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WORLD MARITIME UNIVERSITY

Malmö, Sweden

**IMPROVING MARITIME SURVEILLANCE IN
KENYA'S REMOTE COASTAL ISLANDS:
APPLICATION OF RENEWABLE ENERGY
SOLUTIONS.**

BY

JOHN CHURCHILL OMONDI

Kenya.

A dissertation submitted to the World Maritime University in partial
Fulfilment of the requirements for the award of the degree of

MASTER OF SCIENCE

In

MARITIME AFFAIRS

(MARITIME ENERGY MANAGEMENT)

2017

DISSERTATION DECLARATION FORM

I certify that all the material in this dissertation that is not my own work has been identified, and that no material is included for which a degree has previously been conferred on me.

The contents of this dissertation reflect my own personal views, and are not necessarily endorsed by the University.

(Signature):



(Date):

19th September, 2017

Supervised by: *

World Maritime University

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ABSTRACT

Title of Dissertation: **Improving Maritime Surveillance in Kenya's remote Coastal Islands: Application of renewable energy solutions.**

Degree: **MSc**

Maritime Surveillance encompasses tools and activities designed to enable governments gain understanding of everything in the maritime environment that can pose security threat. Such threats can take the form of piracy and armed robbery, organized crime such as, human and drug trafficking, smuggling, illegal exploitation of marine resources or the destruction of marine resources through dumping and pollution. Kenya's geographical position, in the vicinity of a piracy prone region inevitably puts her at risk.

This thesis analyses Kenya's maritime surveillance regime as currently constituted, with a view to identifying gaps and possible areas for improvement. The absence of grid connection has often been cited as a major handicap to the installation of robust electronics for maritime surveillance. The Kenyan Maritime Administration, which has the overall regulatory mandate on maritime affairs in Kenya was incorporated in May 2004 and is in the process of setting up the necessary infrastructure for maritime surveillance. Among the projects earmarked for prioritization in this regard is a coastal surveillance system. Of particular concern are remote Islands making up the Lamu archipelago, near the maritime boundary with Somalia.

It is very difficult to change or upgrade an energy system after it has been established. In order to choose the right system and technology for a specific application, budget, and geographical location, it is important to take into account all the underlying factors and externalities. This helps in avoiding future switching costs while rendering the performance of the selected option more efficient. In terms of maritime surveillance, each region presents unique challenges, which need to be specifically investigated, in order to leverage available facilities and capabilities in the context of inter-agency engagement.

This thesis concludes that with the available energy resources in Kenya, and mature status of wind and solar energy technologies, maritime surveillance of remote outlying coastal islands in Kenya can be greatly improved through renewable energy power solutions. The aim is therefore to deliver powerful information for decision-makers responsible for planning in the maritime administration.

KEY WORDS: Maritime Surveillance, Situational Awareness, Renewable Energy, Levelised Cost of Energy (LCOE).

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Abbreviations

AIS	Automatic Identification System
BIMCO	Baltic and International Maritime Council
BMP	Best Management Practice
BMU	Beach Management Unit
CBP - USA	US Customs and Border Protection
CCTV	Closed Circuit Television
CMS	Coastal Monitoring System
DC	Direct Current
DCoC	Djibouti Code of Conduct
DSC	Digital Selective Calling
EEZ	Exclusive Economic Zone
EU	European Union
EUNAVFOR	European Union Naval Force
GEF	Global Environment Fund
GMDSS	Global Maritime Distress and Safety System
GOC	General Operator's Certificate
GPS	Global Positioning System
GRT	Gross Registered Tonnes
GSM	Global System for Mobile Communications
HOA	Horn of Africa
HRES	Hybrid Renewable Energy Systems
ICS	International Chamber of Shipping
IHO	International Hydrographic Office
IEA	International Energy Agency
IMB	International Maritime Bureau
IMO	International Maritime Organization
IRENA	International Renewable Energy Association
ISC	Information Sharing Centre
ITU	International Telecommunication Union
IUU	Illegal, Unreported and Unregulated Fishing
KMA	Kenya Maritime Authority
KMPU	Kenya Maritime Police Unit
KNBS	Kenya National Bureau of Statistics
KWS	Kenya Wildlife Service
LCOE	Levelised Cost of Energy
LRIT	Long Range Identification and Tracking
MCS	Monitoring, Control and Surveillance
MID	Maritime Identification Digits
MDA	Maritime Domain Awareness
MMSI	Maritime Mobile Service Identity
MRCC	Maritime Rescue Coordination Centre

MSSIS	Maritime Safety & Security Information System
NATO	North Atlantic Treaty Organization
NREL	National Renewable Energy Laboratories
PNG	Papua New Guinea
RCC	Rescue Coordination Centre
RDF	Radio Direction Finder
REN21	Renewable Energy Policy Network for the 21 st Century.
RF	Radio Frequency
RLAN	Radio Local Area Network
RMFO	Regional Marine Fisheries Organization
RMRCC	Regional Maritime Rescue Coordination Centre
RR	Radio Regulations
SAR	Search and Rescue
SIDS	Small Island Developing States
SOTDMA	Self-Organized Time Division Multiple Access
SUA	Suppression of Unlawful Acts Convention
SWERA	Solar and Wind Resource Assessment
UNCLOS	United Nations Convention on the Law of the Sea
UNEP	United Nations Environment Program
USGC	United States Coastguard Agency
VHF	Very High Frequency
VMS	Vessel Monitoring System
VSWR	Voltage Standing Wave Ratio
VTs	Vessel Traffic System

1 CHAPTER 1

1.0 Background

The approach to ports, coastlines and navigation channels constitute vital transportation infrastructure that require protection from a myriad of risks and challenges. Kenya has 614 Km. of coastline and 143,000 km² of Exclusive Economic Zone (EEZ) (IHO- Kenya National Report to South African and Islands Hydrographic Commission (SAIHC), as well as a busy shipping lane and remote islands, as depicted in figure 1 below. According to the European Commission's (EC) Joint Research Centre, "Surveillance is a key element to exercise national sovereignty at sea" (2008, EC Joint Research Centre). These sea areas require continuous surveillance and protection.

Depending on the intended mission, maritime surveillance can be realized through a suite of reporting / messaging systems which either rely on vessels to provide own information or sensor systems which autonomously collect information about ships. The scope and mode of surveillance depends upon the domain of interest, ranging from environmental protection, fisheries protection, border control and territorial sovereignty. Ultimately, the primary aim is either to identify and deter infringement to regulations or to ensure safety and security. Africa's coastline, measuring around 30,500 km is confronted with a myriad of challenges. "The vastness of Africa's maritime domain provides great opportunity for exploitation by terrorists. Terrorist



Figure 1: Map of Kenya
Source: Wikipedia

activities therefore constitute a latent threat....” (O.S Ibrahim, 2009). This complicates the maritime surveillance challenges, and calls for complete paradigm shift from the traditional approaches to more proactive and security-focused approach.

Large portions of Kenya’s coastline are very remote and lack reliable communication infrastructure, mainly attributed to lack of connection to the national power grid. At the peak of the piracy menace off Somalia waters, numerous acts of piracy were staged on vessels destined to the port of Mombasa. Such sporadic attacks also targeted fishing boats and dhows, which were then used to further orchestrate the crime (use of mother boats). Between 2013 and 2015, virtually no successful acts of piracy were reported within waters of this region (IMB Piracy Reports on trends of piracy).

However as recent reports show, piracy is still a huge regional challenge because underlying causes, such as illegal fishing and dumping in the Somalia piracy context remain unresolved. The economic cost of maritime piracy is on an upward trajectory, as Somali pirate networks resume attacks on ships. According to a recent report by “Oceans Beyond Piracy” Group, the cost attributable to piracy in Somalia increased to 1.7 Billion Dollars in 2016, from 1.3 Billion Dollars in 2015. This includes costs paid by shipping operators for increased insurance, labour, armed guards and other protection measures, as well as ransoms paid by insurers and the cost of naval deployments. So far in 2017, there have been two high-profile hijackings by Somali pirates: The Aris Tanker in March and an Indian flagged commercial ship in April (Oceans Beyond Piracy, 2017)

Although the combined intervention by Naval escort convoys and military action inside Somalia had appeared to ebb the tide of piracy between 2013 to late 2015, the recent resurgence is an indication that the pirate networks remain strategically poised and ready to attack commercial ships, at any slight opportunity. Dalaklis, 2012 analysed many of the important factors in the Somali piracy context, and concluded that piracy would only diminish when the rule of law is well established in the burdened country. A more effective and sustainable tool to keep vigilance and secure this sea area is

necessary, and focus seems to be gravitating towards Maritime Domain Awareness (MDA)¹.

The sea route bordering the State of Somalia and through the Horn of Africa, is very critical for global trade. International Maritime Organization (IMO), European Union (EU), United States of America (USA) and Regional Governments have made heavy investment in capacity building and technology transfer to make this sea area safe. Under the Global Search & Rescue (SAR) arrangements, Kenya has obligations relating to Search and Rescue coordination over an expansive portion of this sea area as well as 614 km of immediate territorial coastline dotted with a number of small remote islands. A thriving community of fishermen, with generally good understanding of local maritime environment and well-organized Beach Management Units (BMUs), dominates these remote islands. This fishing community can be engaged for proactive roles in maritime situational awareness. However, this capability can be impeded by lack of constructive engagement and poor state of communication infrastructure.

According to a 2013 Watercraft and Baseline Survey Report by Kenya Maritime Authority (KMA) there are 206 fish landing sites along Kenya's Indian Ocean Coastline, with a substantial number of these in private hands. Out of 16,805 surveyed watercrafts, 1894 were anchored and operated on privately owned sites. Given the remoteness of most of these regions, security ramifications can be severe.

Therefore, analysis of the status of existing maritime surveillance forms the gist of this research undertaking. The immediate motivation is to establish the potential for renewable energy solutions in addressing communication gaps, hence improving maritime situational awareness in the areas.

1.1 Research objectives

Despite the compelling need for functional maritime surveillance systems to improve security situation in sea routes and archipelagic waters around Kenya's Indian Ocean coastline, the challenges relating to power source have not come to a fruitful end. In seeking a solution, this thesis will:

¹ MDA is the effective understanding of anything associated with the maritime domain that affects safety, the environment and economy.

- a. Explore the viability of wind and solar power harvesting in these remote Islands for applications in maritime surveillance systems.
- b. Then assess how the identified, viable renewable energy options can be effectively used to power maritime surveillance equipment.
- c. Analyze the existing surveillance structure in the context of evolving maritime challenges in the region, and how renewable energy can deliver improvements.

1.2 Research questions

For an exhaustive investigation of the topic, answers to the following research questions are sought:

- a) Can renewable energy technologies be harnessed for application in maritime surveillance systems in Kenya's remote Coastal Islands?
- b) Are there additional measures and facilities that can deliver improvements to Kenya's overall Coastal Surveillance arrangements within the constraints of the maritime administration and civilian stakeholder agencies' capabilities?

Furthermore, an in-depth analysis of the current operational structure of maritime surveillance will lead to improved understanding of gaps that need to be addressed. In this context, the research questions are,

- c) What are the inherent risks of weak maritime surveillance in these remote coastal Islands? Based on case studies of successful implementations of maritime surveillance systems, how will the envisaged improvements to the maritime surveillance system enhance incident reporting and response capability in these areas?

1.3 Research Methodology

This thesis is compiled in the context of several academic studies, taking into account their insightful findings, recommendations and research methodologies. It involved the analysis of data and information from articles, books, journals, electronic sources, periodicals and reports. Costs and technical data relating to renewable energy technologies were sourced from government departments, renowned institutions, and organizations such as the International Energy Agency (IEA), the Renewable Energy Policy Network for the 21st Century (REN21), the National renewable energy

laboratories (NREL), the International Renewable Energy Agency (IRENA) and the World Energy Council.

Several company documents and expert references were also perused for data on the research topic. Information on the current vessel reporting systems and maritime surveillance arrangements was obtained from Kenya Maritime Authority and Mombasa Regional Maritime Rescue Coordination Centre (RMRCC). Information on the international legal framework and maritime security reports was sourced from the International Maritime Organization (IMO), the Baltic and International Maritime Council (BIMCO), North Atlantic Treaty Organization (NATO) Shipping Centre, International Chamber of Shipping (ICS), International Maritime Bureau (IMB) and Oceans Beyond Piracy.

A practical field survey covering the whole stretch of the Kenyan coastline is included. The physical survey was limited to obtaining GPS coordinates, area elevation above sea level and assessing accessibility. GPS data and area elevation are essential parameters for ascertaining conditions for effective Very High Frequency (VHF) triangulation. This thesis is organized in three thematic areas. The first part discusses renewable energy technologies, with a focus on the economic drivers surrounding renewable energy applications in maritime surveillance. The second part broadly examines maritime surveillance from the standpoint of facilities and arrangements at the disposal of the Maritime Authority and Civilian Agencies in Kenya. The third part analyses the current scenario and arrangements, and concludes with recommendations for the improvement of maritime surveillance.

1.4 Thesis outline

Chapter 1 contains a synopsis of this dissertation task, highlighting the nature of the problem, objectives of the study and the research scope. Chapter 2 is an extensive literature review of contemporary applications of renewable energy technologies and Kenya's policy framework on renewable energy.

Chapter 3 explores maritime surveillance and ship reporting systems, including AIS, VMS, LRIT and Coastal VHF coverage in Kenya. The Global SAR regime in the

context of national, regional and international obligations and arrangements are also examined.

Chapter 4 discusses Kenya's multi-agency approach to maritime surveillance, and civilian agencies' input with respect to maritime safety and security. These are weighed in terms of their adequacy to the huge regional challenge of piracy and maritime crime. Reported maritime incidents are analysed to establish correlation between absence of robust maritime surveillance and the preponderance of incidents. The causal mechanisms approach is applied.

Chapter 5 features a case study pertaining to the successful implementation of maritime surveillance. It examines how Papua New Guinea (PNG), with a coastline measuring 20,197 km and EEZ covering 3,120,000 km², has successfully implemented a surveillance system fully powered from renewable energy sources. The chapter delves into the scope for improvement in Kenya's surveillance arrangements, by juxtaposition to the PNG system. This is followed by a consolidation of the main outcomes and assumptions, into a coherent and focused roadmap for the overall improvement of maritime surveillance. Conclusions and recommendations drawn from the study are presented in this chapter.

1.5 Delimitations.

This dissertation explores the status of maritime surveillance in detached remote islands in light of the lingering challenges of maritime crime and piracy. It then examines how the application of renewable energy can be used to mitigate the challenges. It further analyses the regulatory framework to cope with maritime crime, including regional arrangements to improve situational awareness, in order to identify opportunities for improvement. The conclusions derived are construed to be specifically representative of Kenyan scenario.

2 CHAPTER 2

2.1 Literature Review

This chapter reviews some studies so far undertaken on renewable energy. The focus is on the economic considerations pertinent to planning and uptake of renewable energy for maritime surveillance applications in remote coastal islands. Generally, prospects for the application of renewable energy technologies across many facets of human endeavours appear bright. The Renewable Energy Policy Network for the 21st Century (REN21) reported in 2016 that 44 million off-grid pico-solar products had been sold globally by mid-2015, representing an annual market of 300 million US Dollars. There are huge prospects for maritime surveillance systems to tap into the fast expanding renewable energy sector.

2.2 Renewable Energy

Renewable energy is a concept that is fast capturing global attention. It has been variously described, as energy from a source that is not depleted when used, and according to "Dictionary.com", it is "any naturally occurring, theoretically inexhaustible source of energy for instance biomass, solar, wind, tidal wave and hydro, that is not derived from fossil or nuclear fuel" (Dictionary.com)

A more concise and encompassing definition is by Islam et al, (2014) which states that renewable sources are "those that are abundant in nature, and derived from natural processes with no depletion in the course of utilization" (Islam, Shahir, Uddin, & Saifullah, 2014).

There is a vast collection of available literature on renewable energy. L.A Kristoferson and V. Bokalders, (2013) explored the renewable energy technologies, and demonstrated their growing prominence in developing countries. Dimakis et al. (2011) examined the various methods and tools to evaluate the potential and exploitable

energy sources. The approach emphasized attention to site-specific environmental aspects.

Weisser (2004) analysed the dynamics of power generation in Small Island Developing States (SIDS) and extolled the unique characteristics in SIDS that make fossil fuel-based electricity generation very costly. He emphasized the need for paradigm shift in energy planning. The conclusions of his study immensely lend themselves to the scenario under review in this thesis.

Bergmann et al. (2006) evaluated external benefits and costs with respect to renewable energy investment. Although the study was based on the Scotland scenario, the conclusions on external costs and benefits to be considered for optimal investment in renewable energy options have universal applicability. Mondal et al. (2010) analysed the drivers, barriers and strategies for implementation of renewable energy technologies in rural areas in Bangladesh, through an innovative approach with immense applicability in developing regions with similar circumstances.

2.3 Renewable Energy Potential

To maximize the benefits obtainable from a renewable energy technology in a country, it is important to weigh the technology in the context of existing energy strategies and plans, financial, institutional as well as legal frameworks. J. P. Painuly, (2000) proposed three dimensions upon which to gauge potential: technological potential, techno-economic potential and economic potential.

2.4 Costs and Trends in Renewable Energy uptake

The aspect of cost and projections on its trend is a core decision attribute in renewable energy applications. In its 2017 outlook on renewable energy, the Frankfurt School (FS) – UNEP Collaborating Centre for Climate Change and Sustainable Energy Finance projects that: “There were two main reasons for the fall in investment in renewables in 2016. One was lower costs, with average dollar capital expenditure per MW down by more than 10% for solar photovoltaics, onshore wind and offshore wind, improving the competitiveness of those technologies. The other was not so positive – there was a marked slowdown in financings in China, Japan and some emerging markets during the course of the year” (Frankfurt School (FS)-UNEP Collaborating Centre for Climate Change and Sustainable Energy Finance, 2017).

In a similar assessment, the Renewable Energy Policy Network for the 21st Century (REN21) concluded that: “Rapid growth, particularly in the power sector, is driven by several factors, including the improving cost competitiveness of renewable energy technologies, dedicated policy initiatives, better access to financing, energy security and environmental concerns as well as growing demand for energy in the developing and emerging economies” (REN21, 2016).

2.5 Levelised Cost of Electricity (LCOE)

The World Energy Council defines LCOE as the price that has to be received per unit of output as payment for producing power, in order to reach a specified financial return or put simply “the price that a project must earn per megawatt hour in order to break even.” (World Energy Council, 2013).

According to the Frankfurt School FS-UNEP Collaborating Centre for Climate change and Sustainable Energy Finance, (2017) it is the “all-in one cost of generating each MWh of electricity from a power plant, including not only fuel used, but also the cost of project development, construction, financing, operation and maintenance”. (Frankfurt School FS-UNEP Collaborating Centre, 2017)

Analytically, LCOE₂ is denoted by:

$$LCOE = \frac{\text{Lifecycle Cost (\$)}}{2a\text{Lifetime Production (kWh)}} \dots \dots \dots \text{Equation 1}$$

LCOE Computation

Based on National Renewable Energy Laboratories’ (NREL) Solar-PV Manufacturing Cost Model, the Plant envelope incorporates the following elements

² Equation 1: Levelised Cost of Energy

Table 1: LCOE Elements

	Category	Elements
1	Infrastructure	Land acquisition Site preparation Installation of underground components Access roads Fencing Operations buildings and related maintenance
2	Equipment	Module supply Power electronics AC and DC components Installation.
3	Electrical Infrastructure	Transformers Switchgear Electrical Systems Connecting Modules.
4	Financial Costs	Preliminary Feasibility & Engineering studies Environmental studies Permits Legal Fees Insurance costs Development Costs Property taxes during construction.

.In this study, a Levelised Cost of Energy calculator was used to compare the LCOE cost of 17 technologies. The results and excel extract are included in appendix. For solar power the LCOE is US\$ 85/MWh while for onshore wind, it is US\$ 58/MWh.

2.5.1 Capital Expenditure (CAPEX) and Operating Expenditure (OPEX)

The World Energy Council defines CAPEX as the total cost of developing and constructing a plant, excluding any grid-connection charges. Feldman et al, (2015) and also Beamon and Leff, (2013), view CAPEX as representing the total expenditure required to achieve operation in a given year. On the other hand, OPEX is “the total annual operating expenditure from the first year of a project’s operation, given in per unit of installed capacity terms.” (World Energy Council, 2013).

2.5.2 Capacity factor (Load Factor)

The World Energy Council defines Capacity Factor as “the ratio of the net megawatt hours of electricity generated in a given year to the electricity that could have been

generated at continuous full-power operation, or 8,760 (per annum) full hours” (World Energy Council, 2013).

2.5.3 Society’s Cost of Energy.

This ascribes a much broader scope to the cost of energy, by taking into account factors such as the number of jobs created by energy source, subsidies, transmission costs, variability costs, geopolitical risk impact, besides also taking into account the Levelised Cost of Energy (LCOE). It was proposed by Siemens “to measure the true cost of electricity generated by various sources” (Siemens AG, 2014)

2.5.4 Maritime Surveillance Systems powered by Solar and Wind:

Several studies have been undertaken to establish the suitability of renewable energy for powering up surveillance systems in remote areas lacking connection to the national power grid. In 2011, the Border and Maritime Security Division (BMD) of the United States (US), the U.S. Department of Energy (DOE) and National Renewable Energy Laboratories (NREL) conducted a joint study on border-security energy demands. The rationale of their study was to ensure that advances in renewable energy and energy storage would be reflected in improved security situation..

They summarized the factors that make renewable energy particularly attractive for applications in maritime surveillance and border security, including the following: Operational continuity arising from grid failure. Installed renewable energy sources can sustain critical loads until grid service is restored. The greater the proportion of renewable energy technologies, the longer the operations can be sustained without grid power.

Renewable energy technologies can reliably operate independent of the grid in remote locations, and often require very little maintenance. This can extend the capabilities in remote border-security operations. Also Some renewable energy technologies such as PV operate silently and require little maintenance. These characteristics make them very useful in locations where covert operations are necessary.

On the other hand, aging energy infrastructure poses a threat to national security. Electricity generated near the load reduces reliance on the grid infrastructure, thereby eliminating the operational burden relative to the grid infrastructure. Renewable energy offer strategic advantages by helping hedge against volatile fuel prices and supply interruptions, as well as reducing dependence on fossil fuels supplied from regions of conflict. Renewable energy technologies are also clean, sustainable and mostly emission-free.

To ascertain whether the power requirements of a given surveillance system can be met from renewable sources, it is necessary to establish the operational energy profile of the unit, in terms of peak power consumption, the duration of consumption (volts (V), amps (A), watts (W), phase, and whether it draws alternating current or direct current. It is also necessary to establish whether the unit is optimized for off-grid deployment, whether there is need for emergency backup and if so, the redundancy level necessary.

2.5.5 Solar Energy

Solar Energy can be processed either through Photovoltaic (PV) systems that directly convert the solar energy into electrical, or Concentrated Solar Power (CSP) systems which first convert the solar energy into thermal energy, then onwards to electrical engine through a thermal engine.

There is a downward trend in the cost of solar systems worldwide. The International Renewable Energy Association (IRENA) has made a projection that reflects this downward trend, as depicted in figure 3 below. The plummeting cost of solar systems across the entire gamut of application areas justifies initiatives to explore usage in maritime surveillance systems.

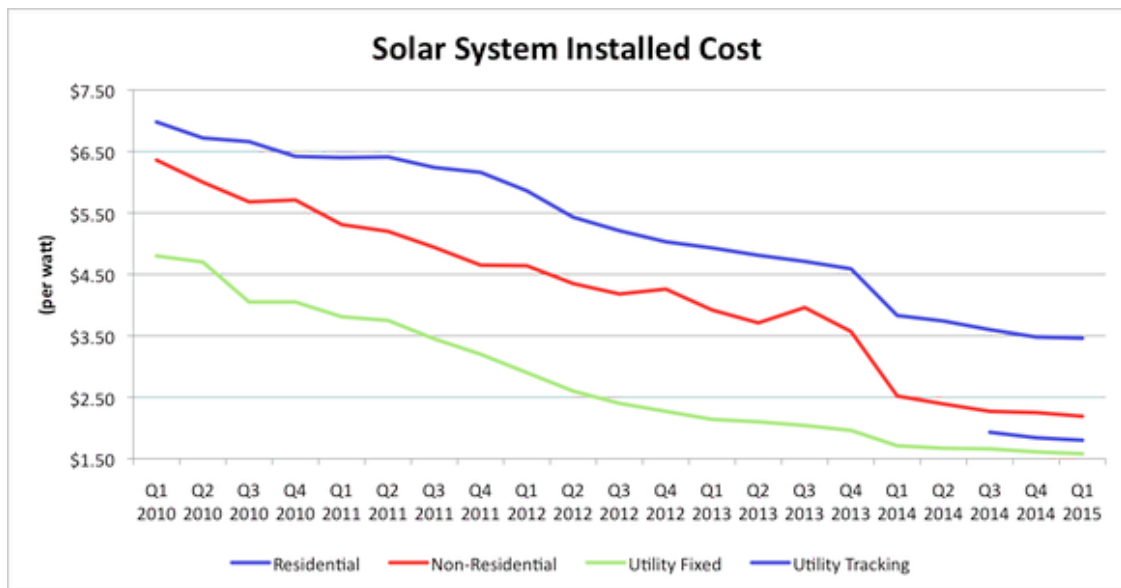


Figure 2: Solar System Installed Cost: Worldwide Trend
Source: IRENA, 2017

Table 2 below provides a snapshot of typical efficiency figures for thin film and wafer technologies in the category of Commercialized PVs.

Table 2: Solar PV Technologies,
Source: NREL

	PV technology	Variation & Properties	Efficiency
1	Thin Film	Lower cost per unit of power produced	
		Amorphous Silicon	7%
		Cadmium Telluride	11%
		Copper, Indium, Gallium, Selenide (CIGS)	11%
2	Wafer PV	Have greater efficiencies than thin film technologies	14% to 20%
3	Multi-junction PV	Capture different spectra of light, thus increasing overall efficiency of the composite system.	Up to 30% efficiency in systems that concentrate sunlight by up to 500 times

2.5.6 Photovoltaics

Based on assessment conducted by the National Renewable Energy Laboratories (NREL) of USA, PV panels do not have moving parts, and when combined with batteries they are very reliable. They also operate silently which accords a measure

of stealth. Some of the shortcomings cited with respect to photovoltaics include their requirements for additional equipment such as inverters to convert DC to AC, storage batteries for on-grid connections and the fact that land mounted PV panels require relatively large areas for deployment, thereby committing the land for 15 to 20 years or longer. PVs also feature relatively low efficiencies (between 14 to 25%) compared to other renewable energy technologies. PV panels are fragile and susceptible to easy damage, necessitating additional overheads on insurance costs.

2.5.7 Wind

According to the NREL, the economic viability of a wind project depends on the cost of the wind resource compared to that of electricity. A strong wind resource (Class 5 and Class 6) can compete against electricity. A modest wind resource (Class 2 and Class 3) can compete against high-priced electricity. According to NREL, “the high cost of electricity in an environment where there is strong wind makes wind a compelling option with a short payback” (NREL, 2016)

Over the past decade, wind energy has experienced annual growth rates in installed capacity of more than 30%. The wind industry has several distinct sectors, each characterized by specific technology and deployment strategies. Each of these wind sectors essentially envisage different technologies, assessment methods, economics, environmental considerations, and factors that serve as the drivers for those sectors. According to NREL, “There is no one design or size that is “the best in all applications”; rather, there are applications that favor certain sizes and designs, as they provide the better relative economics and performance within the application driven constraints” (NREL, 2016).

2.5.8 Wind Power

The amount of wind varies with the season, time of day, and weather events. The wind speed at any given time determines the amount of power available in the wind and subsequently the power that can be harnessed using a wind turbine generator. This power is given by:

$$P = \frac{1}{2} \rho A V^3$$

Where;

P = power of the wind (watts)

A = windswept area of the rotor (blades) = $\pi D^2/4 = \pi r^2$ [m^2] (πr^2 [10.76 ft^2])

ρ = density of the air [kg/m^3] (2.2 lb/3.28 ft^3) (at sea level at 15°C)

V = velocity of the wind [m/s] (3.28 $ft./sec$)

Wind power (P) is proportional to velocity cubed (V^3). If wind velocity is doubled, wind power increases by a factor of eight ($2^3 = 8$). Consequently, small differences in average speed cause significant differences in energy production.

2.5.9 Hybrid Photovoltaic/ Wind Energy plus Battery System:

Hybrid renewable energy projects involve the siting of different renewable energy projects within the same location: like solar and wind, or solar thermal and geothermal. The main attraction here includes the ease of distribution resulting from the sharing of one grid connection, production of more electricity per hectare of land, economy in operating and maintenance costs, and reduction of overall intermittency. “Mini grids are particularly viable in developing countries and on remote Islands especially with wind and solar or wave paired with batteries or even diesel back-up generators” (Frankfurt School (FS)-UNEP Collaborating Centre for Climate Change and Sustainable Energy Finance, 2017)

Various researchers have evaluated Hybrid Renewable Energy Systems (HRES) using different methods such as energy to load ratio, battery to load ratio, and non-availability of energy. In order to select an optimal combination of a HRES to meet the demand, evaluation may be carried based on reliability and economics of power supply.

According to the Frankfurt School (FS) – UNEP Collaborating Centre for Climate Change and Sustainable Energy Finance, some 5.6GW of hybrid projects, each of more than 10MW have been constructed or are under various stages of development

worldwide. There is huge potential for this number to grow significantly in the years ahead, as developers take advantage of synergies from co-locating two or more technologies.

2.6 Hybrid Optimization Model for Electric Renewables (HOMER) Software.

HOMER renewable energy optimization software application, developed by the National Renewable Energy Laboratory (NREL) in the United States, is helpful in designing and evaluating technical and financial variables for off-grid and on-grid power systems in remote, stand-alone and distributed generation applications. The software enables assessment of a large number of technology options to account for energy resource availability and other variables.

Using the HOMER software a user can input an hourly power consumption profile and match renewable energy generation to the required load. Okedu et al, 2014 summed up the powerful tools unleashed by HOMER software: “it allows a user to analyze micro-grid potential, peak renewables penetration, ratio of renewable sources to total energy, and grid stability, particularly for medium to large scale projects. Additionally, HOMER contains a powerful optimizing function that is useful in determining the cost of various energy project scenarios” (Okedu & Uhunmwangho, 2014)

The HOMER software simulates real technological scenarios in renewable energy, providing very detailed results for analysis. It enables the determination of possible combinations of technologies and sizes, hence powerful tools for optimization. On the flip side, its accuracy entirely depends on the quality of input data. In terms of the research topic under review, the HOMER software can provide convenient metrics for comparing between the various power generating technologies, without practically engaging the rigorous field research process.

2.7 Renewable Energy technologies for Maritime Surveillance applications

For purposes of this study, renewable energy options for maritime surveillance applications are analysed from two perspectives: applications involving off-grid wind/solar power generation - requiring the construction of small off-grid power generating

systems. The second scope covers maritime surveillance equipment, primarily powered by solar, with wind as a standby source (similar to the system used by Papua New Guinea³)

The assessment of prospects for stand-alone wind/ solar power generation in remote Islands of Kenya necessitates an analysis of the environment, the regulatory context of renewable energy generation in Kenya and cost aspects such as LCOE, CAPEX, OPEX and Capacity Factor.

2.8 Energy situation in Kenya:

According to Kenya's Energy Regulatory Commission, Kenya's energy mix consists of biomass (68%), hydrocarbons (22%), electricity (9%), solar and other forms of energy (1%), with petroleum and electricity dominating the commercial energy sector. "As at June 2015, Kenya had an installed electricity generation capacity of 2,299MW" (Energy Regulatory Commission Annual Report, 2016). This energy mix is depicted in figure 3 below, which projects the relative significance of each source in the country's overall energy mix.

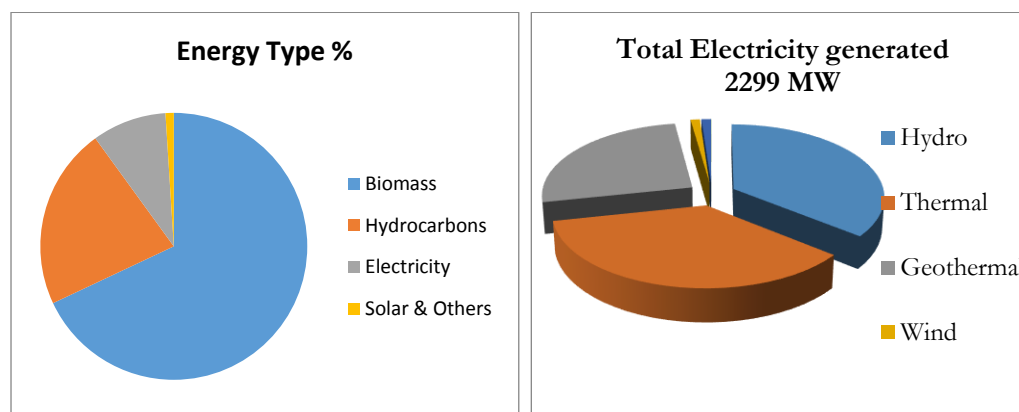


Figure 3: Kenya's Energy mix

³ Papua New Guinea Maritime Surveillance System is analysed in chapter 5

2.8.1 Management of the Energy Sector in Kenya

Several Government bodies are responsible for management of the energy sector in Kenya. These are listed in table 3 below. Overall operation and administration of the sector is under the remit of the Ministry of Energy & Petroleum.

Table 3: Government Bodies responsible for Energy Management in Kenya

Government Bodies		
	Body	Mandate
1.	Ministry of Energy and Petroleum	Provides policy direction and prepares the least cost energy development plan for the whole country. Operates four Directorates, reflecting the various forms of energy sources. These are Electric Power, Renewable Energy, Geothermal, Oil and Petroleum.
2.	Energy Regulatory Commission, (ERC)	Established through the energy Act 2006- provides technical, economic and regulatory oversight on the energy sector in Kenya.
3.	Rural Electrification Authority (REA),	Incorporated in 2007- has the mission to implement rural electrification program.
4.	The Energy Tribunal	Has responsibility for arbitration between the Energy Regulatory Commission (ERC) and aggrieved stakeholders in the energy sector.
Electricity (Power) generating companies		
1.	Kenya Generating Company (KenGen)	Generates 76% of the total country output, equivalent to 1238 MW. It is government owned.
2.	Independent Power Producers (IPPs)	Generate 24% of the total energy produced, equivalent to 391 MW.
Distribution		
1.	Kenya Power & Lighting Company (KPLCo)	Distribution of electricity to end users/ retailing.
2.	Kenya Electricity Transmission Company (KETRACO)	Incorporated in 2008- is responsible for planning, designing, constructing, owning, operating and maintaining new high voltage (>132 KV) transmission grid and regional interconnections.
3.	Geothermal Development Company (GDC)	Responsible for surface exploration of geothermal fields, exploration, appraisals, drilling, steam production and negotiating steam sales agreements with investors in the geothermal electricity generation subsector.

2.8.2 The National Regulatory Framework on Renewable

Energy Regulations in Kenya are anchored in Sessional Paper No: 4 of 2004, the Energy Act of 2006, Energy Policy of 2004, which lays the foundation for the current energy policy and the Feed-in Tariffs policy of 2008 (Revised in 2012), which together encourage electricity generation through renewable sources. A key pillar with regard to renewable energy is the *Feed-in Tariff policy* (FiT) initiated in 2008, which provides investment security and market stability for investors while motivating private investors towards renewable energy technology.

The National Climate Change Response Strategy enacted in 2014 aims to strengthen and focus nationwide actions towards climate change adaptation and GHG emission mitigation. Another important feature is the zero-rating of import duty and removal of Value Added Tax (VAT) on renewable energy equipment and accessories.

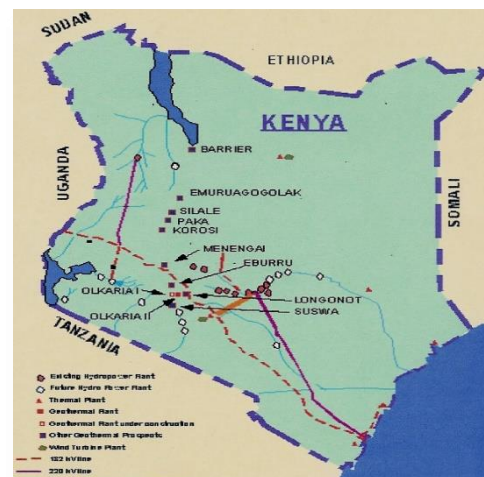


Figure 4: Electricity Grid Network in Kenya
Source: Kenya Power & Lighting

2.8.3 Kenya Electricity Grid Network:

The national grid network in Kenya comprises over 30400 km of both transmission and distribution lines, made up of some 1323 km of 220 kV lines, 3767 km of 132 kV and 630 km of 66 kV lines. Figure 4 below depicts the transmission network (Solar & Wind Resource Assessment- Kenya)

According to a study report dubbed “*Scaling-Up Renewable Energy Program (SREP) Joint Development Partner Scoping Mission*, February 7-11, 2011”, “inadequate power supply and weak electricity network infrastructure is a brake on Kenya’s economic performance and threatens Kenya’s ambition set out in its overarching development program (Vision 2030) to be a middle-income country by 2030”

(Government of Kenya, 2011). This provides further impetus to the need to consider self-sustainable off-grid sources for critical infrastructure.

2.8.4 Renewable Energy potential in Kenya:

In its 2002 Kenya Country Report, the Solar and Wind Resource Assessment (SWERA) projected that about 25% of the country was compatible with current wind technology. Along the coast, the wind resource varies between 5-7 m/s at 50 metres height. This finding reflects the fact that Kenya, generally, and her coastal region in particular, is endowed with adequate wind resources

Studies by the Solar and Wind Energy Resource Assessment (SWERA) on solar energy resource potential in Kenya established Kenya received an average solar radiation equal to 4.5 kWh per square meter per day.” (Kenya Country Report Solar and Wind Energy Resource Assessment, 2008).

3 CHAPTER 3

3.0 Maritime Surveillance

Maritime surveillance involves the application of various tools and techniques to monitor a state's territorial waters and Exclusive Economic Zone (EEZ). Dalaklis, 2016 viewed maritime surveillance from two perspectives:

NATO perspective: Maritime Situational Awareness (MSA) is “the understanding of military and non-military events, activities and circumstances within and associated with the maritime environment that are relevant for current and future NATO operations and exercises -where the Maritime Environment (ME) is the oceans, seas, bays, estuaries, waterways, coastal regions and ports” (Dalaklis, 2016)

IMO perspective: Maritime Domain Awareness (MDA) is “the effective understanding of anything associated with the maritime domain that could impact the security, safety, economy, or environment”. In the later definition, the maritime domain includes all areas and things of, on, under, relating to, adjacent to, or bordering on a sea, ocean, or other navigable waterway, including all maritime related activities, infrastructure, people, cargo, and vessels and other conveyances” (Dalaklis, 2016)

3.1 Legal basis for Maritime Surveillance:

Two pertinent elements of the UN Convention on the Law of the Sea (UNCLOS) underpin maritime surveillance: the provisions on Maritime Zoning and the notion of the nationality of ship. Pursuant to UNCLOS (Articles 24 & 25), a Coastal State has the exclusive right to undertake monitoring and surveillance within its territory including its territorial sea, which, may extend up to 12 nautical miles (nm) from the 'baseline'. Figure 5 below depicts the maritime zones. A state's sovereign rights vary, across the maritime zones.

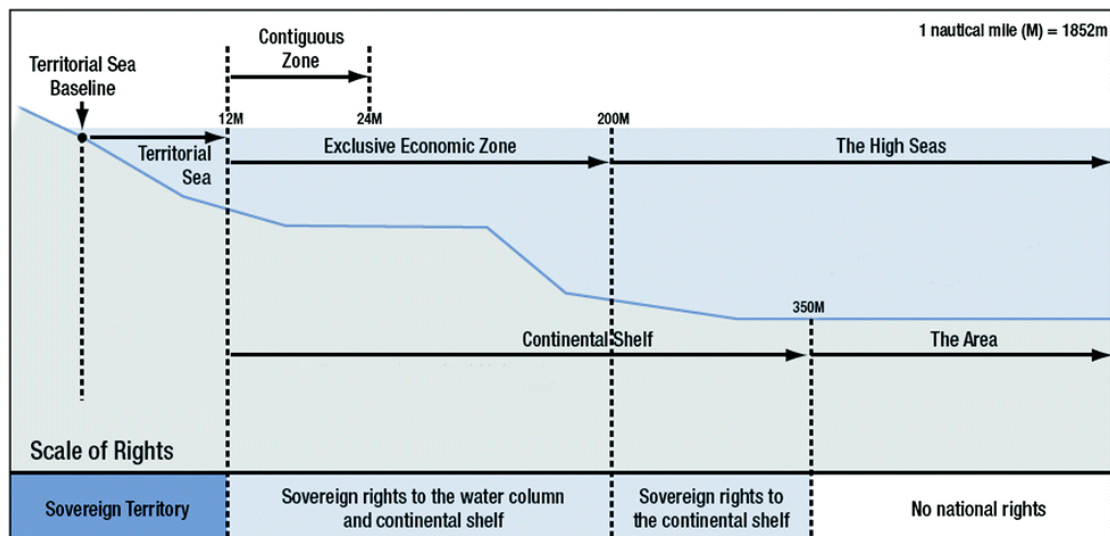


Figure 5: Maritime Jurisdictions

As provided for in UNCLOS, a Coastal State has exclusive rights to undertake monitoring and surveillance in connection with economic exploitation and exploration of its EEZ. Further, all States have the implied right to undertake monitoring and surveillance in the high seas, subject to not interfering with the exercise of the freedom of the high seas by ships flying a foreign flag. Search and Rescue (SAR) regions, with purely functional purpose and no correlation with maritime zones claimed pursuant to UNCLOS, constitute an important basis for maritime surveillance.

3.2 IMO instruments pertaining to the safety of shipping

Dalaklis, 2016 summarized IMO's global shipping regulatory framework from legal, trade, environmental and safety perspectives. The various enshrining conventions are depicted in figure 6 below.

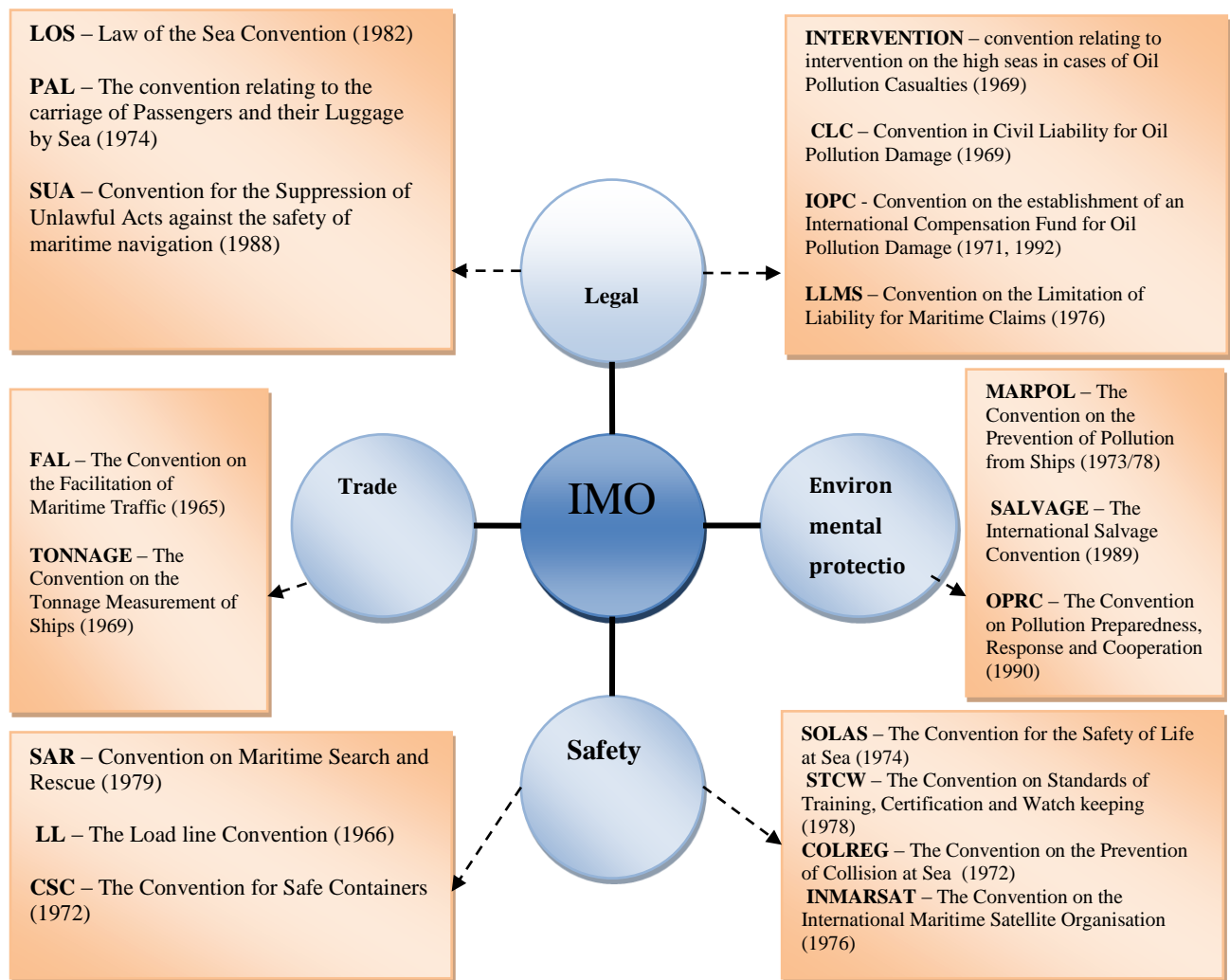


Figure 6: IMO Conventions
Courtesy: Dalaklis, 2016

In the context of this study, the *SAR* Convention and the *SOLAS* Conventions embody the international regulations that underpin maritime surveillance. *SOLAS* Convention covers equipment specification, while the *SAR* Convention lays down the operational framework for maritime surveillance. In Kenya, IMO Conventions are enshrined in the Merchant Shipping Act, 2009, following domestication of the IMO Statutes by Kenya.

3.3 Surveillance systems

Surveillance systems include visual sightings, still cameras, closed circuit television (CCTV), radar and infrared imaging. Such systems and techniques are pivotal in the construction of a maritime picture in situations where either data is not provided under a reporting regime (whether deliberately or not), in respect of (typically smaller) vessels that are not subject to a reporting regime.

3.3.1 Military surveillance systems

Gathering of surveillance data is an integral component of the roles undertaken by navies for defense purposes. This came in the aftermath of the International Ship & Port Security (ISPS) Code - primarily designed to deter terrorism. Ascertaining precise amount and scope of data within the purview of military surveillance is not easy, owing to the confidentiality that surrounds this. Nonetheless, standard modes of gathering such data include physical observation from military vessels and aircraft, unmanned vehicles and drones, remote sensing, coastal radars, and underwater sensors. Military surveillance systems are characterized by their robustness and rigorous energy requirements.

3.3.2 Commercial Surveillance and Ship reporting systems

These feature less stringent requirements in terms of robustness and energy consumption, but are applied to fulfil specific monitoring or surveillance needs. Ship reporting systems include LRIT (Long Range Identification and Tracking) as mandated by IMO via SOLAS chapter V, Regulation 19-1 in 2008, AIS (Automatic Identification System) by the International Telecommunication Union (ITU) vide: ITU-M 1371, 2014 (Rev) and Vessel Monitoring System (VMS) for fishing vessels, mandated by the Food and Agriculture Organization (FAO) - 1998, plus non-automatic reporting through transceiver radio call-in.

Despite differences in architectural design, all these systems enable the automatic transmission of ships' identity and position, sometimes with additional information. "For many applications, there is a requirement to have an up-to-date awareness of where, within a certain area of interest, all the ships are, who they are, and where

they are going: i.e. to know the Maritime Situational Picture” (Greidanus, et al., 2013). This requirement is consistent with obligations pertaining to maritime safety and security.

Popa, (2011), analysed the success of LRIT in addressing the challenge of piracy, while Chen, (2014) made a comprehensive comparison between LRIT and Satellite – based AIS in terms of costs, communications scheme, coverage, information scope and credibility and emphasized the complementary roles delivered when both systems are operated concurrently.

Ship reporting systems are provided for in Regulation 11, Chapter V of SOLAS. Several ship-reporting regimes are incidental within European waters. These include mandatory systems that apply to specific stretches of water, general obligations to notify the Ports of destination, and reporting regulations under Vessel Traffic Services (VTS).

3.3.3 Automatic Identification System (AIS)

Based on Regulation 19 of Chapter V of the International Convention for the Safety of Life at Sea (SOLAS), AIS is mandatory for all vessels of 300 GRT and above on international voyages, cargo ships of over 500 Gross Registered Tons (GRT), and passenger vessels irrespective of size. Warships and government owned vessels are exempted.

AIS enables exchange of data between ships as well as coastal stations, including the unique Maritime Mobile Service Identity (MMSI) of the vessels, Call Sign and Name, IMO Number and details of the ship, automatically generated dynamic navigational data and details of the ship’s position, course and speed over ground

and navigational status, plus manually entered static data. The messages are transmitted un-encrypted over open frequencies (161.975 MHz & 162.025 MHz for terrestrial communications and 156.775 MHz & 156.825 MHz for satellite communications) (ITU-R, 2012) hence allowing everyone with suitable equipment to receive it. AIS reduces the workload for authorities tasked with monitoring and controlling coastal and offshore vessels calling at Ports. The slot mapping architecture of the AIS system is based on Self Organized Time Division Multiple Access (SOTDMA), depicted in figure 7 above.

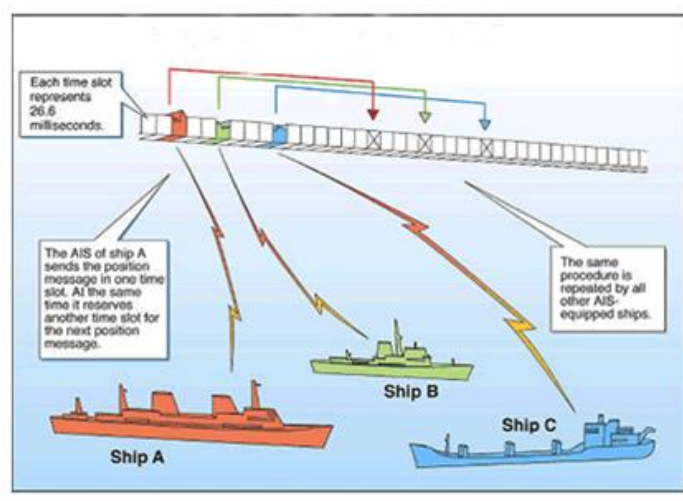


Figure 7: AIS System slot mapping architecture,
Source: US Coastguard (USCG)

3.3.4 Long Range Identification and Tracking (LRIT)

LRIT is a collection and distribution system for basic information on vessels. Following IMO's adoption of amendments to SOLAS chapter V, Regulation 19-1 in 2008, LRIT regulations apply to the following ships engaged on international voyages: all passenger ships including high speed craft, cargo ships, including high speed craft, of more than 300 GRT, and mobile offshore drilling units. These categories of vessels are required to automatically transmit their identity, position, and time at six hourly intervals, with the ability to increase this rate to once every fifteen minutes when requested while on international voyages.

3.3.6 Maritime Safety and Security Information System (MSSIS)

The Maritime Safety and Security Information System (MSSIS) is an unclassified, near real-time AIS data collection and distribution network. It promotes collaboration and data sharing among international participants, with the primary goal of increasing maritime security and safety. Data sources may range from a single sensor to an entire national vessel-tracking network. MSSIS enables password-protected, Internet-based sharing of AIS data using encrypted data links.

The client software for MSSIS runs on Trans view (TV32), providing a common system interface and vessel tracking display for users. Apart from a suite of standalone display features, it also serves as a platform for users to access and contribute to the aggregated, global data.

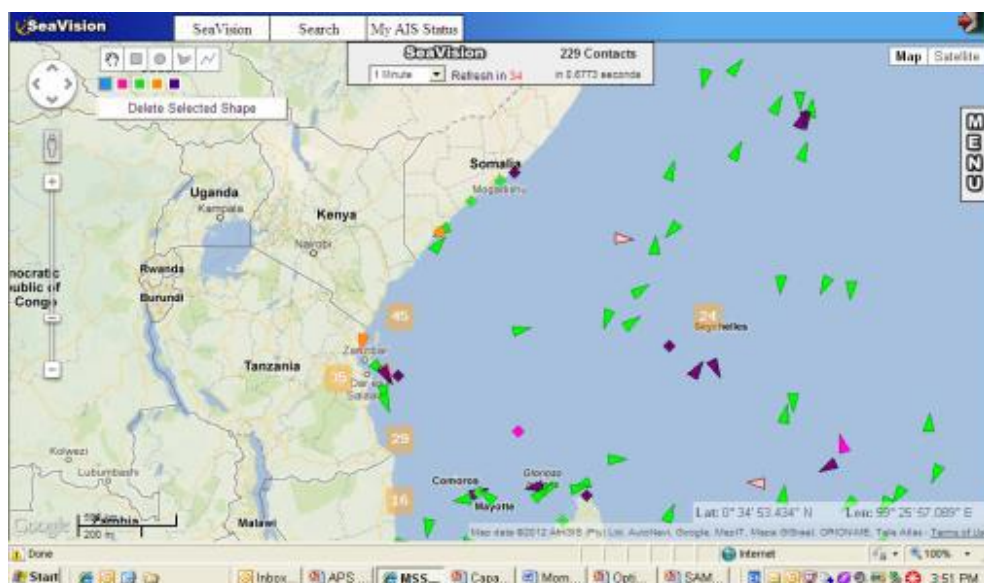


Figure 9: MSSIS Display at Mombasa RMRCC,
Source: RMRCC Mombasa.

3.3.7 Automated Mutual Assistance Vessel Rescue System (AMVER)

AMVER is a worldwide voluntary vessel reporting system operated by the US Coastguard to promote safety of life at sea. Mooted in the wake of the Titanic disaster in 1912, AMVER's main contribution is to quickly provide Search and Rescue Authorities with accurate information on the positions and characteristics of vessels near a reported distress. Request for AMVER assistance with respect to a vessel in

distress is sent to the US Coast Guard. The request should specify position, vessel's details, the center and radius, and request for SURPIC (surface picture). The US Coastguard promptly faxes back the result, with a rich amount of detail regarding ships within vicinity of the distressed craft from whom assistance may then be promptly sought, in tandem with GMDSS distress response procedures.

3.3.8 Vessel Monitoring System (VMS):

Vessel monitoring systems help fisheries administrations to monitor vessel position, course and speed, with a view to ensuring fishing vessels are doing the right thing. It is one of the most widespread cooperative surveillance tools currently used for fisheries management. A VMS system incorporates a transceiver unit that transmits its GPS coordinates via a communications satellite to a monitoring station ashore. Currently VMS uses satellite GPS technology that provides position data within 10 m resolution globally. While there are currently no binding global agreements regarding the use of VMS, most Regional Fisheries Management Organizations (RFMOs) as well as many States have mandated its use on larger commercial fishing vessels.

3.3.9 Vessel Traffic Service (VTS)

These are shore based-systems founded on Regulation 12 of SOLAS, supplemented by guidelines adopted pursuant to IMO Resolution A.857 (20) of November 1997. Port VTS is primarily concerned with traffic management in and around ports while Coastal VTS deals with ship traffic through a specific area. Upon entering a VTS area, the master of a ship is under obligation to report to the authority responsible for the VTS, and then monitor a specific radio frequency for navigational or other warnings. The activities of a ship within a VTS area are also monitored via radar, AIS, remote video cameras, and in some cases radio direction finders (RDF).

4 CHAPTER 4

4.0 Management of Kenyan waters.

Management of Kenyan waters is a shared responsibility among several Government Agencies, with Kenya Maritime Authority (KMA) having the lead role in regulatory aspects. KMA collaborates with several government bodies like the Kenya Ports Authority (KPA), Ministry of Fisheries, Kenya Maritime Police Unit, Kenya Ferry Services Ltd, Kenya Wildlife Services (KWS) and Kenya Navy among others. Maritime policies provide a framework that guides the growth of the sector while ensuring compliance with international and institutionalized approach to maritime issues. Each Agency's mandate is stipulated in their respective enabling Acts.

KWS' main role involves protection and conservation of the marine environment in the five gazetted national marine parks and reserves through the Wildlife Conservation and Management (Amendment) Act, 1989. The Kenya Navy mans and patrols the EEZ against external aggression and illegal activities besides offering support in search and rescue operations for persons in distress at sea. The Kenya Maritime Police unit patrols the territorial waters, and supports search and rescue activities at sea. The Unit was established in April 2007 as a law enforcement agency to deal with maritime activities to provide security along the seas and lakes in Kenya.

4.1 The Institutional framework for Maritime Safety & Security in Kenya.

This is based on a multi-agency approach, achieved through collaboration between several Government agencies with mandates that cut across the maritime spectrum as follows:

<u>Lead Government Agency</u>	<u>Maritime Security component</u>
Kenya Maritime Authority	Maritime Search & Rescue and Pollution control
Kenya Navy	Patrolling / securing Kenya's EEZ
Kenya Ports Authority	VTMS and Mombasa port compliance with ISPS code
Kenya Wildlife Services	Preservation of marine environment/ Law enforcement capabilities.
Kenya Maritime Police Unit	Patrolling territorial waters/ Law enforcement
Kenya Revenue Authority	Border control/ Prevention of contraband goods
Kenya Fisheries	Prevention of illegal fishing activities
Immigration Department	Border control & prevention of illegal immigrants
Criminal Investigations Department	Investigations/ prosecution
National Security Intelligence Services	Gathering of intelligence related to piracy/ terrorism.

4.2 The regulation of watercraft in Kenya.

The existing regulatory framework incorporates rules and guidelines for safety, security and protection of the environment and registration, certification, licensing and authorization documents, which govern the management of the maritime sector. The enshrining documents include:

1. The Merchant Shipping Act 2009, (Revised 2012)
2. The Kenya Maritime Authority Act 2006 – Cap No. 5 of 2006,
3. The Fisheries Act, 1989 –Cap 378 - August 1989
4. The Fisheries (Beach Management Unit) Regulations, 2007
5. The Ports Authority Act, 1987-Cap 391 - January 1978
6. The Ferries Act-Cap 410, October 1936
7. The Wildlife (Conservation and Management (Amendment) Act, 1989-No.16 of 1989.

8. Lakes and Rivers Act-Cap 409, December 1930

4.3 Kenya Maritime Authority (KMA)

Kenya Maritime Authority (KMA) was incorporated in June 2004 as a semi-autonomous agency with regulatory oversight over the Kenyan maritime industry. It operates under the Ministry of Transport and Infrastructure, with head office in the coastal city of Mombasa. Pollution control, Port and Flag State Control are among core functions of KMA (KMA Act, 2006). The Authority bears overall responsibility for the enhancement of Kenya's regulatory and institutional capacities for maritime safety and security, effective implementation of international maritime conventions and other mandatory instruments relating to maritime safety and security. It is also responsible for the promotion of maritime training, coordination of Search and Rescue, prevention of marine pollution and promoting preservation of the marine environment besides generating an enabling environment for trade and maritime investment. These responsibilities are anchored in the Merchant Shipping Act, 2009 (amended in 2012). KMA has the mission to strengthen maritime administration in Kenya.

4.3.1 Mombasa Regional Maritime Rescue Coordination Centre (RMRCC)

Mombasa RMRCC was established following the Florence Conference 2000, which set up a Search and Rescue (SAR) Global Fund and recommended the establishment of five Regional SAR Centres to cover sea areas adjacent to the African continent (IMO, 2006). It was commissioned by the IMO Secretary General on 5th May, 2006, in the implementation phase of the Florence 2000 recommendations, and became the first Regional Centre in Africa to be so established. The three Sub-Centres that operate under Mombasa RMRCC are Dar es Salaam, Seychelles, and Somalia Search region, which still has no GMDSS/ SAR infrastructure in place.

This Centre is the designated focal point for Kenya on all aspects related to maritime safety information, with coverage extending from Kenya's territorial waters to the expansive East Africa Search and Rescue Region. All maritime distress alerts activated within the region are routed to the Mombasa RMRCC. For incident reporting, vessels have to originate transmissions to the center.

System	Connection Platform	Primary function	Area of applicability	Cost Implication to the Centre (US\$)
1. LRIT	Internet	Vessel tracking	1000 NM and global for flag vessels	Annual fixed cost @ 1,200 USD. Tracking expenses charged per vessels tracked.
2. AIS		Vessel tracking	30 – 40 NM within port vicinity	Quarterly maintenance
3. Electronic Chart (C-Map)	Internet	Vessel location and Distance estimation	Worldwide	Regular software updates
4. 111 Toll free line	GSM Network	Incident reporting by non-SOLAS vessels & fishing boats.	Territorial waters, subject to GSM network coverage.	Monthly ISDN standing charges @ 300 USD. Billing also done as per usage.
5. GMDSS Console	Radio communications & Satellite	Alerting function and communication with vessels in distress	Sea Areas A1 to A4	Annual maintenance of equipment
6. Mercury System	Secure Internet	Real time tracking and anti-piracy messaging and chats.	Closed system - Restricted to authorized entities.	Nil.
7. MSSIS Sea Vision	Satellite AIS delivered via Internet	Locating vessels of interest and safety related vessel tracking.	Global	Nil
8. ISC VOIP Facility	Internet	Voice communication with other ISCs and National Focal Points on Piracy.	Djibouti Code of Conduct Partner States and National Focal Points.	Nil.

Figure 11: Communication facilities at RMRCC Mombasa

Source: RMRCC Mombasa.

4.4 Discussion of the various systems and arrangements

The consolidated effect of the various facilities, arrangements, regulations and agreements give effect to Maritime Domain Awareness. Weaknesses in the various systems and arrangements are reviewed below.

The LRIT system obligates SOLAS Contracting Governments to bear operating costs of the system. The high cost of tracking vessels does not favour small flag states and tracking is only possible when the ship borne transmitter equipment is switched on. Vessel position reports are made available to other Member States for purchase, whenever a vessel is within 1000 nautical miles of the purchasing coast, or when a vessel seeking entry to a Member State's port is at a pre-determined distance or time period from that port. When the LRIT system in Mombasa is activated on the 1000NM polygon, vessels as far away as the Gulf of Aden are tracked. This is depicted in the figure below.

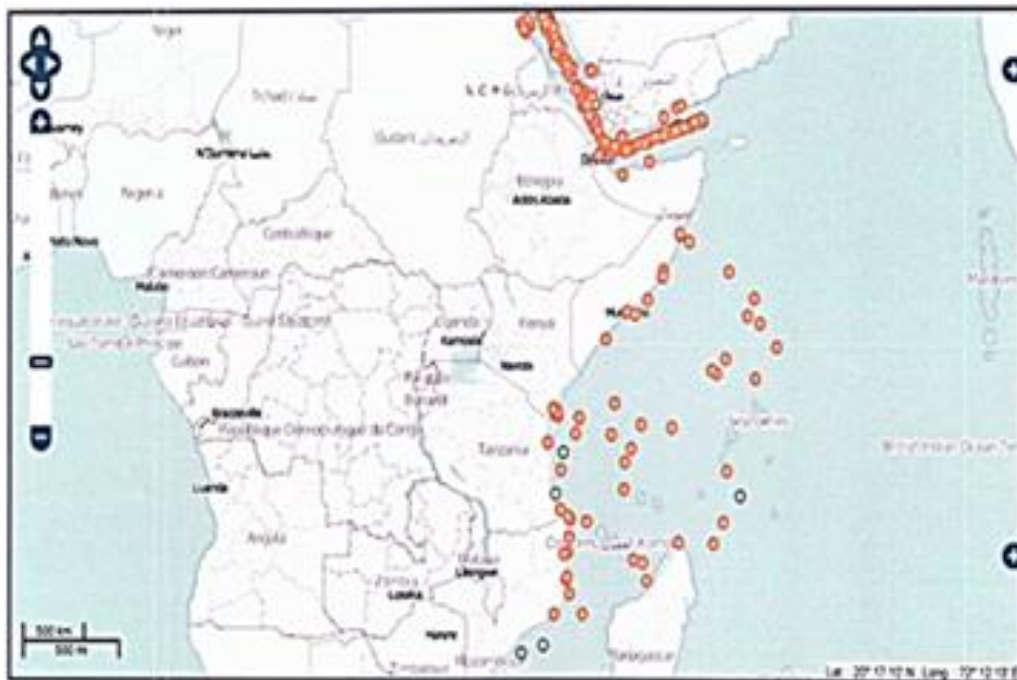


Figure 12: RMRCC Mombasa, LRIT 1000 NM Polygon activation,

Source: RMRCC Mombasa

The AIS System is primarily a collision avoidance system with a protocol that involves a simple and easily manipulated exchange of electronic data via unsecured connections. While vessels are obligated to transmit their position through the AIS, there is no system to validate whether the information transmitted is accurate (Windward Assessment Report, 2014). There are a number of loopholes in the system, which can be used to manipulate real world AIS/ Satellite data, including: neglecting to transmit a vessel's final destination, shutting AIS transmissions, creating 'Ghost ships' and manipulating the GPS information.

Vessel Monitoring Systems (VMS): Due to its status as a cooperative system, VMS does not help much with IUU fishing and does not monitor non-participating vessels. Vessels can also evade VMS regulations by registering with states which do not require its use, are not members of RFMOs that require its use, or which require VMS use but lack the will or capacity to enforce regulations. Vessels may also tamper with their VMS and disable the equipment, jam signals, or broadcast false position data. Kenya has not yet operationalized VMS as a fisheries vessel-monitoring tool.

4.5 Maritime Surveillance challenges.

Wambua, 2010, examined the nature and severity of these challenges. In his assessment: "IUU fishing and maritime security issues stand out as the two main challenges that have had the greatest impact on the African nations and on the entire maritime world" (Wambua, 2010). The main challenges facing African states in their quest to bring order and sound governance to their maritime zones are summarized below:

-
1. Challenges pertaining to the delimitation of the maritime zones
 2. Weak legal and institutional frameworks for governance of the maritime zones
 3. Lackluster focus on training facilities and institutions to develop a pool of competent human resources for the governance process
 4. Funding challenges for the exploration of and research on marine resources
 5. Threat of marine pollution from land-based and ship-based sources
 6. IUU fishing from foreign vessels and trawlers
-

-
7. Piracy, armed attack against ships and hostage taking
 8. Inadequate preparedness to deal with maritime Search and Rescue
 9. Illegal immigration
 10. Drug trafficking
 11. Smuggling and contraband goods and arms
 12. Inadequate port security
-

B. Hamand, 2016 conducted a study on maritime terrorism (why East Africa community is the next potential target of maritime terrorism) and observed that the terrorist activities in the East African Community (EAC) have so far been staged on land, and mainly in Kenya. The study concluded that “lack of a regional maritime security strategy (including a Maritime Domain Awareness program), unpoliced maritime waters and poor cooperation between Kenyan and Tanzanian maritime law enforcement agencies makes the region extremely vulnerable to maritime terrorism” (Hamand, 2017)

4.6 Maritime surveillance challenges in remote Islands: Causal Mechanisms

The Kenyan coastline extends for 614 km, stretching along four administrative Counties: Lamu, Malindi, Mombasa and Kwale and supports approximately 9,000 fishermen, directly through fisheries. According to the Kenya Marine Fisheries Research Institute (KMFRI) Kenya’s EEZ, measuring some 143,000 km² is located within the rich Tuna belt in the South Western Indian Ocean. Statistics gathered by the MRCC in Mombasa indicate that most of maritime incidents reported in Kenyan waters happen very close to the shore and in the Inland lakes and affect small vessels ferrying passengers and fishing community. These vessels are generally ill equipped with lifesaving and emergency communication facilities, but provide a source of livelihood for a significant proportion of the nation’s maritime community.

Crime statistics recorded along the Kenyan Coastline by the Kenya Maritime Police Unit (KMPU) indicate that there is risk of infiltration of small arms, drug trafficking, influx of refugees, threats of terrorism, piracy, illegal fishing and trawling, and contraband activities among many other crimes. (KMPU, 2016)

4.6.1 Lamu Island.

Several studies have been reviewed to project a comprehensive overview of the current issues at hand. “Lamu district, which includes a very unique island archipelago, is an area of huge marine potential with a vast amount of underutilized

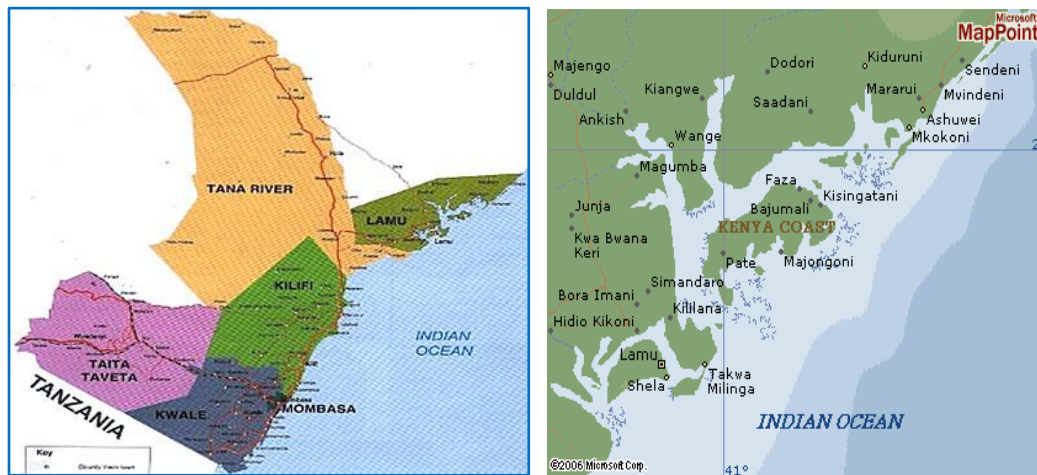


Figure 13: Lamu Island

assets” (Heddon & Lali, 2006). Lamu Old Town has the status of UNESCO Cultural Centre (inscribed in 2001), “as the oldest and best preserved Swahili settlement in East Africa (UNESCO, 2001).

Lamu County extends from the Somali border to about 2° 22’S encompassing the entire Lamu archipelago which consists of several islands, fishing villages and hubs. According to the Kenya Marine Fisheries Research Institute (KMFRI), fishing is a major economic activity in the area, sustaining 70 % to 75 % of the residents either directly or Indirectly. The fishing tradition in Lamu dates back to more than 1,200 years. Lamu people are famous for their skills in fish production, boat building, sailing and other marine activities, which has culminated into a vast seafaring and a thriving mercantile society. Fishing, being mainly artisanal and subsistent in nature, is undertaken mostly from small, non-motorized boats such as outriggers, dhows and planked pirogues. Due to conspicuous challenges in fishing craft technology, fishing effort is mainly exercised within the reef areas and hardly extends beyond Kenya’s territorial waters. Illegal, Unregulated and Unreported (IUU) fishing is phenomenal in these areas.

4.7 The Piracy challenge.

The subject of Somali piracy has engaged the global maritime community for a long time since it first appeared during the second phase of the Somali Civil War in the 21st Century. Actions that embody crime of piracy are defined in the United Nations Laws of the sea (UNCLOS) Article 101. IMO Resolution A.1025 (26) defines “Armed robbery against ships, while the Suppression of Unlawful Acts (SUA) Convention lays down the legal framework for the prosecution of acts against the Safety of Maritime Navigation (1988). The analysis of Somali piracy is relevant because of the impact it generates in relation to maritime surveillance strategies as well as its adverse effect on commercial vessels destined to the port of Mombasa. During the worst period of piracy, vessels tended to transit far away from the Somalia coastline, with enormous repercussions to the economies of the region.

The AIS density map in figure 14 depicts the effect of piracy- at the peak of the menace. The diversion of ship traffic to avoid the Somalia Coastline meant longer shipment routes, adding approximately 3500 NM for southbound transit through the Horn of Africa (HOA). Immediate repercussion included: increased insurance premiums by shipping lines, reduction of ship traffic as vessels reroute, delays in the delivery of goods, with costs passed down the supply chain to end-users, decline in revenue from tourism following increased perception of insecurity including the “potential use of proceeds from piracy/ ransom to finance terrorism” (Interpol, 2012).

Maritime piracy (The Somali context) was on the steady rise between early 2009 to late 2012. From 2013, there has been a reversal. According to European Union Naval Force (EU NAVFOR), intensified naval operations had by 2012 led to a drastic drop in successful pirate attacks (EU NAVFOR, 2013).

According to the International Chamber of Shipping this decrease has been due

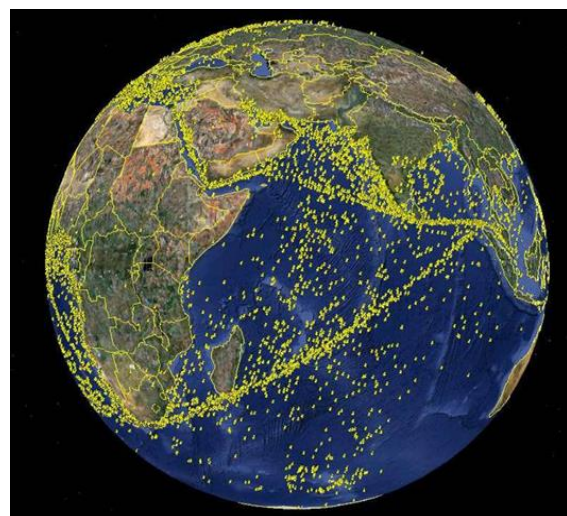


Figure 14: AIS density map

to “the combined success of self-protective measures taken by shipping companies including adoption of Best Management Practices (BMP4), continued use of privately contracted armed security on board ships, and military assets in the region” (International Chamber of Shipping, 2017). But despite this hiatus, the root causes of the problem remain largely unresolved (illegal fishing and smuggling).

A study conducted by Ghassan Schbley and William Rosenau into Piracy, Illegal Fishing, and Maritime Insecurity in Somalia, Kenya, and Tanzania in 2013 concluded that:” As the number of piracy incidents has dropped, other transnational threats have emerged. The maritime sector—including commercial vessels, fishing boats, and small artisanal craft, such as dhows—enables drug traffickers, arms dealers, and those engaged in human smuggling and trafficking to travel almost undetected up and down the coastlines of Somalia, Kenya, and Tanzania. Some of these illegal activities are conducted for purely criminal reasons. However, there is evidence of ties between criminal actors and terrorists associated with al-Qaeda’s affiliates in Africa” (Schbley & Rosenau, 2013)

Official list by Somalia Government of 40 apprehended suspects noted that 80% were born in Somalia’s southern conflict zones, while only 20% came from more stable regions. According to a BBC assessment report (published in 2008), pirates can be ranked in three categories: Local fishermen – considered the brain of the pirates’ operation because of their skills and knowledge of the sea, Ex-militiamen who previously fought for the local clan warlords or ex-military from the former Barre Government and Technical experts – who operate equipment such as GPS devices. Their illegal activities have tended to escalate southwards, towards the maritime boundary with Kenya. Because of the proximity and ease of access to the Islands constituting the Lamu archipelago across the maritime border with Kenya, concerns over resurgence of these vices are well founded.

4.7.1 Maritime Incidents in Lamu

These can be characterized as either security related (terrorist/ piracy) or safety related (distress incidents like capsizing, man overboard and the like). The two outstanding security related incidents with landmark effect on Kenya's maritime surveillance strategies in Lamu are visited below:

In September 2011 a UK national, Judith Tebbutt, was kidnapped and her husband David killed following a terrorist raid on Kiwayu Island, one of the outlying remote Islands close to the maritime border with Somalia. A pirate gang released her six months later. Invoking Article 51 of the UN Charter, Kenya sent troops in mid-October 2011 across the border to Somalia, in pursuit of the invaders. The military and political stalemate occasioned by this event remain outstanding to date.



Figure 15: Mpeketoni in Lamu,

Source Google maps

In another incident in June 2014, at least 48 people were killed in a terrorist raid in Mpeketoni, a trading center on the mainland 20 miles south-west of Lamu Island. This incident was another milestone in shaping up maritime surveillance strategies in the Lamu area. As depicted in figure 15 above, access to Mpeketoni is possible both by sea and by land. The first kidnap attack in October, 2011 was launched from the sea side.

4.7.2 Safety related incidents.

Based on IMO taxonomy and the code of “the International Standards and Recommended Practices for a Safety Investigation into a Marine Casualty or Marine Incident” (Casualty Investigation Code), boat accidents recorded along the Kenyan coastline between 2014 to 2016 were very serious - 14, serious – 14, less serious - 3 and marine incidents - 10.

Table 4: Maritime incidents recorded along the Kenyan Coastline

Severity	2014	2015	2016	Total
Very serious	3	2	9	14
Serious	2	4	8	14
Less serious	0	2	1	3
Marine Incidents	1	4	5	10
Total	6	12	23	41

4.8 Analysis using Pareto 80-20 rule.

“The Pareto rule is extremely helpful in bringing swift and easy clarity to complex situations and problems, especially when deciding where to focus effort and resources” (businessballs.com, 2017). Named after Vilfredo Pareto (1848 – 1923), it propagates the following widely accepted and empirically tested hypotheses (among others): 80% of results come from 20% of efforts, 80% of problems come from 20% of causes, and 80% of activity will require 20% of resources.

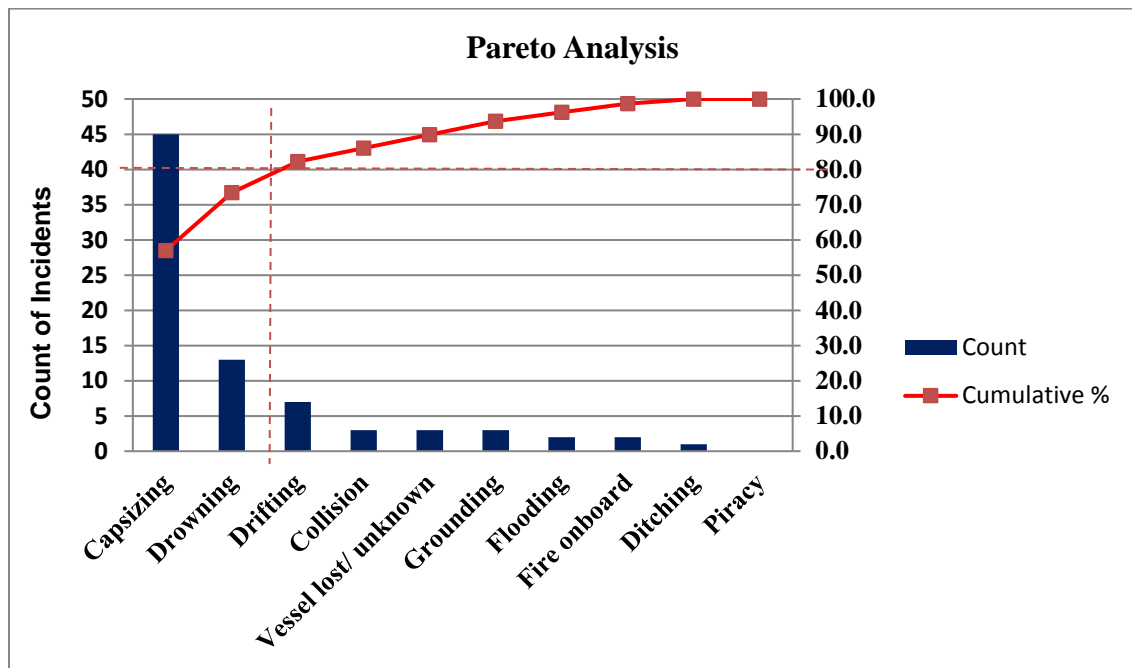
The principle is broadly applicable in situations requiring rationalization, streamlining, and greater focus. A. Gorny, 2015, applied the principle to analyze occupational accidents in Poland. According to Gorny, “the tool helped in the identification of event causes and measures necessary to effectively reduce accident rates and severity” (Gorny, 2015). Based on his studies the empirical relationship whereby roughly 20% was helpful in effectively identifying the causes of the majority of problems was ascertained. With respect to accidents, one may assume that by diagnosing 20% of accident causes one can eliminate approximately 80% of the effects, which elevate accident rates and constitute the key driver of losses suffered by organizations.

Pareto analysis was also applied to the analysis of safety at sea by R. Ziarati, 2007. In his assessment, “Pareto focuses on the problems that offer the greatest potential for improvement, showing their relative frequency or size in descending order. It helps a team to concentrate on those causes which have greatest impact if remedied” (Ziarati, 2007)

4.8.1 Analysis of the Kenyan scenario.

Data on maritime incidents in Kenyan waters (Coastal and Inland) recorded at the RMRCC in Mombasa between 2014 to 2016, is depicted below. Although not considered in this analysis, incidents encountered in 2017 so far (by August 2017) has reached the level of 20.

Incident type	2014	2015	2016	Total	Descending order	cumulative	Percentage
Collision	2	1	0	3	45	45	57.7%
Capsizing	9	20	16	45	12	57	73.1%
Flooding	0	2	0	2	7	64	82.1%
Drifting	0	3	4	7	3	67	85.9%
Man overboard	0	1	0	1	3	70	89.7%
Drowning	1	2	9	12	3	73	93.6%
Unknown/ Vessel lost	1	0	2	3	2	75	96.2%
Fire onboard	0	0	1	1	2	77	97.5%
Grounding	0	3	0	3	1	78	98.7%
Ditching	0	0	2	2	1	79	100%
Pirated	0	0	0	0	0	79	100%
Total	13	32	34	79			



The main observation from this analysis is that there is need to place more focus on measures to minimize capsizing and drowning incidents. This is under the remit of Kenya Maritime Authority (with overall mandate on maritime safety). Either water ingress or heavy seas were responsible for most of these capsizing incidents. This calls for tightening of the regulatory regime round vessel inspections, to ensure overall compliance with safety and lifesaving appliances.

5 CHAPTER 5

5.0 Maritime surveillance in Papua New Guinea (PNG), A case study

In this chapter, maritime surveillance of remote islands in Kenya is compared to that in Papua New Guinea. Kenya's approach is labour intensive, relying more on patrols and regulatory vessel inspections, whereas following installation of state of the art surveillance system in remote locations, powered through solar and wind, PNG's system can be deemed to be comparatively more technology intensive.

5.0.1 Country background

Papua New Guinea is an island state in the southwestern Pacific Ocean with 5,152 km of coastline and 2.7 million square km of Exclusive Economic Zone (EEZ). Out of the country's 22 provinces, fifteen are coastal or island provinces, providing home for



Figure 16: Papua New Guinea,
Source: Source: <https://www.britannica.com/Papua-New-Guinea>

some 60% of the national population. Much of the country's coastline is only accessible by sea. The national capital, Port Moresby, is located in southeastern New Guinea on the Coral Sea.

Papua New Guinea has been a member of the International Maritime Organization (IMO) since 1976, and is a signatory to the following international maritime safety conventions: Load Lines Convention (1966), Tonnage Convention (1969), Collisions Prevention (COLREG) (1972), Safety of Life at Sea (SOLAS) (1974), Standards of Training, Certification and Watch keeping for Seafarers (STCW), (1978), and Search and Rescue (SAR) (1979). The National Maritime Safety Authority (NMSA) is responsible for PNG's compliance with the above international safety conventions.

5.1 PNG Maritime Surveillance System.

PNG's maritime surveillance system was installed in 2013, at a cost of 48 Million US Dollars. It is an integrated system, incorporating Vessel Traffic Service (VTS), Vessel Traffic Management Information System (VTMIS) and Coastal Monitoring System (CMS). It comprises all the necessary components for integration of radar and AIS sensor data, real-time traffic data processing, GPS-time-stamped traffic data recording for farther playback, distribution of traffic data between displaying terminal(s), visual tracking of selected targets by long-range CCTV, VHF Voice Communication and VTS event data storage. The architecture of the system is presented in figure 17 below.

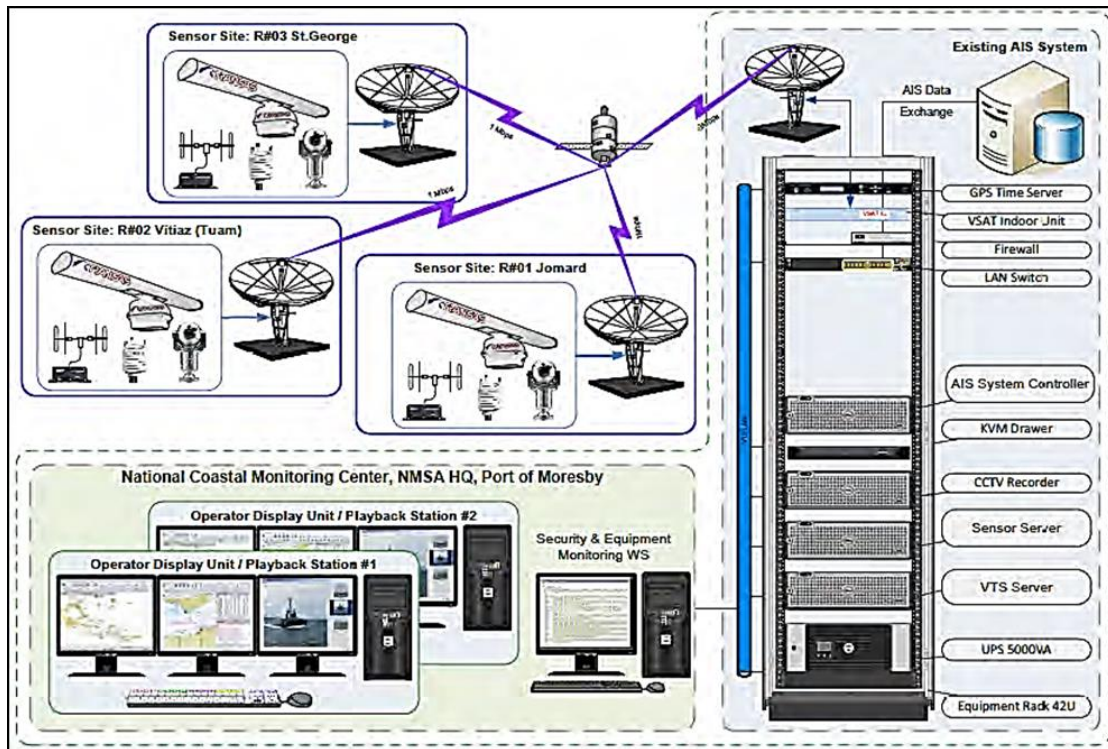


Figure 17: Maritime Surveillance System for PNG,
Source: National Maritime Safety Authority, Papua New Guinea

5.1.1 Discussion of the PNG Maritime Surveillance System:

Papua New Guinea inland waterways covers some 9,980 km² within a coastline measured from the archipelagic baseline. NMSA monitors shipping and shipping activities via five terrestrial AIS base stations, three CMS stations, which also has AIS, RADAR, and VTS compliant Live CCTV capabilities. Other monitoring capabilities include the LRIT system and AMSA's Craft Tracking System shared to NMSA under a data sharing agreement.



Figure 18: Papua New Guinea AIS Map

A major area of challenge involves the detection and tracking of small objects and isolation of possible threats from legitimate shipping, fishing and other maritime activities. Issues that present overbearing challenges include gaps in detection of small targets, low-level coordination and information sharing between responsible agencies (fragmentation of organizations in the maritime security domain), limited inter-operability between

sectoral stakeholders and systems and the need to link up networks of heterogeneous sensors as an avenue to developing early warning systems.

5.1.2 Power arrangements and energy profile:

Papua New Guinea's maritime surveillance system is fully powered from solar PV, with planned wind integration to provide back up and redundancy. The powering scheme of the system is tabulated below. As per the records of the National Maritime Safety Authority, only three power related issues have occurred. These were reported between August and September 2014 – shortly after commissioning of the system, and involved overload in the various sites. These were resolved through replacements with larger automatic restart marine circuit breakers.

Table 5: PNG Maritime Surveillance System: Power demand,
Source: National Maritime Safety Agency, PNG

	Unit	Voltage	Power	
			Peak	Mean
1	Radar Sensor 9ft (9 ft) 25 kw	24 VDC	200	90
2	Radar Processor	24 VDC	60	40
3	AIS Base-station	12/ 24 VDC	70	70
4	CCTV (MIC-400)	12/ 24 VDC	25	10
5	RS/ IP Converter	10 – 30 VDC	19	10
6	IP Relay plus Sensors	12/ 24 VDC	10	2
7	LAN Switch	24 VDC	8	5
8	Weather Station	5 – 32 VDC	1	1
9	Enclosure Fans	24 VDC	10.4	5.2
	Total Consumption	24 VDC	408.4	235.2
	Average Power Consumption		321.8 Watts	
	Selected full system power for calculation		345 Watts	
	Calculated system current		14.375 Amps	
	Total usage in Ampere-hours in 24 hour period		345 Amps	

Solar Panel Calculations.

1	% of total generation from wind turbine	0%
2	Remaining power to be generated by solar	345 Amps
3	Average sun-hours	6
4	Solar power input from sun-hours	57.5 Amps
5	Solar power required	1380 Watts
6	Quantity of 330 Watts Solar Panels	4 Panels

Battery Calculations

	Description	Total
1	Load Current	345 AH
2	Battery autonomy	3 Days
3	Load Current with autonomy	1035 AH
4	No. of 12 V, 100AH batteries	22

5.2 Improvement of Maritime Surveillance in Kenya

This section reviews some actions and planning necessary, for the enhancement of maritime surveillance in Kenya's coastal remote islands. The maritime situation along Kenya's 614 km Coastline can be summarized as follows: there are piracy challenges towards the maritime border with Somalia, IUU fishing challenges along the entire stretch of the coastline, small boat safety concerns and constrained capacity in relation to maritime search and rescue services- specifically for small boats and passenger ferries.

In Lamu area, (whose outlying remote islands constitute the main subject of this study), a Mega Port Project (LAPPSET) is underway therefore necessitating urgent paradigm shift by all stakeholders for safer navigation and use of the waterway, which will be open to international maritime traffic once the Lamu port commences operations.

5.2.1 Policy context and key issues

Interagency engagement has been a key pillar in Kenya's maritime strategies. The synergies, which come with this approach, are reaffirmed by the overall improvements witnessed in both maritime safety and security in the country, following the establishment of a Presidential Blue Economy Committee in 2017. "A number of other Committees, including, Security, Border Management and Fisheries, deal with Kenya's marine policy" (Bueger, 2017).

Through revisions to the National Security Act, 2015, Kenya has codified her Inter-Agency relations, which now provides the overarching legal framework for inter-agency engagements in the pursuit of maritime safety and security. Much more can be achieved by extending this Inter-Agency engagement to the level of procurement of maritime surveillance equipment. This could involve encouraging joint procurement of monitoring equipment, whereby priority could be given to equipment that concurrently feeds the information needs of several agencies in the maritime sector, whilst applying renewable energy solution. Such an approach would ensure sustainability and minimum operating costs.

5.2.2 Institutional framework for the improvement of Maritime Surveillance.

The proposed roadmap borrows from the EU system, which is designed to deliver “a cost effective decentralized interconnection of different information layers that increases the efficiency of maritime surveillance systems by filling existing information gaps, while avoiding data duplication” (European Commission, 2010). The framework was recommended to the European Parliament by a special commission on the “Draft roadmap towards establishing the common information sharing environment for the surveillance of the EU Maritime Domain (COM 2010 – 584).

Four steps are clearly mapped in this approach: (1) Identifying user communities, (2) Mapping of data sets and Gap Analysis, which involves identifying relevant data that each agency avails (supply mapping), its demand for data from other agencies (demand mapping) and indicating the legal basis for each data set. (3) Common data classification levels and (4) Developing the supporting framework. The framework is hereby contextualized to the maritime scenario in Kenya. In terms of step (1), the following user communities apply for the Kenyan case:

- a. Maritime Safety (including search and rescue, maritime security and prevention of pollution by ships) – Kenya Maritime Authority.
- b. Fisheries control – Ministry of Fisheries
- c. Marine Pollution Preparedness and Response – Oil Spill Mutual Assistance Group (OSMAG)
- d. Customs – Kenya Revenue Authority.
- e. Border Control – The Kenya Immigration Department.
- f. Law Enforcement – Kenya Maritime Police Unit.
- g. Defense – Kenya Navy

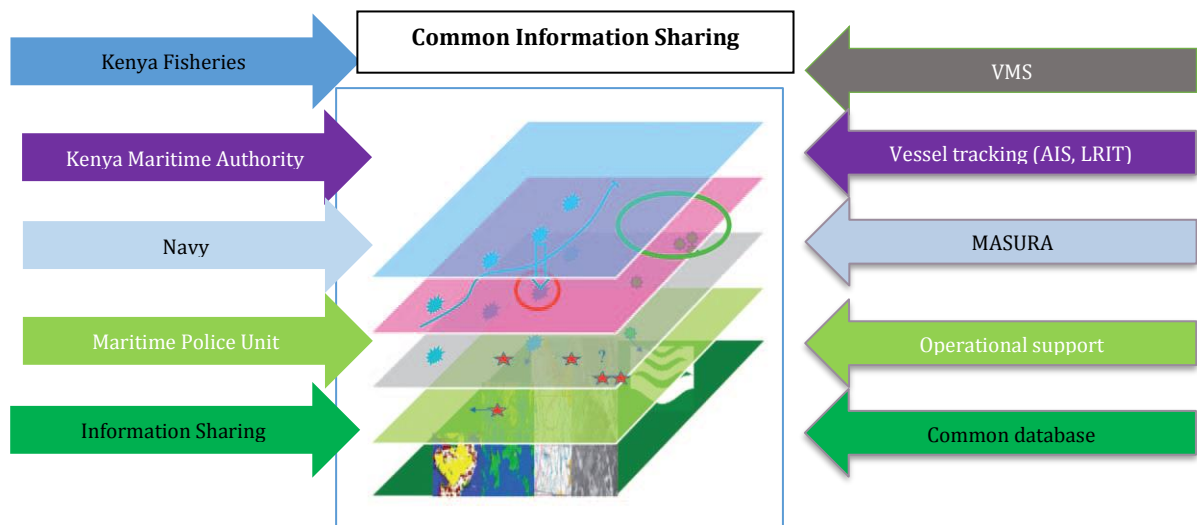


Figure 19: Information Layers (Nonhierarchical),
Adapted from: Integrating Maritime Surveillance, EC.

5.2.3 Improvement of incident reporting: VHF Radio Repeater network.

The effectiveness of technology was demonstrated in a study undertaken by the US Border and Maritime Security Division and NREL in 2013, in a joint research into the potential for renewable energy applications in border security. The study concluded that renewable energy technologies can provide sustainable, reliable power for a variety of applications within maritime surveillance. Their findings provide interesting impetus for consideration in this study.

According to the Centre for Strategy and Evaluation Services, 2011, one major challenge with most surveillance systems stems from the fact that, “Maritime Surveillance systems are developed mainly for maritime safety purposes, and were not designed with sufficient attention to security aspects” (Centre for Strategy and Evaluation Services, 2011).

Maritime surveillance in Kenya’s remote coastal islands can be improved through appropriate interagency information sharing arrangements and the installation of facilities and equipment to improve incident reporting.

A technical field survey was conducted to identify suitable sites for VHF radio repeaters, within the remote coastal islands. The survey had specific eye on existing manned radio base stations by maritime stakeholders, the expectation being that

critical requirements such as security of equipment, would be granted. Although Kenya Maritime Authority has a broad remit in relation to maritime safety, she is still in the process of establishing presence along the coastline. So far, only one Rescue Sub-Centre is operational in Lamu. In the spirit of the National Security Act (2015), the focus of this survey was on sites/ radio base stations manned by the following Agencies: Kenya Maritime Police Unit, Kenya Wildlife Service, and Kenya Fisheries. Based on reports from the RMRCC in Mombasa, there have been claims of the existence of radio blind spots⁴ in some offshore areas, hence necessitating the installation of VHF radio repeaters. Therefore important parameters considered in this survey included:

Range: whereby communication on VHF is limited to the line of sight (LOS) and the range is estimated using the formula:

$$\text{Range}_5 \text{ (km)} = 4.12(\sqrt{H_1} + \sqrt{H_2})$$

Where H_1 and H_2 are the two effective antenna heights in meters. For maritime communications, the antenna heights are referenced to height above sea level. Based on IMO guidelines for GMDSS shore-based facilities, it is assumed that antenna height on board ships may be as low as 4 meters.

Distance between stations: VHF antennas with omnidirectional radiation provide circular coverage, hence some dips occur in the coverage areas between two adjacent stations and such dips are dependent on the distance between the antennas. Table 1 below indicates typical variations of range within the dips.

⁴ Areas where complete degradation/ cancellation of the VHF signal is experienced as a result of topography.

⁵ The equation for deduction of line of sight distance between two adjacent antennas.

Table 6: Dips in the VHF Range,
Source: Eirik Bliksrud, 2016

Distance between antennas	1 times full range	1.5 times full range	1.7 times full range	1.8 times full range	1.9 times full range	2 times full range
Range in the dip as a percentage of full range	87%	66%	53%	44%	31%	0%

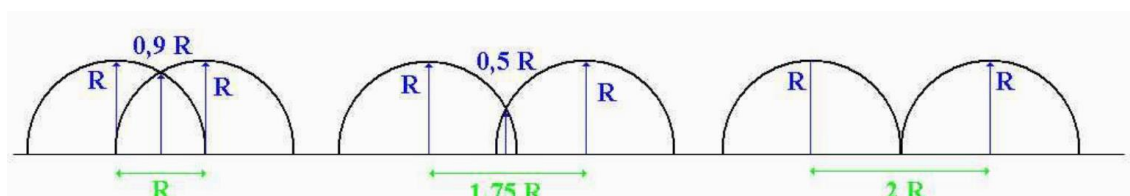


Figure 20: Dips in the VHF Range

Table 7: Range for various antenna heights

Shore based antenna height above sea level (mts)	Calculated range (mts)		SITE	Government Agencies	Coordinates	Elevation Mts.
10	21		Shimoni	Kenya Fisheries K.W.S KMPU	4° 39' 48" S, 39° 21' 06" E	2
15	24		Msambweni	K.M.P.U	4° 28' 36" S, 39° 28' 36" E	10
20	27		Lamu	KMA Site offices	2° 17' 49" S, 40° 54' 47" E	20
25	29		Kiunga	K.W.S K.M.P.U	1° 44' 53" S, 41° 29' 24" E	10
30	31		Kiwayu	Kenya Police	2° 0' 58" S, 41° 15' 54" E	3
35	33		Kipini	K.W.S Kenya Police	2° 31' 22" S, 40° 32' 20" E	5
40	34		Malindi	K.W.S	3° 07' 51" S, 40° 21' 06" E	10
45	36		Watamu	K.W.S	4° 39' 48" S, 40° 21' 06" E	3
50	47		Ngomeni	K.M.P.U Kenya Fisheries	2° 59' 39" S, 40° 12' 09" E	40
100	49		Kilifi	Kenya Fisheries	3° 38' 05" S, 39° 50' 44" E	5
			Mtwapa	K.W.S Kenya Police line	4° 39' 48" S, 39° 21' 06" E	2

5.2.4 Antenna arrangement:

Maritime VHF service employs frequency modulation (FM) and vertical polarization, using half-wave omnidirectional dipole antennas in the horizontal plane with 2.15 dBi antenna gain. The VHF wavelength is 2 meters. Both single dipoles and folded dipoles may be used. The single dipole has approximately 75-ohm antenna impedance,

whereas the folded dipole has similar radiation properties, but the impedance is 300 ohms and a larger frequency bandwidth of the antenna.

For VHF systems operating on more than one channel in the one-frequency simplex mode with individual antennas on frequencies in the same band, the antennas are installed at different levels in a straight vertical line, one antenna above the other as per the figure below. The distance between the extremes of the different antennas should be at least one wavelength.

5.2.5 Proposed Station Solution:

It is assumed that each station would handle DSC distress calls (channel 70), voice distress/safety and calling on channel 16, navigation information on channels AIS 1 and AIS 2, and voice communications. The figure below indicates schematic structure of the station solution operating on channel 70, channel 16, the terrestrial AIS channels and one voice communication in accordance with ITU Radio Regulations Appendix 18. The AIS equipment would operate on both AIS 1 (161.975 MHz) and AIS 2 (162.025 MHz).

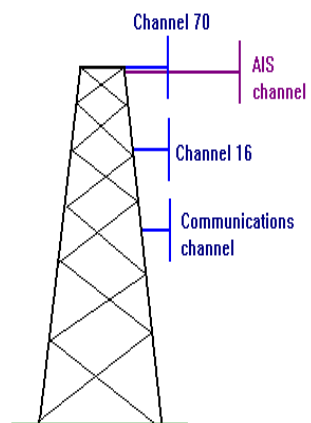


Figure 21: VHF antenna structure



Figure 22: Proposed VHF coverage area,

Source: Google map

5.2.6 Estimated solar power requirement for each station:

Data from the Solar and Wind Resource Assessment (SWERA), a UNEP supported global initiative, projects that the wind resource along the Kenyan coastline averages 5 – 7 m/s at 50 metres height, while for solar, the country receives an average of 4.5 KWh/m² per day (Ministry of Energy and Petroleum, 2013). With these average figures, the renewable energy resources are in sufficient quantities for standard application in the maritime surveillance domain. For the VHF Radio repeater network, the estimates for solar energy requirement per site is presented in table 4 below.

Table 8: Solar PV requirement per VHF Repeater site,
Source: Solar PV Quotation by Wilken Telecommunications (K) Ltd

Item	Quantity	Watts	Total Wattage	Operating hours	Watthours
130 W Panel	1	130	130	24	3120
				Total	3120
Item	Description			Items	QTY
Batteries	12V, 200 AH			1.87777	2
140 Watt Panels				2.857142857	3
Inverter	36 watts				
Charge controller	30 Amps				

5.3 Conclusion

This paper has examined the subject of maritime surveillance in Kenya's remote coastal islands, and established a justification for improvements in the current state of facilities and arrangements. These improvements can be realized piecemeal, through the establishment of an enabling policy framework, strengthening inter-agency engagement and then applying appropriate technology. Following the enactment of the National Security Act, 2015, the stage is already well set for active inter-agency participation. At the regional and international levels, it is important to harness the networks established through cooperation agreements and memoranda of understanding (such as the Djibouti Code of Conduct) and more recently the Regional Maritime Information Fusion Centres.

This study also investigated the possibilities of solar power in maritime surveillance applications and ascertained that energy requirements for powering a single VHF repeater can range between 312 watts per site to 3180 watts for a complete maritime surveillance package, as per the Papua New Guinea System..

Owing to various site-specific parameters including land acquisition process in Kenya, the ascertainment of full cost requires the consideration of various additional factors and externalities, and is therefore recommended as the subject of future research.

5.4 Recommendations

Other operational measures, alongside the discussed measures include, strengthening Beach Management Units (BMUs). BMUs in Kenya are established in accordance with the provisions of the Fisheries Act, (Beach Management Regulations, 2007 Cap 378). Among other important functions, BMUs provide an avenue for strengthening the management of fish landing sites, fishery resources and aquatic environment. More importantly, they are equipped to prevent or mitigate conflicts in the fisheries sector (FAO, 2012). According to Ngige and Jaeckel, 2007, the essence of BMUs is that “it creates a link and a partnership between the government level and artisanal fishermen.

Along Kenya’s Indian Ocean coastline, there are 27 BMUs and 209 fish landing sites (KMA, 2015). A close collaboration exists between Fisheries, BMUs and the Maritime Authority in Kenya. Kenya Maritime Authority has dependability on BMU members’ skills who are normally the first to arrive on-scene whenever local fishing and small passenger boats are involved in accident. This makes them dependable partners on search and rescue operations involving small boats. Through sensitization and general awareness campaigns, BMUs can be made proactive partners in relation to developing a resilient Maritime Domain Awareness (MDA) structure to cope with maritime crime in Kenya’s coastal remote islands.

The author recommends further research into how the following renewable energy options can be harnessed for both mobile and fixed maritime surveillance

applications: photovoltaics, wind, energy transfer (batteries), energy transfer (wireless), and fuel cells.

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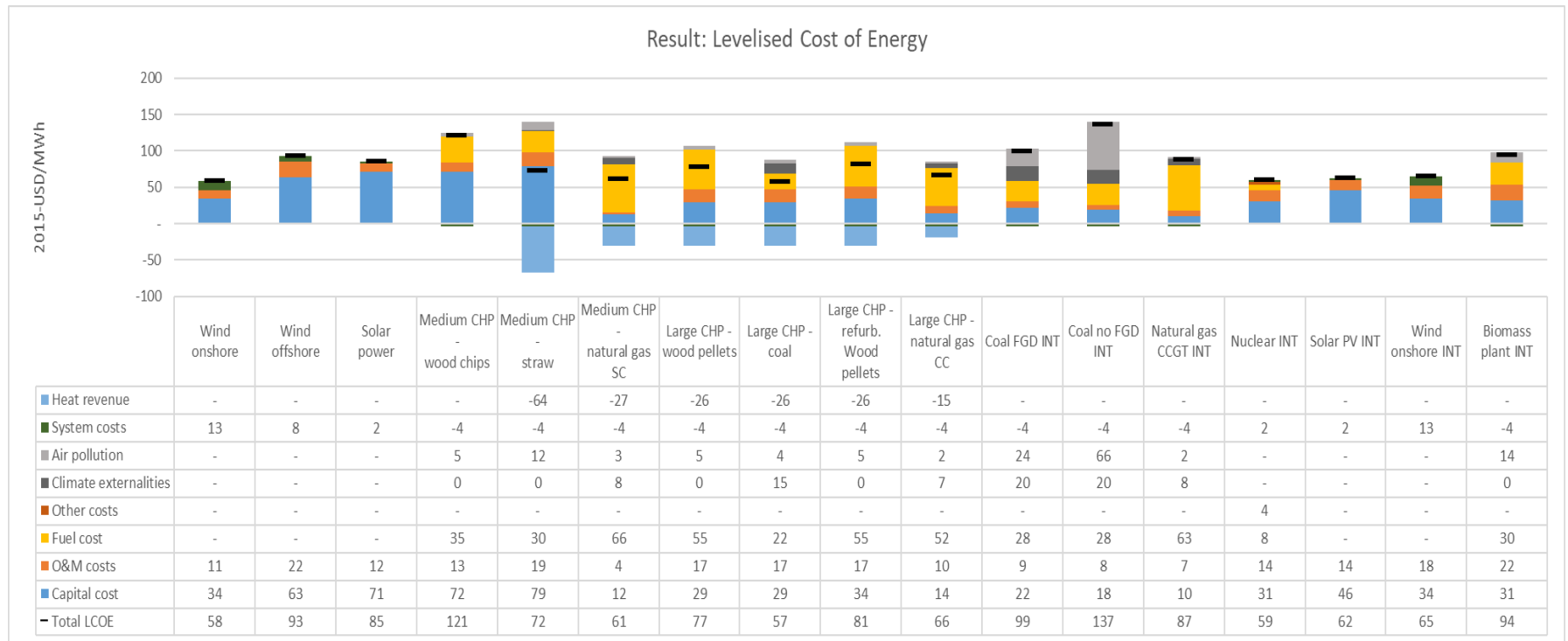
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7 Appendix 1 Levelised cost of Renewable Energy



7.1 Appendix 2

Solar PV Project Cost Calculator			Levelized Cost of Energy (LCOE) - Coastal Surveillance			August, 2017			
Inputs highlighted in Yellow									
System Inputs			Input Description			LCOE Calculator			
System Size (kW-DC)	3	(Please insert the aggregate system size for a site)	Year	Production (kWh)	Direct Purchase Cost (\$)	O&M Cost (\$)	PPA Escalator (%)	PPA Rate (\$/kWh)	PPA Cost (\$)
1st-Year Production (kWh)	187	(Please insert the aggregate forecasted system production at a site)	0		\$ 2,308				
Annual Degradation	0.50%	(Please insert the expected system yearly performance degradation)	1	187		\$ 45		\$ 0.1500	\$ 28
			2	186		\$ 46	3%	\$ 0.1545	\$ 29
			3	185		\$ 48	3%	\$ 0.1591	\$ 29
			4	184		\$ 49	3%	\$ 0.1639	\$ 30
Direct Purchase Inputs									
Cost (\$/W)	\$ 0.769	(Please insert total system cost per Watt. If not available, use the formula: Cost (\$/W) = (Total-system-cost/Total-system-size-in-watts)	5	183		\$ 51	3%	\$ 0.1688	\$ 31
Initial Rebate/Incentive	\$ -	(Please insert the total value of rebates/incentives received within the first year)	6	183		\$ 52	3%	\$ 0.1739	\$ 32
O&M Cost (\$/kW)	\$ 15.00	(Please insert the per kW O&M cost. If not available, use the formula: O&M Cost (\$/kW) = (1st-year-O&M-Cost/Total-system-size-in-kW)	7	182		\$ 54	3%	\$ 0.1791	\$ 33
O&M Escalator (%)	3%	(Please insert the expected yearly escalation)	8	181		\$ 55	3%	\$ 0.1845	\$ 33
			9	180		\$ 57	3%	\$ 0.1900	\$ 34
			10	179		\$ 59	3%	\$ 0.1957	\$ 35
PPA Inputs									
PPA Rate (\$/kWh)	\$ 0.15000	(Please insert the per kWh PPA Rate. If not available, use the formula: PPA Rate (\$/kWh) = (1st-year-PPA-Cost/1st-year-system-prduction)	11	178		\$ 60	3%	\$ 0.2016	\$ 36
PPA Escalator	3.00%	(Please insert the expected yearly escalation. If not uniform, manually insert yearly escalation in Column I)	12	177		\$ 62	3%	\$ 0.2076	\$ 37
			13	176		\$ 64	3%	\$ 0.2139	\$ 38
			14	175		\$ 66	3%	\$ 0.2203	\$ 39
			15	175		\$ 68	3%	\$ 0.2269	\$ 40
LCOE Outputs*			16	174		\$ 70	3%	\$ 0.2337	\$ 41
Direct Purchase			17	173		\$ 72	3%	\$ 0.2407	\$ 42
20 Year	\$ 0.98473	* Compare to expected utility costs over the next 20 years	18	172		\$ 74	3%	\$ 0.2479	\$ 43
25 Year	\$ 0.89539		19	171		\$ 77	3%	\$ 0.2554	\$ 44
			20	170		\$ 79	3%	\$ 0.2630	\$ 45
PPA			21	169		\$ 81	3%	\$ 0.2709	\$ 46
20 Year	\$ 0.20054	* Compare to expected utility costs over the next 20 years	22	168		\$ 84	3%	\$ 0.2790	\$ 47
25 Year	\$ 0.21709		23	168		\$ 86	3%	\$ 0.2874	\$ 48
			24	167		\$ 89	3%	\$ 0.2960	\$ 49
			25	166		\$ 91	3%	\$ 0.3049	\$ 51
			Total	4,410	\$ 2,308	\$ 1,641			\$ 957
			Item	Description	Quantity	QTY			
			Batteries	12V, 200 AH	1.87777	2			
			140 Watt Panels		2.857142857	3			
			Inverter			36 Watts			
			Charge Controller			30 Amps			
			Total		23.3333				

In this sheet the levelized cost of energy is visible in a graph, which also displays a table with the cost element. The user can adjust a number of settings in the calculation of the LCoE. A summary table of the LCoE-results gives the data input for the graph (Row 53-83)

Functions:

Basic user settings
(this sheet row 13 to 34)

In this table the user can adjust a number of the input parameters; some of them according to predefined options and others are free to set.

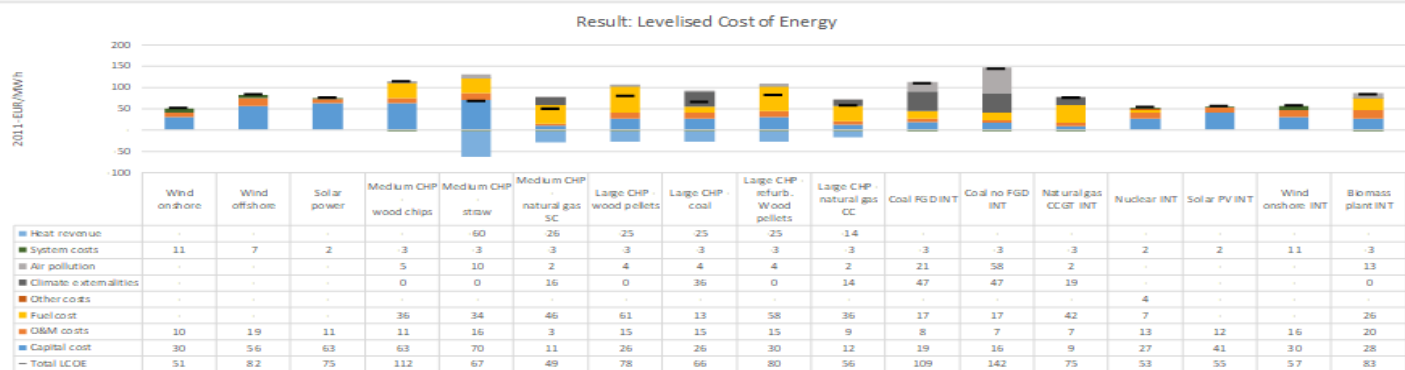
Select technologies for graph

The user can choose which technologies and cost elements to be viewed in the graph.

Change order of technologies
(this sheet row 57)

In the calculation table, the technology in each column can be changed in the drop down function and thereby the order of the technologies can be swapped around in order to compare them better. Changes

Basic user settings	Default value	Override	Current value	Explanation
Result view				
Currency	EUR	EUR	EUR (Predefined)	The results can be viewed in number of currencies. All input data should be in EUR2015.
Price year	2015	2011	2011 (Predefined)	Price year for results
Financial settings				
First year of production	2016		2016 (Predefined)	The first year of production should be related to the technology year.
Lookout period (years)	Technical		Technical (Predefined)	Period for discounting fuel and CO ₂ prices. If you choose "Technical" the lookout period equals the technical lifetime of the specific technology
Discount rate	4%		4% (Free to set)	Set discount rate. Used for annuation of capital costs and discounting fuel and CO ₂ -prices. The value 0 will not work. Choose instead a very small value
Discount prices	YES		YES (Predefined)	Choose YES to discount prices for fuel, CO ₂ -prices etc. through lookout period
Interest during construction	YES		YES (Predefined)	Set to YES to take into account interest during construction
Scenarios				
Fuel and CO ₂ -price scenario	New Policy 2015	450ppm 2015	450ppm 2015 (Predefined)	Choose which scenario for future fuel and CO ₂ -prices should be applied. The IEA fuel and CO ₂ price projections from World Energy Outlook 2015 are predefined in the model. In the sheet "FuelPrices" custom fuel and CO ₂ -prices can be defined
Technology scenario	TechBase	TechBase	TechBase (Predefined)	Choose scenario for technical data. See the TechData sheet for further information
Technology year	2015		2015 (Predefined)	Year for technology data
Heat value				
Set methodology to value heat production	Cost allocation		Cost allocation (Predefined)	Choose method to value heat from combined heat and power plants. Set to YES to use a cost allocation methodology. Otherwise a heat price will be used
Heat efficiency if cost allocation is selected	125%		1.25 (Free to set)	Set the efficiency of heat production used for allocation of fuel and CO ₂ costs. It is by default set to 125%. Other often used efficiencies are 150% and 200%
Heat price (EUR/GJ) if heat price is selected	6.7		6.7 (Free to set)	Choose the price of heat (set to NO). New values should be typed in EUR2014/GJ. If heat price is selected the value of heat is shown as a heat revenue (negative cost) in the graph.
Inclusion of costs				
Include air pollution	YES		YES (Predefined)	Set to YES to include air pollution in the LCOE calculation



User instruction -selection of data in the graph

Newer version of Excel: select the chart, click the filter, and (un)select the elements and categories to be viewed. All versions of Excel: Hide the columns with technologies not wanted in the graph according to the summary table (B52 to AC62).

Summary of the LCoE-calculation																
	Wind onshore	Wind offshore	Solar power	Medium CHP - wood chips	Medium CHP - straw	Medium CHP - natural gas SC	Large CHP - wood pellets	Large CHP - coal	Large CHP - refurb. Wood pellets	Large CHP - natural gas CC	Coal FGD INT	Coal no FGD INT	Natural gas CCGT INT	Nuclear INT		
Capital cost	30	56	63	63	70	11	26	26	30	12	19	16	9	27		
O&M costs	10	19	11	11	16	3	15	15	15	9	8	7	13	12		
Other costs	-	-	-	-	-	-	-	-	-	-	-	-	-	-		
Fuel cost	-	-	-	36	34	46	61	13	58	36	17	17	42	7		
Climate externalities	-	-	-	0	0	16	0	36	0	14	47	47	19	-		
Air pollution	-	-	-	5	10	2	4	4	4	2	21	58	2	-		
System costs	11	7	2	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3		
Heat revenue	-	-	-	-	-60	-26	-25	-25	-25	-14	-	-3	-3	-		
Levelized cost of electricity production, 2011-EUR/MWh	51	82	75	112	67	49	78	66	80	56	109	142	75	53		

7.2 Maritime incidents recorded in Kenyan waters (Source RMRCC Mombasa)

N O.	DATE	COAST REGION	INCIDENT/ ACCIDENT TYPE	CAUSE	REMARKS
1	01/05/2014	Malindi Marine N. Park	Not stated	Not stated	No Casualties
2	03/11/2014	Mombasa - Neptune Beach Hotel	Collision	Jetski rammed into a boat	1 died
3	16/12/2014	Lamu	Collision	Human error	1 died
4	20/11/2014	Mombasa Marine park	Capsized	Rough Weather	5 rescued
5	21/11/2014	Kipini	Capsized	Rough Weather	1died
6	22/12/2014	Mombasa Marine park	Capsized	Rough Weather	6 rescued
7	2/1/2015	Diani - South Coast	Capsized	Rough weather	4 persons rescued
8	10/1/2015	Diani - South Coast	Vessel flooding	Aground	15 persons rescued
9	14/01/2015	Lamu	Vessel Adrift	Mechanical Problems	Vessel repaired
10	19/01/2015	Kisite mpunguti Area	Grounding	Vessel ran aground	12 crew rescued
11	6/4/2015	North coast - whitesands Beach	Capsizing	-	3 Children rescued, 9 bodies recovered
12	19/05/2015	Kiwayu - Shimo La Tewa	Capsizing	-	4 persons rescued
13	25/05/2015	Malindi Marine N. Park	Taking on Water	Mechanical Problems	Vessel repaired
14	9/7/2015	Mkundeni - Lamu	Capsizing	Strong Currents	3 Rescued 1 Died

15	24/7/2015	Lamu	Capsizing	-	2 Rescued 3 Died
16	25/7/2015	Lamu	Capsizing	-	2 Rescued.
17	23/08/2015	Lamu	Accident - swimming person	Human error	1 rescued
18	22/9/2015	Mambrui Malindi	Grounding	Hitting Sand Dune	20 crew all rescued.
19	19/10/2015	Mombasa	Drifting	Failed steering	2 Rescued
20	20/01/2016	Shimoni	Lost Vessel	Drifting, lost main sail	4 persons Rescued
21	28/02/2016	Lamu - Manda bay	Capsizing	Strong waves	2 rescued
22	11/3/2016	Magogoni	Capsizing	-	-
23	28/03/2016	Dongo Kundu	Drowning	-	1 Body found
24	15/04/2016	Mtwapa bridge	Drowning	Diving. Human error	1 Body found
25	10/5/2016	Mkokoni - lamu	Capsizing	Unknown	2 persons rescued
26	17/05/2016	Shimoni	Overdue.drifted due to mechanical failure	Fishing	5 Kenyans on board
26	24/05/2016	Junda creek	Drowning		
28	25/05/2016	Likoni	Drowning		
29	28/05/2016	Mtwapa Creek	Drowning	-	1 Body found
30	6/6/2016	Likoni Channel	Ditched	Mechanical Problems	1 body retrieved

31	9/6/2016	Mkandani (Kililawa channel)	capsized	Hit a rock	All 18 passengers rescued
32	13/06/2016	English point	Capsized	Strong waves	All 6 people on board rescued
33	7/7/2016	Diani - near Congo Mosque	Drowning	Strong waves	1 died
34	26/7/2016	Mtwapa Creek	Capsized	Rough Weather	2 swam to safety, 1 drowned
35	26/7/2016	Pemba channel	Drifting	Engine Breakdown	towed by Swabil Jamil boat 5 rescued
36	29/7/2016	Mtwapa	Drowning	Rough Weather	2 swam to safety, 2 drowned
37	2/8/2016	Tudor creek	Capsizing	Rough Weather	2 swam to safety , 1 drowned
38	17/08/2016	Diani - Tiwi	Drowning	Strong waves	2 died
39	24/08/2016	Lamu	Capsizing	Rough Weather	4 rescued
40	29/08/2016	Mvudheni (Lamu - Kiunga)	Capsizing	Rough Weather	5 rescued
41	6/9/2016	Msambweni	Capsizing	Rough Weather	12 survived 4 dead
N O.	DATE	LAKE REGION	INCIDENT/ ACCIDENT TYPE	CAUSE	REMARKS
1	10/01/2014	Sumba Channel (L. Victoria)	Possibly Capsizement	Rough Weather	No Casualties
2	18/04/2014	Masinga Dam	Capsizement	Rough weather	1 died.
3	12/05/2014	Lake Naivasha	Drowning	Falling overboard	1 died

4	18/05/2014	Lake Naivasha	Capsizement	Waves and panic hence alteration of the vessel stability	2 died
5	11/11/2014	Wakondo - Lusinga Island	Capsized	Hippo knocked down boat	1 died 3 swam to safety
6	18/11/2014	Budalangi	Capsized	Not stated	1 died
7	18/11/2014	Luyoro - Turkana	Capsized	Overloading and bad weather	1 person died 7 were rescued
8	8/1/2015	Kusa Beach - Lake Victoria	Trapped	Stuck in hyacinth	2 persons rescued
9	29/03/2015	Lake Turkana	Capsizing	Overloading	11 people rescued,
10	13/4/2015	Gwasssi, North Mbita	Capsizing	Old boat	2 men died
11	15/04/2015	Kisagi, Gwasssi Mbita	Capsizing	Unknown	3 persons saved
12	17/04/2015	Uterere Beach	Capsizing	Unknown	3 Fishermen rescued
13	19/04/2015	Kisegi Beach, Guasi North	Capsizing	Old boat	2 persons rescued
14	13/05/2015	Shelly Beach	Engine Failure	Going for repair	2 persons rescued
15	16/05/2015	Luyoro - Turkana	Capsizing	Bad weather	4 persons rescued
16	27/05/2015	Busia	Capsizing	Strong Winds	2 drowned 1 survived
17	19/06/2015	Nyandiwa, Suba	Sinking	Drifting, Hit rocks	3 drowned, 3 rescued
18	2/7/2015	Omena Beach	Drowning	Drunkardness	1 Person died

19	11/7/2015	Longech - Turkana	Capsizing	Unknown	4 Rescued
20	5/8/2015	Homabay Sori	Collision	No lighting at night	2 Children perished, 21 adults rescued. The boat was sailing without lights.
21	12/8/2015	lake Naivasha	Capsizing	Strong winds	3 Rescued 3 Died
22	4/10/2015	Asebo - bay , L. Victoria	Capsizing	Bad weather	1rescued 1 died
23	18/10/2015	Uganda waters	Drowning	dropped in the water	1 died
24	23/11/2015	River Sio Busia	Capsizing	Swell of River Sio	2 Rescued 2 Drowned
25	25/02/2016	Masinga Dam	Capsizing	Overloading	3 Rescued 2 Drowned
26	2/4/2016	Sori Beach	Capsizing	Unknown	2 drowned
27	25/6/2016	Liunda Beach to Denda Island	Capsizing	Strong winds	9 rescued 9 drowned
28	4/7/2016	Kisiu Beach	Drowning	Hippo attack	1 person died
29	4/7/2016	Mahanga beach	Capsizing	Hit rocks	2 survived , 2 drowned
30	7/7/2016	Misori beach	Capsizing	Strong Winds	2 Rescued 2 Drowned
31	16/8/2016	Mageta - Usenge Island	Capsizing	Strong waves	1survived 1 drowned
32	24/08/2016	Lake Kenyatta	Drowning	slipped	1 dead
33	9/9/2016	Kisumu port	Fire on board	Engine room	5 rescued