Economic Assessment of Sustainable Blue Energy and Marine Mining Resources Linked to African Large Marine Ecosystems

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Abstract

African sustainable energy and marine mineral resources have the potential for significant contributions to African economic development goals through job creation and contributions to the Gross Domestic Product of the countries bordering the seven African Large Marine Ecosystems – Canary Current, Mediterranean Sea, Red Sea, Somali Coastal Current, Agulhas Current, Benguela Current and the Guinea Current. Though their potential is not fully assessed, based on our preliminary assessment it is expected that by 2030 and 2063 blue energy could add value of about USD1.6 billion and USD2.3 billion, in mining of minerals about USD76 billion and USD123 billion, and in oil and gas production about USD100 billion and USD138 billion, respectively. By 2030 and 2063 blue energy employment can reach about 0.2 million and 0.5 million jobs, in ocean mining about 2 million and 4 million jobs could be created, and in oil and gas production about 1.8 million and 5 million jobs would be expected. In order to achieve these benefits, Africans need to tackle complex technical and policy related challenges. Among the recommended changes, it would be necessary to unlock sustainable blue energy regulations with forward looking new development policies.

Key Words: Ocean energy, blue energy, African Large Marine Ecosystems, deep-sea-bed mining, oil and gas, seawater mining, innovative industries, job creation, GDP

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1. INTRODUCTION

The potential of ocean blue energy and marine mineral mining are the least known economic sectors in Africa's Large Marine Ecosystems (LMEs) including the Canary Current, Mediterranean Sea, Red Sea, Somali Coastal Current, Agulhas Current, Benguela Current, and Guinea Current LMEs (Fig. 1a) that could contribute to achieving African economic development goals, Millennium Development Goals (MDG), and Africa Union's 2063 strategic goals. In this regard, we have provided this assessment to unlock the potential of these 2 sectors of the African Economy.

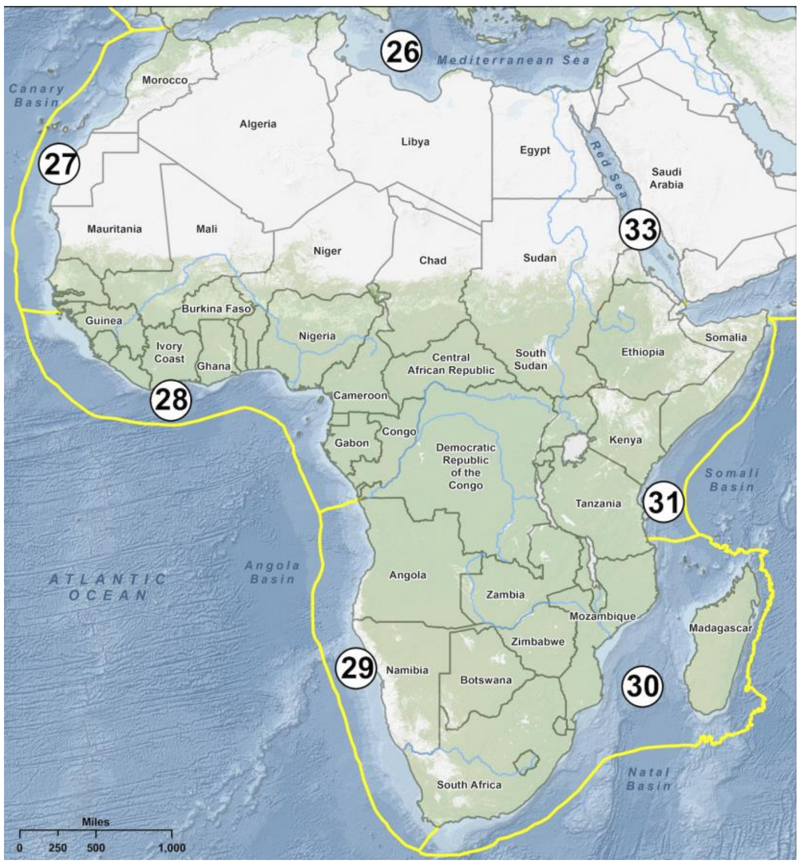

Fig 1a: African LMEs discussed in the text and their map numbers in parentheses as depicted in the World Map of Large Marine Ecosystems: Benguela Current LME (29), Guinea Current LME (28), Canary Current LME (27), Mediterranean Sea LME (26), Red Sea LME (33), Somali Coastal Current LME (31), and Agulhas Current LME (30), as adapted from Satia (2016).

The integration of ocean energy in the conventional national renewable energy mix, efficient, equitable and strategic exploitation of oil and gas, and advancement of the exploitation of deep-seabed and seawater-based minerals to unlock the blue economy potential of Africa's Large Marine Ecosystems (LMEs) in general is an urgent task that Africa needs to address. In this regard, this paper assesses the blue economy potential of these sectors in helping increase access to electricity to meet the increasing demand, meeting global demand for minerals and economic development.

It also provides cost completeness of some of the energy technologies and ocean mining potentials in which the cost is expected to decrease as the technology matures and its efficiency improves. The sustainable blue energy and mining in African LMEs also have a very high job creation and GDP contribution potential. However, in order to realize its potential, the challenges identified in this paper should be implemented.

The following sections provide a preliminary assessment of the potential of ocean/blue energy, oil and gas, and marine mining resources of African LMEs. Whenever applicable, the economics of exploiting such resources are quantified and high potential countries bordering the African LMEs are identified.

2. BLUE ENERGY POTENTIAL

African LMEs have huge untapped blue energy potential including offshore wind energy, floating solar photovoltaic (FPV), wave and tidal energy, hydropower energy (small and pico), ocean thermal energy conversion (OTEC), salinity gradient energy, and marine algae biofuels.

Offshore Wind Energy

One third of the African coastal area could have very good wind resources potential (Elsner, P., 2019) which include ***the Agulhas Current and Somali Coastal Current areas off Mozambique,*** South Africa, Somalia, Madagascar and in the Morocco area of the Canary Current LME in ***northwest Africa***. More than 90% of offshore wind resources are concentrated in three African Power Pool regions such as the Southern African Power Pool (SAPP), the Eastern African Power Pool (EAPP), and the Maghreb Electricity Committee (commonly known as the Comité Maghrébin de l'Electricité (COMELEC)) (Figure 1b). Though the Levelized Cost of Electricity (LCOE) of offshore renewable energy resources is still higher than conventional power generation, with a growing interest in offshore resources and considering the high potential of offshore renewable resources, they are anticipated to contribute a larger share of electric power in the next decade (Gondal, I.A., 2019). In addition to providing electric power, offshore wind energy can also be used for the production of hydrogen. Using the existing offshore gas pipeline or new gas pipeline, hydrogen could be transported to the demand centers (Gondal, I.A., 2019.) in land locked countries. Harnessing such potential through a joint regional approach in the three power pools could offer national and regional benefits.

Floating Solar Photovoltaic

Floating Solar Photovoltaics (FPV), one of the blue energy sources, is one of the evolving solar energy technologies making traction in the market. Several African countries, for example, Seychelles, Mauritius located in the Agulhas Current area and Ghana located within the coastal area of the Guinea Current LME, are implementing utility scale FPVs. Moreover, its potential of for integration with hydropower in landlocked countries is becoming an attractive energy technology ready for its deployment. The most recent installable FPV assessment study indicates that if 10% of installable areas are used in African water bodies, about 1,011gigawatt (GWp) FPV could be installed with a potential of annual energy generation of 1,671,648.00-gigawatt hour/year (GWh)/yr) (World Bank, 2019).

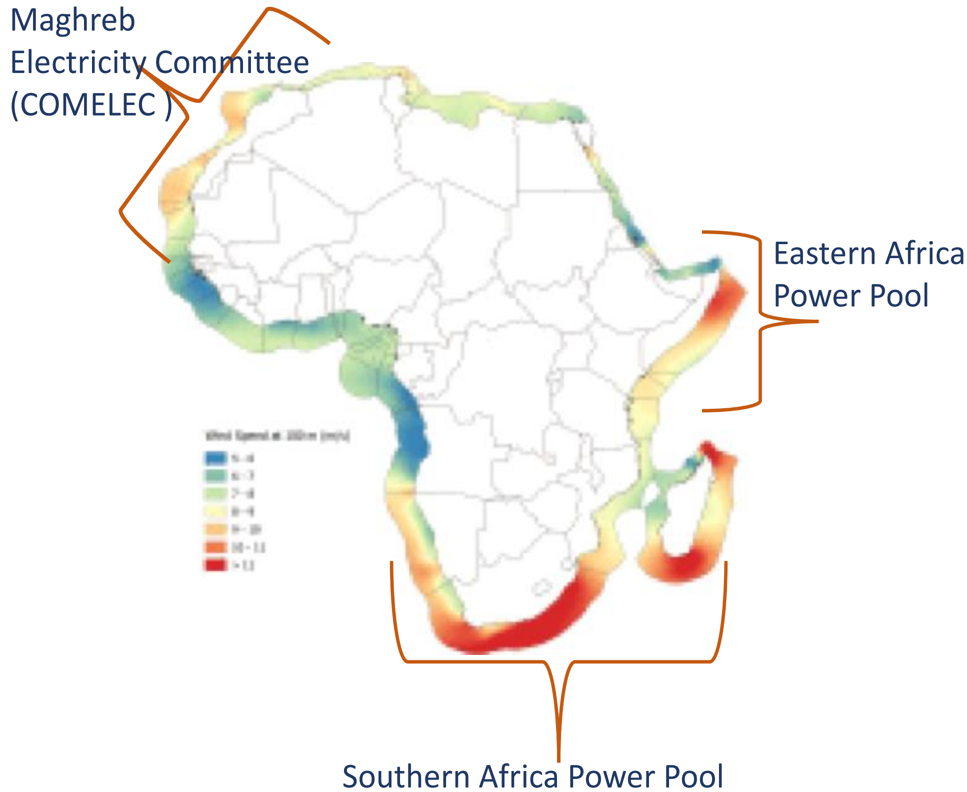

Figure 1b: Offshore wind resources assessment of Africa

Wave Energy Conversion

Wave energy converters (WECs) capture the kinetic or potential energy contained in ocean waves to generate electricity. Though the global wave energy potential is still relatively uncertain, the Intergovernmental Panel on Climate Change (IPCC) estimated a theoretical global potential of around 29,500 terawatt-hour per year (TWh/yr) (Lewis, *et al.*, 2011, IRENA, 2014). The global distribution of annual wave power flux is provided in **Figure 2** (ADB, 2014.) where the Benguela Current and Agulhas Current LMEs in southern and the Canary Current LME in northwestern Africa have the highest potential. Some African countries like Ghana are already implementing a 100 Megawatt (MW) wave energy, the largest in the continent, with a long-term construction plan of reaching about 1000WM wave energy plant capacity (UNECA, 2014). Probably, Ghana is ahead of its projected 1.4 % contribution of wave energy conversion by 2050 (Britton, B., 2017), which indicates this type of energy has already making traction in the country.

The wave energy conversion (WEC) technology capacity close to commercialization is in the range of 10 MW (IRENA, 2014) While the capital cost of the first generation WEC is about 10,000 $/kW, the capital cost of future generation with the capacity of 90MW, which is about $3000/kW (ADB, 2014), is expected to be cost competitive. The first generation refers to a single device and future generation refers to wave farms that consists numerous devices. The levelized cost of the future generation ranges from 0.13 – 0.45 $/kWh, which could be competitive with other energy sources.

One of the most attractive aspect of the WEC is its efficiency: WEC can generate 65% of energy per year compared to wind and PV which has the efficiency of 22-24% energy production per year (Britton, B., 2017).

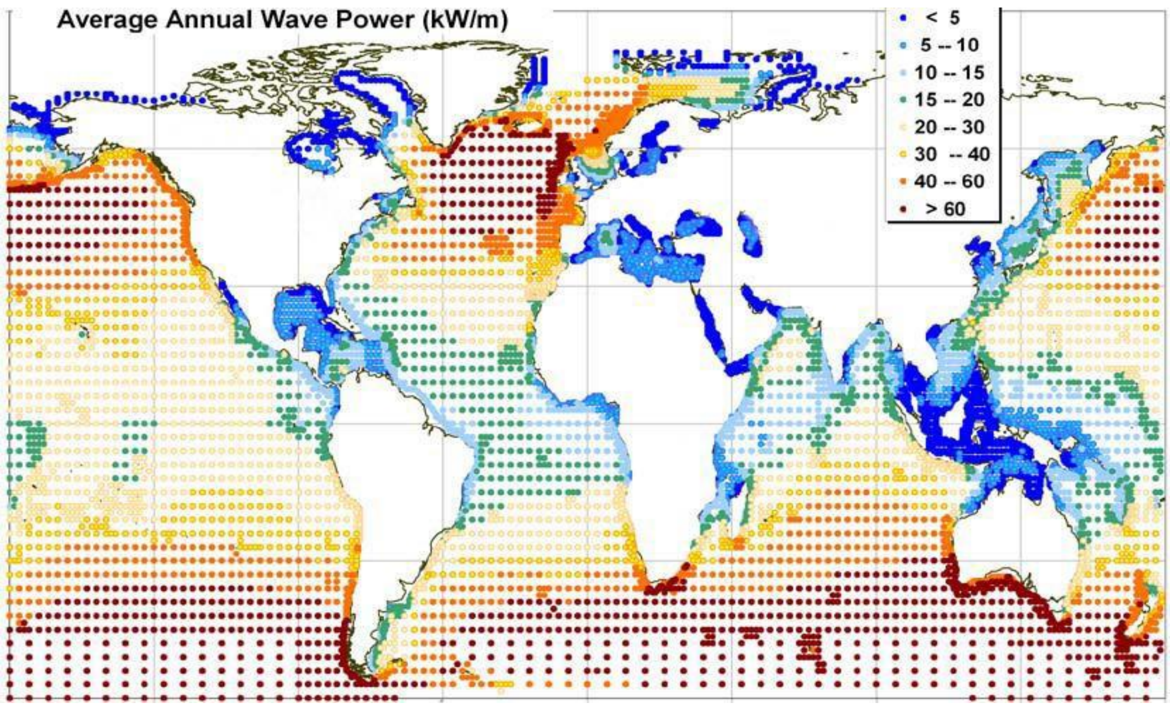

Figure 2: Global Distribution of Annual Wave Power Flux from Fugro OCEANOR World Waves Model (kilowatt per meter) (ADB, 2014).

Ocean Thermal Energy

Ocean thermal energy conversion (OTEC) is the type of ocean energy, which uses the temperature difference between surface warmer water and deeper colder water encountered in tropical oceans as the source of thermal energy. Based on the global ocean thermal energy resources shown in Figure 3 (IRENA, 2014), twenty-three African countries (seventeen mainland and six islands) with potential Ocean Thermal Resources (OTR) within their 200-Nautical Mile Exclusive Economic Zones (EEZ) have been identified. In West African countries bordering the Guinea Current LME and in East Africa countries bordering the Somali Coastal Current and Agulhas Current are included. More than half of the identified African countries can harness more than 1250 GWh per year (Table 1). Though most of the OTEC technologies are at pilot stage; they have a promising potential for full commercialization. For example, the size of the first commercial design ranges from 50–100MW, with a capital investment requirement of about $750 million for a 100MW plant.

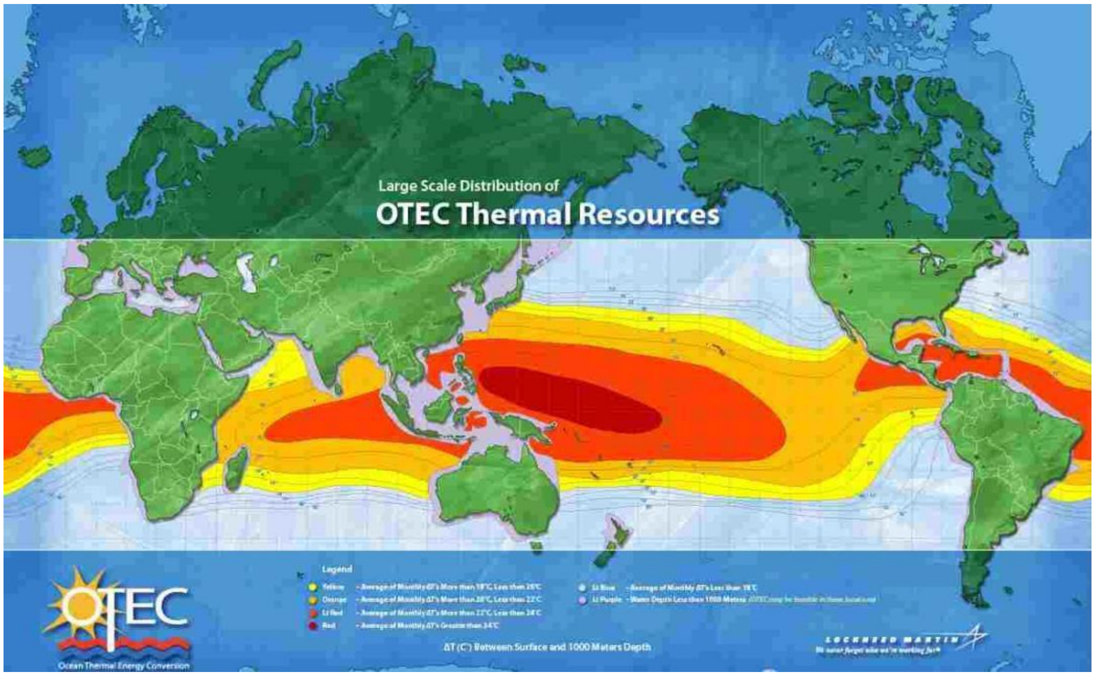

Figure 3: Ocean Thermal Energy Conversion World Potential Locations

Table 1: Countries and Large Marine Ecosystems with Appropriate Ocean Thermal Resources within Their 200-Nautical Mile Exclusive Economic Zones (Vega. L., 2010) and annual electricity generation with 100 MW OTE Conversion Plants, Guinea Current LME (1), Somali Coastal Current LME (2), Agulhas Current LME (3).

Country	**Annual Production (GWh)**	**Country**	**Annual Production (GWh)**
Angola (1)	750	Nigeria (1)	1500
Benin (1)	1250	Sierra Leone (1)	1500
Cameroon (1)	1500	Somalia (2)	650
Congo, Dem. Rep. (1)	750	Tanzania (2)	1000
Congo, Rep. (1)	750	Togo (1)	1500
Cote d'Ivoire (1)	1500	Aldabra	950
Equatorial Guinea (1)	1500	Ascension	1000
Ghana (1)	1500	Comoros	800
Guinea (1)	1500	Gabon (1)	1250
Kenya (2)	900	Madagascar (3)	800
Liberia (1)	1500	Sao Tome & Principe (1)	950
Mozambique (3)	850		

Source: Authors Compilation (Extrapolated from Vega. L.,2010)

Salinity Gradient

Salinity gradient energy is another type of ocean energy that could be harvested from the difference of salt concentration between seawater and fresh water. Salinity gradient power is available around the clock and could be used to stabilize the intermittent power supply of variable energy sources such as wind, wave, and solar. The availability and predictability of salinity gradient energy is very high, which makes it a solid baseload energy source.

The total technical potential for salinity gradient power is estimated to be around 647 GW globally, which is equivalent to 5177 TWh, or 23% of electricity consumption in 2011 (IRENA, 2014). The Ocean Energy Europe (OEE, 2019) indicated that the energy released from 1m3 fresh water is comparable to the energy released by the same m3 falling over a height of 260 m. Nevertheless, the technology is not mature and not yet economically feasible, which requires more technical and financial viability studies. The most advanced salinity gradient technology is Reverse Electro Dialysis (RED) and salinity gradient farms will soon follow across Europe (OEE, 2019). This indicates that it is time for Africa to positions itself on how to make use of the evolving technologies.

Marine Algae Biofuels

Marine algae specifically macroalgae (seaweed) and some microalgae can be grown at sea to produce biofuels, animal feed, and other coproducts. Though biofuels from algae are more expensive than from terrestrial biomass, improvements in yields, scale, and operations could lead to competitive marine algae biofuels (NREL. 2017). In addition to their use as biofuels, they can also be used as sources of foods, feeds and high-value bio actives with high potential to meet sustainable development goals in Africa. For example, Kenya, a Somali Coastal Current LME country, is aiming to transform into a newly industrialized country with a high quality of life for all its people by the year 2030. A study indicated that not only does Kenya, the Somali Coastal Current LME, occupy an optimal geographical region for microalgal cultivation (Moejes, F.W., and Moejes, K.B., 2017), but that microalgae has the capability to fulfil some of the 'Kenya Vision 2030' goals of which is biofuels.

3. OIL AND GAS

Though there are uncertainties in the exact estimate of oil and gas in Africa, the most recent geological survey sets the upper bound of Africa's potential at 1,273 billion bbl of oil (including condensate gas from gas extraction) and 82 trillions of cubic meters (tcm) of natural gas (including associated gas from oil extraction). About 70% oil and gas are available in a deep or ultra-deep-water offshore fields. It would be "technically and economically feasible" to recover about 381 billion bbl of oil and 73.8 tcm of gas (Modelevsky MS, Modelevsky MM, 2016).

Based on known reserves, there is *potential* for approximately 400 gigawatts (GW) of gas-generated power in sub-Saharan Africa. It is estimated that Côte d'Ivoire, Senegal, Angola, Ghana and Niger along the Guinea Current LME coast, South Africa, Mozambique and Tanzania along the Agulhas Current LME coast, and Kenya bordering the Somali Coastal Current LME hold the potential for around 16,000 MW (86 percent) of new gas-fired power generation projects through 2030 (USAID, 2018) (Figure 4). This potential could be unlocked through investment in developing indigenous gas resources, gas infrastructures, and liquified natural gas (LNG) import projects. These countries, which relatively have large populations and high gross domestic product (GDP), either have local gas resources (in operation or under development) or are planning LNG import projects. Making use of oil and gas resources for economic development and increasing access to electricity has a paramount importance.

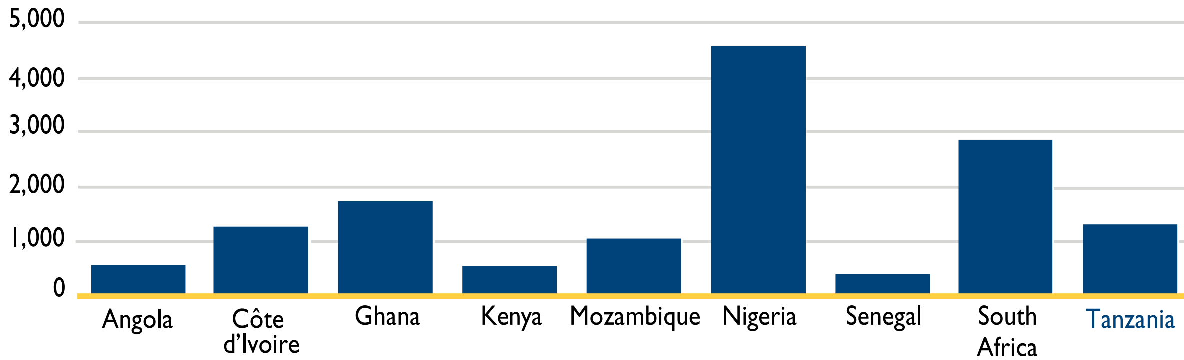

Figure 4 : Projected gas-fired generation capacity in focus countries through 2030

4. MARINE MINING POTENTIAL

The two major components in the mining sector are deep-seabed mining and seawater mining. Similar to ocean energy, they are also one of the untapped potentials in Africa with a potential for meeting global demand and national economic development needs.

Deep-Seabed Mining

Marine mining could be defined as "*the production, extraction and processing of none-living resources in seabed or seawater*" (UfM, Secretariat, European Union, 2019). The seabed constitutes three major marine mineral deposits including polymetallic nodules; polymetallic or seafloor massive sulfides; and cobalt-rich ferromanganese crusts (Figure 5). While Red Sea and Indian Ocean has massive sulfide deposits, western and south western parts of Africa have deposits of polymetallic nodules and cobalt-rich crusts. Some of these minerals have a very high demand for high-tech companies and clean energy technologies. From an African LME perspective two areas are of interest, deep water on the seaward edge of the Benguela Current LME off southwest Africa, and the deep-water area of the Agulhas Current LME off southwest Africa (Figure 5).

For many years, the exploitation of marine mining has been limited in shallow areas near shores for mining diamonds, tin, magnesium, salt, sulphur, gold, and heavy minerals. However, as inland minerals are being exhausted, countries are going into deeper water bodies where phosphates, massive sulphide deposits, manganese nodules, platinum, and cobalt-rich crusts are regarded as potential future prospects. For example, Namibia bordering the Benguela Current LME is one of the African countries that has started marine mining in 1960's. As its land mining is waning, it is moving aggressively to exploiting it's ocean-based mining. As a result, in 2017, the country's marine diamond mining company and the Namibian Government (CNN, 2017) produced 1.378 million carats (The Chamber of Mines of Namibia. *2017 Annual Review* **)** of diamonds. With the aim of expanding it's deep-seabed mining activities, Debmarine Namibia is planning to construct a $142 million ship-cum-tanker for seabed mining which will be the largest in the World. The ship is expected be ready for operation by 2021. The major countries with sea-bed mining potential include *South Africa*, *and Namibia bordering the Benguela Current LME*, *Mozambique bordering the Agulhas Current LME, and Senegal bordering the Canary Current LME.*

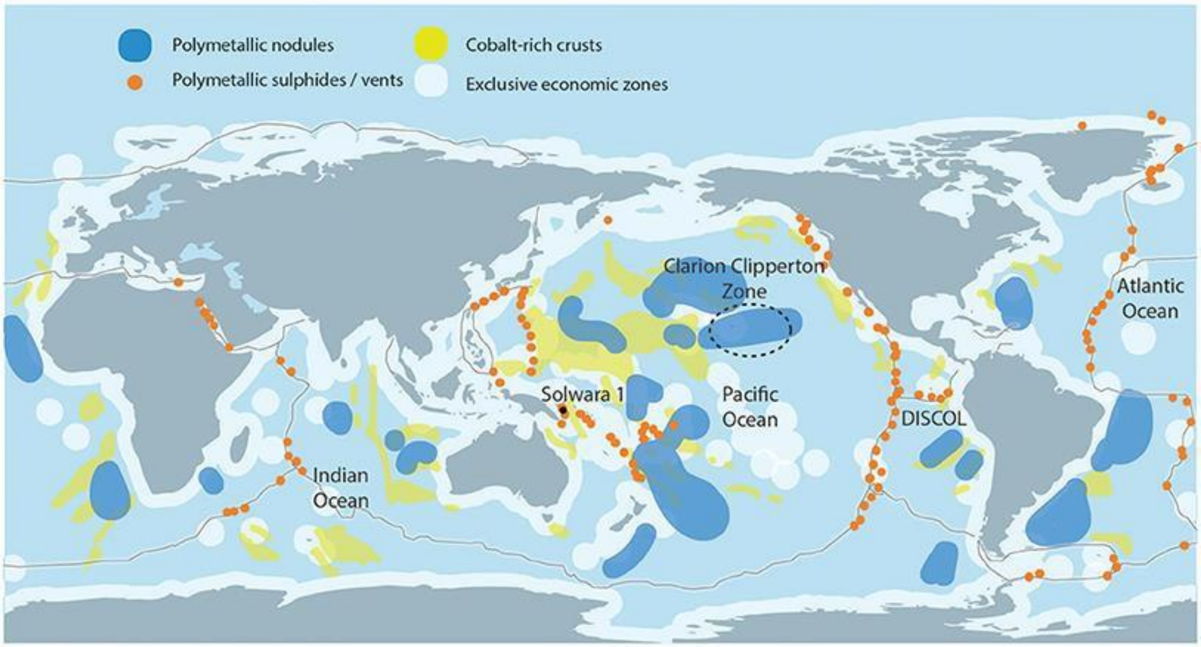

Figure 5: A world map showing the location of the three main marine mineral deposits: polymetallic nodules (blue); polymetallic or seafloor massive sulfides (orange); and cobalt-rich ferromanganese crusts (yellow). Redrawn from a number of sources including Hein et al. (2013) (Miller, K.A., Thompson, K.F., Johnston, P., and Santillo, D., 2019).

It should be noted that at global level, full potential of deep-seabed mining has not been realized. Though about 50 exploration licenses have been granted worldwide, no concrete results have been achieved mainly due to low technological advancement and lack of the regulatory system by many coastal countries. For example, as of 2017, only two deep-seabed mining projects have been granted in the World: Solwara 1 in Papua New Guinean and Atlantis II in the Red Sea of Sudan/Saudi Arabia (IUCN, 2019), in which extraction has not yet started (UfM Secretariat and European Union, 2019).

In addition to the need for a regulatory framework for exploration, for the fact that most of the locations where the minerals are deposited are located in ecologically significant areas (EBSA) and ecological hotspots (Figure **6**), developing an environmental management plan is critical to preserve the marine ecology.

Seawater Mining

Seawater contains large amounts of valuable minerals including rare earth elements (REEs), precious metals, lithium, and uranium. Although land-based minerals are concentrated in specific geologic formations and geographic areas, seawater minerals are generally distributed evenly (U.S. Department of Energy, 2018) in seawater with some higher concentrations near the mainland. If about 10% of the present worldwide market for minerals could be mined from seawater, the markets would be substantial (Table 2) (U.S. Department of Energy, 2018). For example, about 10% Lead (Pb) could add about USD 0.6 trillion to the global economy in which Africa should be able to extract it's share for its economic prosperity.

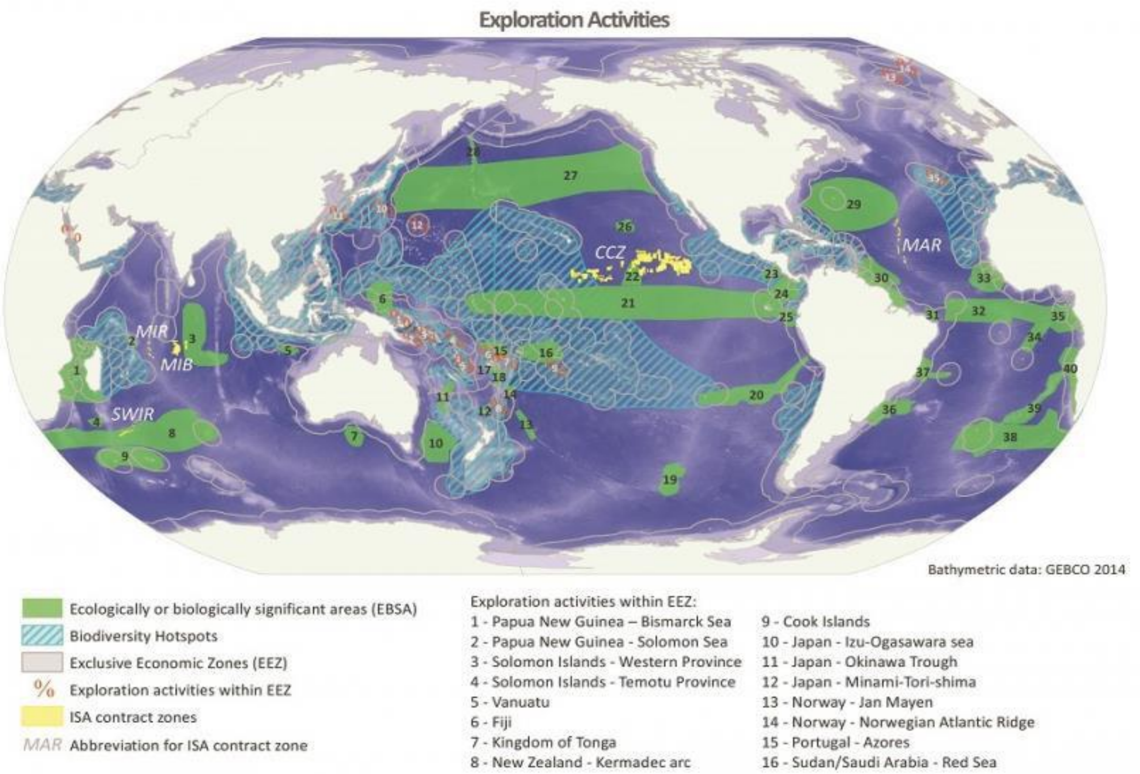

Figure 6: Global seabed mining exploration activities, and bathymetric map of ecologically significant areas (EBSA) and ecological hotspots (IUCN, 2019).

For the fact that extracting minerals from seawater is a more environmentally friendly enterprise than terrestrial mining (U.S. Department of Energy, 2018), this could have huge potential for Africa. Some of the critical minerals, which could be defined as mineral essential to the nation's economy or for national defense purposes, are found in seawater. These critical miners are usually exposed to supply disruptions and needed for development and deployment of clean energy technologies (DOE, 2011), advanced military applications (DOD (U. S. Department of Defense), 2015), and essential civilian and industrial uses, (U.S. Department of Energy, 2018).

Table 2: Estimates of Global Magnets for Key Minerals that Could Be Mined from Seawater

Element	**2017 Price ($/kg)**	**2017 Global Production (metric tons)**	**2017 Market Value ($)**	**Market Value from Seawater Mining* 10% of Global Production from Seawater ($)**
Li (Lithium)	$139.00	43,000	$5,977,000,000	$597,700,000
U Uranium)	$47.00	62,027	$2,925,193,320	$292,519,332
V(Vanadium)	$59.00	80,000	$4,744,000,000	$474,400,000
Cu (Copper)	$6.27	19,700	$123,519,000	$12,351,900
Co (Cobalt)	$59.00	110,000	$6,437,200,000	$643,720,000
Nd (Neodymium)	$58.00	130,000	$7,475,000,000	$747,500,000
Dy (Dysprosium)	$185.00	130,000	$24,050,000,000	$2,405,000,000
Tb (Terbium)	$475.00	130,000	$61,750,000,000	$6,175,000,000
Re (Rhenium)	$1,530.00	52,000	$79,560,000,000	$7,956,000,000
Pd (Palladium)	$27,650.00	210,000	$5,806,500,000,000	$580,650,000,000

5. GDP CONTRIBUTION AND JOB CREATION POTENTIAL

5.1 GDP Contribution

Blue Energy GDP Contribution: Blue energy penetration has already started in many African countries such as Ghana (Wave Energy), Mauritius (FPV) and prospective countries for offshore wind projects. Considering Ghana's electricity contribution to GDP of about 1.5% (Ghana Statistical Services (GSS), 2019) as our reference and assuming that progressively the share of the BE will be 5% of the total energy contribution in 2030 and 7% of the total energy contribution in 2063 the GDP contribution of the blue energy could reach about USD1.6 billion and USD2.3 billion, respectively (Table 3).

Ocean Mining GDP Contribution: One of the only estimated values of deep-sea minerals is in Papua New Guinea with a deep-sea mineral potential worth of hundreds of millions of dollars for gold, cobalt, zinc and copper. Assuming that the coastal African countries have similar potential of Papua New Guinea (IUCN, 2019) the value added from deep-sea mining is about 6 billion. It should be noted that two southwestern Africa countries, Namibia and South Africa bordering the Benguela Current LME have conducted offshore diamond mining which could soon be ahead of the curve to benefit from deep-sea mining. If African countries exploit about 2% of the market value from seawater mining of 10% of global production from seawater potential, it is worth about USD 50 billions of value added. This gives a combined value added of about USD 56 billion. It could reach about USD 76 by 2030 and USD 123 by 2063 (Table 3), respectively.

Oil and Gas GDP Contribution: In 2018, the total GDP contribution of oil and gas in the major oil and gas producing countries bordering the Guinea Current, Benguela Current, and Agulhas Current LMEs, such as Angola, Congo. Dem. Rep., Cote d'Ivoire, Equatorial Guinea, Ghana, Mozambique, Nigeria and South Africa is about USD 80 billion. Assuming the oil and gas exploration and new exploitation like South Africa starts producing, by 2030 and 2063, the value added could reach about USD 100 billion and USD 138 billion, respectively (Table 3).

Table 3: GDP Contribution (value added) by the energy, minerals and oil and gas sectors

Sector/ component	**VA 2017**	**VA 2030**	**VA 2063**	**Comments**
Energy	0.5	1.6	2.3	In Ghana, along the coast of the Guinea Current LME, electricity contribution to GDP is about 1.5%. This assumes that blue energy contribution to GDP will be about 1.5%, 5% and 7% share of the traditional electricity by 2020, 2030 and 2063.
Mineral	56	76	123	Total Added Value Assuming about 1% annual production rate of the 2% global production share.
Oil and Gas	80	100	138	Annual value added based on 2017 constant over the years.

5.2 Job Creation

Mining Job Creation: For the Guinea Current LME coastal area of Ghana, from 2004-2014, jobs created in mining sector increased by about 11% to reach about 48,631 (Baah-Boateng, W., 2018). This is an annual addition of direct jobs of 4421. The Ghana's experience disputes the general assumption that mining industries doesn't create much jobs. Assuming that the potential of the deep-sea mining and seawater mining could immediately create about 4,421, by 2030, it could create about 2 million jobs in 38 coastal countries and about 4 million by 2063 (Table 4).

Energy Job Creation: The current number of employments in Africa is about 322,000 (IRENA, 2019)**.** In Egypt in Benban solar complex of 1,650 MW opened in early 2019, employed 650 people (IRENA, 2019). This is without considering the job created during construction (10 000 workers) and operations and maintenance (4000 workers). Assuming that the 54 African countries exploited their energy potential and immediately start the use of the energy using the Egypt project as a baseline, by 2030 and 2063, the number of jobs could reach about 0.2 million to 0.5 million, respectively (Table 4).

Oil and Gas Job Creation: In the USA, oil and gas industry created about 5.6 percent of the total U.S. employment, which is about 9.8 million jobs (API, 2013). Assuming Ghana's 1% job created assumption by the mining sector, which could be translated to about 22,105 jobs by oil and gas (using 5% of the total of the USA), the jobs created in the oil and gas sectors in eight African countries including coastal countries of the Guinea Current, Benguela Current and Agulhas Current LMEs, Angola, Congo. Dem. Rep., Cote d'Ivoire, Equatorial Guinea, Ghana, Mozambique, Nigeria and South Africa, could total about 1.8 million in 2030 and about 5 million in 2063 (Table 4).

Table 4: Direct Job Creation in Mining, Energy and Oil and Gas

Sector/ Component	**2020**	**2030**	**2063**	**Comment/Reference**
Mining	1.70	2.00	4.00	Assuming 38 coastal countries with the base case of Ghana mining job creation.
Energy	0.16	0.20	0.50	Assuming 0.5% (2020), 5% (2030) and 10% (2063) of the current renewable energy related jobs (322,000) comes from blue energy. IRENA, 2019.
Oil and Gas	1.20	1.80	5.00	Assuming 5.6% percent jobs comes from oil and gas focusing on eight African countries and with 2.79% and 5% increase in 2030 and 2063, respectively. API, 2013.

6. CHALLENGES AND INTERVENTION

In unlocking the potential of sustainable blue energy, mineral resources and oil and gas in African LMEs, technical, institutional, regulatory, human skills and other barriers exist that hinder the realization of substantial benefits. Some of the challenges and potential interventions for consideration are discussed below.

6.1 Challenges

Blue Energy Challenges

The major challenges that drive the need for the application of sustainable blue energy and the challenges potentially hindering its application are technical, institutional, financial and regulatory in nature include the following.

- **Not Adequately Known Sustainable Blue Energy Potential**: Knowing the potential of sustainable blue energy and their monetization could drive investment in an expedited manner. However, though global scale potential assessments are available, continental and country specific sustainable blue energy potential are not adequately assessed, quantified and monetized. Thus, there is a need to monetize and quantify their potential in respective countries and LMEs.

- **Unavailability of Enabling Policy and Regulatory Frameworks:** Though progress has been made in increasing the share of renewable energies, there are some key challenges such as the lack of enabling policy frameworks and adaptive regulations as well as strong support from governments and other policymakers. The availability of such frameworks are the driving forces for attracting businesses to invest in sustainable blue economy.

- **Lack of Policies That Promote R&D**: The lack of **policies that promote R&D (**Bahar, H., 2019) are hindering the integration of ocean energy in the energy mix, albeit further cost reductions and large-scale development could be needed.
- **Lack of Access to Finance*:*** There is no adequate finance which supports the implementation of blue energy projects that need to be addressed.
- **Unavailability of Affordable Energy**: Due to high electricity prices and high connection fees, and low economic status of users in most Sub Saharan African (SSA) countries, energy affordability could also inhibit energy access and remains a serious concern. Some African countries are subsidizing electricity prices to resolve social concerns, which is not a lasting solution especially for attracting new sustainable blue energy.
- **Inadequate Power Grid Infrastructure**: The lack of sufficient power grid infrastructure (Hafner et. al., 2018) necessary to process, transport and distribute energy to the final users are a characteristic of the SSA region except in South Africa, which has a fairly decent power grid, and the North African region with its far-reaching power and gas infrastructure. Nevertheless, in most SSA countries the insufficient infrastructure could eventually hamper the development and distribution of sustainable blue energy infrastructure especially hydrogen production, and natural gas and oil pipeline and power transmission grid.
- **Unreliable Electricity Supply**: The ***lack of reliable and affordable electricity (***RES4MED&Africa and Enel Foundation, 2018) in Sub Saharan Africa is hampering the growth of businesses. As reliable and affordable power supply is an essential prerequisite for economic growth, sustainable blue energy can play a key role in improving electricity supply (IRENA, 2012) and blue energy could expedite the achievement of reliable and affordable power supply.

- **Unconducive Regulatory Systems and Capacity to Drive Competitiveness and Ensure Profitability*:*** Electricity demand, profitability and competitiveness are the major drivers for boosting renewable energy technologies in Africa. Like traditional energy, the application of sustainable blue energy will also depend on electricity demand, profitability and competitiveness. Most sustainable blue energy might become more attractive and profitable, if there is high demand and a very good regulatory system that gives confidence for collaboration. The ***unavailability of a regulatory system*** could mainly deter collaboration among countries.
- **Lack of Sustainable Blue Energy Specific Environmental Management Plan**: Sustainable blue energy resources should be exploited in a manner that doesn't impact the environment. Thus, **marine *ecology related environmental conditions and sensitive*** areas and legal matters should be in place to minimize environmental impacts and ***expedite*** the application of sustainable blue energy resources.

Mining Resources Challenges

The challenges in the implementation of deep-seabed and seawater mining resources are similar to the blue energy, which could be summarized as follows:

- **Not Adequately Known Ocean Mining Potential:** Though a very rough potential of Minerals, both in deep-seabed and seawater exist, they are not accurate. Moreover, as it is an emerging territory, there are many unknowns (World Bank and UNECA, 2017) and there is no detailed baseline assessment that provides the state and potential of mineral resources.
- **Lack of Regulatory Framework**: Though many inventors are interested in the exploration of ocean mining, due to the lack of regulatory framework, such initiatives could not be encouraged to proceed. Thus, the development of regulatory framework and system for licensing and exploration is needed.
- **Lack of Strategic Plans:** Deep-seabed mining also requires ***long range planning*** in which most countries have no guidelines on how to proceed.
- **Unavailability of Economic Value:** Economic viability of any mining is a prerequisite for implementation and in order to extract such potentials, potential knowledge of their monetary value is critical. Thus, ***economic Valuation*** of its potential and how it contributes to the national economic development should be evaluated.
- **Lack of Environmental Management Plans**: Deep-seabed mining requires the availability of stringent policy guidelines that protects the marine environment and goods and services including fisheries, water quality, and tourism. According to the International Union for Conservation of Nature (IUCN), regulations under development at the International Seabed Authority (ISA) to manage deep-sea mining are considered as insufficient to prevent irrevocable damage to marine ecosystems (IUCN, 2018). Thus, ***environmental impact assessment*** regulation specific to the deep-seabed mining need to also be in place and should be very stringent to protect marine ecology.

6.2 Interventions

The challenges identified are complex in nature that require multidisciplinary intervention actions to match the need for solutions. Here under are potential suggested interventions for sustainable blue energy, oil and gas, and mining resources, respectively.

Sustainable Blue Energy Intervention

Based on the above identified challenges, the following interventions are suggested including:

- **Undertake Sustainable Blue Energy Potential Assessment**: Undertake sustainable blue energy potential assessment for ocean based and land locked countries
- **Increasing Sustainable Blue Energy Mix**: In order to increase access to electricity, by 2030, Africa's power capacity is expected to add about **30,000 MW power capacity.** This is in accordance with the prioritization and support for transactions rooted in a country's national power strategy, particularly those using renewable technologies, such as solar, wind, biomass, and geothermal. The sustainable "blue energy" should be integrated as part of the traditional energy mix to achieve the target and go beyond. As many countries proposed to increase the share of renewable energy, the share of sustainable blue energy should be integrated in their strategic plan.
- **Increasing Grid Infrastructure to Support Sustainable Blue Energy**: In order to mitigate the lack of insufficient power grid infrastructure, by 2030, Africa is expected to implement about **60 million connections**, which will double the electricity connections in Sub Saharan African LME countries. As creating new generation capacity, without being delivered to homes and businesses, is not an end by itself, SSA countries should integrate and address the grid connections needs for sustainable blue energy.
- **Developing Regulatory Frameworks**: Developing appropriate legal and regulatory frameworks is needed not only to achieve the 30,000 MW capacity and 60 million connections, but also to accelerate the implementation of sustainable blue economy. Thus, developing clear and stable **national policy frameworks** that enable the private sector to invest with confidence (IRENA, 2012) is required to realize its potential.
- **Promote Market Driven Electricity System:** Market driven electricity system design**,** which is not widely practiced in most African countries, is regarded as the preferred approach to finance energy infrastructures and attract investment. This need to be promoted and enforced for practical results.
- **Promote Regional Power Sector Integration:** Regional power sector integration to harness sustainable blue energy especially in regional power pools for the implementing offshore wind projects is very important. For example, developing a join and integrated plan for offshore wind energy in three regions with the highest potential that include the Southern African Power Pool (SAPP), the Eastern African Power Pool (EAPP), and the Comité Maghrébin de l′Electricité (COMELEC) could be a very important step that could also be adopted for other ocean energy sources.
- **Implement De-centralized Electricity Power Systems:** Implementing de-centralized electricity generation, distribution and evacuation are viewed as a solution to deliver socio-economic dividends faster and at lower costs than the conventional past solutions

especially in rural and remote areas. Thus, decentralized systems, which continues to be considered a critical uncertainty should be addressed through the development of a regulatory framework that allows the integration of new energy opportunities.

- **Financial Support**: To ensure long-term sustainability of reforms and new power generation **investing in African institutions**; **supporting capability building** in local governments and civil society organizations; and promoting the establishment of **private sector trade associations** is critical.
- **Promoting Dialogue**: Facilitating **dialogue** between the private sector, governments, civil society, and development partners.
- **Opening Business Opportunities for Local Manufactures:** Exploring **opportunities for local manufacturing** as a means to reduce capital costs, create local employment opportunities, and improve trade balances (IRENA, 2012)
- Develop and Integrate Profitable Business Models: Integrate sustainable blue energy in the **renewables in economic development strategies**, develop long-term energy sector scenarios and strategies, and develop business/entrepreneurship models for renewables and their productive use.
- **Develop Location Specific Road Map:** In order to optimize the application of sustainable blue energy, assess and identify specific sustainable blue energy technology needs and applications for each of the African LMEs. Such strategies and roadmaps could help to tailor blue energy technologies to local conditions and accelerate their deployment.
- **Develop Decision-Making Tools:** Develop spatial maps of blue energy potentials and make the information publicly available to accelerate investment opportunities and increase knowledge for each of the African LMEs.
- **Tariff-restructuring:** Tariff-restructuring is important for renewable energy integration in which some of the energy, like FPV, have intermittency behavior that require price adjustments as needed.
- **Development of An Integrated Sustainable Blue Energy Planning:** Sustainable blue energy planning is needed which requires data collection and exchange of information for informed decision-making.
- **Undertake Regional analysis for Integrated Approach:** Sustainable blue energy potential could not only support coastal countries, but also land locked countries. Thus, in order to optimize and increases access to electricity at regional level, a regional assessment need to be conducted and applicability presented for regional benefits.

Oil and Gas Interventions

Oil and gas is another top ocean energy resource that could transform the economic development of the continent. While most countries, who are already engaged in the exploration and production, 638 have strategic plans, there are emerging opportunities that require an innovative and sustainable approach the expedites the sustainable use of the resources. For example, South Africa is now a new oil and gas frontier. In South Africa's oil and gas related blue economy priority focuses in **enhancing the enabling environment for exploration (**Spamer , J, 2015) of oil and gas wells, resulting in an increased number of wells drilled, while adding value to the country. According to their plan, they are expected to drill about 30 deep-water oil and gas exploration wells within the spatial domains of the Benguela Current and Agulhas Current LMEs, which is expected to create 130,000 new jobs. The mechanisms are intended to achieve an enhanced enabling environment including:

- *Providing an enabling policy and legislative environment;*
- *Promoting inclusive economic growth;*
- *Addressing the skills gaps, and*
- *Overcoming infrastructure challenges*.

In this regard, oil and gas specific sustainable blue energy should also address outstanding challenges and device interventions. Some of the top strategic interventions (in no specific order) extracted from the Africa's Gas Master Plan (USAID, 2018) and discussed with relevant experts are outlined hereunder, including:

- **Integrated Gas Economy Planning:** Develop an integrated gas economy planning tool for each country and region, which focuses helping in quantifying current and future market and supply options.
- Develop and Update **Gas Master Plan:** Develop and/or update gas master plans to ensure streamlining, relevancy and correct implementation;
- **Update Regulations:** Update regulations and policies to fit the current requirements to support the increase of gas in the energy mix;
- **Financial Capacity:** Strengthen the financial capacity and creditworthiness of state entities.
- **Strengthen Institutional Entities:** Create a simplified and streamlined protocol for more efficient decision-making within and among each of the various state entities and regulators to provide certainty regarding approval and permitting procedures for potential investors in the sector.
- **Implement Compressed Natural Gas (CNG) and Small-Scale LNG**: Assist in the development of CNG and small-scale LNG projects to monetize local gas resources, as well as serve local demand centers.
- **Develop Regulatory System**: Enhance an enabling environment for exploration and develop environmental sensitive areas of corridors to expedite the exploration and licensing of oil and gas resources.
- **Engage Oil and Gas Companies**: Engage oil and gas companies so that they can make sure they create local jobs not only focus in exploiting the natural resources. This is becoming a concern as oil and gas, and seabed mining can be exploited without being stationed fora long time at a site and without constructing pipelines

Ocean Mining Resources Interventions

Deep-seabed and seawater mining are the new evolving territories that require new approach and innovative intervention strategies for each of the 7 African LMEs - Canary Current, Mediterranean Sea, Red Sea, Somali Coastal Current, Agulhas Current, Benguela Current, and Guinea Current LMEs. Some of the propose interventions include:

Regulatory system: Regulatory system should be developed with respect to licensing for exploration and mining, which could expedite the process for exploration and minimize risks.

- **Assess Mining Potential**: Determine deep-sea mining potential and undertake its economic valuation to determine its national economic contribution potential.
- **Develop Environmental Management Plan**: Undertake environmental surveys and develop effective **regulation and mitigation strategies** to limit the impacts of deep-sea mining. It also includes undertaking comprehensive baseline studies that should be conducted to improve our understanding of the ecosystem of deep-sea floor.
- **Engage Mining Companies:** Engage mining companies so that they can make sure they create local jobs not focus in exploiting natural resources. This is becoming a concern as companies can use innovative mining technologies without being stationed for a long time at a site.

7. RECOMMENDATIONS

In order to reap the benefits of ocean energy and ocean mining for all 7 African LMEs (Canary Current, Mediterranean Sea, Red Sea, Somali Coastal Current, Agulhas Current, Benguela Current, and Guinea Current LMEs), challenges need to be addressed and potential intervention implemented. It is evident that their potential could contribute in increasing access to electricity, meet global mineral resources demand, and substantially contribute to the economic development. In addressing the challenges and harnessing their potential, the following strategic goals are proposed to help identify targets and actions so as to make use of the huge potential of blue energy, mining resources and innovative industries.

- ***Unlocking sustainable blue energy potential:*** Despite the huge untapped sustainable blue energy potential, no assessment and technical viability is being conducted. Thus, assessing its potential, investing in research and piloting, and implementing several projects should be one of the continent's top strategic goal. This strategic goal is aimed to address the technical aspect of the sustainable blue energy.
- ***Creating conducive regulatory environment for the development and application of sustainable blue energy:*** The current clean energy infrastructure suffers from the lack of clear policy, and institutional and regulators challenges. To ensure the success of assessing and implementing sustainable blue energy potential, technical considerations are not enough, and a conducive environment should be achieved through re-structuring of the developing regulatory frameworks, financial mechanisms, and updating renewable energy policies to incorporate blue energy so as to expedite the integration of sustainable blue energy. This goal is aimed to address the policy aspect of sustainable blue energy.
- ***Meeting the growing demand of mineral resources for economic prosperity***: As deep-seabed and seawater minerals could play an important role in the continent's economic prosperity, developing regulatory frameworks, long-range seabed mining plans, integrated marine management, and effective social and environmental impact procedures, and strengthening human, regulatory and institutional capacity, and promoting regional cooperation, and technology transfer are some of the components required to achieve the intended benefits.

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