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Towards environmental sustainability: further evidences from decarbonization projects in Kenya's Blue Economy

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Kenya is committed to the global efforts on climate change mitigation and adaptation as seen through investments in various sustainable green and blue economy projects. In this review paper, we present the current status of what has been done, particularly on the blue carbon offset initiatives undertaken in the mangrove and seaweed ecosystems as well as the decarbonization activities at the port of Mombasa and which should form reference information for local, regional, bilateral/multilateral partners, scientists and other climate change stakeholders. The blue carbon offset projects involve mangrove conservation, reforestation and carbon credit sale as well as seaweed farming. The initiatives have several unique features amongst which are the community-led income generation systems that simultaneously act as an inducement for ecosystem preservation, co-management and benefits sharing which are recipes for economic, socio-cultural, and environmental sustainability. A notable project impact is the conferment of economic power to the locals, particularly the women and the youth The model used embraces a collaborative approach involving multisectoral engagements of both the government, multilateral organizations, NGOs, and local communities. This integrated top-down (government) and bottom-up (local community) method deliberately targets the strengthening of economic development while ensuring sustainability.

KEYWORDS

sustainability, mangroves, seaweeds, decarbonization, carbon credit

1 Introduction

Global warming and the attendant climate change are worldwide challenges that are mainly driven by emission of greenhouse gases (GHG) particularly the carbon dioxide (CO2) (IPCC, 2022). GHG emissions keep on increasing due to unsustainable use of resources particularly energy, land use and land-use changes (IPCC, 2022). Other causes include lifestyles, consumption patterns, and methods of production within regions, countries and amongst individuals (IPCC, 2022). The incessant increase in CO2 emissions is a major threat to a sustainable environment as it is raising the temperatures and increasing weather anomalies in every region across the globe with heatwaves, floods, droughts and tropical cyclones a common occurrence (Clarke et al., 2022). Since the environment is a finite resource central to the survival of our planet and humanity, achieving environmental sustainability has become another international challenge in addition to climate change and its effects. As has been observed that carbon dioxide emissions are produced chiefly by the burning of fossil fuels, energy consumption is therefore considered a principal driver of climate change (Xue et al., 2021). Consequently, environmental sustainability therefore requires making a gradual transition from use of non-renewable energy sources (in the form of fossil fuel) to sustainable and low-carbon energy sources such as wind, geothermal, solar, and hydro energy (IRENA, 2020).

Although Africa is one of the lowest contributors (less than 10 percent) to global GHG emissions, its limited adaptation ability renders it one of the most susceptible continents to the effects of climate change (Wang and Dong, 2019; Bouchene et al., 2021; Trisos et al., 2022; Yang et al., 2022). It is worth mentioning that climate change and associated threats have a massive impact on the continent largely due to environmental and public health related challenges such as poverty, poor planning, disease burdens, illiteracy and corruption. Both Yameogo et al. (2021) and Aleman et al. (2017) further suggest that the weak policy environment around sustainable use of resources in the continent is another contributor to the continual increase in global warming and climate change. Indeed, global warming and the changing climate is already severely affecting key development sectors and infrastructure and impacting the social fabrics and livelihoods of millions of African families (Adekunle, 2021).

As is the case in most African countries, Kenya's economy relies heavily on natural resource-related sectors which are extremely susceptible to climate change and variability (Government of Kenya (GoK), 2016). To address these vulnerabilities, the government, through various mitigation, adaptation, and resilience-building measures is promoting investment in sustainable resource efficient green development initiatives that use renewable energy while reducing GHG emissions (Government of Kenya (GoK), 2016). One such project is the Lake Turkana Wind Power Project, a wind farm which generates 310 MW of clean energy. Another project is the Olkaria Geothermal Development Company project generating over 500MW of clean energy from geothermal sources and which makes Kenya a pioneer in geothermal energy exploitation. As a consequence, in terms of climate change mitigation, up to 90% of Kenya's energy generation is now from renewable sources (40% geothermal, 35% hydro-generated, 13% wind power and 2% solar). Furthermore, the country has embraced the M-Kopa Solar project which is providing affordable solar power to households all over Kenya thus helping reduce reliance on use of kerosene.

Like most countries participating in the REDD+ program, Kenya has developed a National REDD+ Strategy as required by the Cancun Agreement to UNFCCC (Government of Kenya (GoK), 2021; UN-REDD+, 2018) and implemented the "Greening Kenya Initiative" geared towards expanding the country's forest cover to total 10% of its land areas. This project has seen the planting of millions of trees, which help to mitigate the effect of climate change by absorbing atmospheric carbon dioxide as well as promoting biodiversity. More recently, the country commenced the Kenya Climate-Smart Agriculture program which promotes sustainable farming practices that increase productivity, ensures food security and sustainable livelihoods while reducing GHG emissions and building resilience to climate change risks.

Kenya's commitment to the pursuit of sustainable natural resource exploitation is further evidenced by signing and ratifying key multilateral environmental conventions, treaties, and agreements including United Nations Framework Convention on Climate Change (UNFCCC), the Kyoto Protocol, and Paris Agreement. Furthermore, to demonstrate leadership in climate action, the country has enacted several climate-specific policies including; National Climate Change Strategy (2010), Climate Change Act (2016), Climate Finance Policy (2018), National Climate Change Action Plan 2018-2022 (which is a 5-year rolling plan), and National Adaptation Plan (2015-2030) which guides the climate actions of the National and County governments and other stakeholders. Others include; Energy Act 2012, Environmental Management and Coordination (Amendment) Act 2015, Green Economy Strategy Implementation Plan (GESIP) (2016-2030), and Vision 2030.

Kenya firmly believes that Blue Economy (BE) is an integration of green growth and sustainable development and essentially to promote social,economic, and community development (Government of Kenya (GoK), 2023) Taking cognizance of the BE potential for employment creation, alleviation of poverty, nutrition and food security, and its role as an economic driver (OECD, 2016; World Bank and United Nations, 2017; UN Habitat, 2018; United Nations Development Program (UNDP), 2018; Taillardat et al., 2018; AU-IBAR, 2019; Childs and Hicks, 2019; Intergovernmental Authority on Development (IGAD), 2020), the Government of Kenya (GoK) has made BE one of the key sectors to be prioritized in order to achieve the country's long-term development blue print; the Kenya Vision 2030 (AU-IBAR, 2019; Rasowo et al., 2020). Recognizing the multiple ecosystem services provided by mangroves and associated blue carbon ecosystems, Kenya included blue economy (BE) climate commitments to the earlier land-focused (green economy) interventions in her updated Nationally Determined Contributions (NDCs) and subsequently increased the target of abating its carbon emissions from 30 percent to 32 percent by 2030 (Government of Kenya (GoK), 2017a; GoK, 2020). In 2023, the country's National Blue Economy Strategy 2023-2027 was formulated and aligned to the BE Strategies of the African Union (AU) and Intergovernmental Authority on Development (IGAD), (AU-IBAR, 2019; Government of Kenya (GoK), 2023).

In the past five years, Kenya has taken a global leadership role by spearheading various high-profile BE engagements. The country, in 2018, co-hosted with Canada and Japan, the first "Sustainable Blue Economy Conference". Again, in collaboration with Portugal, Kenya co-hosted the 2022 UN Ocean Conference (UNOC) in Lisbon, Portugal. UNOC came up with the "Lisbon Declaration" which reaffirmed the support to the achievement of Sustainable

Development Goal 14 (referred to as Life below water), the Paris Agreement, and the implementation of UN Decade for Ocean Science (2020-2030). Furthermore, Kenya is currently the champion for the sustainable blue economy sector in the Commonwealth Blue Charter (Commonwealth Blue Charter, 2021). Meanwhile, Kenya is a key partner in the 14-member states of the High-Level Panel for a Sustainable Ocean Economy (referred to as The Ocean Panel), a panel which functions as a global pillar for sustainable BE undertakings. In December 2020, Kenya together with other members of the High-Level Panel, pledged to sustainably control 100% of the ocean area under their national jurisdiction by 2025. Furthermore, the GoK has pledged to create a network of Marine Protected Areas (MPAs) encompassing 30% of its Exclusive Economic Zone by 2030.

In this review, we discuss the blue carbon projects being undertaken in the mangrove and seaweed ecosystems and the decarbonization initiatives at the port of Mombasa. We report on carbon offset projects that are integrating mangrove conservation and reforestation while incorporating the sale of carbon credit in the form of payment for ecosystem services. Notably, the seaweed farming is mainly for production of seaweed for food and for sale as a source of income. These two nature-based initiatives balance community livelihood improvement with conservation and are proof that environmental conservation and economic development can be achieved concurrently if well planned.

2 Carbon offset projects in the mangrove ecosystem

2.1 Overview of mangrove functions and uses

Mangroves are amongst the utmost productive ecosystems on planet earth and provide a myriad of valuable goods and ecosystem services to humanity and nature. These include; regulating (e.g. controlling floods, storms and erosion; stopping intrusion of salt water); habitat (e.g. habitat for spawning, breeding and nursery for various marine organisms, refuge for mammals, birds); provisioning (e.g. fruits, charcoal, timber, and fish); cultural services (e.g. sport, aesthetic), and global climate regulation through sequestering carbon dioxide (Lee et al., 2014; Alongi, 2020; Das, 2020; Menéndez et al., 2020; zu Ermgassen et al., 2020; Adame et al., 2021; Afonso et al., 2021; Macreadie et al., 2021; Quirost et al., 2021).

Together with saltmarsh, coral reefs, seaweed, and seagrass ecosystems, mangrove forests have been termed "blue carbon" ecosystems since they can store organic carbon (C) for a long period making them major contributors to marine C burial (Nellemann et al., 2009; Mcleod et al., 2011; Duarte et al., 2013; Macreadie et al., 2019; Jennerjah, 2020; Wang et al., 2020). Mangroves are of special interest since they amass and sequester relatively higher quantities of C than the other ecosystem types (Ezcurra et al., 2016; Atwood et al., 2017; Kauffman and Bhomia, 2017; Adame et al., 2018; Zeng et al., 2021; Chatting et al., 2022). According to evidences adduced from several studies, the high productivity combined with slow rates of decomposition in the soil significantly improves mangroves' capacity to capture and eventually store organic carbon, especially in the soils (Bouillon et al., 2008; Alongi, 2012; Suello et al., 2022). Estimates by Atwood et al. (2017) indicate that organic carbon stowed in mangrove sediments up to a depth of 1 m, globally equates to 2.6 billion Mg of C. Furthermore, above-ground net primary productivity reported for mangroves (8.1 t DW ha−1 yr−1) match the records from highly productive tropical forests on land (11.1 t DW ha−1 yr−1) (Alongi, 2012; Cooray et al., 2021). Research on carbon stocks in the Kenya mangroves report an estimated range of 500-1000 t C ha-1 which is ten times higher than the average carbon content of terrestrial forests in the country (Huxham et al., 2015). Indeed, it is noteworthy that whilst covering only ca. 2 per cent of the world ocean, mangroves effectively account for over 10 per cent of the global carbon sequestration by the world's oceans (Alongi, 2014).

World-wide, mangroves are faced with a myriad of threats particularly from organic and inorganic pollution, wanton deforestation, and sea-level rise with the leading drivers causing these threats being the rapid population growth, climate change, and infrastructural developments in coastal areas (Barbier et al., 2011; Giri et al., 2011). Mangrove conservation and restoration efforts including innovating financing instruments should be speeded up to save these natural blue carbon ecosystems and to ensure that the critical function of provision of goods and services are not destroyed (Laffoley and Grimsditch, 2009; UN Environment (UNEP), 2018).

2.2 Projects in the Kenya mangrove ecosystem

Mangroves occur throughout the coastal Kenya region starting from the north in Kiunga in the Kenya-Somalia border and up to Vanga at the Kenya-Tanzania boundary to the south (Figure 1). The forest inventory show that the mangrove forest area cover about 61,271 ha, 62% of which is found in Lamu County (Figure 2) (GoK, 2017b), and that all the nine species of mangrove recorded to occur in the region of the Western Indian Ocean are also found in Kenya namely: grey mangrove (*Avicennia marina*), oriental mangrove (*Bruguiera gymnorhiza*), tagal mangrove (*Ceriops tagal*), black mangrove (*Lumnitzera racemosa*), red mangrove (*Rhizophora mucronata*), apple mangrove (*Sonneratia alba*), cannonball mangrove (*Xylocarpus granatum* and *Xylocarpus molucensus*) and *Heritiera littoralis*. Unfortunately, the mangroves have experienced loss and degradation with the National Mangrove Ecosystem Management Plan estimating a loss of 40% of the mangroves occurring between 1990 and 2010 (FAO, 2016; GoK, 2017b; Kairo et al., 2021). However, Kirui et al. (2013) reported an annual net mangrove cover loss of 0.7% between 1985 and 2000 with the loss rate dropping to 0.28% between 2000 and 2010. Hamza et al. (2022) estimated a mangrove cover loss of 0.15% per year between 2010 and 2016 indicating a trend of gradual reduction in loss of forest cover (Gitau et al., 2023).

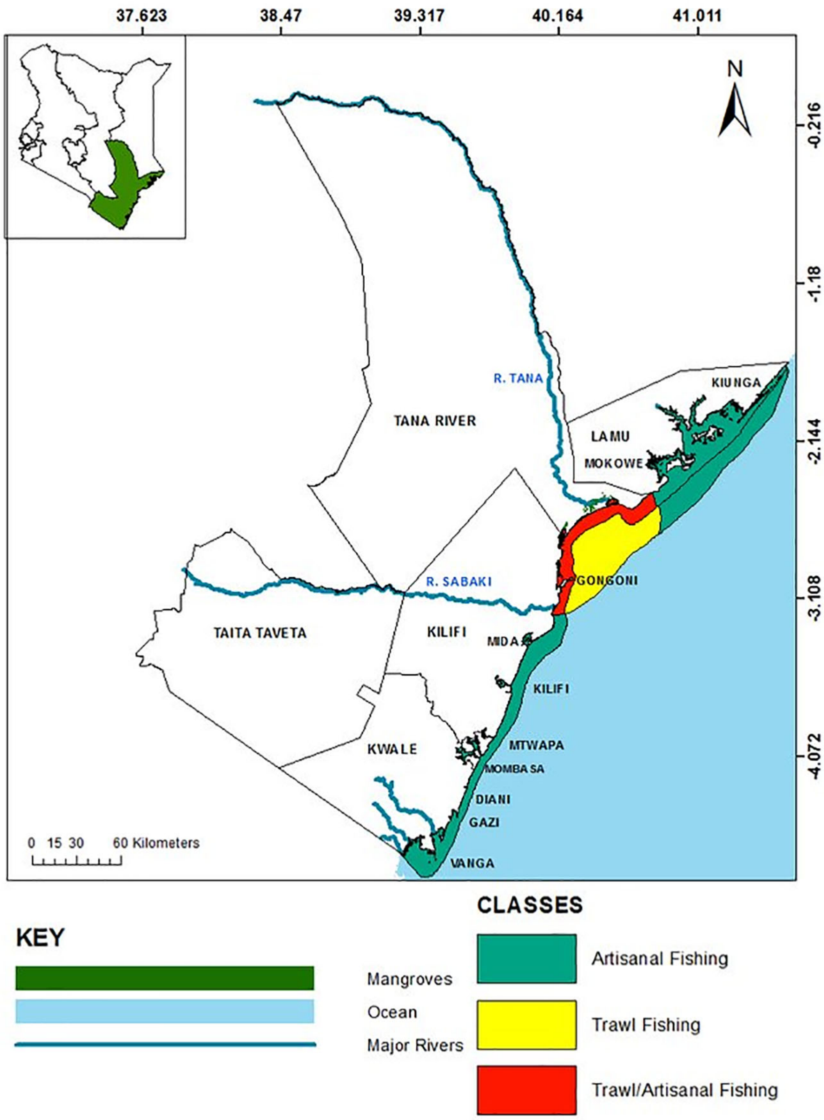

FIGURE 1
Mangrove restoration and conservation and Seaweed farming project sites in Gazi, Vanga, and Lamu (Adapted from Morara et al., 2015).

To further counter the mangrove forest loss and degradation, Kenya has launched several projects in the mangroves aimed at protecting and restoring mangrove forests through avoided deforestation and establishment of new mangrove plantations. Some of the projects have added the aspect of payment for ecosystem services (PES) aimed at providing long-term incentives for restoration and protection of the mangroves through selling blue carbon credits (Locatelli et al., 2014; Huxham et al., 2015). Additionally, the projects encompass establishing community-managed conservation zones and promoting alternative livelihoods such as ecotourism and crab farming. Appreciating the high demand for poles for building and fuelwood and in order to mitigate carbon leakage, the projects support the planting of fast-growing trees, mainly Casuarina spp (*Casuarina equisetifolia)*, to create a maintainable supply of timber for construction, wood for fuel and income from their sale; thus, removing pressure from the mangroves. Here we report on three of such initiatives namely; the Mikoko Pamoja Project, the Vanga Blue Forest Project, and the Lamu Marine Conservation Trust Mangrove Project.

Mikoko Pamoja Project (MKP) is a community-based initiative located in Gazi Bay (Figure 1), some 50 km south of Mombasa in Kwale County. Gazi Bay has a total cover of 615 ha of natural mangrove forest. The forest has suffered major degradation in most areas while in some places total destruction has been recorded due primarily to its proximity to Mombasa city, which offers a quick market to sell mangrove timber (Dahdouh-Guebas et al., 2004; Kirui et al., 2013; Rideout et al., 2013; Musyoka, 2015; GoK, 2017a, b; Omondi, 2017; Plan Vivo Project Design Document (PDD), 2020). The project aims to reduce GHG emissions through protecting and restoring the mangrove forests in the Gazi Bay area. Since its inception in 2012, the project has conserved as well as

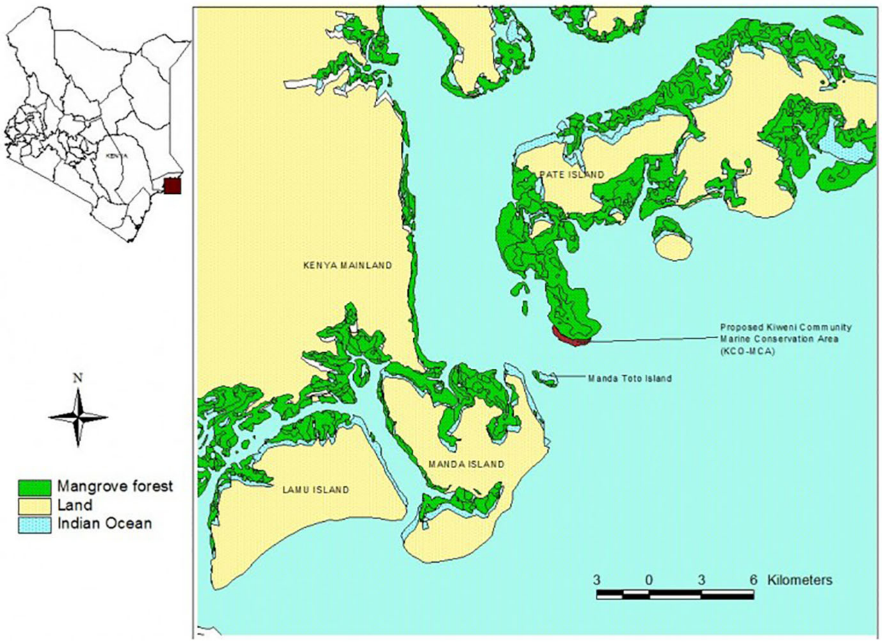

FIGURE 2
Lamu County is home to nearly 62% of Kenya's mangrove forests (SOURCE: Lamu Marine Conservancy).

planted over 117 hectares of mangroves with about 10 hectares out of the 117 ha being newly planted mangrove trees. The MKP is accredited, as per regulatory requirements, by the Plan Vivo System and Standard to trade up to 3000t CO2 for an initial 20-year period. The carbon credits generated by MKP are marketed and sold on the international voluntary carbon market through the Association for Coastal Ecosystem Services (ACES), a charity registered in Scotland (https://aces-org.co.uk/our-projects/). Benefits from the sale are ploughed back into the community to support various community projects including various small and medium enterprise that meet the needs of the Gazi community (Huff and Tonui, 2017; Murungi, 2017; Kairo et al., 2019; Vanga Blue Forest Project Design Document (PDD), 2019).

The Vanga Blue Project (VBF) launched in 2019 as a result of the huge success of MKP, is also located in the south coast of Kenya (Figure 1), approximately 110 km from Mombasa city. The project coverage encompasses the mangroves of Vanga, Jimbo, Kiwegu and Majoreni totaling about 4,428 ha (https://aces-org.co.uk/our-projects/). According to Omondi (2017), a major decline in forest cover in this locality occurred between 1991and 2016, changing the forest cover from 3685 ha to 3234 ha with the drivers of losses and degradation identified as population pressure, poverty and inequality, and poor governance. The VBF project has planted more than 1,000 native mangrove trees since its inception, with future plans to work with neighboring communities in Tanzania to restore mangrove forests along 140 kilometers of the East African coastline. VBF targets avoided emissions of over 100,379 t CO2-eq over the 20 years' crediting period, which approximates to 5,019 t CO2 yr-1 from both the soil carbon and above and below-ground biomass carbon pools (Kairo et al., 2009; Cohen et al., 2013; Huxham et al., 2015; Gress et al., 2017; Vanga Blue Forest Project Design Document (PDD), 2019; Aigrette et al., 2021). Money produced from trading carbon credits is utilized in supporting community-initiated development projects in the area (Kairo et al., 2019).

In Lamu County, the Lamu Marine Conservation Trust (LaMCoT) and The Nature Conservancy, two non-profit organizations work to encourage sustainable and efficient management of marine and coastal resources in the county. The organization has implemented several projects aimed at conserving and restoring mangrove forests in Lamu County, including the establishment of community-based management systems and the promotion of alternative livelihoods such as eco-tourism and sustainable fishing.

3 Carbon offset projects in seaweed ecosystem

3.1 Overview of seaweed functions and uses

Seaweeds, also known as macroalgae, provide diverse ecosystem services such as; supporting (biogeochemical cycles, primary producer, biodiversity conservation, habitat for various organisms), provisioning (source of food, source of energy), cultural (recreation, aesthetics, heritage) and regulating (climate, eutrophication, biological) (He et al., 2008; Chung et al., 2011; Chung et al., 2013; Kraemer et al., 2014; Ferreira et al., 2021; Yong et al., 2022).

Previous exhaustive studies have shown that seaweeds provide bioremediation services as the dissolved nutrients such as nitrogen, phosphorus and carbon are abstracted by seaweed during growth then removed when the seaweed is harvested (Kim et al., 2017; Wu et al., 2017; Hasselstrom et al., 2018). Further studies have reported that seaweed reduces the hydrodynamic wave energy thus abating erosion of coastal areas from wave forces in addition to protecting tidal zones from erosion (Christianen et al., 2013). Furthermore, growing seaweed, directly on the seafloor in shallow areas or on ropes suspended off the bottom normally in deep areas, adds complexity to growth environment, normally creating a three-dimensional habitat which offers refuge plus more surface for settlement for other organisms as well as more feeding and more nursery areas for a greater diversity of associated marine and terrestrial organisms (Smale et al., 2013).

Seaweed can be used as direct food for human consumption or can be processed into other food additives, animal feeds, medicines, pharmaceuticals, fertilizers and cosmetics among other products (McHugh, 2003; Bixler and Porse, 2011; Wells et al., 2016; Anis et al., 2017). Related research has reported that seaweed species are rich in bio compounds majorly proteins, dietary fibers, proteins, and lipids and contain bioactive elements with a broad range of applications (Fleurence, 2004; Sánchez-MaChado et al., 2004; Macartain et al., 2007; Mišurcová et al., 2011; Pereira et al., 2011). Furthermore, they contain vitamins A (beta carotene), K, B12, and C in addition to being rich in potassium, iron, calcium, iodine and magnesium. From a practical perspective, the very high iodine content of the macroalga makes them ideal for tackling malnutrition in children and pregnant women. Meanwhile, according to the research conducted by Demarco et al. (2022) and Barbier et al. (2019), seaweed contains polyphenols and essential fatty acids since the principal components of their cell membranes are polyunsaturated fatty acids, principally omega 3 (ω-3) and omega (ω-6) although their bioavailability is not clear and is still an area of research. In addition, many studies have enumerated several other properties of seaweed to include anti-cancer, anti-fungal, anti-viral, antidiabetic, antihypertensive, immune-modulatory, anticoagulant, anti-inflammatory, anti-parasitic, and antioxidant among others (Smit, 2004; Mayer et al., 2013; Barbosa et al., 2014; Besednova et al., 2015; Ruan, 2018) consequently making seaweeds beneficial to human health. Seaweeds are routinely used by the cosmetic industry as coloring agents, stabilizers, emulsifiers and are also a source of different compounds used in the skincare sector (Yuan and Athukorala, 2011; Pimentel et al., 2017). Recently, Guillerme et al. (2017) reported that seaweed produce compounds that absorb UV rays, such as mycosporin-like amino acids, phenolics, carotenoids and terpenes, that are normally useful photo-protective elements for the formulation of sunscreen products.

Seaweeds are able to sequester atmospheric CO2 and the surrounding seawater through the process of photosynthesis (Krause-Jensen and Duarte, 2016). During photosynthesis, they absorb CO2 and convert it into organic matter and in the process release oxygen into the surrounding environment. The organic matter produced by the seaweed is used for growth, or can be buried in the sediment at the bottom of the ocean, effectively removing atmospheric carbon and storing it for a long-time duration. In addition to sequestering carbon, seaweed farming has many other environmental benefits, including improving water quality, providing habitat for marine life, and reducing the impact of ocean acidification (Krause-Jensen et al., 2015; Mongin et al., 2016). Ocean acidification is an increasing threat to all the marine ecosystems as decreasing pH levels interferes with the life processes of most marine species.

3.2 Seaweed farming projects in Kenya

After an extensive study of the seaweed resources of Kenya, over 380 species have been documented (Moorjani, 1977; Yarish and Wamukoya, 1990; Oyieke, 1998; Coppejans et al., 2000) with several of the species found to be potential candidates for farming namely: the carrageenophytes *Eucheuma* spp., *Kappaphycus* spp. and *Hypnea* spp.; the agarophytes, *Gracilaria* spp. and *Gelidium* spp.; and the alginophytes *Sargassum* sp *Turbinaria* spp. and *Cystoseira* spp. (Wakibia et al., 2006; Wakibia et al., 2011; Nyundo, 2017; Ollando et al., 2019). The first seaweed farms of *Eucheuma denticulatum* and *Kappaphycus alvarezii* were started in 2010.

Currently, seaweed farming is established in Kwale County with farms concentrated in 10 villages situated in Gazi, Nyumba Sita, Tumbe, Funzi Island, Mwambao, Mkwiro, Jimbo, and Kibuyuni. (Figure 1) The most common technique of seaweed cultivation is the peg and line (off-bottom) monoline method, which involves tying seaweed seedlings to monofilament polypropylene ropes (lines) with the main lines tightly stretched amid two wooden pegs (stakes) drilled securely to the seafloor. Other farming practices including the raft, the net, broadcasting, and floating long-line methods are still being piloted (Kimathi et al., 2018; Nyamora et al., 2018; Brugere et al., 2020; Garcia-Poza et al., 2020; Msuya et al., 2022).

Farming cycles are aligned to the tidal cycles with the farmers working in the farms during the low tides. Low tides occur fortnightly each month and each low tide takes seven days; hence farmers work on their farms for about 10-14 days each month. The planted crop is harvested after 6 weeks of growth (Overbeeke et al., 2020; Msuya et al., 2022). This relatively short cycle of production lasting 6 weeks allows for a fairly quick return on investment and subsequently in a regular income to the farmers. Farming is carried out year-round although the yields are highest when conditions are good during the inter-monsoon season from March through to early May and are low from June to mid-August, during the South-East Monsoon when conditions are not so favorable due to extreme wind and rough sea conditions. Normally, the water temperatures are relatively high from December to February, so farmers halt production until the rainy season (Msuya and Porter, 2014; Largo et al., 2020; Overbeeke et al., 2020). On average, farmers produce 300 - 500kg per each production cycle and are paid between US$ 0.2 and US$ 0.25/kg for dry seaweed product, yielding on average total revenues ranging between US$ 70 – 115 every six weeks during production seasons (Odhiambo et al., 2020; Msuya et al., 2022). This price is averagely high for the farmers considering the opportunity costs and the fact that the farming is not a full-time engagement.

4 Decarbonization through greening Kenya's ports

Maritime transport is the lifeblood of the global trade and the manufacturing supply chain , carrying over 90% of global commercial goods (World Bank, 2023). Shipping is particularly important for Kenya with the ports of Mombasa and Lamu playing a strategic role in the national and international trade as well as serving an extensive hinterland comprising Democratic Republic of Congo, Rwanda, Burundi, Uganda, Southern Sudan and southern Ethiopia. The ports lie in a very busy shipping route with a majority of international ships spending time in Kenyan waters or docked at the ports. However, maritime transport is highly polluting as ships use carbon heavy fuels to power their engines (International Maritime Organization (IMO), 2018).

Kenya has shown its commitment as a member of International Maritime Organization (IMO) by signing the International Maritime Organizations Initial Strategy on Reduction of GHG Emissions from Ships. This strategy targets to reduce GHG emitted from the shipping sector by 50% by 2050 as compared to the levels of 2008 and also includes the goal of reducing carbon intensity in ships by 40% by 2030 (International Maritime Organization (IMO), 2018). Furthermore, after acknowledging that the port of Mombasa (Figure 1) produces high concentration of GHG emissions from ships that are docked at the port as well as from trucks and vehicles hauling cargo, Kenya has taken steps to green the port by undertaking several decarbonization projects. In 2020, the GoK launched the "Greening of Ports" project in Mombasa aimed at reducing GHG emissions related to its port's operations. Kenya Ports Authority (KPA), the government parastatal charged with managing the ports, has developed and is implementing an elaborate Green Port Policy (GPP) aimed at transforming the Kenyan ports into ports of clean fuels and which purposes to allow only new technologies and equipment that use clean fuel to operate at the port. Consequently, KPA is implementing cold ironing at the port after installing a 10MW solar photo-voltaic plant for the generation of renewable energy shore power to provide electrical power at the berths for ships calling at the harbor. As per the GPP, all ships calling at the port of Mombasa are to be compelled to switch off their auxiliary diesel engines and power their vessels using shore electric power while docked. Normally, ships emit enormous amounts of carbon dioxide from their diesel engines while discharging cargo and the switching to shore solar electricity- power to supply clean energy is recommended as best practice for green ports. By embracing green technology particularly the switch to electric cranes, and by aggressively investing in equipment modernization and upgrade, efficiency at the port of Mombasa has greatly improved with the turn-around time for ships calling at the port of Mombasa currently standing at an impressive 2 days only (World Bank, 2023; Kenya Ports Authority Magazine (KPA), 2023).

The shipbuilding sector holds great promise as a future growth area for Kenya's economy. To cater for the increasing demand of shipbuilding and repair services within the country and the region, while helping decarbonise this industry, the government, through public and private partnerships (e.g., Kenya Shipyards Limited), is supporting initiatives that embrace green shipping technology in its production. One example is the use of wind-assisted propulsion technologies (European Maritime Safety Agency (EMSA), 2023) inspired in the ancient technology of wind sails.

5 Discussion and conclusion

As part of the strategies aimed at limiting the rising global temperatures and the reduction of man-induced CO2 emissions, most countries have committed to the aspirations of the Paris Climate Agreement which provides for a climate neutral world by 2050 (IPCC, 2022). Achieving climate neutrality entails reducing GHG emissions as much as possible and then offsetting any residual emissions by investing in projects that actively remove atmospheric carbon dioxide including afforestation, reforestation, and carbon capture and storage technologies until net-zero point is reached.

Through its mangrove conservation and restoration and PES projects, Kenya has been able to trade the carbon in the international market as certified carbon credits. Indeed, with over ten carbon credit projects in the country, most of which involve forest cover restoration or protection, Kenya has been hailed as a continent leader in carbon credit markets (Rasowo et al., 2020). However of late, using carbon credit markets to finance adaptation and mitigation activities is facing criticism on a global scale and their future as a sustainable source of climate finance particularly for Africa and other developing countries is not bright. Arguably, carbon markets appear to legitimize the pollution by the big polluters while seemingly appeasing the low-polluting and unindustrialized nations. It is also debatable whether the revenues that the carbon credit markets earn the developing nations are enough to compensate for the losses and damage caused by climate change which they have contributed least to.

Kenya is in an ecological deficit thus the mangrove conservation and restoration mitigates by reducing Kenya's production footprints while increasing its biocapacity (Marti and Puertas, 2020). Additionally, non-deforestation and forest conservation provides a range of benefits to an ecological deficit country like Kenya by protecting biodiversity, mitigating climate change, regulating water cycles, conserving soil resources, and providing social and economic benefits.

The incomes realized from sale of carbon credit and the sale of seaweed has resulted in financial resilience in the local coastal community, increased the community's capacity towards climate adaptation, and decreased their dependence on the limited local resources. Indeed, research by Rimmer et al. (2021) show that financial betterments precipitate wider economic benefits which eventually build the community's capacity to adapt to climate change. In general, the projects have diversified livelihood opportunities for the communities whose main source of income, primarily, was fishing. Furthermore, diversification has been shown to be a critical factor for building household economic resilience (Rimmer et al., 2021). In addition to climate mitigation and adaptation, the above projects generate multiple benefits to the community including supporting education services, improving sanitation, provision of clean water, shoreline protection, and various mangrove-based livelihood enterprises (e.g. in bee-keeping, crab farming, small-scale farming, mangrove ecotourism, agroforestry).

Seaweed farming, in particular, has proven attractive to the rural coastal communities due to the low barriers to farmer entry, relatively low cost of input, short cycles of production thus providing regular income, low-technology, and relatively easy to master best farming practices. Since seaweed is produced throughout the year and does not need full-time care (relatively low labor requirement), the farming not only ensures constant cash flow, but also creates supplemental rather than replacement income, hence an appropriate alternative livelihood option to the coastal households (Msuya, 2013; Hurtado and Msuya, 2017). Because of the unique characteristics enumerated above, seaweed farming is a more female-oriented activity with over 90% of the current farmers being women (ODINAFRICA, 2020; Msuya et al., 2022).

In order to expand production space and volumes, the government is mapping the whole Kenya coastline to identify more zones that are ideal for seaweed farming with the aim of expanding production space and volumes produced. In addition, the government is funding infrastructural development in the form of good road networks, electricity, water, education, housing, healthcare facilities (Mirera et al., 2020) and training the farmers on entrepreneurial skills including making business plans, market intelligence as well as on value addition processes and technologies as a strategy to enhance economic returns and sustainability. Further government support is through development of coherent policies on conservation, and setting up frameworks and programs that strengthen governance while promoting equality and inclusion.

These Blue Economy projects are unique in that they have embraced a collaborative approach involving a multisectoral engagement of both the GoK, NGOs, international and the local communities. The integrated top-down (GoK) and bottom-up (local community) management model adopted has deliberately targeted the strengthening of economic development while taking cognizance of sustainability (Baker and Mehmood, 2013; Okafor-Yarwood et al., 2020). Studies have documented that a collaborative approach that emancipates the locals by ensuring their involvement in the processes of decision making and management, results in social equity, better economic outcomes, and ecological sustainability (Simane and Zaitchik, 2014; Butler et al., 2015; Mackenzie et al., 2019; Chen et al., 2020). In a related study, El Asmar et al. (2012) further show that when stakeholders are all involved equally in the project's implementation, it makes them take ownership of the project message eventually ensuring sustainability. Furthermore, the component of education and capacity building particularly of the local partners in a project ensures that the community gain adequate skills to run the project on their own at the end of the project contract period. Government engagements at county, national and international levels jointly with the civil society and private sector can play a critical role in aiding and accelerating development pathways geared towards climate resilience and sustainable development in local communities. This is even more effective when activities, financing, and decision-making processes are integrated across all the various governance levels, the sectors, and the timeframes (IPCC, 2022).

From the experiences gained from the activities undertaken at the port of Mombasa, greening a port requires not only investment in modern equipment that does not consume fossil fuel but also the dedicated participation of all value-chain actors including the government, port managers, terminal operators, ship owners and operators, cargo owners, logistics companies, and the communities around the port. In addition, it requires increased efficiency in the form of short turn-around time for ships in the docks since the longer the ships spend floating in the docks, the more GHC gases they emit in the surrounding environment. In general, decarbonizing the shipping sector needs a combination of technological, regulatory and economic approaches including: utilizing renewable energy sources to generate electricity for on board systems, shifting from fossil fuels to low-carbon green fuels, improving the energy efficiency of vessels, and using more efficient propulsion systems to reduce fuel consumption (International Maritime Organization (IMO), 2018). IMO has already established global targets to reduce emissions from the shipping sector but the individual governments do have the leeway to adopt stricter regulations for ships operating in their waters (International Maritime Organization (IMO), 2018).

In conclusion, the observed outcomes of the projects reveal that they are significantly impactful while contributing to the improvement of the livelihoods of the local communities and in particular, conferring economic empowerment to the women whose livelihoods would otherwise depend solely on their husbands. BE needs compliance with the United Nations Sustainable Development Goal (SDG) 14 (Life below water). It is noteworthy that both the mangrove conservation and seaweed farming ventures address problems associated with the realization of several of the UN SDGs in addition to SDG 14 namely; SDG 1(No poverty), SDG 2 (End hunger), SDG 4(Quality education), SDG 5 (Gender equality), SDG 6(Clean water and sanitation), SDG 8 (Sustainable economic growth), SDG 13 (Action to combat climate change), and SDG 15 (Life on land). Kenya's "Green Growth Economy Strategy" and the "Blue Economy Strategy" policy documents are part of the country's effort to realize the bigger circular economy principle which is part of the SDG 12 (Sustainable consumption and production).

Author contributions

Conceptualization, writing plus editing of this manuscript was undertaken by all the five authors: JR, BN, RO, PO and SO. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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