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Assesment of energy production potential from tidal stream currents in Indonesia

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Abstract

A multi-criteria assessment methodology that accounts for physical and environmental constraints is applied to assess the tidal stream power potential at eleven straits between Indian Ocean and inner Indonesian seas. In this paper, preliminary results of an assessment at the Strait of Larantuka are presented. The tidal stream power potential is evaluated on the basis of a calibrated and validated numerical model. It was found that the average tidal stream power density at some of the locations can exceed about 6kw/m^2 and the practically exploitable energy yield from the Strait of Larantuka is about 20Gwh per year.

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Keywords: tidal power; numerical model; Strait of Larantuka; Indonesia

1. Introduction

Energy is one of the most important necessities for human life and a reliable and accessible supply of energy is crucial for the sustainability of modern societies. At the moment, about 80% of the global energy consumption is supplied by fossil fuels. So far, renewable energy and nuclear power contribute only to about 13.5% and 6.5% of the total energy respectively. This situation brings multiple challenges i.e. depletion of fossil fuel reserves, environmental concerns, geopolitical and military conflicts as well as a continuous rise of fuel price [1]. Therefore, much effort is currently being made worldwide to use renewable sources of energies, which have the capacity to

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meet the present and future energy demands of the world. As a result, the conversion of wave and tidal current power is recently growing up to a crucial sector of renewable ocean energy. However, the lack of reliable data for the estimation of the effective power, particularly in more remote areas, represents a major limitation. In order to improve the reliability of the information concerning the potential of power form available renewable sources, it is vital to improve resource characterization and rationale for site selection.

In this paper preliminary results of an assessment of the tidal stream power at several straits in Indonesia are presented. The investigations have been carried out in the framework of the joint research project "Potentials of Ocean Renewable Energy in the Indonesian Seas- ORE-12" funded by the German and Indonesian governments. The project aims at the identification of marine environments in the Indonesian Archipelago, which are suitable for the efficient generation of electric power by tidal in-stream energy conversion (TISEC) devices and wave converters. The overall goal of ORE-12 is establishing a "Decision Support System" (DSS) to process, to analyze and to evaluate the results of the numerical simulations of flow and to estimate the tidal stream power potentials in order to identify best sites for the use of ocean renewable energy. For the evaluation of power potential of the tidal stream currents, all the straits between Indian Ocean and inner Indonesian seas are currently under investigation. Preliminary results of an assessment of the energy production potential carried out at the Strait of Larantuka between the Islands of Flores and Adunara in the East are summarized below.

Nomenclature

$A_{channel}$ cross-sectional area of the channel (m^2)
$A_{turbine}$ turbine rotor swept area (m^2)
APD average power density (kW/m^2)
P tidal stream power per unit area of flow (kW/m^2)
$P_{electric}$ electric power that can be delivered to the local electrical grid by each tidal current turbine (kW)
P_{flux} total power available in the channel (kW)
U depth averaged current velocity magnitude (m/s)
U_{hub} current velocity magnitude at the turbine hub height (m/s)
ρ water density (kg/m^3)
$\eta_{drivetrain}$ drive train efficiency
$\eta_{generator}$ generator efficiency
η_{pcon} power conditioning efficiency
$\eta_{ptake\text{-}off}$ power take-off efficiency
$\eta_{turbine}$ turbine efficiency

2. Methodology and application

A stepwise methodology leading to the estimation of the effective stream power potential in the sites under investigation is adopted. This includes the modeling of the tidal steam currents, selection of suitable sites for the installation of the convertors, resource assessment and estimation of the stream power potential. The methodology has been applied to the eleven straits between Indian Ocean and inner Indonesian seas indicated in Fig. 1. Results of the application of the methodology to the Strait of Larantuka area summarized below. The strait divides East Flores from Adunara Island as shown in Fig. 2. It is approximately 12km long and the width of the strait varies from 650m at its narrowest section to 4.5km at mouth. The water depths in the strait of Larantuka are up to about 20-25m. It links Flores Sea at north to the Flores Strait at south. The predicted tidal range in Flores Sea is slightly larger than 1m reaching ca. 1.5m in Flores Strait. Currents typically have peak velocities at spring tide in the strait of 3-4m/s. The tidal currents are intensified by the Indonesian Throughflow, which are highly variable oceanic currents flowing to and from the Indian Ocean and the Java Sea [2, 3].

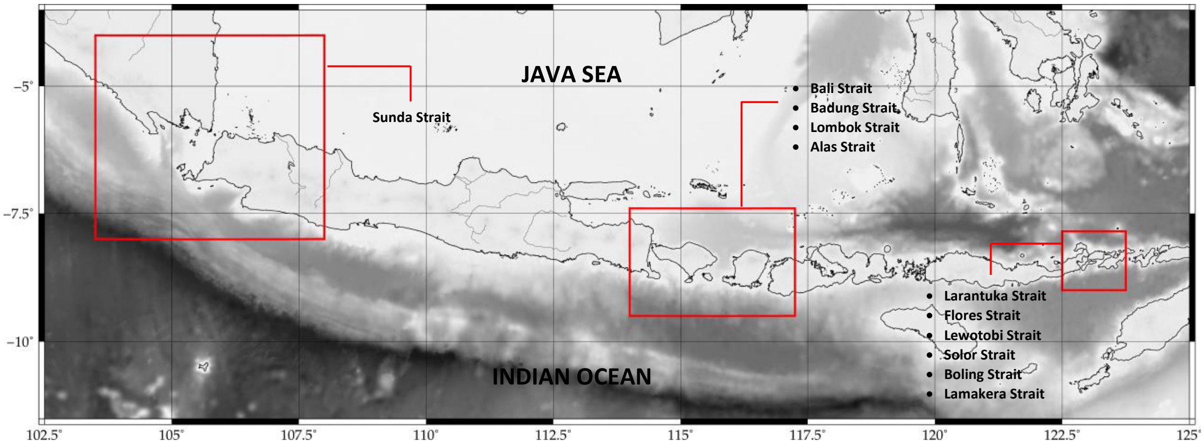

Fig. 1. Straits in Indonesia being investigated within the Project ORE-12.

2.1 Modelling of tidal currents

Tidal currents are numerically modeled with the Delft3D Modelling System developed by Deltares, the Netherlands. Meteorological forcing and spatial density gradients are accounted for. A nesting sequence comprising of two models was set-up for the Strait of Larantuka. The nesting sequence and model bathymetries are illustrated in Fig. 2. The larger scale 2DH model extends from the Flores Sea in the North to the Indian Ocean in the South. The grid resolution ranges between 500m at the open sea boundaries to less than 250m in the vicinity of the Strait of Larantuka. A detailed (nested) 3D model with a grid resolution of ca. 50m was set-up has for the Strait of Larantuka. Bathymetric data for flow models have been obtained from GEBCO 30 arc-second global grid of elevations (GEBCO_2014 Grid). Data from Global Forecast System of NOAA's National Climatic Data Center have been used as meteorological input. Thus, effects of air cloudiness, air temperature, atmospheric pressure, relative air humidity and wind (in E and N directions) have been considered in simulations. Much attention has been given to the conditions at the open sea boundaries of the larger scale model. Tidal forcing is supplied from TPXO Indian Ocean Atlas (1/12° regional model). 11 harmonic constituents (M2, S2, N2, K2, K1, O1, P1, Q1, M4, MS4, MN4) were considered in this study. In addition, the sea surface height, salinity and temperature at the open sea boundaries are based on HYCOM and NCODA Global 1/12°.

The assessment of the model in predicting tidal water levels was done with the help of water level elevations supplied from a tidal gauge located in the model domain (8° 20' 31" S, 122° 54' 33" E). The location of the operational measuring device is indicated in Fig. 2. Fig. 3 shows comparisons of modelled and measured values from 1 to 31 of July 2014. The agreement between modelled and measured values was tested with the Pearson's product moment correlation coefficient. The *r* value was resulted equal to 0.98, which indicates a strong, positive linear relationship.

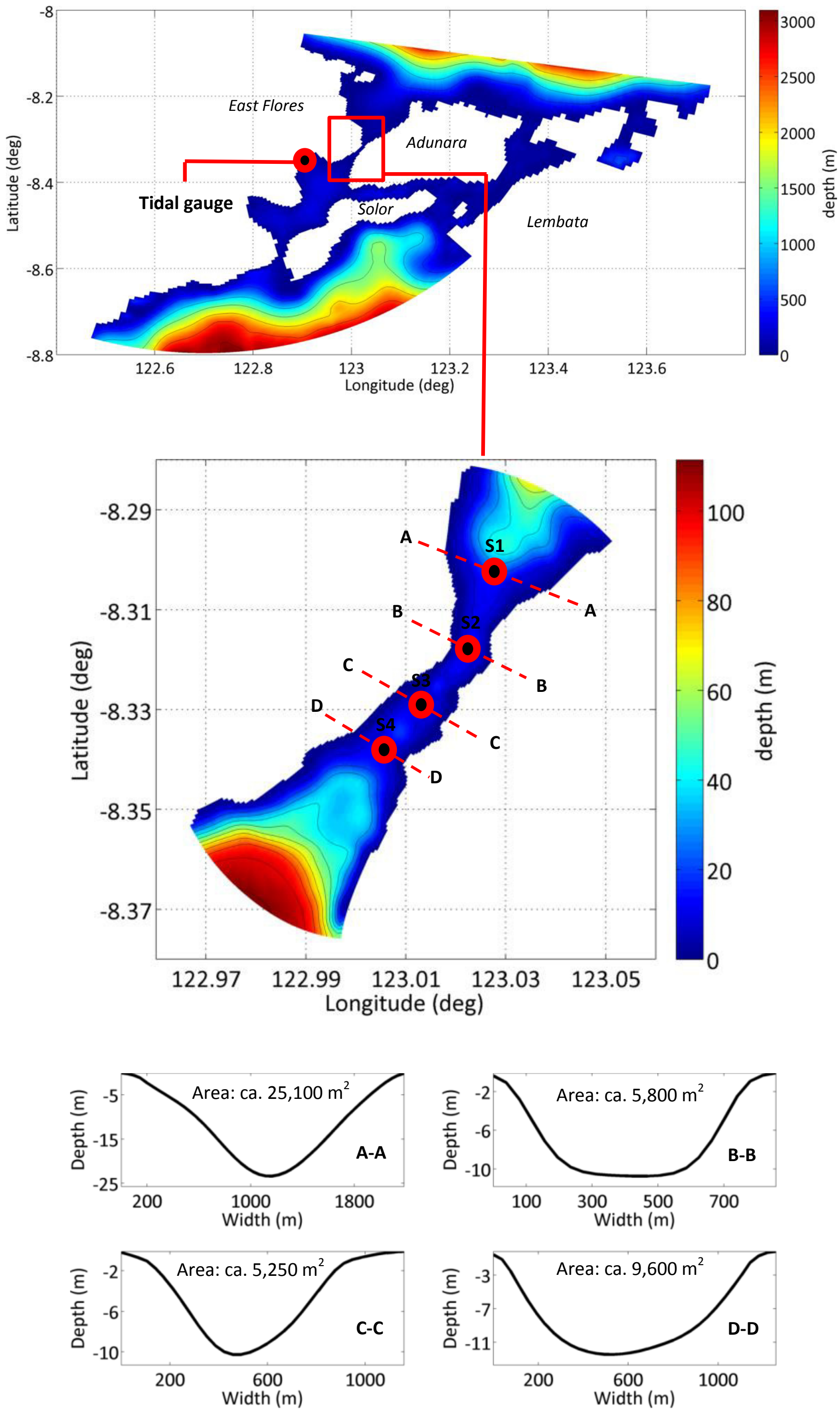

Fig. 2. Nesting sequence and model bathymetries (top) and cross-sectional variation along the Strait of Larantuka (bottom).

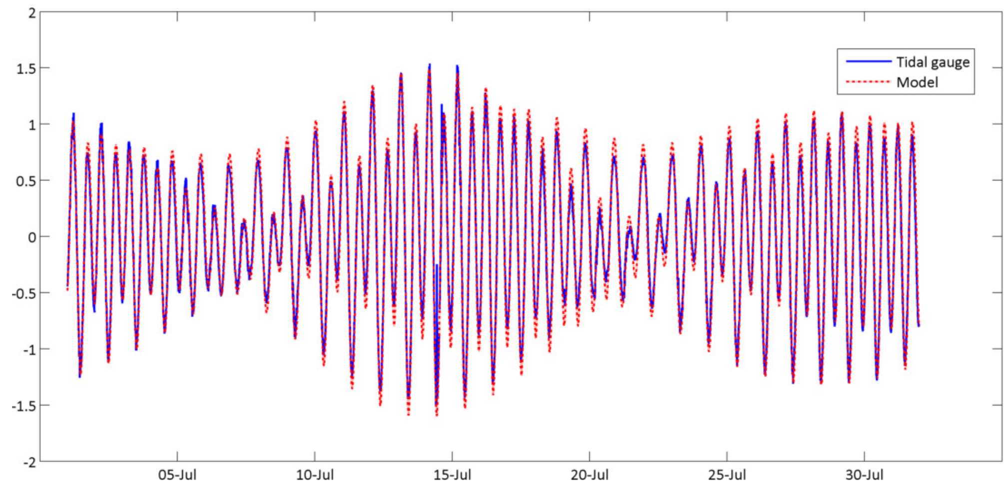

Fig. 3. Comparison of measured and modelled tidal water levels (r = 0.98).

2.2 Selection of suitable locations for tidal stream power conversion

A multi-criteria assessment methodology that accounts for physical and environmental constraints is applied to determine suitable locations for tidal stream power conversion. Horizontal axis tidal turbines, which can harness a strongly bi-directional flow with rotor diameters ranging between 1.5m and 18m are considered. The near free surface upper 5m is eliminated for recreational activities (small boats, swimmers, etc.) and to minimize turbulence and wave loading effects on the turbines, as well as damage from floating materials [4]. At the bottom, the turbines are located above the low-speed benthic boundary layer, which is usually 10% of the mean lower low water depth [5]. Considering these clearances, minimum depth is defined as 7.5m, which is adequate to install a turbine with a rotor diameter of 1.5m. Average kinetic power densities in the region have been estimated as follows:

$$P = \frac{1}{2} \cdot \rho \cdot U^3 \tag{1}$$

where P is tidal stream power per unit area of flow, ρ is the density of sea water and U is the current speed. Regions with maximum of the average kinetic power density larger than 0.5 kW/m^2, surface area larger than 0.5km^2 and water depths larger than 7.5m are defined as suitable locations for tidal stream power conversion. Fig. 4 shows the spatial variation of the average kinetic power density at the Strait of Larantuka. The total area of the defined suitable locations resulted equal to ca. 4.5km^2.

In addition to the physical constraints a methodology to account for the main environmental constraints is currently being developed in the framework of the Project ORE-12. Emphasis is given to the assessment of the impacts of the operation of power converters on marine environment. Tidal power converters are rather large structures built within a potentially sensitive and vulnerable environment and they bring along certain risks like emissions in form of exhaust gas, wastewater, light and noise. Preliminarily defined pressures and state for environmental impact assessment is shown in Fig. 5. Moreover, the intersectorial Zoning Plan for Marine, Coast and Small islands proposed by the Directorate General of Coastal Zones and Small Islands shall be accounted for. The scheme envisages the reduction of conflicts with other activities and stakeholders and defines guidelines and activities, which are allowed, permitted with license, and/or prohibited in the region under consideration.

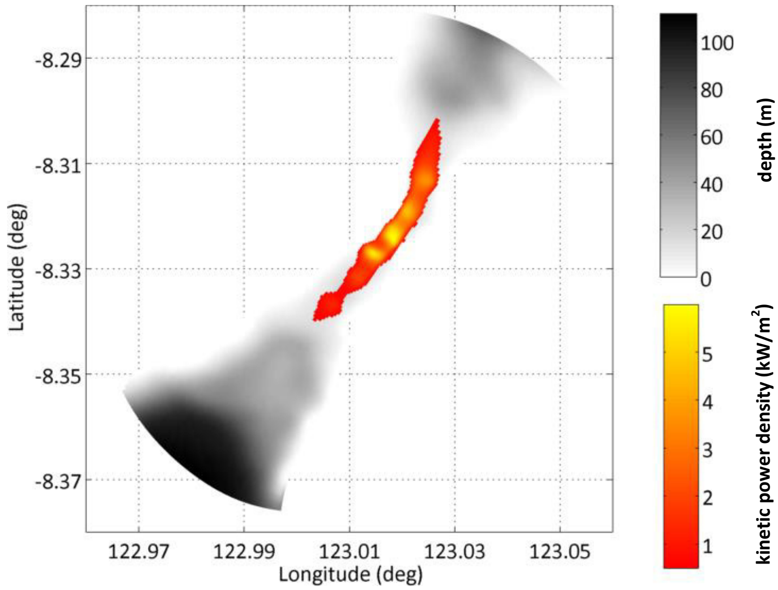

Fig. 4. Spatial variation of average kinetic power density from tidal stream power conversion in the Strait of Larantuka.

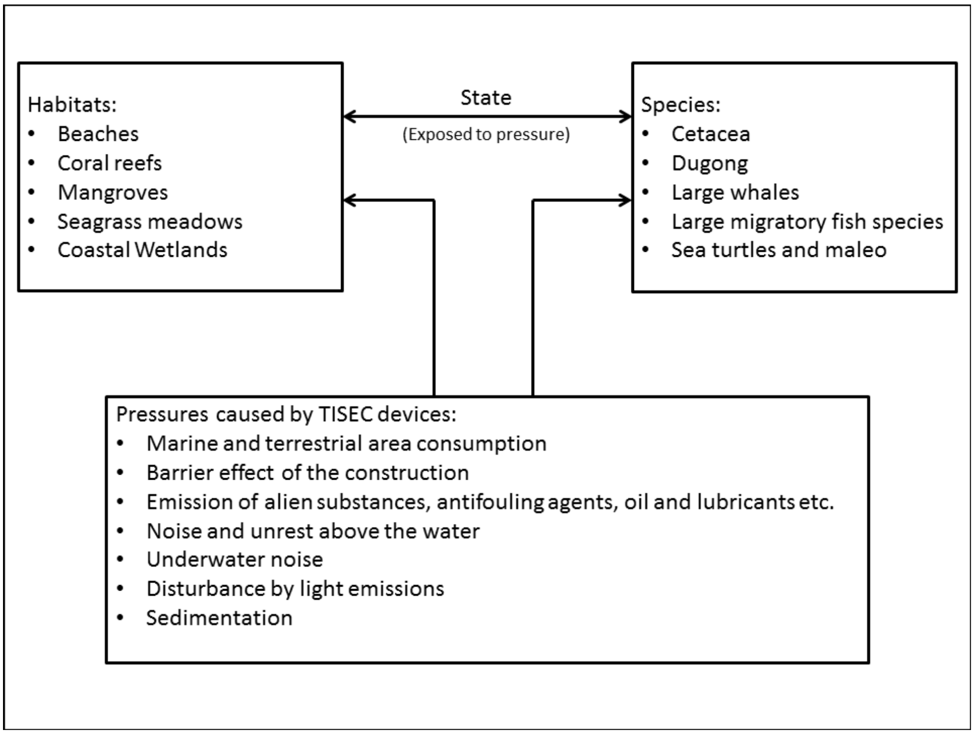

Fig. 5. Pressures and state for environmental impact assessment.

2.3 Resource assessment

The total power available in the cross-sectional area of the channel, P_{flux}, was estimated as below:

$$P_{flux} = APD \cdot A_{channel} \tag{2}$$

where APD is average power density and $A_{channel}$ is cross sectional area of the channel [4]. To compute the exploitable power densities using tidal current turbines, current velocities at the hub height of the turbines have been used. Considering a chain of water to wire efficiencies, the electric power that can be delivered to the local grid by each turbine was estimated using:

$$P_{electric} = A_{turbine} \cdot \frac{1}{2} \cdot \rho \cdot U_{hub}^{3} \cdot \eta_{turbine} \cdot \eta_{ptake-off} \tag{3}$$

where $A_{turbine}$ is turbine rotor swept area, ρ is water density and U_{hub} is current velocity magnitude at the turbine hub height. $\eta_{turbine}$ (= 45%) is the efficiency with which the turbine extracts kinetic energy from the incoming flow and $\eta_{ptake-off}$, power take-off efficiency was given using Equation (4).

$$\eta_{ptake-off} = \eta_{drivetrain} \cdot \eta_{generator} \cdot \eta_{pcon} \tag{4}$$

where $\eta_{drivetrain}$ (= 96%) is the efficiency with which the energy extracted from the flow is delivered to the generator, $\eta_{generator}$ (= 95%) is the efficiency with which the mechanical energy input to the generator is converted to electricity and η_{pcon} (= 98%) is the efficiency with which the electricity produced by the generator is conditioned to meet phase and voltage requirements of the local electrical grid interconnection point. These given values for component efficiencies are typical when the turbines are operated at their rated conditions [5].

2.4 Stream power potential

Modelled tidal stream current velocities, taken from observation stations S1, S2, S3 and S4 (Fig. 2) are shown in Fig. 6. Peak velocities at spring tide reach up to about 3-4m/s. Higher velocities are mostly observed at the narrowest section of the strait in the South. To represent the density of total available tidal stream power in the channel, time series of power density of the cross-sectional area B-B are shown in Fig. 7. The location of the cross-section is indicated in Fig. 2. Annual tidal stream energy resource of the cross-sectional area is estimated as 101.16Gwh. To minimize the effect of the turbines on downstream and upstream environments, the mean annual power extracted should not exceed about 10% to 20% of the naturally available physical energy flux [5]. As a result the practically exploitable energy yield from the Strait of Larantuka resulted equal to approximately 20Gwh per year. Considering the criteria described in section 2.2, distributions of the applicable tidal current turbine rotor diameters within the selected domain is shown in Fig. 8 (left). It can be seen that the applicable rotor diameter varies from ca. 5m at the narrowest section of the strait to about 18m at the mouth, where the water depth is relatively higher. Fig. 8 (right) shows the spatial variation of estimated electric power that can be delivered to local electrical grid by turbines. It can be seen that the resulting density of the extractable electric power by tidal turbines corresponds more with current velocities than with rotor diameter. At the locations where the current velocities are higher, extractable electric power density can exceed about 180kW.

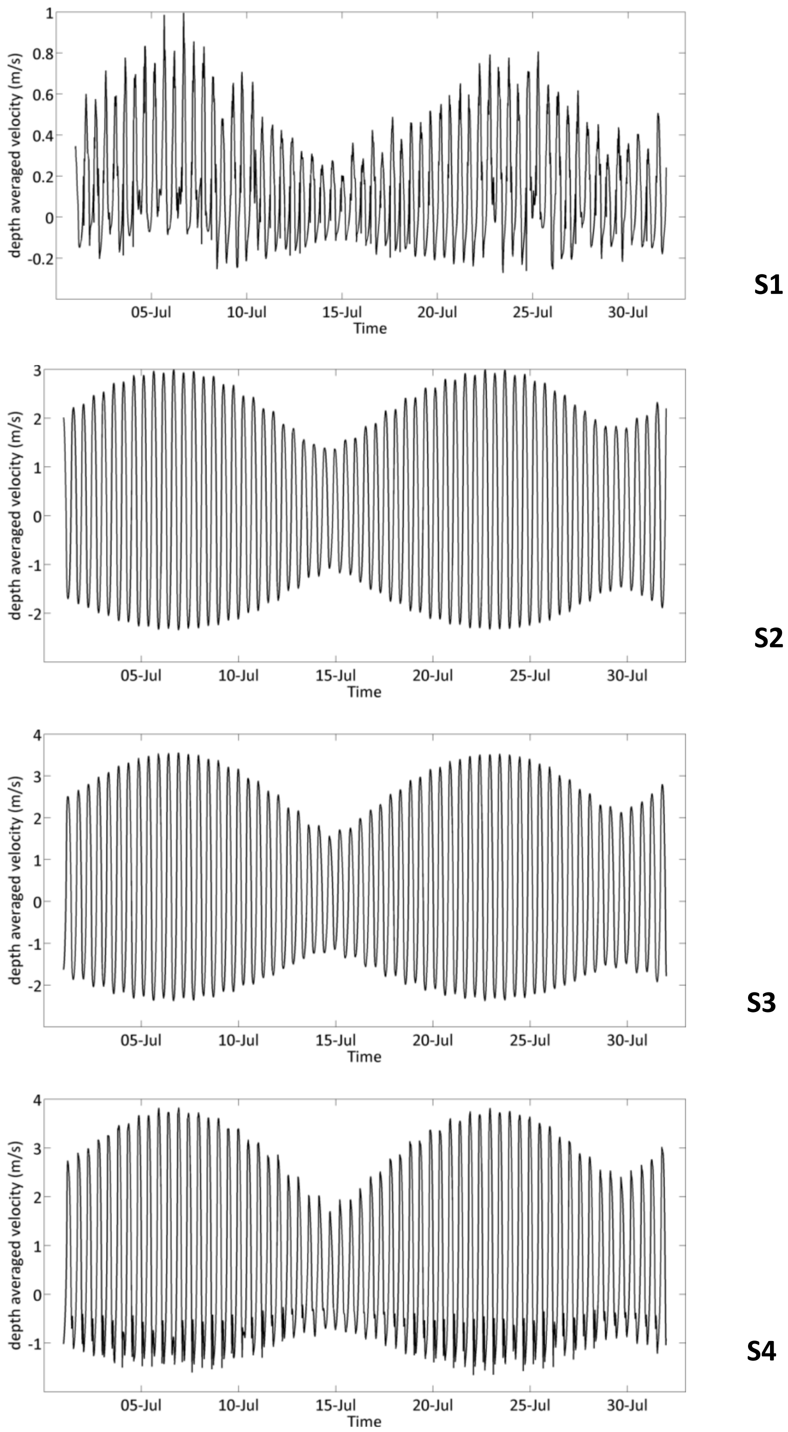

Fig. 6. Magnitude of the tidal current from model prediction at the Stations S1, S2, S3, S4.

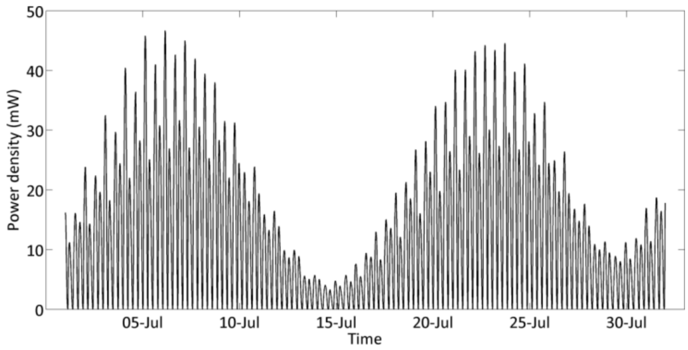

Fig. 7. Time series of power densities at cross-section B-B of Larantuka Strait (July, 2014).

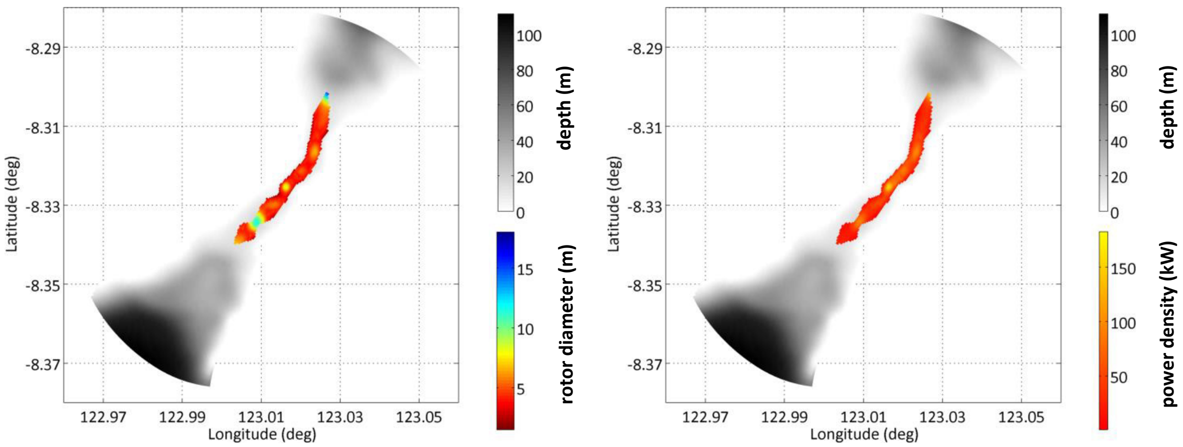

Fig. 8. Spatial variation of applicable tidal stream turbine rotor diameters (left) and of average exploitable power density with the tidal stream turbines (right) at the Strait of Larantuka.

3. Conclusions and outlook

The tidal stream power is currently being evaluated at several straits in Indonesia using high-resolution numerical models. A methodology for the selection of suitable sites for the installation of tidal stream power and estimation of the effective power potential has been developed and successfully applied. Both physical and environmental constraints are accounted for. It was found that the main difficulty in the estimations is the lack of accurate bathymetric data particularly at the straits. The results obtained showed that the straits under investigation have tremendous potential for the development of renewable energy production. Current velocities are up to 4m/s and the power density at some locations can exceed 6kw/m^2. A decision support system to support decision makers in the identification of suitable locations is currently being set-up. The results of the simulations and application of the methodology shall be stored into a GIS database. A ranking procedure with relevant weighting factors has been adopted to support decision makers before allocating resources for a more detailed evaluation. Emphasis has been given to the level of power density, accessibility of the site and environmental challenges. To facilitate the dissemination of the results a web based interface for accessing the data and using the GIS tools more effectively shall be constructed.

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