ASSESSMENT OF POTENTIAL MARINE CURRENT ENERGY IN THE STRAITS OF THE LESSER SUNDA ISLANDS

KAJIAN POTENSI ENERGI ARUS LAUT DI SELAT-SELAT KEPULAUAN SUNDA KECIL

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ABSTRACT: The Lesser Sunda Islands extend from Bali to Timor and consist of two geologically distinct parts formed by a subduction system of oceanic crust along the Java-Timor Trench. The northern part which includes Bali, Lombok, Sumbawa, Flores, Wetar, Pantar and Alor, is volcanic in origin; whilst the southern part is non-volcanic, encompassing the islands of Sumba, Timor and Rote. The straits along the Lesser Sunda Islands are formed as a result of very complex geological processes and tectonics in this area. These straits are the most important cross-sections in the southern part of the Indonesian Throughflow (ITF), functioning as outlets for the mass flows of seawater from the Pacific Ocean to the Indian Ocean through the Flores and the Savu Seas. In these straits, relatively high current speeds are occurred, not only caused by the ITF but also due to its geometry, the influence of tidal flow, and monsoonal currents.

Site study and ocean current measurement were conducted by using an echosounder, a pair of Acoustic Doppler Current Profilers (ADCP), and other supporting equipment. In general, the average of most ocean current speeds is less than 1.5 m/s with a duration flow of 8 -12 hours a day, and the maximum speed reaches up to 3 m/s. The tidal types in almost all the straits are mixed semidiurnal tides, in which two high waters and two low waters occur twice a day, with the high and low tides differ in height.

The Lesser Sunda Straits were selected as the potential sites for ocean current power plant because their current speeds are relatively high and their characteristics are more predictable compared with other straits from other regions. Based on the results of bathymetry survey and current characteristics from the deployed ADCP at a fixed (stationary) location on the seabed, the best location for the current power turbines is at the depth of 15-30 m where the seabed gently sloping.

Keywords: Ocean Current, Sunda Lesser, Renewable Energy

***ABSTRAK**: Kepulauan Sunda Kecil membentang dari Bali ke Timor yang terbagi menjadi dua bagian yang Kepulauan Sunda Kecil membentang dari Bali ke Timor yang terbagi menjadi dua bagian yang berbeda secara geologis dan terbentuk karena subduksi kerak samudera di sepanjang Palung Jawa-Timor. Bagian utara Kepulauan Sunda Kecil, yang meliputi Bali, Lombok, Sumbawa, Flores, Wetar, Pantar dan Alor, merupakan kepulauan busur vulkanik, sedangkan pulau-pulau di bagian selatannya adalah pulau non-vulkanik yang mencakup Sumba, Timor dan Rote. Selat-selat di sepanjang Kepulauan Sunda Kecil adalah bentukan dari proses geologi dan tektonik yang kompleks yang terjadi di daerah ini. Selat-selat tersebut menjadi perpotongan yang paling penting pada bagian selatan Arus Lintas Indonesia (Arlindo) dan berfungsi sebagai alur keluar aliran massa air laut dari Samudera Pasifik yang melintas melalui Laut Flores dan Laut Sawu hingga ke Samudra Hindia. Kecepatan arus di selat-selat tersebut relatif tinggi. Hal ini tidak hanya disebabkan oleh adanya Arlindo, tetapi juga karena adanya pengaruh geometri, siklus pasang surut dan arus Muson.*

Studi lokasi dan pengukuran arus laut telah dilakukan dengan menggunakan alat perum gema, sepasang Acoustic Doppler Current Profiler (ADCP) dan peralatan pendukung lainnya. Secara umum kecepatan arus laut rata-rata kurang dari 1.5 m/detik dengan durasi aliran 8 -12 jam per hari, dan kecepatan maksimum bisa mencapai lebih dari 3 m/detik. Jenis pasang surut di hampir semua selat perairan Sunda Kecil adalah pasang surut campuran harian ganda, yaitu dalam satu hari terjadi dua kali pasang naik dan dua kali pasang surut yang berbeda tinggi.

Selat-selat di perairan Sunda Kecil dapat dijadikan pilihan sebagai lokasi potensial untuk pembangkit listrik arus laut karena kecepatan arusnya yang relatif tinggi dan karakteristik dari arus yang lebih dapat diprediksi dibandingkan dengan selat-selat di lain daerah. Berdasarkan hasil survei batimetri dan karakteristik arus dari ADCP stasioner di dasar laut, lokasi terbaik untuk pembangkit listrik saat ini adalah pada kedalaman 15-30 m yang memiliki kemiringan dasar laut yang landai.
Kata Kunci: *Arus Laut, Sunda Kecil, Energi Terbarukan*

INTRODUCTION

The possibility of generating electrical power from the ocean current in Indonesia has been recognized for many years. It started since 2007 when the Ministry of Energy and Mineral Resources established Nusa Penida Island as the selected Renewable Energy Village for renewable energy development program (Lubis and Yuningsih, 2012). However, significant research and development of renewable energy from the ocean such as ocean current, tidal, wave and ocean thermal energy conversions in this area has only started recently.

Currently, ocean current power demonstrates as a possible and significant energy resources for developing renewable energy. There are several advantages of ocean current energy utilization compared to other energy generation. The production of electricity generated from ocean currents is renewable, more predictable and more environmentally friendly. An important initial step in exploring ocean energy is to characterize and to map the resources of ocean currents for generating electrical energy. The utilization of ocean currents to produce electricity, however, is still not developed favorably and need to study in more depth (Hidayati et al., 2016). Hence, site study and ocean current resources observation has been conducted by Marine Geological Institute in the selected straits of the Lesser Sunda Islands, such as Bali and East Nusa Tenggara area (Figure 1).

The Lesser Sunda Islands are a group of islands located between the waters of Southeast Asia and Northern Australia. The Lesser Sunda Islands is a volcanic strip of the Sunda Arc, consists of two geologically distinct parts formed by a subduction system of oceanic crust along the Java-Timor Trench. The northern part of the Lesser Sunda Island are active volcanic in origin consists of the islands of Bali, Lombok, Sumbawa, Flores, Wetar, Pantar and Alor. Meanwhile, the islands in the southern part, such as the islands of Sumba, Timor and Rote, are non-volcanic archipelagos which are geologically derived from the Australian plate. Geologically, Flores Sea is a morphostructure feature, coinciding a back arc basin due to the collision between the Nusa Tenggara island arc and the Australian continent (Prasetyo and Sarmili, 1994). The geological structure of this area is quite complex. Compression tectonics in the Flores Basin to Timor High resulted in the formation of a horizontal fault and a rising fault along the Lesser Sunda Islands. The intersections of the fault zones in the Lesser Sunda Islands formed straits, connecting the Flores Sea and the Savu Sea. These straits become the most important cross section of the Indonesian Through Flow (ITF), further function as an outlets for the mass flow of seawater from the Pacific Ocean through the Flores Sea to the Savu Sea and then to the Indian Ocean (Gordon A.L., 2005), In these straits, relatively high current speeds occur, not only

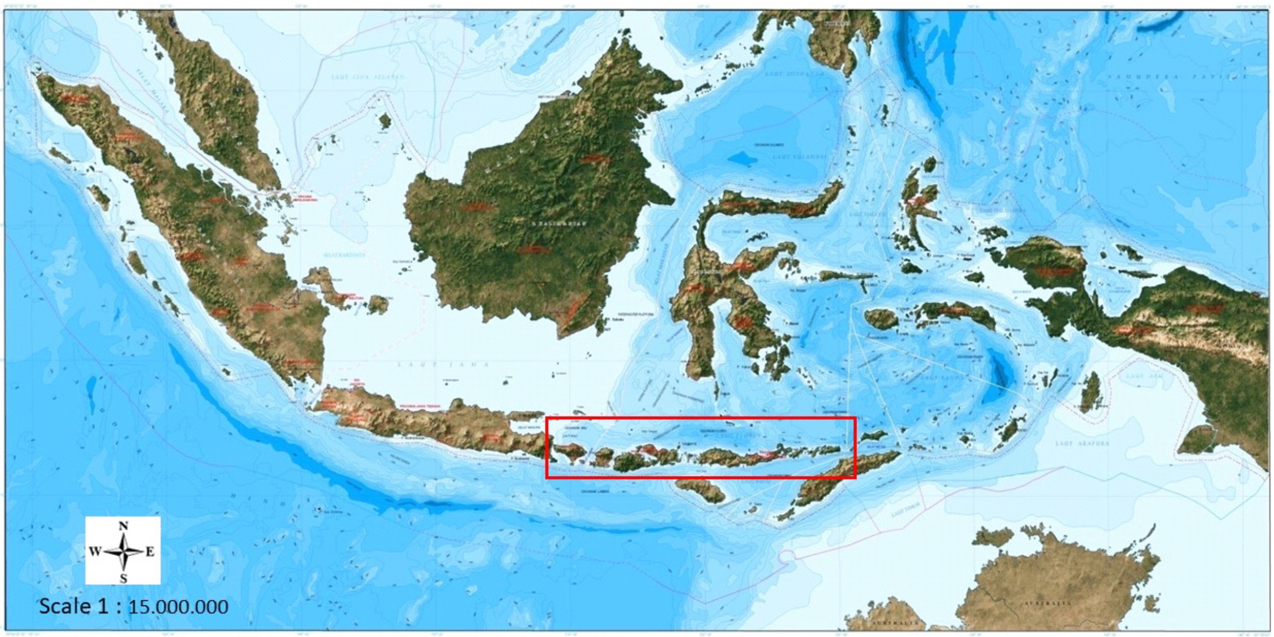


Figure 1. Site study area located at the straits of Lesser Sunda Islands, Indonesia.

caused by the ITF but also due to its geometry, the influence of the monsoon currents, and the South China Sea - Indonesian Seas Transport/Exchange (SITE). The locations of ITF, SITE and Trades influences are shown in Figure 2.

sufficient electricity. Referring to the ocean current turbine site selection criteria from Marine Current Turbine Ltd., a decent location to develop ocean current power generation must be located not far from the beach, be closed to the power grid, have an ocean current speed of 2.0 - 3.0 m/s

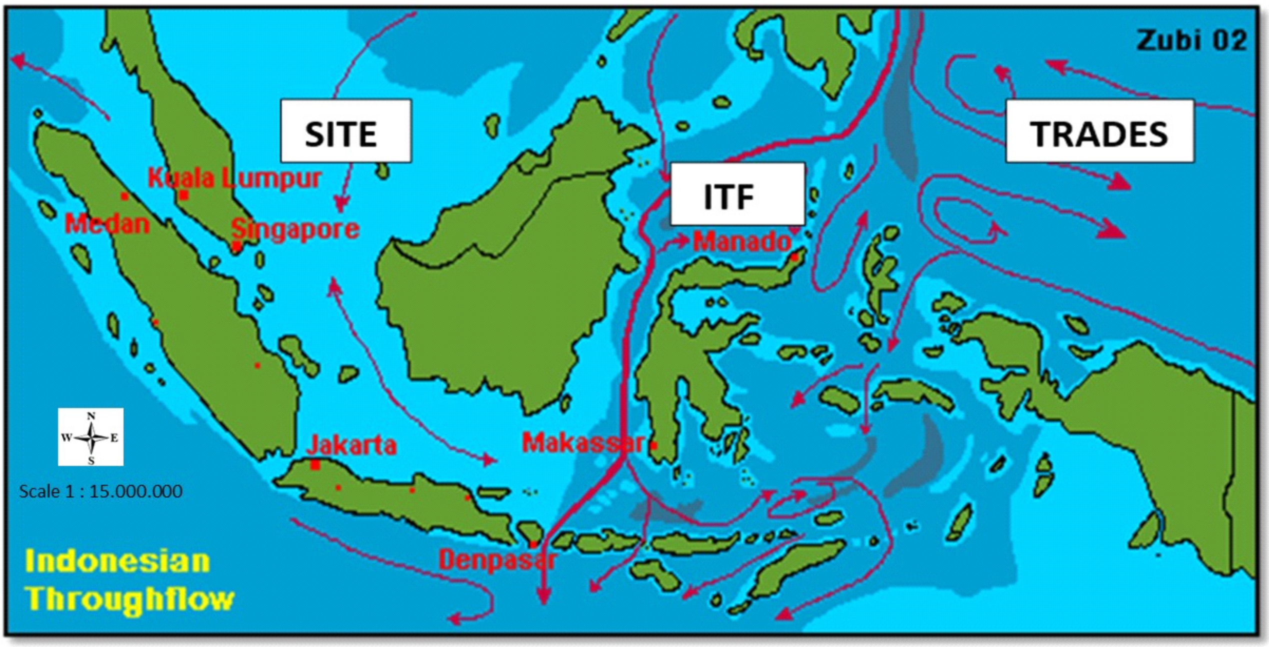


Figure 2. The influences of ITF, SITE, and Trades (monsoon currents) in Indonesian water area (after Susanto, et al., 2000).

In general, the electricity distribution in Bali and Nusa Tenggara is still insufficient for the entire islands, resulting electrical blackout arrangements in some settlements for more than 6 hours per day. To hinder insufficiency of electricity, PT PLN, the national electricity company, has been hiring more diesel generators to increase the supply of electricity. Based on data issued in 2013, the ratio of settlement electrification facilitated by PT PLN in the islands is still quite low at only less than 45 %. This number is much less below the national average electricity consumption which reached 60 - 80 % at the same year.

The purpose of the study is to identify the characteristics of ocean currents in the straits of the Lesser Sunda Islands in order to observe the potential of ocean currents as renewable energy resources in the strait areas. Research was conducted to collect data from the selected sites by determining the seabed morphology and the hydro-oceanographic characteristics.

METHODS

Survey methods applied during field works at the strait of the Lesser Sunda Islands from 2008-2015 were measurement of currents, tidal observation, observation of meteorological parameters, conditions of the seabed morphology, seabed nature and the coastal characteristics. Additionally, some methods of observations were applied to collect field data to assess the selected site and the proper type of ocean current power turbine for generating (depending on the turbine type), and have relatively flat seabed morphology (Ainsworth and Thake, 2006).

In this study, Tidal Range Observation was measured by using an Electronic Tide Gauge and a tidal harmonic analysis was carried out by applying Royal Admiralty method. To obtain the tidal characteristics, this measurement was also necessary in order to determine the Chart Datum for bathymetric survey result correction and to obtain correlating data with the current observations.

Ocean Current Characteristics was measured by using an Acoustic Doppler Current Profiler (ADCP). There were two survey methods applied, such as Transect and Stationary Surveys. A transect survey is carried out by towing an ADCP instrument to measure the currents under a moving boat. A static survey is so called because it engages the deployment of a sea current measurement device (ADCP) at a site to moor on the seabed. Typically, ADCP measurements of the tidal currents must be taken for at least 30 days. This allows a tidal harmonic analysis of the flow to be completed (EMEC, 2009).

Bathymetric survey was conducted using a single beam echosounder (SBES) with spacing of sounding lines approximately 50 - 100 meters. Mobile ADCP and Single Channel Echosounder equipment were integrated by Global Positioning System (GPS) device. Both equipment recorded data of current speeds and ocean depths according to survey ship trajectories. The ocean depth data was then correlated with the result stream data from the recording of mobile ADCP to infer the relationship between the morphology of the seabed and the current velocity distribution.

Ocean Current Data recorded from mobile ADCP and static ADCP was correlated with the tidal data to indicate pattern movements of the ocean currents at high and low tide conditions.

Weather Observation was conducted by using an Automatic Weather Station (AWS) during the field works. The AWS measures weather parameters, such as air temperature, humidity, wind speed and directions, air pressure, and rainfall. Weather conditions can change the current flow. Large pressure system may enhance or reduce the current flow, and storm surges can cause strong flow that can damage the turbines. Weather can also affect deployment and maintenance by limiting access to the site (EMEC, 2009).

Current Data obtained from field measurements were presented in time graph series, scatter plots, stick plots, and current rose.

In this study the current energy conversion calculated from the current speed data is indicated in the form of power density unit (watt/m^2). We adopt the formula from Fraenkel (2002), the power density can be obtained through the following equation:

$$P/A = \frac{1}{2} \times \rho \times V^3 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where P is power (Watt); ρ is the density of seawater (kg/m^3); A is the cross-sectional area of the turbine location (m^2); and V is the speed of the ocean current (m/s). The density value of seawater used here is the same as 1025 kg/m^3. The turbine cross-sectional area (A) is considered to be 1 m^2 so that the most influential variables in the conversion calculation process into electric current are the current velocity and the turbine area (Fraenkel, 2002).

tide, while the neap tide has shorter time length. Have the spring tide shown the slope of the water level at high and low tides, this condition will be followed by an increased current speed. Thus, the current speed will reach its maximum condition.

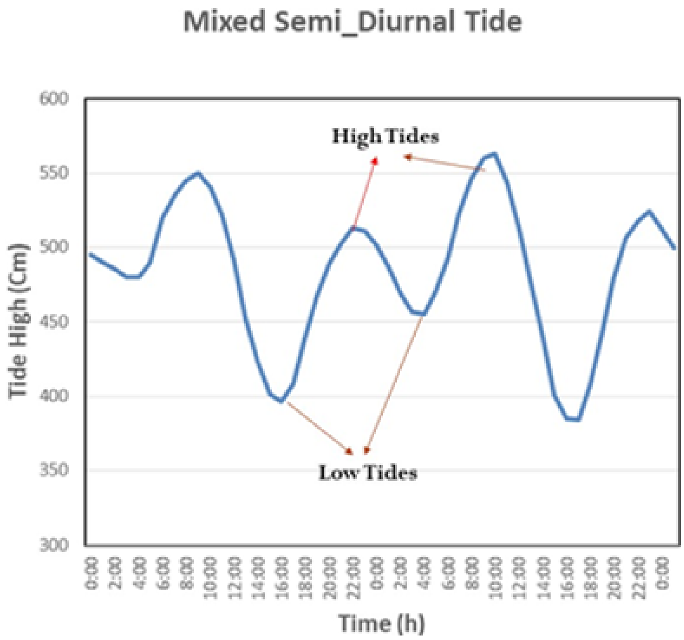


Figure 3. A 50-hour plot of the tidal range at Toyapakeh Strait, Nusa Penida

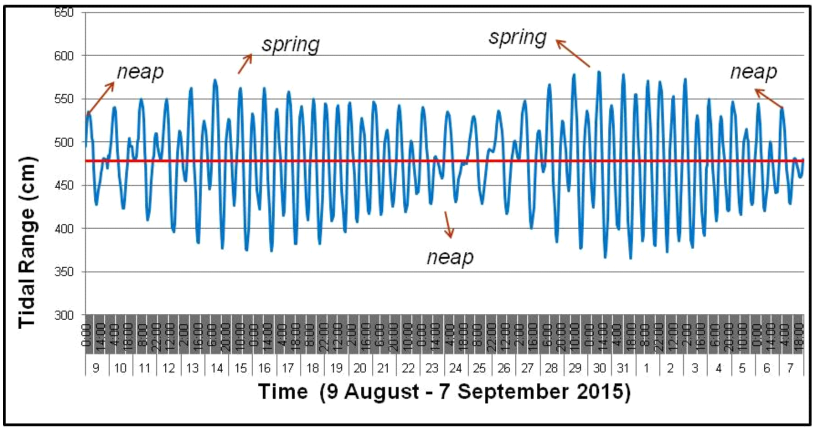


Figure 4. Tidal curve of 30-day cycle at Toyapakeh Strait, Nusa Penida (Yuningsih et al., 2015)

RESULTS AND DISCUSSION

3.1. Tidal Characteristics

Based on the harmonic tidal analysis using the Royal Admiralty method, the tidal type in almost all of the straits are mixed semidiurnal tides, with two high tides and two low tides each day. The high and low tides variability can be seen in Figure 3. The tidal curve of 30-day cycle at Toyapakeh Strait (Figure 4) shows the tidal current pattern in which two high tides and two low tides occurs within 24 hours with a maximum water level of 2.15 m. This situation causes the time length during high tide and low tide conditions are about 6-7 hours on average in the spring

3.2. Current Speed and Direction.

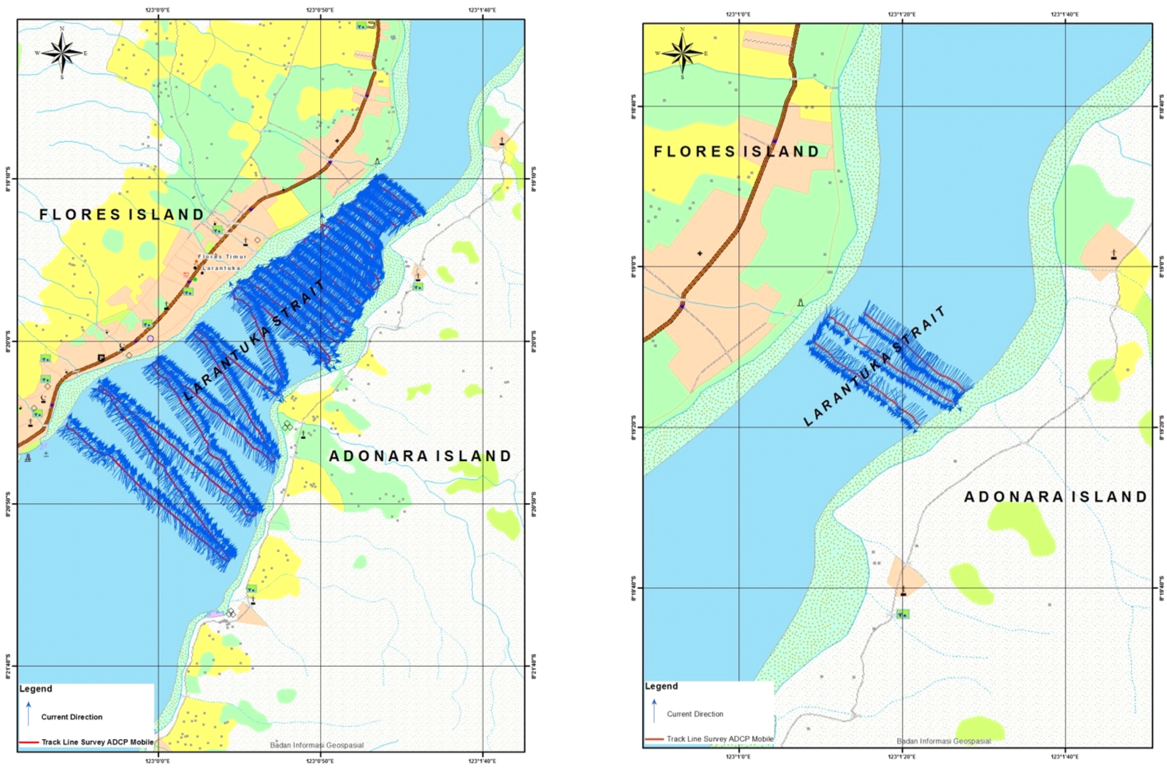
The Lesser Sunda Straits were selected as the potential site for sea current power plant due to their relatively high current speeds and their more predictable characteristics. The route of the current exchanges reveals that owing to the narrow straits of the Lesser Sunda Islands, inflow waters are trapped here before flowing to the Indian Ocean. This is the reason why the current speeds of the straits are relatively high.

Table 1 shows the range of current velocities for certain depths. The current velocity in this table is the minimum and maximum velocities recorded by a device during high and low tides at up to 27 m depth. The maximum velocity is above 2 m/s, particularly above 3 m/s from 3 m to 22 m depth where the greatest speed is at the depth of 5 m. Based on the current distribution data and the performance of continuous long-term current measurements, one can estimate the best position and depth for the placement of the ocean current power plant equipment/turbine.

The result of stationary current measurement and current transect survey during high and low tides indicates that in high tide conditions the current direction tends toward the northeast; and during the low tide conditions the current tends to flow to southwest direction (Yuningsih and Lubis, 2011). The current speed and direction at Larantuka Strait with the two conditions, i.e. during the high and low tides, are shown in Figure 5; whereas the distribution of the current speed derived from the ship-mounted ADCP survey during the field work are shown in Table 1.

Table 1. The range of current velocities for each depth at Larantuka Strait based on current transect survey during spring tide

Depth (m)	Minimum Speed (m/s)	Maximum Speed (m/s)
3	0.011	3.436
5	0.004	3.676
7	0.011	3.531
9	0.016	3.462
11	0.015	3.441
13	0.014	3.505
15	0.026	3.527
17	0.014	3.350
19	0.014	3.283
21	0.006	3.087
23	0.010	3.105
25	0.019	2.928
27	0.015	2.381



(a) During high tide, northeastward current

(b) During low tide, southwestward current

Figure 5. Tidal currents tend to flow northeastward during the high tide (a) and southwestward during the low tide (b).

Specifically for the Toyapakeh Strait - Nusa Penida, the current direction has a unique pattern. The results of field measurements and observations during the survey are plotted in a current rose diagram. It shows the dominant current direction to the southwest in all the high and low tides conditions, as well as in all the conditions of the spring and neap tides (Figure 6).

Based on the results of current data processing using World Current 1.03 after Leverani et al. (2016), the types of currents in Toyapakeh Strait are tidal currents. The current direction describes the movement of two directions (bi-directional current), namely southwest - northeast direction. The direction of the current is formed due to the changes in water level elevation and seabed morphology.

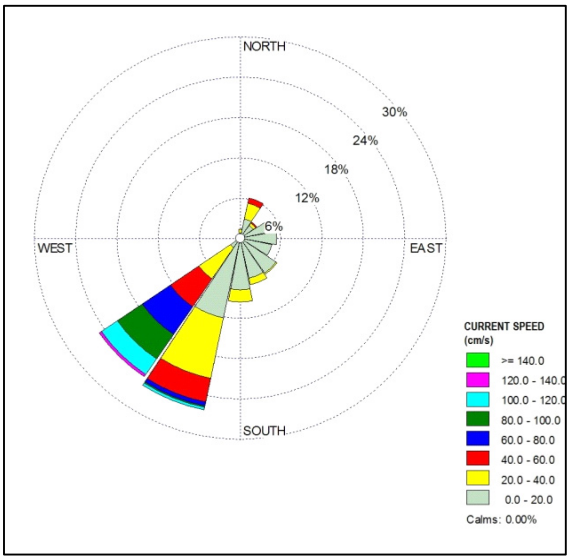


Figure 6. Current Rose diagram from field measurement results

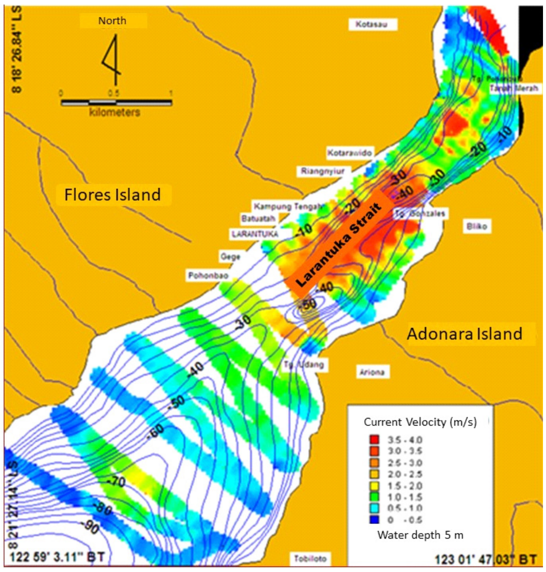


Figure 8. Bathymetry and horizontal distribution of current speed along the ship-mounted ADCP survey at 5 meters depth at Larantuka Strait (Yuningsih and Masduki, 2011)

3.3. Bathymetry

Vertically and horizontally, the current velocity distribution in the straits of the Lesser Sunda Island are not only influenced by the tidal conditions, but also by the condition of seabed morphology, the width of the strait and the depth of the sea. Based on data from several trajectories of the ship-mounted ADCP, the current velocity in these strait correlates with the depth of the sea, where the current speed is relatively high. The highest current velocity occurs in the deepest and narrowest part of the strait channel during the high and low tides (Figure 7 and Figure 8).

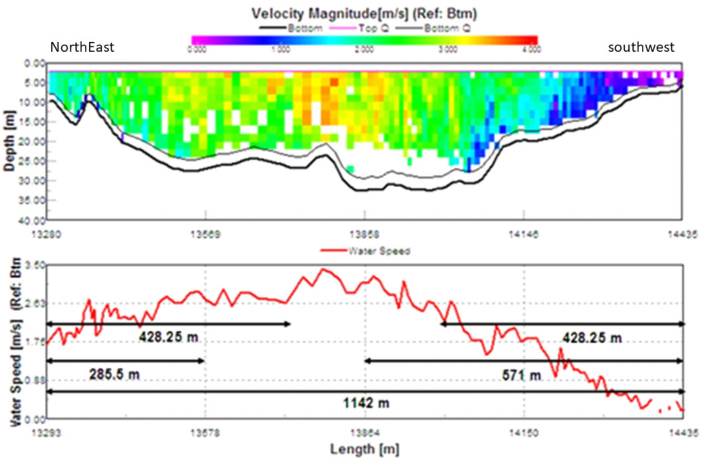


Figure 7. Correlation between vertical and horizontal distribution of current velocity and sea depth

In general, potential energy of ocean current that is possible to harvest depends on both parameters, i.e. the current speed and the swept area of the marine turbine blades (Thomas, 1991; Fraenkel, 1999). Another important consideration that has a significant impact to the ocean current power plant is the right position of turbine installation at the proper depth where the optimal current speed occurs.

The basic technical factors that may affect the assessment of a site for turbine deployment are the site must have a large enough current speed between 0.5 m/s - 3.0 m/s with relatively uniform velocity from the surface to the bottom, the site must be not too far from the beach (ideally less than 1 km), the sea depth must be ranging from 15 m - 50 m, and the morphology of the seabed must have a gentle slope.

The water depth at the Toyapakeh Strait and Boleng Strait generally ranges between 5-50 meters in the outer channel with a gentle seabed morphology, whereas in the middle channel the depth is increasing gradually to more than 200 meters (Figure 9 and 10). Bathymetric contour pattern from both straits shows a steep and narrow morphology. Some closed-pattern contours are found at the depth up to 200 meters, indicating several deep hole morphologies. Herein, some of the closed bathymetric contour patterns of more than 100 meters depth have the potential to cause a vortex of ocean currents.

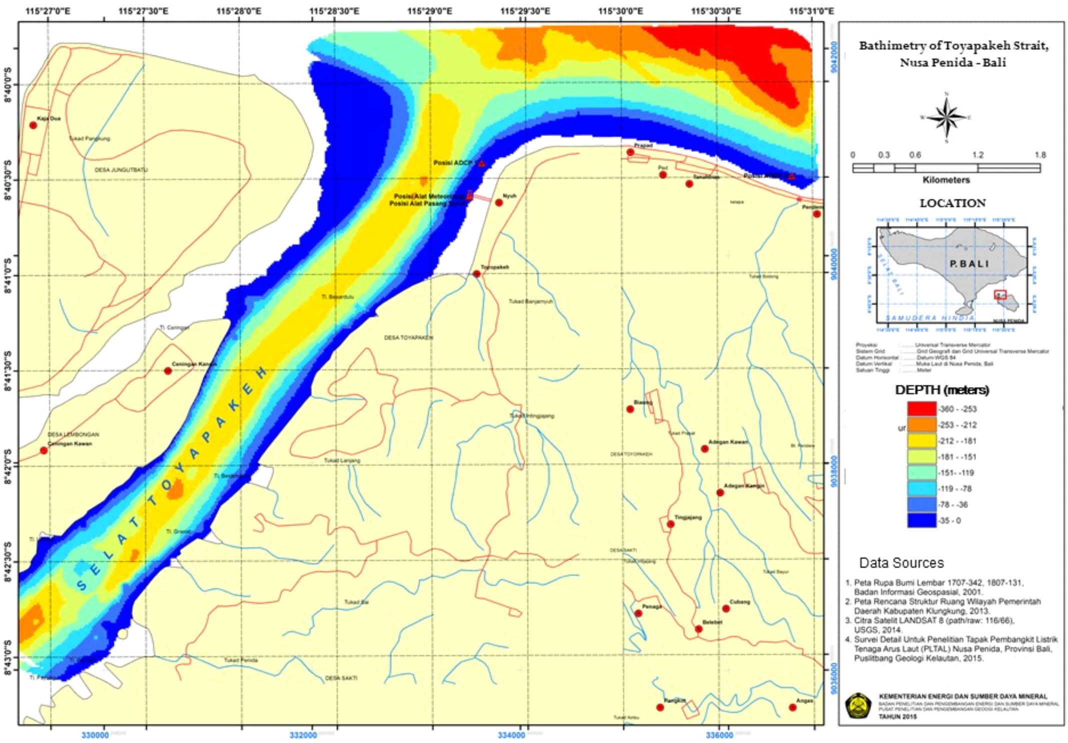


Figure 9. Bathymetry of Toyapakeh Strait - Nusa Penida, Bali (Yuningsih et al., 2015)

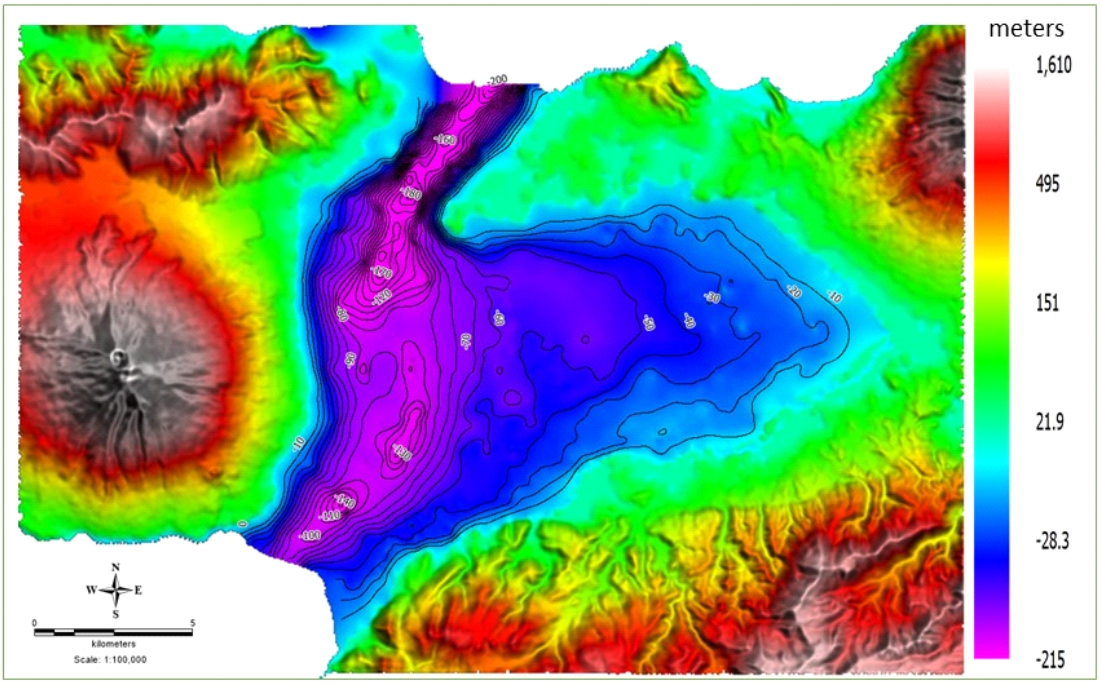


Figure 10. Depth contour and seabed morphology of Boleng Strait (Yuningsih et al., 2012).

The bathymetry of almost all straits reflects the tectonic activity in the area, which is characterized by a deep channel in the middle and a small shallow platform in the outer channel on a gentle seabed morphology. This condition gives rise to a strong tidal current that can be utilized to generate electricity. One of various information from the area for designing an ocean current turbine is the sediments that composed the seafloor and coastal area (Kurnio et al., 2018).

At the Larantuka Strait, the water depth ranges from 5 to 80 meters on a gentle slope morphology (Figure 8). Observing the strait width, the bathymetric contour pattern, the depth, and the seabed morphology, there is a possibility for a fast channeling of the mass flow of seawater to occur from the Flores Sea to the Savu Sea, especially of the surface ocean currents. No potential for a vortex of ocean currents was found. The current pattern in the Larantuka strait is also more predictable than other straits. From some of these technical aspects, the Larantuka Strait is more preferable to be selected as a site for ocean current power plant compared to other straits.

3.4 Current Energy Conversion

Based on ocean current characteristic and the territorial water profile, the straits of the Lesser Sunda Islands have a great potential for the utilization of ocean current power plants. Although the ocean current power is not widely implemented at present in Indonesia, it has an important potential for future renewable electricity generation, especially in remote coastal areas.

There are many selected sites of the straits of the Lesser Sunda Islands that have potency to generate electricity due to the significant current speed of more than 2.5 m/s. In general, the average of sea current speeds in the Lesser Sunda Straits are less than 1.5 m/s with the duration flow of 8-12 hours a day. The maximum speed reaches 2.5 m/s up to more than 3.0 m/s with the duration flow of 2-3 hours a day.

The calculation result of ocean current energy using Fraenkel formulation (2002) in the several straits of the Lesser Sunda Islands, e.g. Toyapakeh Strait, Larantuka Strait, and Boleng Strait, is shown in Table 2. The ocean current power calculated from the current speed data is indicated in the form of power density unit (W/m^2).

Table 2. The calculation results derived from current speed data at several straits of Sunda Lesser.

	Toyapakeh Strait	Larantuka Strait	Boleng Strait
Current speed from seabed mounted ADCP	0.5-3.4 m/s	0.5-2.83 m/s	0.5-2.0 m/s
Current speed from Transect Survey	0.5-2.5 m/s	0.5 - 3.67 m/s	0.5 - 3.4 m/s
Maximum Power Density	13.8 kW/m^2	25.5 kW/m^2	20.8 kW/m^2

CONCLUSION

The study conducted in the Lesser Sunda Straits draws some conclusions as follows:

- The straits through Bali and Nusa Tenggara namely the Lesser Sunda Straits can be selected as the potential sites for the sea current power plant due to the strong current speeds between 0.5 m/s to more than 3.0 m/sec.
- In general, the current direction tends toward the northeast during the high tides and toward the southwest during the low tides.
- Based on several moving ADCP trajectories data, the relatively high current velocity in these straits is correlated with the depth of the sea. The highest current velocity occurs in the deepest and narrowest part of the strait channel during high tide and low tide conditions.
- From some of the technical aspects, i.e. the tide, the current speed, the bathymetry and the seabed morphology, the Larantuka Strait is more preferable to be the selected site for developing ocean current power plant.
- Based on the speed and the duration of the flowing current, the ocean current turbine technology suitable to apply in the waters around Bali-Nusa Tenggara is the technology which requires a minimum speed to move (low cut in speed, 0.5 - 1 m/s) to obtain sufficient electrical power.

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