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Oil, Gas and Renewable Energy

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Opposite page: Ultra-deepwater drillship active in waters 2 000 m deep, off Tanzania. © Matthew D. Richmond.

INTRODUCTION

This chapter describes the status of development and utilisation of the various energy sources present in or accessed from the marine environment. For over ten years, natural methane gas extracted from below the seabed has been used to produce energy in some countries, famously in Tanzania and Mozambique. However, there are other less obvious alternatives to energy available in the sea, notably from tides, currents and waves and the thermal properties of waters from the deep ocean.

With the exception of Reunion and Mayotte (France), all countries in the WIO region are exempt from reducing greenhouse gas emissions under the Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC). Consequently, there is no international obligation to reduce emissions from the burning of coal, oil or gas. The realisation is that these countries need energy to develop and reduce poverty and that their contributions to climate change are insignificant. However, they are still committed under the treaty to reduce their emissions. Actions taken to reduce emissions include support for renewable energy, improving energy efficiency, and reducing deforestation.

A common feature of the eastern Africa countries of Kenya, Tanzania and Mozambique, as well as Madagascar, is the generally poor coverage and irregular availability of electricity, infrastructure shortcomings that affect people's businesses, education and well-being. In Tanzania for example, with a population now exceeding 40 million, results from the 2010/11 National Panel Survey show that access to electricity had increased from 13 per cent to 17 per cent between 2008/09 and 2010/11, but that in rural areas access to electricity was only 5.3 per cent (NBS 2013).

This chapter considers the sources, impacts and potential of energy derived only from the marine environment, yet it is important to note that a number of land-based, renewable energy sources are being explored within the region. For example, Kenya is exploring benefits from geothermal energy (CDKN 2013) while Madagascar has identified significant small and micro-hydropower potential (Liu and others, 2013); solar and wind sites are considered on Reunion and Comoros (African Energy 2013), and the expanded use of biofuels on Mauritius (Republic of Mauritius 2014). In Tanzania and Mozambique, sugar cane and cassava projects to produce ethanol and biomass to fuel power generators are gaining support (Arndt and others, 2010, Wiggins and others, 2011). These are all land-based sources of energy.

Seychelles has plans for renewable sources to contribute at least 15 per cent to power needs by 2030 (Vannier 2013) mainly using wind and solar energy. Currently there are eight recently-installed windmills generating 6 MW of power (about 2.5 per cent of the total demand) (Vannier 2013), on reclaimed coastal land. The French island of Reunion is targeting renewable energy contributing 50 per cent of local electricity needs by 2020 and a further goal of 100 per cent of all energy use by 2030 (IEA-RETD 2012), mainly through wind and solar, as well as marine-based cold water energy (see OTEC below).

The need for energy by WIO countries

At present, all nine countries in the WIO region rely on the importation of oil to fuel power stations to generate electricity. For some, fossil fuel is the main source of energy, notably for the smaller island states like Mauritius, Comoros, Seychelles and France (Reunion), but also Madagascar and even some of the larger mainland Africa states like Kenya. In Mozambique and South Africa, coal is the predominant source of energy for power stations, with hydropower also contributing significantly. The latter source is also important in Tanzania, contributing 49 per cent of energy needs (Kihwele and others, 2012).

The main *driving force* for increased energy supply in most WIO countries is to supply electricity to local industry, commerce and their citizens. In most countries, population growth remains significant, between 1-3 per cent *per annum*, with Tanzania having the highest growth rate (World Bank 2014), thus the needs increase each year. Added to population growth is the desire to reduce the dependence on imported fuel (for power stations, vehicles, plastic industries and other consumers of oil and gas). Over the last decade, the electrical power demand in Mauritius has increased at an average rate of 4 per cent *per annum* (AFD 2012). This implies a doubling time of about 18 years. Similar consumption/usage apply to mainland African countries. If local energy options exist, these countries could potentially eliminate the costs of importation of oil, often one of the largest items on the domestic budget. For example, in Kenya, oil imports are the second largest item, accounting for 25 per cent of imported commodities (Mengo 2014). Over the first quarter of 2012, Tanzania spent US$ 842.4 million on imported oil, equivalent to 33.7 per cent of the cost of all imported good (BoT 2012), whilst in Seychelles, oil imports in 2009 amounted to US$ 205 million, or 25.4 per cent of total imports (Reegle 2012).

One common realisation by most countries in the WIO region is that energy diversification is key to addressing the growing needs of the expanding populations and industries (African Energy 2013). It is recognised that not all energy systems are large scale nor can they all be integrated into national power grids which themselves are often lacking and extremely costly to install. A more realistic approach is to consider a range of power generating systems of varying sizes to reduce risks and maximise coverage, while also involving the private sector (Kihwele and others, 2012). All countries are already benefitting from the use of solar photovoltaic systems, from the domestic, mainly at the single household level, making a valuable contribution to rural livelihoods (Hammar and others, 2009).

The status of marine-based energy sources in the WIO region

This section presents the status of energy use and describes the potential for future use of renewable and non-renewable (fossil fuel) energy sources from the sea in the WIO region. Although wind and solar energy technologies can be installed in the marine environment, and wind towers are present for example in the Irish Sea, off the coast of Denmark and many other parts of the world, the design and challenging maintenance issues result in significant additional costs compared to installations on land. As such, their use in the WIO region is not considered here.

Fossil fuels from the coastal zone and offshore

Nations whose landmasses and maritime EEZ are of volcanic origin have little to be optimistic about in terms of the likelihood of making discoveries of fossil fuels (hydrocarbons), unlike those nations that comprise sedimentary basins. The latter are a feature of the Kenya, Tanzania, Madagascar, Mozambique, Seychelles and South Africa territorial seas, as well as those surrounding the Comoros. For hydrocarbons to develop, the following four factors or criteria need to be present: (i) there needs to be deposition of an organic-rich source rock, typically derived from phytoplankton and algae; (ii) there needs to have been a means whereby this organic material became buried and trapped under layers of sediment rapidly enough to avoid oxidation (decomposition); (iii) the trapped organic material must experience appropriate heat and pressure over time, to crack the organic compounds into oil and gas - a process generally requiring burial of several hundred (ideally thousands) of meters; and, (iv) 'traps', such as anticlines or fault blocks, need to be present to create a reservoir into which hydrocarbons will accumulate, and to seal it - such traps for oil and gas are generally found at depths of 2 000 to 4 000 m below the seabed. The composition of natural gas varies depending on source and processing, but typically consists of over 90 per cent methane and small amounts of ethane and other hydrocarbons as well as nitrogen, carbon dioxide and trace amounts of water vapour (Demirbas 2010).

The US Geological Survey (USGS) has identified four geological provinces in the WIO region (Figure 26.1) for undiscovered, technically recoverable conventional oil and gas resources. The USGS study, by Brownfield and others (2012), revealed estimated mean volumes, for all four provinces combined, of 27 632 million barrels of oil (mmbo), 441 051 billion cubic feet of gas (bcfg) and 13 772 million barrels of natural gas liquid (mmbngl). To put the estimated volumes into perspective, the conversion rate of gas units to oil barrels is one barrel of oil (200 litres) being equivalent to 6 000 cubic feet of gas (cfg).

Recent discoveries and developments

The primary offshore discoveries recently made in East Africa (between 2010 and 2014) have been off the southern coast of Tanzania and northern coast of Mozambique, where combined estimates indicate the presence of at least 150 trillion cubic feet (tcf) of natural gas. This is based on Tanzania Petroleum Development Corporation's confirmation that the country's natural gas deposits are now estimated at 50 tcfg. Nellist (2014) and Deloitte (2013) report of at least 100 tcf of confirmed recoverable natural gas for Mozambique. Gas volume estimates change rapidly though, as more wells are drilled and existing wells are re-evaluated, but it is safe to say that at present, the above volume is the minimum found to date in this region.

The existing combined discoveries from the Ruvuma and Mafia basins (150 tcfg) is roughly equivalent to 25 000 million barrels of oil. The top African proven gas reserves are Nigeria (181 tcfg), Algeria (159 tcfg) and Mozambique (100 tcfg), with "east Africa deepwater" ranked overall third, according to Hanner (2014). Returning to the USGS estimates above, clearly there is potentially a great deal more gas (and oil) to be found in the provinces of the WIO that cover mainland Africa, western Madagascar and the Seychelles Plateau.

Both Tanzania and Mozambique have been benefitting from domestic gas supplies for the last ten years. Investment in development and production of the few methane reserves discovered in the 1970s, namely, in central and southern Tanzania, at Songo Songo and Mnazi Bay respectively, took place at the start of the new millennium. The Songo Songo field then began production in 2004, providing gas to Dar es Salaam for electricity, with the southern districts of Mtwara and Lindi now supplied with gas-generated electricity from the Mnazi Bay fields (Figure 26.2). The two producing gas fields (Songo Songo and Mnazi Bay) have a life expectancy of 25 to 30 years.

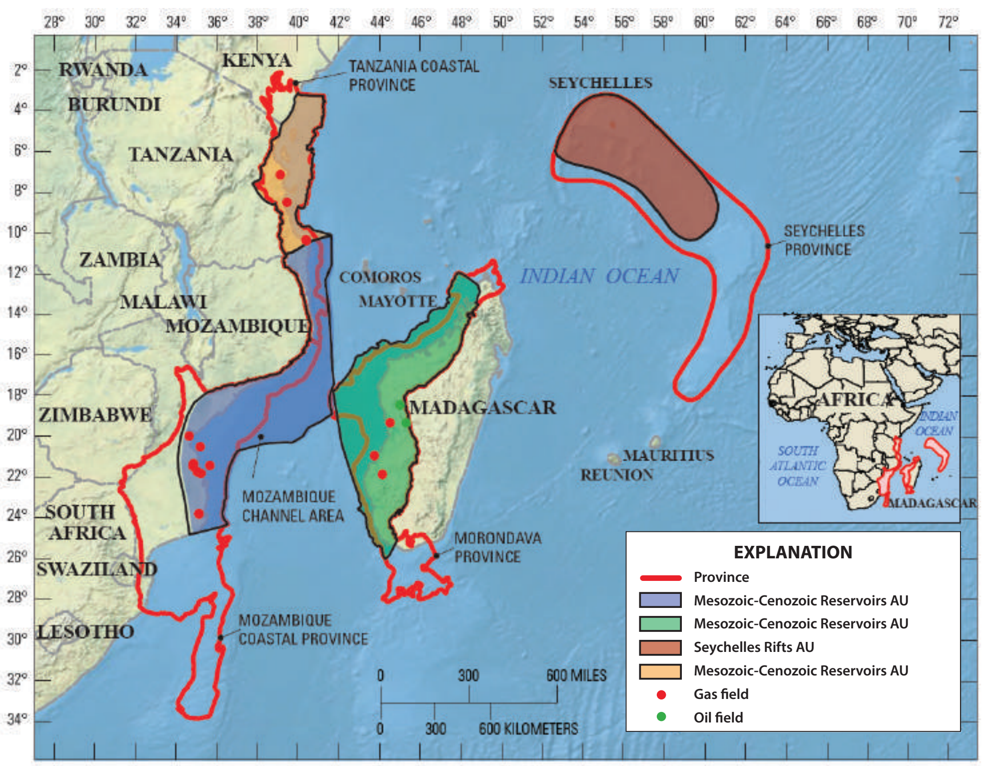


Figure 26.1. Locations of the four assessed geologic provinces and assessment units (AU) in the WIO region. Source: Brownfield and others (2012).

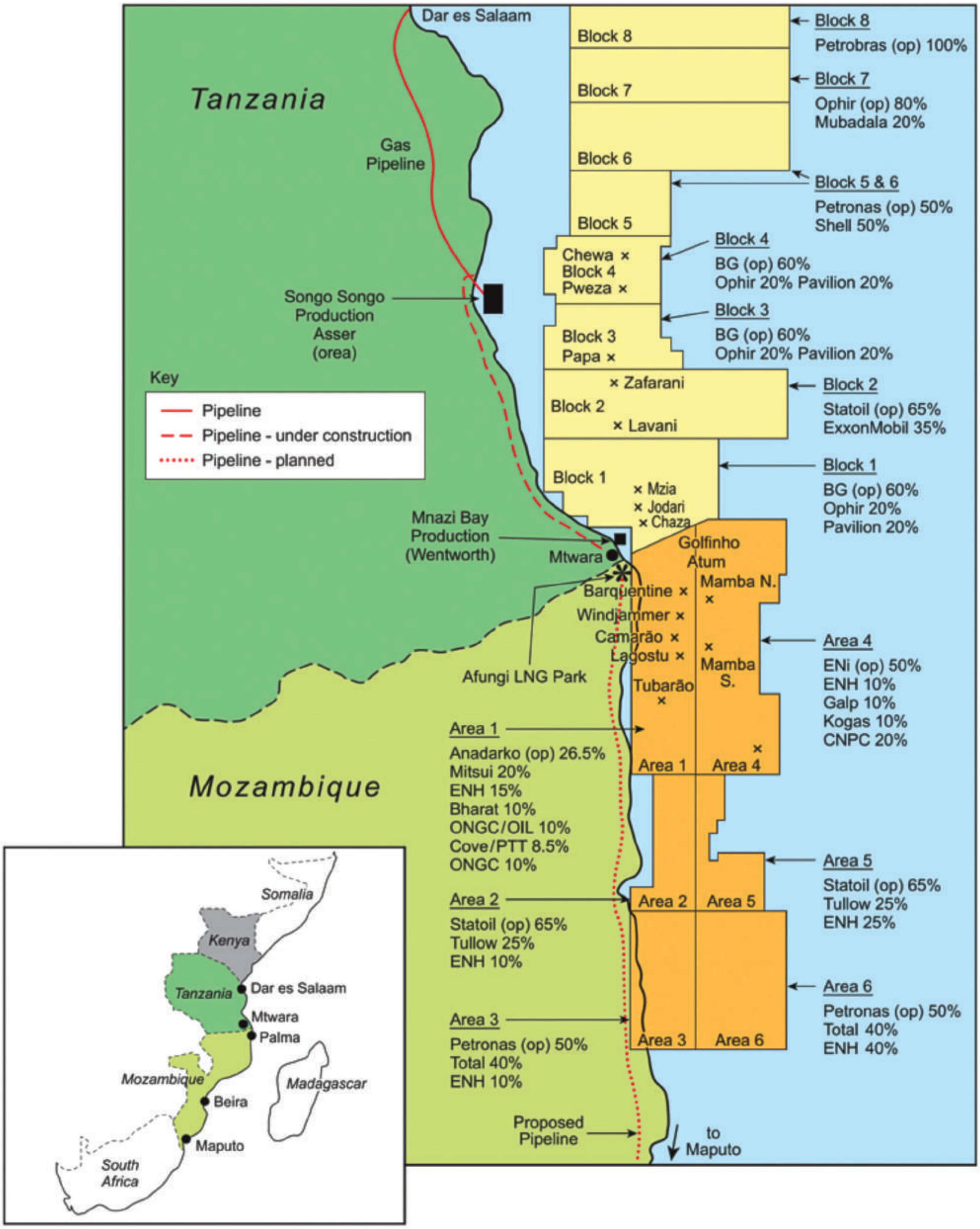


Figure 26.2. Southern Tanzania and northern Mozambique, showing most of the offshore exploration blocks, gas wells drilled (x), operator and other exploration companies involved, the locations of the Songo Songo and Mnazi Bay gas fields, various gas pipeline infrastructure and the site of Mozambique's Afungi LNG plant (under construction). Source: Wood Mackenzie (2014).

A number of industrial and commercial customers in the Dar es Salaam area already uses gas, and the soon to be completed additional gas infrastructure will boost usage. Expansion includes a 785 million cubic feet per day (mmcfpd) capacity, 542 km, 36" pipeline extending from Mnazi Bay to Dar es Salaam (see Figure 26.2) plus two new gas processing plants, on Songo Songo Island with a 140 mmcpfd capacity and at Madimba (Mtwara) with a 210 mmcfpd capacity (23 333 and 35 000 barrels of oil, respectively). The pipeline will provide gas transportation access to smaller discoveries by other gas exploration companies both on land and offshore. Two new gas-fired power stations to receive the processed gas are now under construction close to Dar es Salaam. The estimated completion of the entire expansion project is the end of 2015.

Similar developments also occurred in southern Mozambique, at the Pande and Temane gas fields, inshore of Vilanculos, near Bazaruto Archipelago (Figure 26.3). The gas supplies the Sasol Natural Gas Project in South Africa, a project that also included the construction of a central processing facility to clean the gas as well as the 865 km cross-border gas pipeline to Secunda in South Africa supplying gas to a petrochemical plant. The project started in March 2004 relying on wells located close to shore and in shallow water, with a combined volume of 5.5 tcfg, and an estimated lifespan for the production wells of approximately 25 years.

In Kenya, oil and gas exploration are on-going, with mixed results from offshore, though successful drilling and discoveries on land have been made in the Turkana Basin (Deloitte 2013). A recent exploration well drilled offshore, close to the EEZ border with Tanzania has intersected an oil column – the first-ever oil discovered off the East African coast, with high prospects for finding commercial quantities of the commodity in the area called the Lamu Basin (Pancontinental 2014). There are no commercial finds from exploration so far in Madagascar other than of minor heavy tars at Tsimiroro, 100 km inland. In Somalia there was past support for drilling operations but recent instability has precluded further development.

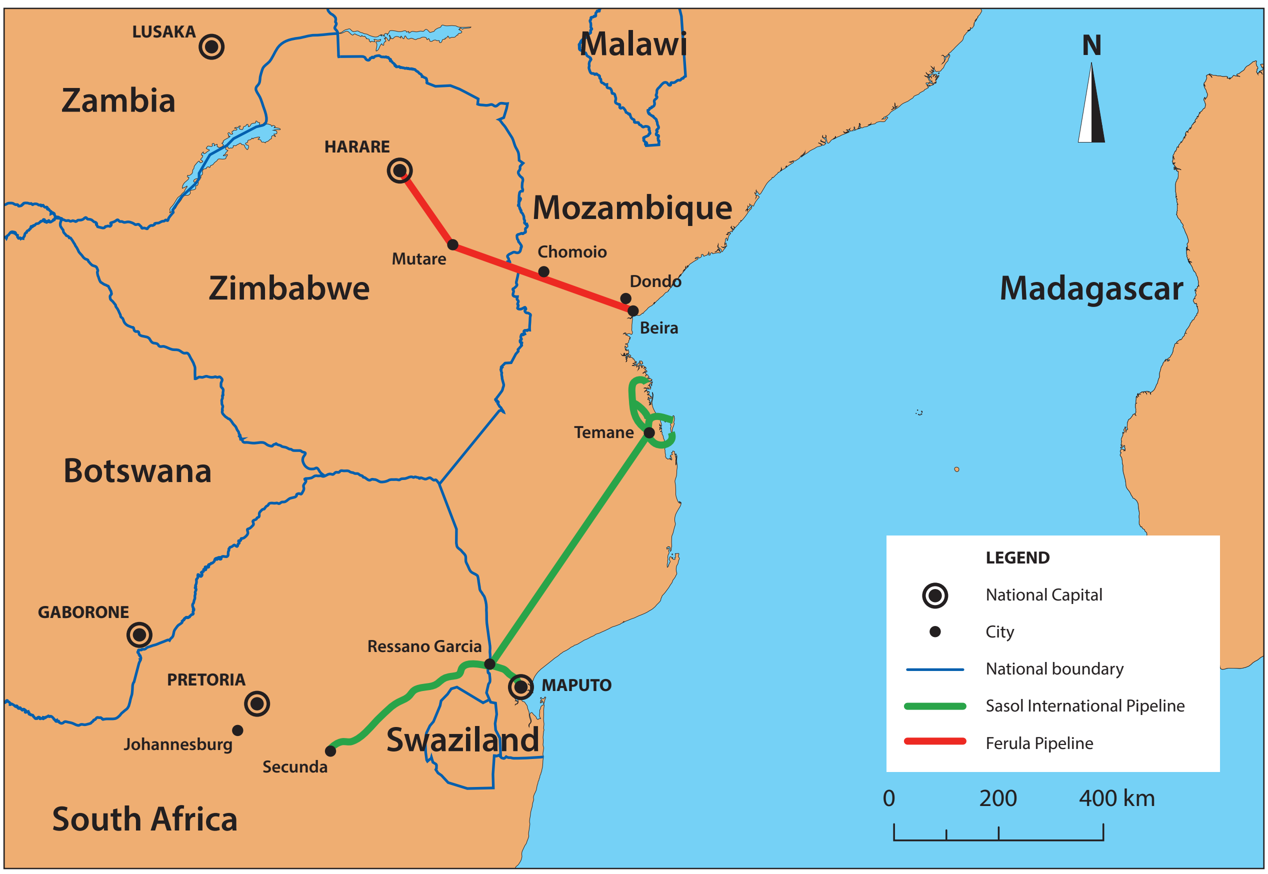


Figure 26.3. The Sasol Natural Gas project map, showing pipeline extending from the coastal gas fields of Temane and Pande to the industrial hub at Secunda in South Africa. Note: the Feruka pipeline, built in 1966, is 408 km long and supplies fuel oil to Harare, Zimbabwe. A similar pipeline exists in Tanzania, the Tazama pipeline, commissioned in 1968, extending 1 710 km from Dar es Salaam, supplying oil to Ndola, Zambia. Modified from: Wildcat International FZ-LLC 2013.

The East Africa discoveries have fuelled interest in the neighbouring islands of Comoros, as well as around the islands of Europa, Juan de Nova and Bassas de India, all in the Mozambique Channel. In the Comoros, exploration is beginning in the western portion of its EEZ, in the Mozambique Channel, with expectations of discoveries linked to those of neighbouring Mozambique with possible similar geological features. Seismic surveys are soon to commence (Spectrum 2014).

Seychelles conducted 2-D seismic surveys across much of the Seychelles Plateau in the 1970s with the first exploratory wells drilled in the early 1980s. Though no commercial quantities were encountered, the presence of oil and gas "shows" proved that a "working hydrocarbon system" was present (Petro Seychelles 2014). The fourth exploration well was drilled in 1995 and 3-D seismic surveys completed in 2012. The near future includes additional exploration drilling with participation of four international oil and gas exploration companies.

Drilling and costs

The only way to really confirm the presence of oil and gas and fully understand the geology of the various sedimentary strata is to drill an exploratory well. On land, the cost (in Tanzania), to drill a single exploratory well, in an area from which only seismic data was gathered, can reach US$ 38 million, an example being SS-11 on Songo Songo Island, where additional costs are incurred for transportation by sea of all equipment and materials (Orca Exploration 2012). Deepwater drilling is much more expensive. For example, the day rate for a drillship from Transocean, for ultra-deepwater drilling such as recently taking place offshore Mozambique and Tanzania, is typically above US$ 500 000 (Forbes 2013), while Fred Olsen ASA, another supplier of deepwater drilling platforms, including the "Bedford Dolphin" to Anadarko, also in Mozambique, charged a day rate of US$ 484 000 (Fred. Olsen-Energy 2014). Combined with the cost of two supply boats, one anti-pirate gunboat, two service helicopters, plus technical personnel aboard and shore base personnel and equipment, the overall day rate for such as operation was US$ 1.2 million in Tanzania (Hoole 2012). A typical single well drilling program, assuming no unforeseen delays, lasts 45-60 days (Pancontinental 2013), hence the total costs amount to some US$ 50-70 million. Even with very good quality seismic data, the worldwide success rate for an exploratory well in a new region (a 'wildcat'), is usually much less than 20 per cent. From well-drilling to final production of oil in barrels (or gas in pipes, or compressed into liquid and in tanks on ships) requires large investment, rapidly amounting to thousands of millions of dollars. For most countries in the WIO region, local investors are unable to match the costs of exploration and are not prepared to take the risks, hence the need for participation of the large independent and major companies in the oil and gas industry.

Other than the supply to local gas-fired power stations and large industries (eg cement plants, bottling companies, glass manufactures, fertilizer and chemical factories), large gas discoveries need large consumers. These are also not present in the region. However, the gas finds have generated a marked interest, due to not only their size, but also their placement in proximity to Asia. The discoveries have placed East Africa in the running to supply major Asian Liquefied Natural Gas (LNG) importers, putting them in competition with the USA and Australia (see Box 26.1).

The second *driving force* behind fossil fuel exploration is the potential to export to energy-hungry consumers such as India and China. Over the last ten years, the USA changed from being a net importer of oil and gas to a net exporter of gas and only a minor importer of oil (see Zuckerman 2013). The dramatic change in fortune within the USA, largely due to new technologies applied to extracting oil and gas using hydraulic fracturing (or "fracking") of oil- and gas-bound shale rock, demonstrates the unpredictable nature of the industry and production.

Deep Ocean Water Application

Deep Ocean Water Application (DOWA) is the name for the use of the deep bottom seawater with temperature of 5° C or colder, found at a depths below 1 000 m that, when brought to the surface, can be used for a variety of energy-related applications. Its most useful property is its low temperature. Deep ocean water makes up about 90 per cent of the volume of the oceans. The profile of the deep-water changes little seasonally, and therefore, cold water is always available.

A temperature differential indicates energy potential. Where there is an energy gradient there is potential for productive use by humans. Assuming the extraction of deep ocean water is environmentally friendly and the source is replenished by natural mechanisms, it creates the potential for cleaner energy than that derived from fossil-fuels. The simplest use of cold water is for air conditioning: using the cold water itself to cool air saves the energy that

BOX 26.1. THE NEED FOR LIQUEFIED NATURAL GAS (LNG) IN TANZANIA AND MOZAMBIQUE

Testing a new methane gas well, Songo Songo Island, Tanzania. © Matthew D. Richmond.

It is important to note that not all the gas is recoverable, that estimates vary and change considerably, and, more importantly, if the gas is to be liquefied so that it can be exported overseas, then 40 per cent of the gas is consumed in order to liquefy the remaining 60 per cent. Consequently, natural gas is not as desirable as oil because it is harder to extract and takes much longer to get to market (especially when in remote areas). On an energy equivalency basis it sells at a deep discount to oil mainly because there are fewer applications (at present) for its use, requiring more complex infrastructure.

In Tanzania, the construction of the joint venture LNG plant between Statoil (from Norway) and the BG Group (UK) is expected to begin at Lindi in 2016. The costs are expected to range from US$ 20 000 million to 40 000 million (IMF 2014). These include construction of the liquefaction plant, feeder pipelines from source wells sited at depths of 500 to 2 500 m to shore, delivering gas to processing plants (perhaps two) that then feed the gas to the refrigeration trains (usually multiple trains which reduce the temperature to approximately -160°C, shrinking the gas to 1/600th of its original volume). Storage facilities are needed and a docking facility for loading onto up to three specialized liquid gas carrier vessels, each 200 m in length. At the peak of the development phase, the annual investment would amount to 19 per cent of GDP (IMF 2014).

An almost identical but larger project is close to start on the Afungi Peninsula, near Palma, Cabo Delgado Province, in northern Mozambique (Figure 26.2), coordinated by the American company Anadarko. The other major exploration company in the area is Eni (previously Agip) who are considering a floating LNG facility (or FLNG), as an option to a land-based installation. Whether there will be two separate operations or a combined single investment, the total is expected to exceed US$ 50 000 million (Reuters 2014). By the next millennium, Anadarko (2014) estimates that Mozambique will have the third largest gas liquefaction capacity, after Australia and Qatar. Both the Lindi and the Afungi terminals aim for completion to coincide with an expected shortage of LNG in Asian markets between 2018 and 2022.

Standard Bank (2014) estimated that the Afungi LNG facility, once operational, will result in large and unprecedented economic gains for Mozambique. Six trains of LNG will add an additional US$ 39 000 million to the Mozambican economy by 2035 over a baseline growth case. As such, GDP *per capita* will grow from approximately US$ 650 in 2013 to US$ 4 500 by 2035 in real terms. It is also estimated that after 2020, at full production, the Tanzanian government could receive annual revenues of between US$ 3 000 million and US$ 6 000 million depending on the scale of production, equivalent to 10-20 per cent of (2012) GDP. These would have a transformational impact on the debt outlook, as by way of comparison, the country's national debt stock at the end of June 2013 was $ 17 690 million (URT 2013). However, in both countries, uncertainty remains about aspects of the fiscal regime under which such projects would operate. Negotiations continue and the final investment decision, for Tanzania at least, is unlikely to be taken until late 2015 (IMF 2014). Finally, it is important to note that increasing *per capita* GDP does not guarantee equitable wealth sharing. The history of the oil sector in West Africa is a clear demonstration of how benefits tend to accrue to a tiny minority while the majority remain in poverty. A more appropriate measure would be median income, which would reflect changes that actually affect the people as a whole.

would be used by the compressors for traditional refrigeration (Barrero and Gómez 2012) which in general, consume about 40 per cent of total electrical output (Hurd 2012). Usage could increase ten times by 2050 (Isaac and van Vuuren 2009). Seawater-based air conditioning is not technically complex nor does it involve a high technical risk. This application is currently being developed in Mauritius (see Box 26.2). Ideally, the DOWA technology must be near its intended use-area (eg airport, business or industrial centres) so as to reduce energy loss as the cold water warms up. In the WIO region there are several locations with steep temperature gradients close to shore, for example around Comoros, off the narrow continental shelf of some mainland African countries and off South Africa's east coast, but the latter in a high-energy area with heavy shipping activity (Retief 2007).

Another use could be to replace expensive desalination plants. When cold water passes through a pipe surrounded by humid air, condensation results. The condensate is pure water, suitable for human consumption or irrigation (Summerhayes 1996, PMO 2013). There are also significant secondary applications for the cold deep water. It is rich in nutrients and minerals and when oxygenated at the surface can support a wealth of sea-life. The extra nutrient content provides unique opportunities for mariculture (Nakasone and Akeda 1999) and can boost growth and quality of a variety of natural organisms such as shrimps and sea grapes (green macroalgae) of the *Caulerpa* genus (Martin 2012). Other downstream business activities include cosmetics and pharmaceuticals from shampoos to mineral gels, agrochemicals and thalassotherapy.

Finally, via a technology called ocean thermal energy conversion (OTEC), the temperature difference can be converted into electricity; however, numerous technical challenges persist that have delayed development beyond government-funded trials (IRENA 2014).

Tidal energy

There are two forms of energy derived from tidal changes. The first utilised fixed turbines inserted into tidal streams. This form of tidal energy potential exists along the coast of African countries (Kenya, Tanzania, Mozambique and South Africa) and the west coast of Madagascar thanks to an approximate 4 m spring tidal range. Other parts of the WIO region experience too small a tidal range to create the necessary water velocities needed to operate the submerged turbines that require water currents of 1.0 to 2.5 m/s (EPRI 2005). Though no sites have tested tidal stream energy, in South Africa, two potential sites have been identified, with depth-averaged currents of about 1m/s and water depths of 6 to 7 m, at Langebaan Lagoon and Knysna Heads, both in the Western Cape (Retief 2007). In the USA, several tidal and in-stream current turbine applications are now close to commercialisation, taking advantage of the daily tidal cycles in near-shore ocean environments, or steady water flow from freshwater rivers (MMS 2007).

The second form of tidal energy is obtained by storing water behind a barrier, or barrage, after high-tide, and releasing it through tunnels and turbines once there is a substantial height differential after the ebb has started. It is generally accepted that a minimum tidal range of 5 m (preferably >10 m) is required for economic viability in barrage schemes (Retief 2007). However, the localities where such structures could be constructed in the WIO region without negatively affecting the local marine habitats and the communities that depend on them are rare.

Ocean currents

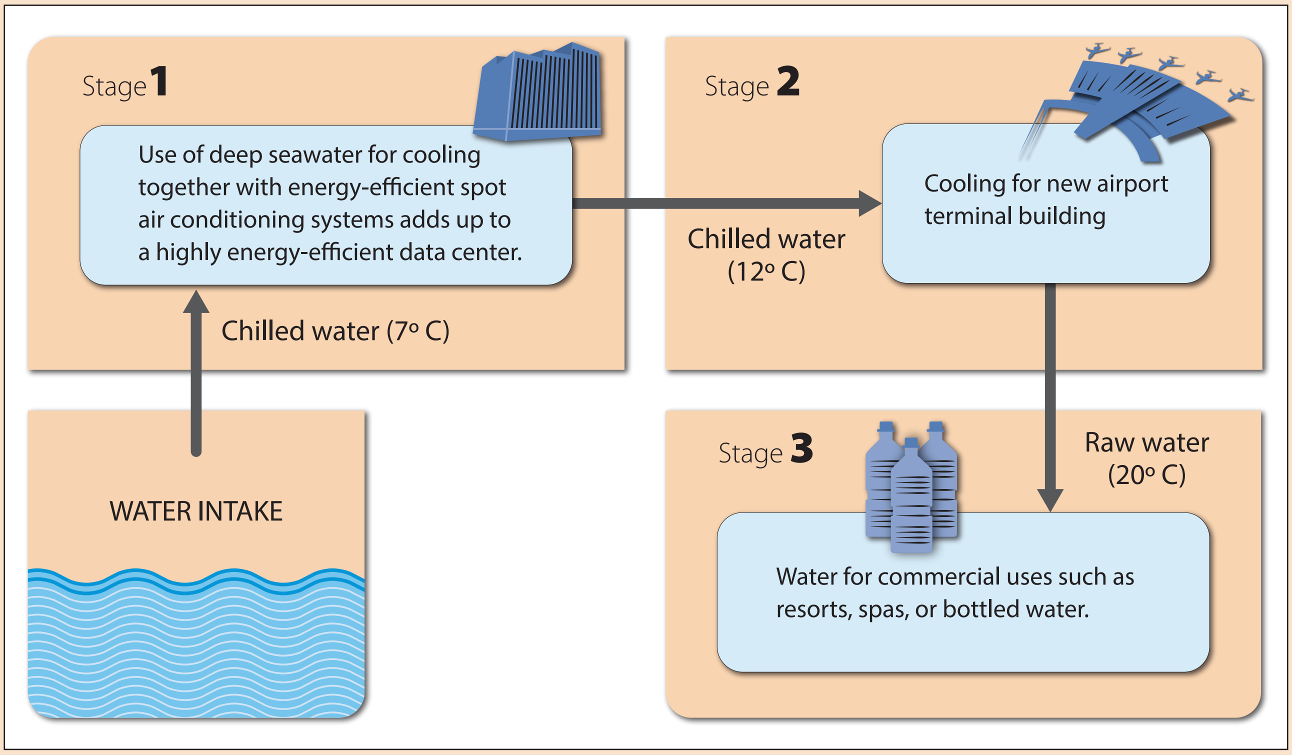
Ocean currents in the WIO region vary from weak in mid ocean to up to 4 or 5 knots along the east African coast (Lutjeharms and others, 1981, Ngusaru 2000, Benny 2002, Tomczak and Godfrey 2003), and unlike tidal current streams, are usually constant and unidirectional. A common feature of the ocean current energy prototypes tested to date is submerged turbines held in place by cables anchored to the seabed (DBEDT 2002).

The USA and other developed countries are pursuing ocean current energy; however, marine current energy is at an early stage of development and the only appropriate site so far identified in the USA is within the Florida Current (MMS 2007). Relative to wind, wave, and tidal resources, the energy resource potential for ocean current power is the least understood, and its technology is the least developed. It is widely acknowledged that the power of the ocean's currents is in general too diffuse to harness easily by conventional means (Summerhayes 1996). In the ocean area from Port Edward to Bashee River, south of Durban in South Africa, potential sites for testing current energy have been identified (Retief 2007).

Wave energy

The principle of harnessing wave energy is to use the energy stored in the motion of waves (namely the rise and fall of waves, or the rocking and heaving), or by focusing

BOX 26.2. DEEP OCEAN WATER APPLICATION (DOWA) IN MAURITIUS by Sachooda Ragoonaden



Business model for Mauritius. The rich mineral content of the deep seawater has the potential for a variety of commercial uses. Modified from: Hitachi Review 2014.

The concept of using deep cold water to cool the air in buildings is already being applied at diverse sites worldwide. At the Natural Energy Laboratory of Hawaii Authority since 1990, standard titanium heat exchangers and cold sea water provide air-conditioning of its main laboratory buildings, saving the facility nearly US$ 4 000 per month in electricity cost, since there is no need for the chiller which is the primary energy consumer for conventional air-conditioning systems (Craven and Daniel 2001). In Toronto, Canada, the system is meeting up to about 40 per cent of the city's cooling needs for office towers, sports and entertainment facilities and waterfront developments (Institute of Science in Society 2014). Others are planned for Curacao, Nassau, Reunion and Maldives.

Tropical countries consume a large proportion of their energy budget, mostly derived from fossil fuels, for air conditioning. Many are however ideally located close to deep cold ocean water and can therefore exploit the benefits of sea water air conditioning and take advantage of other deep sea water applications. Mauritius is planning the utilisation of the pure, nutrient-rich and cold deepsea water to develop DOWA projects. Two upstream projects are planned for implementation as from 2015 (Government of Mauritius 2014). The first one will be in the capital Port Louis whereby about 20 MW energy reduction is expected in the short term for cooling of offices and industrial buildings, with downstream activities following in a second phase. The other one will be implemented in the south of the island, in the vicinity of the international airport (Government of Mauritius 2014).

wave energy through refraction or diffraction. This source of energy has been investigated in some locations (eg Mauritius (NIO 1988) and South Africa (Joubert and van Niekerk 2013)), but it is generally accepted that of all countries in the WIO region, only South Africa has significant wave energy potential. Even there, potential sites are only south of the 30º S latitude (GESAMP 1984, Retief 2007), hence beyond the boundaries of the WIO region. Furthermore, wave energy generation reliability is low in most nearshore locations since the source is wind dependent, which is generally less inshore (Hammar and others, 2009). Despite these general conclusions, Tanzania is presently undertaking a feasibility study of wave energy at three sites, in cooperation with experts from Waveroller in Finland (WavePowerLab 2014).

Summary of energy options

Despite huge gas discoveries in Mozambique, and the start of gas flows to South Africa in 2004, gas contributes only 1 per cent to Mozambique's energy needs, and 2 per cent to those of South Africa. In Tanzania, present day gas supplies from the two coastal gas fields contribute over 40 per cent of national energy needs (MEM 2014). For Tanzania at least, the gas reserves are extremely important, helping secure power supplies in a country plagued for decades with power outages and a massively inadequate power supply infrastructure.

Kenya, Tanzania and Mozambique are at the start of what potentially could be a new and highly significant industry, located in the coastal and marine zone. In the latter two countries, there are already measurable economic benefits. If the projected oil and gas reserves continue to yield even a small portion of the results expected, then most countries of the WIO region will benefit from an income and saving on fuel imports that will significantly alter their economies, and with it contribute to eliminating poverty. However, the reality is that not all WIO countries have such resources, with Mauritius potentially being one of those that may not benefit from domestic fossil fuel reserves. South Africa is likely to exploit some, though from areas beyond the WIO boundaries, while Somalia's territorial waters remain largely unexplored due to the political instability.

Based on the information presented above, lack of development and uncertainties associated with all non-fossil fuel options at present reflect the meagre status of significant marine-based sources of energy in the region (Table 26.1). Aside from oil and gas, of the other three potential marine-based energy options presently available to WIO countries only cold, deep ocean water applications are seeing any development. This source of energy has the potential to expand and contribute meaningfully to reductions in the use of fossil fuel. Whether countries choose to explore its potential depends on the outcome of the oil and gas boom and the success of trials in Mauritius and Reunion.

IMPACTS FROM EXPLORATION, DEVELOPMENT AND PRODUCTION OF ENERGY FROM THE SEA

Impacts common to all structures placed in the marine environment

The presence of any structure placed in the ocean is likely to have some environmental and social impacts, even if only indirect ones. In the offshore oil and gas sector, likely structures include seismic survey and drillships, floating LNG plants, offshore oil and gas production platforms and seabed feed pipelines. Physical obstruction and interference with access for navigation or fishing activities, similarly affecting the movement of marine mammals and fish are the most obvious impacts. There is little by way of

Table 26.1. Current **(C)** and potential **(P)** marine-based energy exploration in WIO countries.

Countries	Oil & gas		Deep ocean water		Tidal streams		Ocean currents	
	C	P	C	P	C	P	C	P
Comoros	-	?	-	?	-	-	-	-
France (Reunion)	-	?			-	-	-	-
Kenya		?	-	?	-	?	-	
Mauritius	-	-			-	-	-	?
Mozambique			-	?	-	?	-	
Seychelles		?	-	?	-	-	-	?
Somalia	-	?	-	?	-	?	-	
South Africa	-	?	-	?	-	?	-	?
Tanzania			-	?	-	?	-	

Status of exploitation:	None -	Beginning trials	Some	Significant	Major

effective mitigation, yet the impact is small in terms of the physical size of the obstruction compared to the available wider open water.

Wave energy devices located close to shore are likely to affect sediment transport and distribution and could result in erosion in some areas and accretion in others. This could affect inshore reefs and impact on other uses of the coastal zone. They could also be a hazard to shipping. Tidal barrages are also likely to cause changes to sediment transportation, water circulation and biological communities. However, over time, an increasingly diverse flora and fauna is likely to become established, indicating a degree of biological adjustment to the new environmental conditions. Related to the physical structures described above, the *pressure indicators* are the use of rock, gravel and sand for their construction.

Impacts from fossil fuel exploration and their mitigation

The initial seismic surveys use compressed air to generate explosive sound waves that penetrate the seabed. These acoustic sound waves, reflected back as echoes from each geological layer penetrated (to 10 km into the earth's crust), are recorded using hydrophones. The sound generated close to the 'air gun' does affect sea life in close proximity (a few metres) and can affect marine mammals such as whales up to 20 km distant or even further (McCauley 1994, Richardson and others, 1995, Gausland 2003, Huelsenbeck and Wood 2013). Avoidance of whale migratory seasons and known whale or dolphin breeding or feeding areas are necessary mitigation measure in most countries. More often than not, seismic surveys include a Marine Mammal Observer (MMO) on board, specifically to address encounters with mammals and to guide mitigation procedures, usually following Joint Nature Conservation Committee guidelines (JNCC 2009). These guidelines include soft start procedures, minimum safe distances from marine mammals and constant monitoring and vigilance during operations.

Deep-water exploration drilling, though expensive and likely to consume between 1 500 and 3 000 tonnes of compounds per well is generally a clean operation. Many benign substances, such as water, bentonite and various salts, comprise the bulk weight of the compounds used (Patin 1999). Some cuttings (the sand and bedrock drilled out) will be discarded back to the seabed after cleaning, resulting in local smothering. This physical impact, measurable in terms of tonnes of waste materials covering given areas, together with noise levels from seismic surveys represents the most recognizable *pressure indicators* during the exploration phase (excluding accidental events).

Waste chemicals, surplus cement, and some oils are usually collected, stored and properly disposed of or recycled ashore. Drilling mud, a lubricant the viscosity of thin honey, is needed to lubricate and cool the drill bit. It also binds the cuttings with which it returns to the surface, in a 'closed' mud system. Cuttings are separated and the drilling mud re-used. For deepwater drilling, low toxicity, biodegradable oil is currently considered the safest compound to use as the binding element, combined with the weighing agent, usually bentonite (also regularly used on land for standard bore-holed drilling). Disposal of waste drilling muds in the deep sea or open water, may have widespread impacts, affecting marine mammals, turtles, birds and fish, though toxicity is typically rapidly diluted by the receiving environment.

Mangrove forests are particularly sensitive to oil pollution. Accidental oil spills or blow-outs during exploration drilling pose the most significant threats to the coastline of eastern Africa. Coral reefs, mangrove forests, seagrass beds, lagoons, turtle nesting beaches, marine protected areas with valuable biodiversity, fishing grounds and tourist facilities, dolphins, dugongs, whale sharks and humpback whales are common features of the region. All would potentially be impacted to varying degrees by a massive oil spill.

In most countries of the WIO region, oil and gas exploration is required by law to be preceded by an Environmental and Social Impact Assessment (or ESIA). ESIAs should identify the likely impacts of activities and the affected areas and stakeholders, and design mitigation measures and monitoring plans to address these. Associated with ESIA is the need for oil spill contingency plans. So far, oil has not been found in viable quantities in the WIO region but with large discoveries of more methane gas confirmed, there is a growing optimism that oil discoveries are only a matter of time. Other than from an extremely unlikely accident (like a crude oil blowout), disturbance to marine life from drilling, including to migrating Humpback whales, should be negligible. While EIAs are generally project-specific, a Strategic Environmental Assessment (SEA) is strongly recommended in cases where a new major resource is being developed, such as the gas industry in countries like Tanzania and Mozambique. An SEA considers the broader scenario, including legislation likely to have an effect on the management, conservation and enhancement of the local environment (including coastal tourism and security) and the sustainable management of natural resources (like fisheries), as well as any relevant regulations, policies, programs and development plans, and helps plot the development of the whole sector.

The *state indicators* associated with exploration for oil and gas include the noise levels that impacts on migrating species such as whales, turtles, tuna and whale sharks; the amounts of discharged drilling muds and fluids at the well locations, on the seabed and into the water column; and, the resulting degraded seawater quality around drilling platforms. Meanwhile, *impact indicators* related to exploration (and at times, production) include reduction in migrating marine species.

Impacts from fossil fuel production

Once gas or oil reserves are identified and production commences, the transportation of fossil fuels is vulnerable to poor maintenance, weak infrastructure and accidents, resulting in potential threats to the coastal and marine environment. Impacts from methane leaks are not well-documented, but impacts on the marine environment from crude oil are much better understood (eg Gilbert 1982, Patin 1999, IPIECA 2000). Consequently, *impact indicators* related to oil and gas production (and at times, exploration) include the loss of mangrove forest and seagrass beds from oil spills.

Social impacts associated with the developing industry in Tanzania and Mozambique have already been felt. Some are positive, like increased local employment associated with the industry, benefits from corporate social responsibility initiatives (often linked to training and education) and increased tax revenues from the spurred business at locations such as Cabo Delgado and Pemba in Mozambique and Mtwara in Tanzania. *Impact indicators* related to these socio-economic aspects include tax revenues, figures of employment and trained and skilled workforce. Negative aspects have, unfortunately, also manifested themselves, particularly in Mtwara where riots developed after rumours circulated that the 542 km gas pipeline (mentioned earlier) would transport "local" gas to Dar es Salaam without benefits to the local inhabitants. Relevant *impact indicators* might be the number of incidences of unrest where police where involved, or the costs of housing and basic foodstuff - inflationary consequences of the rapid development of any industry.

Before natural gas can be utilized, it must be processed (cleaned) to remove impurities and water. The resulting "produced water" is usually discharged to sea after removal of hydrocarbons and other chemicals, though low levels remain. Though the quantities of produced water are generally low, the contaminants (which can usually be removed) do nevertheless present pollution threats which can be measured and thus classified as *pressure impacts*.

Cumulative impacts from methane leaks is a potential major negative aspect of its use as an energy source and represents another *pressure indicator*. As the utilisation of methane increases, there are concerns that leaks of this gas, a far more potent contributor to climate change than carbon dioxide, will offset any gains from reductions in use of more dirty hydrocarbons like coal and oil. Odourless and clear, tracking leaks from pipelines and drilling is very difficult. Even in the USA, where natural gas is increasingly contributing to energy supplies, the Environmental Defence Fund has not yet determined how much gas is escaping to the atmosphere (Zuckerman 2013).

LOCAL PARTICIPATION IN MARINE-BASED ENERGY OPTIONS

The governments and business sectors of most countries in the WIO region have limited capacity to engage in the development of the marine-based energy options described above. Clear weaknesses in capacity include a lack of a maritime sector in the first place, combined with inadequate safety and security considerations, and limited technical skills (in the geological, petrochemical, technological sectors) as well as in engineering, construction, logistics and supplies, health and safety capabilities. There are also inadequacies among national regulators and ESIA consultants.

The gaps are slowly being addressed by international NGOs such as WWF, some companies under their corporate social responsibility (CSR) mandates, Oil for Development (Norway), financial institutions (eg World Bank) and other initiatives. Engaging in capacity building is vital for national buy-in and participation, critical to building confidence, transparency and maintaining long-term sustainability.

With environmental and social issues associated with oil spill response extensively covered in the media following the 2010 Gulf of Mexico spill, oil spill preparedness remains as important as ever. In many WIO countries, government institutions tasked with management of the environment, and ensuring compliance of mitigation measures and monitoring procedures associated with such large projects as deep-sea drilling, are often lacking in technical capacity. Fortunately, there is support from donors, the industry and NGOs, to assist local governments to better manage an activity that may become a significant presence in the region in the years to come.

In additional to national lack of capacity, the development of renewable energy options (including marine-based options) are hampered by a number of issues, as described by Hammar and others (2009), and include the following:

- Absence of long-term hydrological and meteorological data;
- Weak transport infrastructure;
- The need to include local participation in order to develop acceptance;
- Lack of locally-available spare parts;
- Insufficient electricity grid coverage;
- Theft and vandalism, notably in Tanzania; and,
- High dependence of rural communities on ecosystem services (mangrove forests, coral reefs, intertidal flats).

TRAJECTORY AND CONCLUSIONS

The USA and the companies involved in the 2010 Gulf of Mexico Macondo spill demonstrated that they have sufficient capacity to handle the logistics and costs of a rapid and comprehensive response and clean-up, though much of the oil remains unaccounted for. A similar event in coastal East Africa would however be more complex, less certain in outcome and thus potentially a lot more damaging to the local economy and the sensitive coastal and marine environment. There are many lessons from the recent Gulf of Mexico's oil spill that are relevant to the WIO region. These include recognizing the need for governments, industry and NGOs to work together during an accident, but more importantly, before any accident in order to reduce the likelihood that such an accident could occur. The highest technical standards must be applied and monitoring should be thorough. This includes for example, ensuring that well casings have proper seals and are set at proper depths to avoid drilling chemicals leaking into underground aquifers.

Added to the risk of oil spills are the vagaries of the energy market, regional and national politics, social and development issues, and the impacts of changing technology on fossil fuel discoveries. On the latter for example, the recent discovery of shale gas in the USA, among which is the Marcellus gas resource, the same size as the oil and gas resource of the North Sea, with 500 tcfg, equivalent to 83 000 million barrels of oil, becomes a "game changer" (Zuckerman 2013). The USA can now consider itself a net gas exporter, something not imaged a few years back.

Whether China and other Asian countries manage to explore their own enormous reservoirs of natural gas will likely influence the demand for natural gas from sources such as those in the WIO region, where costs of exploration and production are high, even though extraction costs are relatively low because the gas is readily extracted. The projected demand will significantly impact the profitability of the industry in the region, where massive investments are required to explore, liquefy and export the gas. At the very least, if local energy needs are met, the region will significantly benefit, but that will depend on the relationships between the exploration companies and national governments who presently do not have the financial or technical capacity to undertake exploration alone. While some large companies such as the BG Group, Petrobras, Statoil AS, Shell, Exxon, Anadarko and Eni are presently engaged in exploration in the WIO region, there are no guarantees for future involvement. These companies require stability of gas demand and security of their investment, two factors that the countries in the WIO at present cannot guarantee. As described above, the demand for natural gas from the WIO is influenced by factors beyond control of regional governments. Depending on discoveries within the various (often multi-country) assets held by such companies, their presence in any one country can change without notice. Farm-ins, by-outs, mergers, and go-slow are common terms in the industry were companies often come and go within a few years, especially in the early days of exploration and development. Security of their investments at the national level is also somewhat unpredictable, as local politics jostle with issues of ownership, transparency, "local content" and national revenues. The experience from West Africa and the "resource curse" where large proportions of the revenues from oil production that started in the 1960s ended up in the private accounts of politicians, while the citizens remained below the poverty line, is a reminder than young African democracies are not always the safest places to invest (Shaxson 2007). The vision of a gas-powered economy as proposed by some politicians may and hopefully will become a reality, while the "gas bonanza" hoped for by some is subject to many more *driving forces* beyond the influence of the region's governments.

There exists the risk that if the major companies hesitate to invest in the WIO region, smaller companies will partner with local governments to fill the gap. While such a scenario may help fulfil the expectation to exploit local resources, it also potentially increases the possibility of accidents since the mega-companies usually have more stringent technical, environmental and social standards, and the experience and financial means to address associated issues. These standards are mainly driven by the corporate social responsibility targets that are increasingly a requirement of shareholders of major companies in developed nations. Smaller companies often are not pressed to maintain such standards and also do not have the financial base to compensate in the event of a major accidental event such as an oil blow-out at sea. However, the 2010 Macondo well blow-out in the Gulf of Mexico showed how in some instances companies like BP, Haliburton and Schlumberger fail to perform as planned, and accidents still happen.

In Tanzania, the draft Natural Gas Policy includes the following statement: "A Natural Gas Revenue Fund will be established and managed to ensure transparency and accountability over collection, allocation, expenditure and management of all natural gas revenues." A similar gas policy is being drafted in Mozambique. Whether these have come about due to influence from Norway where a special fund ensures that riches from fossil fuels are screened from political interference is not clear, but such policies if implemented may indeed secure the mineral wealth for the population at large and over the long term, avoiding the well-known "resource curse" typical of so many other countries in Africa. It is hoped by many that such policies will bear fruit, but only time will tell. The need for transparency, national dialogue and sound fiscal management of the natural gas revenue cannot be over-emphasized. There is also concern that countries like Tanzania and Mozambique are not "ready" for oil and gas, or natural energies based on the development of new policies and legislation. This is a major part of the response required by governments.

Based on the regional energy opportunities described above, the following are recommended:

- The development of awareness and capacity building in all areas associated with energy exploration are desperately needed in most countries in the WIO region. This particularly includes the environmental regulators (responsible for SEAs and ESIAs) and those charged with developing contracts and agreements with energy sector investors.
- Promote effective management and good governance of the extractive sector, as suggested by the Extractive Industries Transparency Initiative (EITI) and establish a rigorous fiscal regime with transparent tracking of both incomes generated and the fate of that income. Establish ring-fencing of revenues from the profitable sectors (eg oil and gas) to avoid politicising the resource and its benefits and ensure transparent and wise use of the same. Encourage participation of civil society watchdog organisations to help ensure equitable distribution of benefits.
- Protect the marine environment (including migratory species) and ensure oil pollution preparedness and that oil and gas companies have adequate insurance (eg US$ 10 000 million) in the event of a spill and can cover clean-up costs and compensation for loss of livelihoods.
- Sign and ratify all International Maritime Organisation (IMO) conventions relevant to oil and gas exploration, shipping, transportation of oil etc.
- Review legal mandates to ensure that compensation for damages caused by marine-based energy companies are streamlined.
- Adhere to the conditions of the Nairobi Convention. The most relevant articles, among others, are: 5 (pollution from ships), 8 (pollution from seabed activities, including oil and gas exploration), 12 (co-operation in combating pollution in cases of emergency) and 16 (liability and compensation).
- Develop and promote alternative, renewable energy alternatives.
- Promote regional coordination on planning of trans-boundary issues such as oil spill contingency, piracy and security, as well as cross-border developments to minimize negative impacts and maximize benefits from marine-based energy sources.

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