing, Analyzing, and Upgrading*; ACS Publications: Washington, DC, USA, 1988; pp. 179–188.
290. Zhou, D.; Zhang, L.; Zhang, S.; Fu, H.; Chen, J. Hydrothermal liquefaction of macroalgae Enteromorpha prolifera to bio-oil. *Energy Fuels* **2010**, *24*, 4054–4061. [CrossRef]
291. Neveux, N.; Yuen, A.K.L.; Jazrawi, C.; Magnusson, M.; Haynes, B.S.; Masters, A.F. Biocrude yield and productivity from the hydrothermal liquefaction of marine and freshwater green macroalgae. *Bioresour. Technol.* **2014**, *155*, 334–341. [CrossRef]
292. Barreiro, D.L.; Prins, W.; Ronsse, F.; Brilman, W. Hydrothermal liquefaction (HTL) of microalgae for biofuel production: State of the art review and future prospects. *Biomass Bioenergy* **2013**, *53*, 113–127. [CrossRef]
293. Li, B.; Magoua Mbeugang, C.F.; Xie, X.; Wei, J.; Zhang, S.; Zhang, L. Catalysis/$CO_2$ sorption enhanced pyrolysis-gasification of biomass for H2-rich gas production: Effects of activated carbon, NiO active component and calcined dolomite. *Fuel* **2023**, *334*, 126842. [CrossRef]
294. Singh, M.; Salaudeen, S.A.; Gilroyed, B.H.; Dutta, A. Simulation of biomass-plastic co-gasification in a fluidized bed reactor using Aspen plus. *Fuel* **2022**, *319*, 123708. [CrossRef]
295. Shahbaz, M.; Inayat, A.; Patrick, D.O.; Ammar, M. The influence of catalysts in biomass steam gasification and catalytic potential of coal bottom ash in biomass steam gasification: A review. *Renew Sustain. Energy Rev.* **2017**, *73*, 468–476. [CrossRef]
296. Sudhakar, K.; Rajesh, M.; Premalatha, M. A mathematical model to assess the potential of algal bio-fuels in India. *Energy Sources Part A Recover. Util. Environ. Eff.* **2012**, *34*, 1114–1120. [CrossRef]
297. Vyas, A.P.; Verma, J.L.; Subrahmanyam, N. A review on FAME production processes. *Fuel* **2010**, *89*, 1–9. [CrossRef]
298. Singh, A.; Nigam, P.S.; Murphy, J.D. Renewable fuels from algae: An answer to debatable land based fuels. *Bioresour. Technol.* **2011**, *102*, 10–16. [CrossRef]
299. Nkemka, V.N.; Murto, M. Evaluation of biogas production from seaweed in batch tests and in UASB reactors combined with the removal of heavy metals. *J. Environ. Manag.* **2010**, *91*, 1573–1579. [CrossRef] [PubMed]
300. Pourkarimi, S.; Hallajisani, A.; Alizadehdakhel, A.; Nouralishahi, A. Biofuel production through micro- and macroalgae pyrolysis—A review of pyrolysis methods and process parameters. *J. Anal. Appl. Pyrolysis* **2019**, *142*, 104599. [CrossRef]
301. Bax, N.; Sands, C.J.; Gogarty, B.; Downey, R.V.; Moreau, C.V.E.; Moreno, B. Perspective: Increasing blue carbon around Antarctica is an ecosystem service of considerable societal and economic value worth protecting. *Glob. Chang. Biol.* **2021**, *27*, 5–12. [CrossRef]
302. Buditama, A. Blue carbon for reducing the impacts of climate change: An Indonesian case study. *Glob. Ecol. Biogeogr.* **2016**, 68–88.