# Estimating Marine Tidal Power Potential in Kenya

Lucy Patricia Onundo, Wilfred Njoroge Mwema

***Abstract*—**The rapidly diminishing fossil fuel reserves, their exorbitant cost and the increasingly apparent negative effect of fossil fuels to climate changes is a wake-up call to explore renewable energy. Wind, bio-fuel and solar power have already become staples of Kenyan electricity mix. The potential of electric power generation from marine tidal currents is enormous, with oceans covering more than 70% of the earth. However, attempts to harness marine tidal energy in Kenya, has yet to be studied thoroughly due to its promising, cyclic, reliable and predictable nature and the vast energy contained within it. The high load factors resulting from the fluid properties and the predictable resource characteristics make marine currents particularly attractive for power generation and advantageous when compared to others. Global-level resource assessments and oceanographic literature and data have been compiled in an analysis of the technology-specific requirements for tidal energy technologies and the physical resources. Temporal variations in resource intensity as well as the differences between small-scale applications are considered.

***Keywords*—**Energy data assessment, environmental legislation, renewable energy, tidal-in-stream turbines.

## I. Introduction

ELECTRICITY demand is growing rapidly along the Kenyan coast as a result of migration and the increased rate of population growth. Due to the insufficient generation and distribution developments in the power sector, the coastal strip has poor access to the cost-efficient hydro-power. To increase energy security and availability is to intensify the use of ocean energy. Until recently, methods of harvesting tidal energy concentrated on capturing water in a dam or barrage at high tide and generating electricity by releasing the water at low tide.

With the global development of tidal in-stream kinetic energy turbines, which act much like wind turbines, a thought to offer many advantages over other forms of power generation is anticipated. The high density of water (800 times denser than air) and the predictability of the tides suggest that tidal turbines should be able to produce a large amount of reliable power, while the flexibility of individual turbines should make turbines more economically and ecologically attractive than tidal barrages. However, these advantages are yet to be established in practice as most operating projects are small in scale. Tidal currents are being recognized as a resource to be exploited for the sustainable generation of electrical power. The tidal forces are due to gravitational attraction of the moon and sun hence predictable.

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Moreover, international treaties related to climate control such as the Kyoto Protocol, 1997, have triggered resurgence in development of renewable ocean energy technology. Only a fraction of the global ocean energy resource is to be found in sites which are economically feasible to explore with available technology. However, this fraction could still make a considerable contribution to electricity supply. The need to quantify the potential for generating electricity from marine and tidal currents provides the details explored to determine the potential of electricity generation using tidal energy around Mombasa and Lamu in Kenya.

The immense source of ocean renewable energy is classified into six categories of diverse origin and features namely, ocean wave, tidal range, tidal current, ocean current, ocean thermal energy, and salinity gradient [1]-[3]. Currently, all ocean energy industries except tidal range can be regarded at an early stage of development phase from conceptual up to demonstration stage [2]. Ocean wave and tidal current energy are the two types of ocean energy which are most advanced and are expected to contribute significantly to the supply of energy in future [2]. Thus, the research review focused majorly on waves, tides and tidal current energy potential. The ocean energy industry has made significant progress in recent years globally with some advanced prototypes that are currently being tested [4].

Existing challenges include further development analysis of the technology and innovation to prove performance and robustness and to reduce costs but also deployment and risk reduction as reflected in Fig. 1. However, other not technology-related knowledge gaps and barriers exist [4].

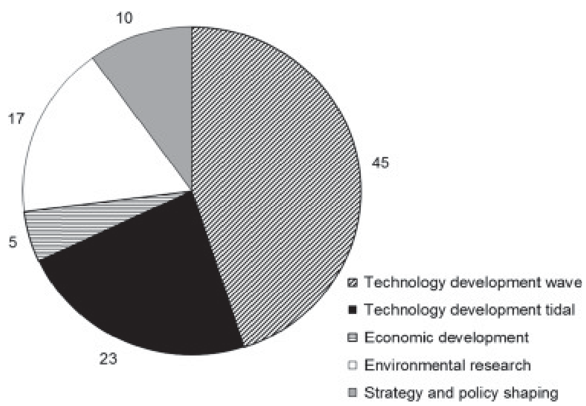


Fig. 1 Research themes funded e.g. by the EU [4]

### A. Purpose of Tides and Tidal Current Energy Research Assessment

(i) Tides and tidal current power greenhouse gas emissions reduction estimates are presented. The hydrodynamic power scheme focused on considering potential benefits, conditions for sustainable development, energy policy context and compliance with environmental legislation. However, the present lack of full spatial-temporal assessment of tidal currents for the Kenyan coastline down to the scale of individual devices is a barrier to the comprehensive development of tidal

(ii) Tidal current energy technology.

(iii) Tidal energy resource assessment in Kenya, a scheme which test, investigate and demonstrate equipment performance through software, data analysis and experiment to evaluate the tide-producing forces is reviewed.

### B. Objectives

The research aim was to provide an overview over the current state of research in the field of tides and tidal current energy production in relation to electrical conversion device characteristics. Further research and innovation in the area of technology is the prerequisite to tap the full potential of ocean energy.

Technological barriers represent the most important issue that the ocean energy sector needs to address in the short-medium term [5].

Priority topics include technology advancement, reliability, sub-system development, deployment, operations and optimization, pre-commercial array sea trial and demonstration, predictive maintenance systems, array electrical systems and environmental impacts [4].

This review focused on research beyond techniques, processes or industrial investment, for sustainable energy demand [4], [6]-[8].

The review state of technology development determine how much of the resource can be exploited with is based on a literature review and desk-based research to provide solutions for the exploitation of the potential ocean energy resources.

Areas covered in mapping the ocean tidal resources along the Western Indian Ocean, with the emerging oil and gas industry have been identified as crucial [2], [7], [9].

## II. Methodology

### A. Resource Assessment and Forecasting Facilities

An important initial step towards market deployment of ocean energy is the characterization and mapping of ocean energy resources. The assessment of wave energy resources and its impact is considered as shown in Fig. 2.

The simulation include the identification of areas with high wave energy, the quantification of average energy resources (e.g. total annual wave energy) and the description of the resource by using parameters such as significant wave height, wave energy period and mean wave direction [10]. Precise estimates and description of available wave energy.

#### 1. Ocean Wave Resource Investigation

Resources at high spatial and temporal resolution are needed for proper planning and the optimization of the design of ocean energy converters [11], [12]. This help to optimize device performance in terms of power produced, for example, the power output of an Oscillating Water Column device [13]. The current the main technical parameters to be improved being device efficiency and capacity factor [10], [14]. In Sections III and IV, an overview of current state combined wave and tidal current energy resource assessment and forecasting is presented.

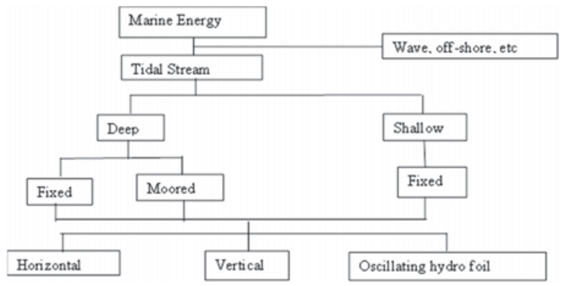


Fig. 2 Tidal current Technology Development (Prototype Stage)

Global Ocean wave energy resources have been assessed for various regions. The first wave energy resource assessments have been made using buoy data limited to local conditions [12]. The second generation of assessments included buoy data in combination with deep water numerical models which can assess offshore wave resources and help in overcoming the limitations of first generation assessments, namely the limited time period of the buoy measurements and the uncertainties of extrapolating local data to other locations [12]. Recent tools incorporate radar measurements and allow modelling wave generation and propagation also in coastal regions [11]. Usually, wind and bathymetry data are used as an input for such models. Typical output parameters are: significant wave height, mean wave period, peak wave period, and mean wave direction.

#### 2. Tidal Current Resource investigation

Similar to wave energy, tidal current energy resources have been assessed since a number of years. Often, direct measurements have been performed on-site. Currently 2-D and 3-D modelling techniques have been applied to assess tidal current energy resources by modelling current velocities [15]. More recent publications assess also the hydrodynamic effects of power extraction and consider for example change to the flow field, change in water surface elevation or disturbances in tidal dynamics [16].

According to [14], tidal current energy is calculated as function of seawater density, velocity, velocity availability factor, neap/spring factor, and peak spring-tide velocity. However, it is not possible to convert all tidal current energy power due to Betz' law and mechanical losses in the turbines. These limitations are accounted via the power coefficient.

The movement of ocean water volumes, caused by the changing tides, creates tidal current energy. Kinetic energy can be harnessed, usually nearshore and particularly where there are constrictions, such as straits, islands and passes. Tidal current energy results from local regular diurnal (24 hours), or semi-diurnal (12+ hours) flows caused by the tidal cycle. Tides cause kinetic movements, which can be accelerated near coasts, where there is constraining topography, such as straits, islands and passes.

*B. Expressing Fluid Flow Processes Mathematically*

1. Bernoulli's principle (Conservation of energy) states that for an inviscid flow of a non-conducting fluid, an increase in speed occurs with a decrease in pressure or decrease in the fluid's potential energy:

$$\rho\vec{g} - \nabla.\vec{P} + \mu\left(\frac{\partial^2\vec{V}}{\partial x^2} + \frac{\partial^2\vec{V}}{\partial y^2} + \frac{\partial^2\vec{V}}{\partial z^2}\right) = \rho\frac{D\vec{V}}{Dt} \Longrightarrow$$

$$\rho\vec{g} - \nabla.\vec{P} + \operatorname{div}\vec{\tau} = \rho\frac{D\vec{V}}{Dt}$$

Tidal model as a harmonic series governed by a linear set of equations expressed and presented as Fig. 3.

$$v(t) = \sum v_i \sin(2\pi f_i t + p_i)$$

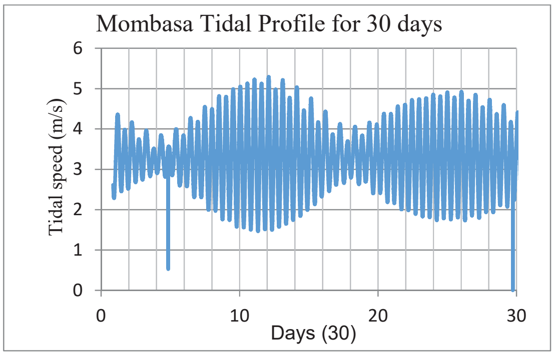


Fig. 3 Tidal current speed profiles for 30 days

2. Tidal Current Power: The stream electrical power that a tidal turbine extracts is less than the power captured due to generator and gearbox efficiencies:

$$P_m = \eta_G \eta_D c_p(\lambda,\beta)\frac{\rho A}{2}v^3$$

where $P_m$ = Mechanical output power $(w)$, $\eta_g$ = generator efficiencies 50% to 80% , $\eta_D$ = gearbox efficiencies 90 – 95% , v is the filtered Ocean current velocity at the hub of the turbine or average velocity of the Ocean water through the surface A in m/s.

3. The amount of hydrodynamic torque, $T_W$ rad/s, is given by the ratio between power extracted from the tidal currents, $P_{Blade}$ and the turbine rotor speed, $\omega_m$ as follows:

$$T_w = \frac{P_{Blade}}{\omega_m} = \frac{c_p(\lambda,\beta)\frac{\rho A}{2}v^3}{\omega_m}$$

$$T_w = \frac{1}{2}\cdot\frac{c_p(\lambda,\beta)\rho\pi R^2 v^3}{\omega_m}$$

There is need for quantifying the potential energy to estimate full and diverse electrical energy generated. Design and potential development of a numerical model to estimate the extractable power for generation at Lamu and Mombasa.

## III. Results and Discussion

The model calibration and results obtained of the hydrodynamic modelling are presented, discussed as well as identification of zones for energy exploration and assessment of TEC array interferences on tides and tidal current types.

The scope of the research study was to estimate the potential development of Tidal In-Stream Energy resource and technology. The success of the scheme is contingent upon naturally occurring geographical elements. Although all tides produce power, only a few locations exist where tidal power can be harnessed. Typically, tidal streams are to be found where underwater valleys force currents to constrict and speed up as demonstrated in varied transport profile, as shown in Fig. 4.

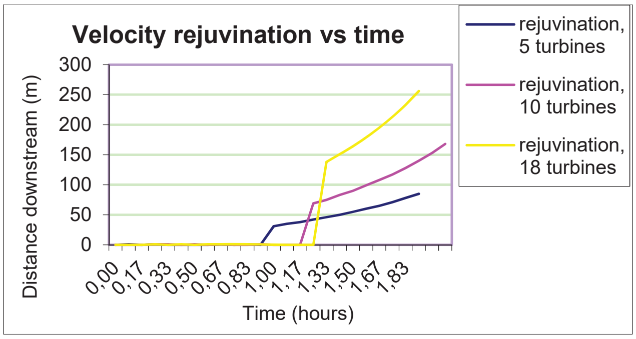


Fig. 4 Channel constriction effect on tidal stream potential

Design, construction features and installation of rotor taking account of site characteristics, systematically predict energy output, Fig. 5. Local geography energy influence, technology features and environmental legislation were factors addressed.

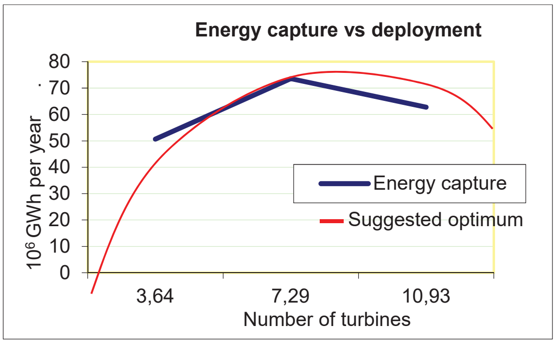


Fig. 5 Tidal energy technologies

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Topography and sea bed roughness affect the flow rate exhibiting the need to model site specific downstream rejuvenation, Fig. 6. Risk and innovation incentives, regulatory agencies and design are basis for technical evaluation with high degree of uncertainty over how devices, if not proved, affect the marine ecosystems.

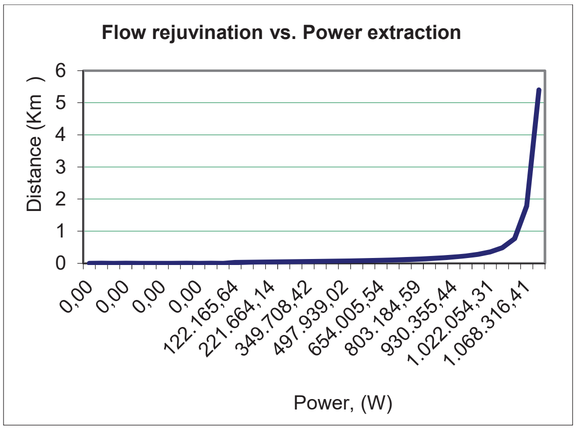


Fig. 6 Power Extraction

Locations that possess tidal-in-stream energy with fast flowing water caused by the tide motion accurately predict the performance of the dynamic tidal power turbines, Fig. 7 and Table I. Flow simulation using computational fluid dynamics (CFD) techniques are applied to determine design behavior. Design tools and simulation models predict loads, dynamic behavior, power conversion and energy performance, fatigue, turbulence and flow characteristics, and device impact on the surrounding environment. Scrutiny over design function, performance, resource, and regulatory agencies cite high degree of uncertainty in technology. Adaptations to Grid Network requirements are hence vital.

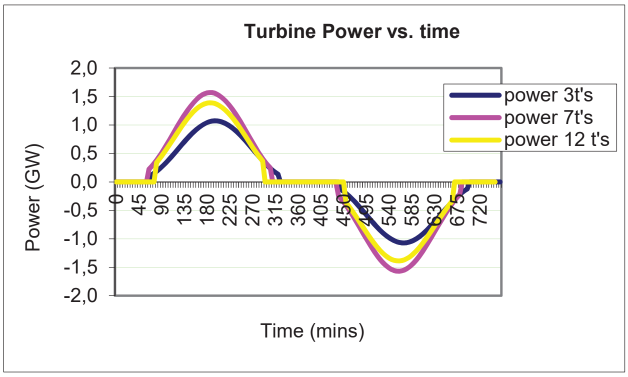


Fig. 7 Graphical representations of results

## IV. Findings

### A. Power Captured

A diversity of energy sources is the foundation of a reliable electrical power system.

Tidal energy technologies are just beginning to reach, maturity for application as commercial power sources. While just a few small projects have been implemented currently, the technology is advancing rapidly and shows high potential for generating power. Recent focus has been on proving that the

Technology works and on lowering costs through operation of demonstration devices thereby demonstrating its commercial viability as shown in Tables II and III.

Tidal stream energy technology will help decarbonize energy supply; increase energy security and reduce dependence on imported fossil fuels. It is a source of employment and will contribute towards continued economic prosperity as we export skills, services and products.

It is essential that the tidal energy industry understands its impact on the marine environment and seek ways for minimizing or mitigating this.

TABLE I
Power Captured in Terra Watt Hour

| Number of Turbines | Power capture per year, Twh | | |
|---|---|---|---|
| 2 | $2.017\times10^4$ | $2.93\times10^4$ | $2.5E+10^4$ |
| 3 | $2.017\times10^1$ | $2.930\times10^1$ | $2.500\times10^1$ |
| 7 | $7.261\times10^4$ | $1.055\times10^1$ | $9\times10^4$ |
| 12 | $5.126\times10^4$ | $7.447\times10^4$ | $6.35\times10^4$ |

Concerns include:

(i) Impact on marine ecosystems and fisheries,
(ii) Effect of electromagnetic field and underwater noise emitted from operating marine energy devices on marine life.

### B. Tidal Energy Economics

Despite the negligible fuel cost for ocean renewable technology equivalent to zero, the capital cost can be notably large in amount, Table II. However, government subsidies exist to help. For renewable energy investment to thrive it must become cost competitive with non-renewable sources. Presently the greatest challenge being the expensive cost to build and maintain; a 1085 MW facility would cost as much as 1.2 billion dollars to construct and run.

TABLE II
Tidal Energy Capital Investment

| Capital Investment | | | |
|---|---|---|---|
| Item | USD $ / kW | USD $ / Turbine | in % |
| Power Conversion System | 1,428 | 1,182,000 | 25.1 |
| Structural Steel Elements | 517 | 428,000 | 9.1 |
| Subsea Cable Cost | 130 | 108,000 | 2.3 |
| Turbine Installation | 1,741 | 1,442,000 | 30.6 |
| Subsea Cable Installation | 1,636 | 1,355,000 | 28.7 |
| Onshore Electric Grid Interconnection | 241 | 200,000 | 4.2 |
| Total Installed Cost | 5,693 | 4,715,000 | 100 |

Technology is not fully developed hence factors including grid connection, suitable site with reliable, strong and consistent currents are vital yet critical, taking into consideration possible security threat to navigation infrastructure from collisions with energy conversion devices, Table III.

TABLE III
OPERATION AND MAINTENANCE

| Item | USD $ / kW | USD $ / Turbine | USD $ / Farm | in % |
|---|---|---|---|---|
| Power Conversion System | 894 | 740,693 | 8,888,000 | 37.6 |
| Structural Steel Elements | 506 | 419,149 | 5,030,000 | 21.3 |
| Subsea Cable Cost | 20 | 16,785 | 201,000 | 1 |
| Turbine Installation | 593 | 491,426 | 5,897,000 | 25 |
| Subsea Cable Installation | 313 | 259,436 | 3,113,000 | 13.2 |
| Onshore Electric Grid Interconnection | 50 | 41,667 | 500,000 | 2.1 |
| Total Installed Cost | 2,378 | 1,969,155 | 23,630,000 | 100 |
| O & M Cost | 63 | 52,540 | 630,477 | 64 |
| Annual Insurance Cost | 36 | 29,537 | 354,488 | 36 |
| Total Annual O & M Cost | 99 | 82,077 | 984,925 | 100 |

## V. CONCLUSION

In the opinion of the authors' the numerical modelling, suggestions presented that the potential for energy extraction from rapid tidal currents is significant. The analysis indicates that the potential energy extraction from the system is almost unlimited, as the feedback on the currents when considering feasible extraction limits from an engineering perspective are negligible. Continued development of this analysis and the numerical modelling tools involved will provide a powerful means of addressing potential environmental concerns that are raised from the installation and operation of tidal 'farm' sites as well as enhancing our understanding of the underlying physics. However, it must be recalled that the results presented relate to steady state flow conditions and the situation may not be as 'simple' and clear-cut when the research is extended to temporally varying tidal flows. Furthermore, the simplified approach presented assumed that energy was being extracted across the entire 2-d or 3-d cell face presented to the flow, whereas in reality the swept area of a tidal turbine would be a small fraction of this area, particularly when considering limitations on turbine spacing both laterally and horizontally to minimize wake interaction. These and other related issues (e.g. laboratory testing and comparison with numerical simulations) will be addressed in research and model development progress.

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