Opportunities for Tidal Stream Energy in Indonesian Waters

Ahmad Mukhlis Firdaus#1, Guy T Houlsby#2, Thomas AA Adcock#3

#Department of Engineering Science, University of Oxford, Parks Road, Oxford OX1 3PJ,UK

[1] ahmad.firdaus@eng.ox.ac.uk
[2] guy.houlsby@eng.ox.ac.uk
[3] thomas.adcock@eng.ox.ac.uk

Abstract — **as a country with emerging economic growth, Indonesia is facing challenges associated with energy security for its future. Currently, Indonesia still relies on fossil fuels as its energy main sources. However, Indonesian oil and gas productivities have been declining in recent years and Indonesia has become a net importer of oil and gas. These conditions have caused the Indonesian government to look for other sources of energy that are more secure and sustainable. In addition, since Indonesia is vulnerable to climate change, shifting energy sources from fossil fuels to clean renewable energy is desirable. Based on the above, tidal energy can be part of the solution to Indonesia's future energy needs. As an archipelagic country, Indonesia has great potential in tidal resources, as there are many narrow straits between the islands of the Indonesian archipelago coupled with phase differences in tidal components across the straits. Its location between the Pacific and Indian Oceans mean that tidal conditions in Indonesia are very different compared to those in the Western Europe and Northern America regions. Assessing the tidal resources in Indonesia requires much further investigation, especially involving the modelling of tidal stream opportunities. Several technical issues need to be addressed to allow rational selection of potential sites for turbine deployment.**

This paper aims to present an overview, to understand the general characteristics of the region, before detailed tidal resource assessment of the Indonesian region is undertaken.

***Keywords*— Tidal Energy, Resource Assessment, Indonesia**

I. INTRODUCTION

A. Electricity Production and Government Regulation

The Indonesian State Electric Company (PLN), a single company supplying national energy needs, generates electrical power in Indonesia. At present PLN relies on fossil fuels, with coal (44%), oil/diesel (23%) and gas power plants (21%) accounting for most of the supply in 2013. The total installed generating capacity (including off-grid generation) was about 44 GW, of which 37 GW was from plant owned by PLN, and the rest procured by PLN from contracted Independent Power Producers (IPPs). Electrical production is, however, lower than the potential energy demand [1].

The government agency for the assessment and application of technology (BPPT) in the 2016 Indonesian Energy outlook [2] also provides data showing that the Indonesian electricity consumption in 2014 was about 199 TWh. The consumption is dominated by the household sector, 42%, followed by the industrial and commercial sectors with 33% and 24% respectively. As an emerging country economically, electricity demand is predicted increase in the coming years. Within the next 20 years, Indonesia is predicted to need from 1205 TWh to 1491 TWh. Total energy demand in Indonesia is predicted to increase almost tenfold from 52 GW to 115 GW in 2020 and 430 GW in 2050.

Increasing energy need requires Indonesia to reshape its future mix of energy sources, reducing reliance on fossil fuels will threaten Indonesian with climate change [3]. Indonesia has already faced major problems believed to be the result of climate change, such as forest burning in dry seasons and flooding in rainy seasons. Presidential Decree No 79 (Fig. 1) shows Indonesia's commitment to increased use of renewable energy by 2050. As the largest archipelagic country, energy from the ocean such as tidal, wave and OTEC is an appealing option.

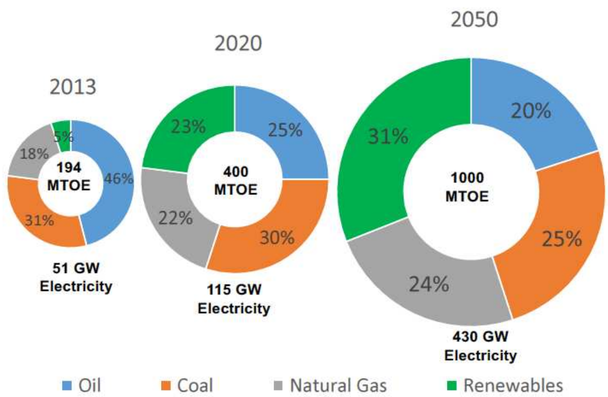

Fig. 1 National Energy Mix Based on Presidential Decree No 79 (2014) (PP no 79 tahun 2014) [4]

B. Indonesian Demography and Electrification Ratio

With one of highest world populations, approximately 230 million people in 2010, providing energy for Indonesia is challenging. Furthermore, the population is not distributed evenly. About 60% of the population is located in the Java Islands. Since electricity consumption is dominated by the household sector, the population distribution plays an important role in determining future Indonesian demand for energy.

Based on 2015 data, the national electrification ratio is about 88.8%. This mean there are nearly 35 million people that have lack of access to modern forms of energy [4]. These are not spread evenly across the country, and there are some regions where less than half the population has access to electricity. Fig 2 shows the electrification ratio and population in each province in Indonesia. This figure shows that the most populated region is West Java, part of Java Island. Meanwhile the lowest electrification ratio is in Papua, which also has one of the lowest populations in Indonesia. This distribution adds to the challenge of providing energy for the Indonesian population.

Providing electricity across Indonesia needs proper study before deploying any investment in this region. For instance, for tidal power, selecting the best location for the first turbine developments is important for the future development of the industry. The scale of developments must be tailored to local demand in order to create a viable supply.

Tidal technology can be divided into two broad groups: megawatt and sub-megawatt installations. The demography and electrification ratio are important factors to be taken into account in selecting appropriate tidal technologies for particular locations in Indonesia. For instance in some locations sub-megawatt installations could play an important role in displacing reliance on diesel generation.

II. Dominant Tidal Constituents and Tidal Asymmetry

Tides occur due to the dynamic response of oceans to gravitational forces applied primarily by the Moon and Sun [6,7]. Tidal resource assessment requires a detailed understanding of these responses. Since prediction of tidal elevations from harmonic components is well established, resource estimation can be based on deterministic modelling of specific time periods. Contrast this with assessment of wind or wave resources, which must be based on probabilistic approaches. Furthermore, satisfactory simulation can often be achieved using a small number of dominant tidal constituents, reducing the necessary simulation time. An understanding of the dominant tidal constituents and their interactions via the shallow water equations is important.

However, in maximising the economic benefit of tidal turbines, operators might not exploit the peak power available to the turbines. Installing a turbine that can extract the peak available power each month may not be economically viable as for much of the time the turbine would operate at well below its capacity. To optimise the economical advantage, limiting turbine operation to a particular limit of velocity by introducing a power capping strategy is inevitable. The net power production is also usefully expressed in terms of the capacity factor, which is the ratio of the average power production to the installed power capacity.

Realistic tidal resource assessment needs to take this important feature of operation into account. The power capping and thus the capacity factor will be specific to the tidal pattern at any particular location, and will be affected for instance in some locations by tidal asymmetry. To date most tidal resource assessments have been carried out for regions that are dominated by semidiurnal tides (M_2 and S_2). Many Indonesian sites do not conform to this pattern, often being dominated by diurnal tides. There appears to be little recent research addressing resource assessment in this type of environment.

We address these issues from a theoretical basis below, deriving some results supporting the influence of tidal asymmetry on tidal resources assessments. We can deduce some preliminary implications for Indonesian waters, although the details require further research.

A. *Velocity Effects from Interaction of Semidiurnal and Diurnal Tidal Constituents*

In most areas in the northern hemisphere that have been studied for tidal resources, the semidiurnal constituents play a

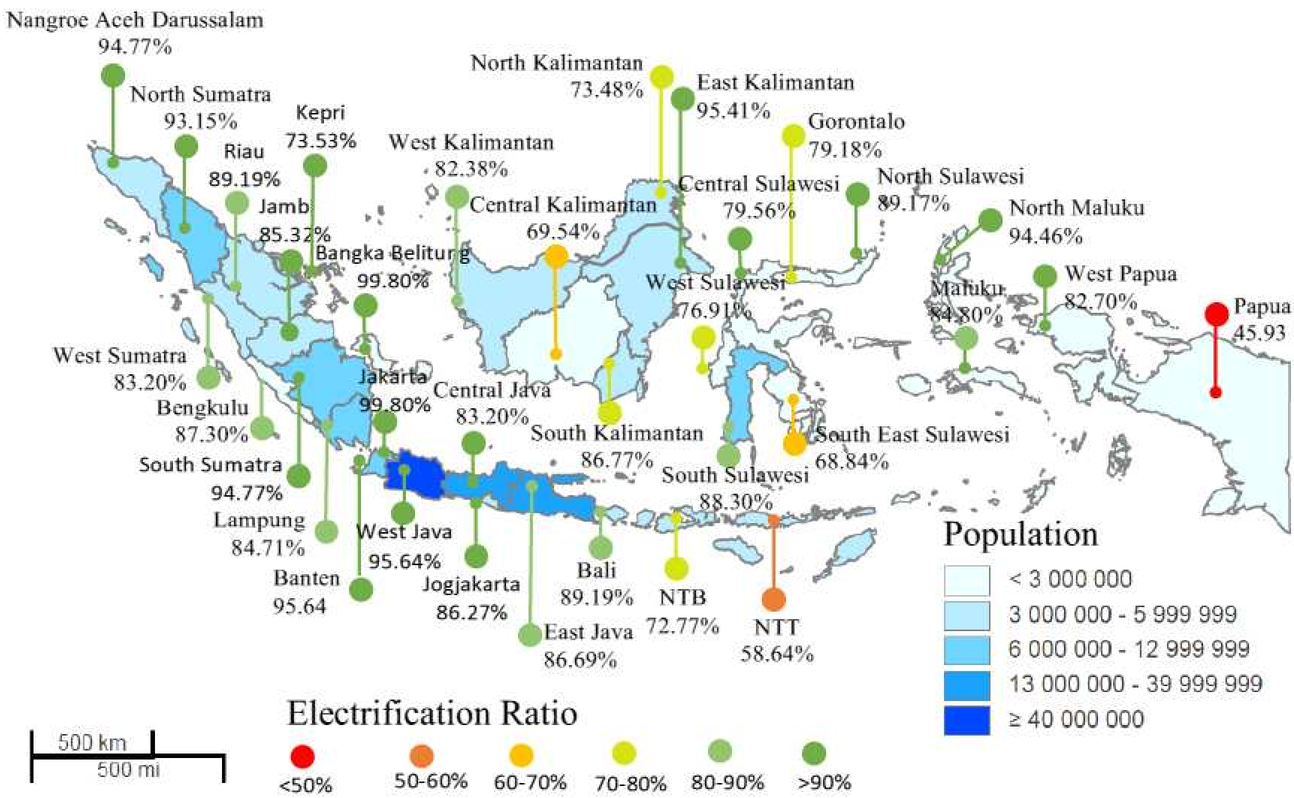

Fig. 2 Indonesian Population [5] and Electrification Ratio [4]

dominant role. NASA's world co-tidal chart shows that the highest influence on large diurnal tides, as well as on the neap-spring cycles is semidiurnal tides, occuring twice a day [8]. The tidal pattern around the UK tidal pattern is, for example, dominated by M_2, the principal lunar tidal constituent. This means that tidal resource assessments conducted for the UK can be conducted using the M_2 and S_2 constituents.

The Pentland Firth, for example, a prime target site for tidal turbines in the UK, can be assessed in terms of M_2 and S_2. Adcock *et al.* have carried out resource assessment seeking an upper boundary for power availability using only S_2 and M_2 in Pentland Firth [9]. They compare the results with analyses using additional constituents (K_1, K_2, MU_2, N_2, NU_2 and O_1), and show that including these only increases mean available power by about 7-9%. In a similar way to [9], many publications for this site use just one or two constituents (S_2 and M_2) as for the forcing in the analysis [10-13]. The reason for use of a reduced number of tidal consituents us principally to simplify interpretation of data, rather than to reduce simulation time.

The question then arises whether this simplification is also applicable for the areas where the diurnal constituents (K_1 and O_1) play an important role. Little research considering this problem is available.

A significant diurnal component (K_1 and O_1) results in different type of tidal cycles. Sites with dominant S_2 and M_2 tides show a simple pattern of two tidal cycles in a day. Areas dominated by diurnal components have one cycle a day. Intermediate cases show more complicated patterns.

The Formzhal number is used to determine the tidal type. This number compares the amplitude of the principal diurnal and semidiurnal constituents (lunar and solar). It is expressed as:

$$F = \frac{AK_1 + AO_1}{AM_2 + AS_2} \tag{1}$$

where, AK_1 and AO_1 are the amplitudes of lunar diurnal tides and AM_2 and AS_2 are the amplitudes of principal lunar and solar semidiurnal.

A Formzhal number $F \leq 0.25$ indicates two tidal cycles per day, and $F > 3$ indicates a single cycle per day. Formzhal number in between create mixed tides. For $0.25 < F \leq 1$ the mix is principally semidiurnal, partly diurnal, whilst for $1 < F \leq 3$ the mix is principally diurnal, partly semidiurnal. However, complex interactions between the components can occur.

In terms of power production, the maximum power available in a day will vary according to the tidal type. Semidiurnal tidal type have two floods and two ebbs daily. It is likely therefore that the cut-out velocity will be reached four times in a day, although this is modulated by the spring-neap cycle. Semidiurnal area such as the UK have low Formzhal number as the amplitudes of K_1 and O_1 are low compared to M_2 and S_2. In like Indonesia, K_1 and O_1 are significant and sometimes even the dominant tidal constituents.

The influence of diurnal components results in tidal asymmetry which will affect the operation and capacity factor of the turbine. Fig. 3 shows the tidal elevation and tidal velocity at a site governed by a combination of M_2, S_2, K_1 and O_1 components. The example uses equal amplitudes of the four components ($AM_2 = AS_2 = AK_1 = AO_1 = 1.0$m), and zero difference of phase (ϕ_N). An asymmetric pattern of both tidal elevation (Fig. 3.a) and tidal velocity (Fig. 3.b) can be observed during each day. Fig. 3.b shows for instance the tidal flow in the positive direction varying more than the negative velocities in each daily tidal cycle.

The presence of a dominant diurnal component in the tidal regime will have a significant impact on tidal power extraction strategy. Firstly, the pattern of intermittency will differ from a site dominated by semidiurnal tides, with fewer highly peaks. Secondly, diurnal tides are often associated with tidal asymmetry, further exacerbating this issue.

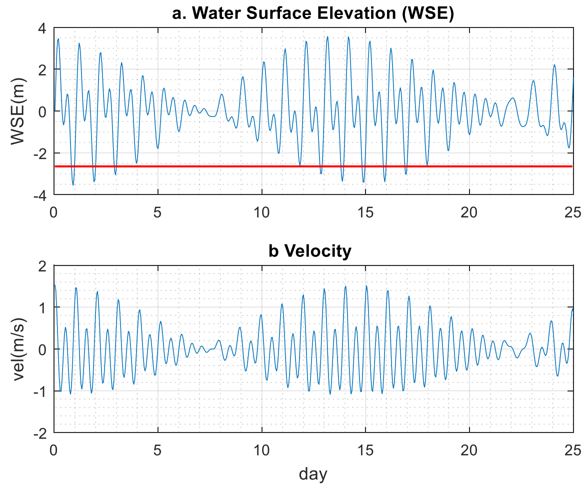

Fig 3. Example of Water surface elevation and velocity magnitude in time series developed by combination of M2, S2, K1 and O1

B. Tidal Asymmetry and Capacity Factor

Tidal asymmetry can be defined as significantly unequal peak velocities of ebb and flood currents. In the absence of a net throughflow, these are related to unequal time periods during which the ebb and flow currents are active. If the time for water level rise is shorter than for water level fall this is termed flood dominant and the reverse is termed ebb dominant.

This asymmetry is relevant for sediment transport problems as well as for power production. Sediment accumulation occurs due to unequal tidal currents.

Tidal asymmetry will affect how a turbine will be operated efficiently, but may also affect the choice of design of the turbine. For instance the support structure design may be selected for a dominant flow direction. Tidal stream turbines are mostly designed for symmetric bi-directional flows and symmetric manner. However, some designs involve asymmetric support structures, for instance the Hammerfest Andritz Hydro device (Fig.4). This type of structure might have an advantage in asymmetric tidal conditions.

As far as tidal resource assessment is concerned, tidal asymmetry must be taken into account in estimating the capacity factor of the turbine. Tidal asymmetry is normally believed to be associated with nonlinear tidal interactions in shallow water, giving rise for instance to the M_4 constituent which interacts with M2 to cause unequal times for ebb and flood [15]. However, [16, 17] demonstrated that astronomical tidal constituents also can generate tidal asymmetry. As a result, asymmetric tidal conditions are common in Indonesian waters.

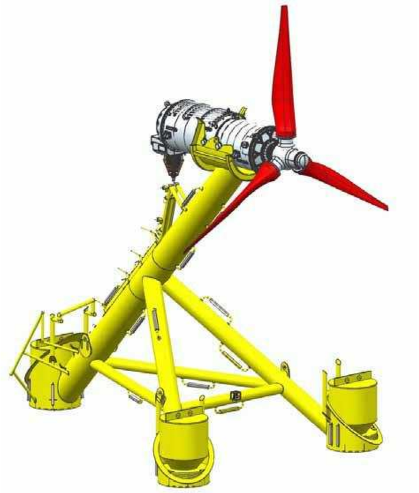

Fig.4 Hammerfest Andritz Hydro Tidal Turbine [14]. This example of a support structure may be well suited for asymmetric flow.

When carrying out resource assessment, in order to capture tidal asymmetry it is necessary to select the appropriate tidal constituents in order to reducing simulation cost but still model correctly the diurnal tidal pattern. Whilst most tides around the UK can, for instance, be modelled as semidiurnal with satisfactory accuracy, in Indonesian waters it is necessary to include a number of other constituents (for instance diurnal constituents K_1, O_1), to achieve satisfactory accuracy.

III. Tidal Resource Assessment In Indonesia

Indonesia is one of the most complex regions in terms of understanding tidally induced currents. Tidal asymmetry, the presence of a net throughflow current, and geographic complexity with many small islands all make the problem even more complicated. Relatively few studies on tidal resources have been carried out for this region. Furthermore, reliable data for calibration of models are sparse in this region. Whilst some data gathered by Indonesian government agencies may exist, little data is available in the open literature.

However, Indonesia is a very promising region for tidal turbine deployment, with many locations with very strong tidal streams. A good understanding of tidal phenomena in this area is required in order to prepare for such deployments.

A. *Dominant Tidal Constituents*

As discussed above, tidal asymmetry, unequal flood and ebb velocities, will affect tidal turbine operations and capacity factor. In Indonesian waters preliminary indicators are that this asymmetry arises primarily from diurnal constituents, although the Indonesian throughflow current may also play a role.

Tidal currents in Indonesian waters are not just driven by semidiurnal constituents. Table I shows the constituents at some representative observation stations of Indonesia, in some of which diurnal constituents (e.g. K_1) are more dominant than semidiurnal constituents (e.g. M_2). Modelling in this area needs to consider this condition, which results in long term variations due to interaction between the components.

TABLE I: Example Tidal Constituents In Indonesian Waters [18]

Tidal Station	Coord		M_2	S_2	K_1	O_1
40. Kota Waringin	2° 9' S	A (m)	0.2	0.1	0.4	0.2
	111° 4' E	Φ (o)	182	244	34	131
41. Semarang	7° 0' S	A (m)	0.1	0.1	0.2	0.1
	110° 4' E	Φ (o)	102	203	7	128
43. Kali Anget	7° 1' S	A (m)	0.4	0.2	0.4	0.2
	113° 9' E	Φ (o)	46	32	61	96
47. Benoa (Bali)	8° 7' S	A (m)	0.7	0.3	0.3	0.1
	115° 2' E	Φ (o)	73	5	59	84
48. Lembar (Labuhan Tring)	8° 7' S	A (m)	0.3	0.2	0.4	0.2
	116° 0' E	Φ (o)	52	43	76	96
50. Sungai Barito (Ambang Luar)	3° 6' S	A (m)	0.3	0.1	0.6	0.3
	114° 5' E	Φ (o)	209	279	20	79
61. Makassar	5° 2' S	A (m)	0.1	0.1	0.3	0.3
	119° 4' E	Φ (o)	279	145	62	95

The existence of tidal diurnal constituents is also captured by Topex Poseidon observations; [18] shows the overall amplitudes of M_2 in Java Sea are slightly lower than K_1 in the Indian Ocean south of Java Island. This results in a steep gradient of M_2 amplitude in the straits between Bali, Lombok and other islands in this region. Meanwhile the K_1 constituent shows a rapid change in the area of the Karimata Straits, located between Bangka and Borneo Islands.

In term of phase differences, the Karimata Straits, Bali and all the narrow straits in the Lombok and Nusa Tenggara regions show rapid change of M_2 phase. The K_1 phase changes rapidly in Karimata, while in the Bali to Nusa Tenggara straits changes are milder. We could conclude that these areas are controlled by both drag and inertia terms for the M_2 (semidiurnal) constituent but these terms are only important in the Karimata Strait for the K_1 constituent. These features of the flow complicate the problem of locating boundaries and establishing boundary conditions for analysis.

C. *Residual Current; Indonesian Through Flow*

Indonesia's location between the Pacific and Indian Oceans means that flows occur in this region due to the "great ocean conveyor belt" or thermohaline circulation. This global flow passes through the islands from Sulawesi and Kalimantan to Bali and Nusatenggara with a velocity of 0.2-0.4m/s [20]. This non-tidal flow might have a significant impact on flow patterns and the tidal stream energy resource.

The thermohaline circulation in this area creates a sub-circulation in the Indonesian archipelago. This unique pattern is also known as the Indonesian Through Flow (ITF). This phenomenon has been extensively studied by the oceanographic community. There is no single explanation for the ITF, but it is due to a combination of temperature and salinity difference between sub-tropical regions and tropical regions, which drives a residual current in this area.

Fig.5 illustrates flow patterns of the thermohaline circulation. This global current goes through the Makassar straits and divides through the Lombok Straits and Timor Passage. The velocity of ITF varies from 0.1-0.2 m/s in Lombok and about 0.2 m/s - 0.3 m/s in the Flores area. Whilst relatively small compared to the tidal currents, this steady current could significantly influence the nature of the tidal resource in the region. This current is, however, highly stratified, generally being much stronger in the upper layer of water.

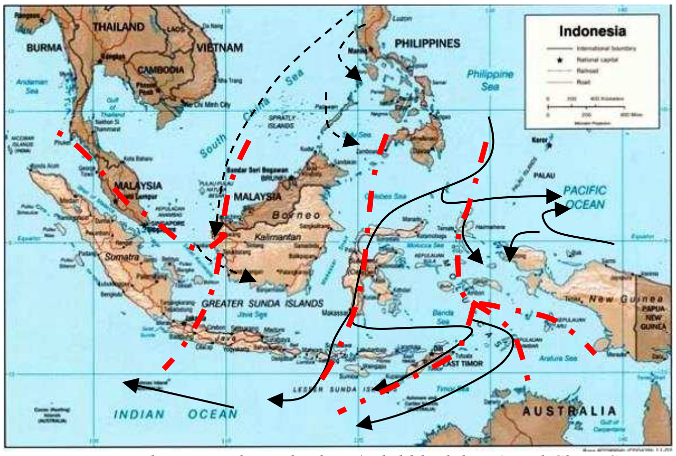

Fig.5. Indonesian Through Flow (solid black lines) and China Sea Through Flow (black dash line) [19]. Red dash dot lines show Indonesian Archipelago shipping routes. This area has thermohaline circulation about 1.7sv in Lombok Straits and about 4.5sv in area of Flores [20].

D. Water depth

Many of the channels through the Indonesian archipelago are deep and have a stronger current near the surface than at the seabed. Thus the resource is concentrated near the free surface. This makes many candidate sites particularly suitable for floating turbines which do not require a rigid connection to the seabed and which only take up the top of the water column where the kinetic flux is significant.

E. Shipping Line Routes

Many candidate sites for tidal energy extraction are also major international shipping routes. There are three major international channels that are known as ALKI or Indonesia archipelago sea-lanes. This use may conflict with any development of tidal stream energy at these sites.

IV. Tidal Energy Resources In Indonesia

The Indonesian government has located some candidate sites for tidal energy extraction based on field measurements. The tidal resource, along with other marine renewable resources, is shown in the "Ocean Energy Resources Map". This identifies ten candidate sites (Fig. 6).

1 Riau Strait

This site is located in the area of Batam Island and Tanjung Pinang regency, and is quite near to capital city of Riau Archipelago Provence. These islands are the most populated area in this province. It is also an industrial area with a high demand for electricity.

Although ref [21] suggests a maximum velocity of 1.39 m/s it also suggests a maximum resource of 6GW. This seems somewhat unlikely and clearly requires further investigation. The area has multiple different channels and water depths of around 20m. This is a suitable water depth for many types of tidal turbine currently under development.

The area is, however, a very busy shipping route. This will limit the development of the tidal stream resource in the area.

Riau Archipelago province has a relatively low electrification ratio of, 75.53%, Fig.1, which means almost a quarter of the population in this area has no access to electricity. Moreover, since this province's population lives in scattered islands, the local demands of electricity is relatively low. Thus, small tidal turbines are more desirable in this area.

2 Sunda Strait

The Sunda Strait is located in between Java Island and Sumatra Island, which means it is near the most populated area in Indonesia. Furthermore, it is also close to Jakarta and Banten regions, where a high proportion of the nation's industry is located. This area has a high electrification ratio and a high demand for electricity.

This area is dominated by the M_2 tide and a strong barotropic current of around 1 m/s. The location is near an amphidrome of the K_1 tide.

3 Toyopakeh Strait

This strait is in the island chain between Java and East Nusatenggara Islands. Toyopakeh is a tiny strait located in between Nusa Penida Island and Nusa Lembongan Island. This strait is only about 1000 m wide and located near to one of most famous tourism spots in Indonesia's Bali Province.

The area has 86% electrification and a strong demand from the tourist industry. Generating power from sustainable sources is potentially attractive for the tourist market. However, marine life is also important for the tourist industry, and the impact of tidal energy extraction on this will have to be carefully analysed.

Both M_2 and K_1 tides are significant in the area.

4 Lombok Strait

This site is located in the same region as Toyopakeh Strait and any development of one will impact on the other.

Lombok Island has a lower electrification than Bali province and hence may be more attractive for tidal stream energy extraction. However, this strait is a major shipping lane which will limit its development.

5 Alas Strait

Similar to sites 3 and 4, this site is located between Lombok and Sumbawa Islands. Lombok Island is closest to the site and would be the likely destination for any power produced here.

Even though this strait also connects the Java Sea and Indian Ocean, the M_2 amplitude in this area is rather peaked in the strait. M_2 amplitude rises from 1.20 m, in the Java Sea Region, to 2.40 m, along the strait, before it falls to 0.6 in the Indian

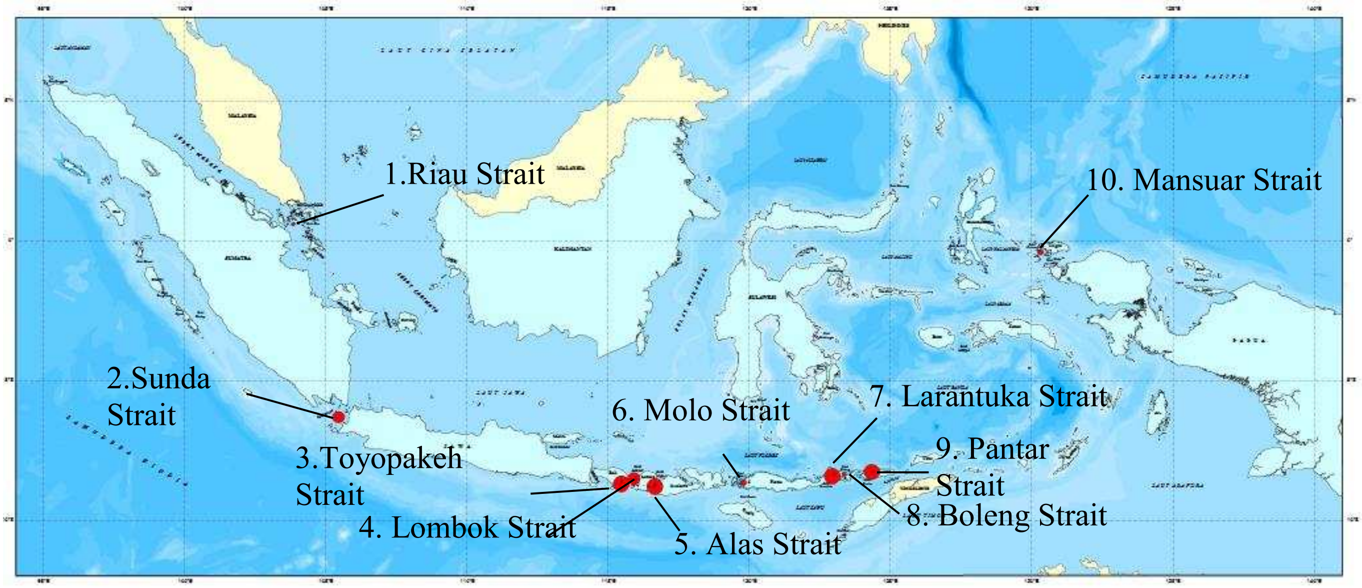

Fig.6 Potential sites for tidal energy generation assessed in [21]

Ocean. Furthermore, unlike any other neighbouring straits, the amplitude change on M_2 and K_1 amplitude in this area is distribute along the channel [22].

This area has been examined by Kobold Nusa Turbine as a potential site in 2007 [23]. This report shows they investigated several sites on the Lombok Island side only. They carried out ADCP tidal velocity measurement for 39-44 days. Velocity magnitude based on measurement is a maximum of 2.4 m/s at a depth of 7 m. However, [23] shows the velocity magnitude in this area reaching a maximum of 2.9 m/s but it is uncertain where exactly along the strait.

Ref [24] also assessed tidal resources in this site using the POM model. With a small domain area of the modelling, this study estimates modest resource of 330 GWh and 640 GWh based on annual energy yield from this area. Meanwhile, [25] shows that this area has 1,260 MW of maximum extractable resources. However, this assessment did not consider the interaction between turbine arrays and the flow in the region.

6 Molo Strait

Molo Strait is a narrow strait in the Manggarai regency, East Nusatenggara. This site is near to Komodo Island, a famous national park for Komodo Dragon conservation, and the city of Labuhan Bajo, famous for tourism.

The Marine Geology Research and Development Centre (P3GL), an agency under the ministry of energy and mineral resources of Indonesia, published a report on tidal resources in this area [24]. This report shows PGL has conducted flow measurement in this area from 11-14 April 2011. This measurement was done during neap tide and flow magnitude during this period is up to 1.8 m/s.

This area has rapid change of M_2 amplitude and phase difference from Java-Banda Sea to Indian Ocean. Meanwhile, in K_1 terms, the changes are milder from 0.3 m to 0.2 m.

Ref. [24] shows this area is applicable for seabed mounted tidal turbines since bathymetry of the area is only about 15-30m depth. However, the strait is narrow, meaning it may be difficult to combine tidal stream turbine deployment with the need for shipping to pass.

7 Larantuka Strait

Larantuka Strait has one of the highest velocities in Indonesian waters. Tidal velocity exceeds 3 m/s in this area. Many turbine developers in Indonesia have considered this site due, and P3GL have carried out a measurement campaign in this area [25]. Ref [26] and ref [27] also consider this as a potential area with current velocity exceeding 3 m/s. Both of these studies carried out the assessment without allowing the turbine to interact with tidal flow.

Similar to Molo Strait, it is 20-35 m deep. Thus, this site is also applicable for seabed mounted tidal turbines. With the width of channel about 650m, the requirement to allow shipping past will be an issue.

The government of Indonesia plan to build a bridge connecting Adonara and Flores Island. This plan has considered the option of combining this with deployment of tidal stream turbines. This area needs to be investigated carefully, especially because of the bridge plan. Larantuka straits along with Boleng Strait form a complex geometry and the sites will interact with each other. The bridge itself, depending on the design, may interact with the tidal stream.

This strait is passed by the ITF from Banda Sea to Sawu Sea. According Gordon *et al* [19], the transport in this area is about 3.5Sv or 3.5 x 10^6 m^3/s.

8 Boleng Strait

The Boleng Strait is located next to Larantuka Strait, between Adonara Island and Lembata Island. This site is far deeper than Larantuka Strait, about 125-150 m deep. Seabed mounted devices are unlikely to be feasible. Furthermore, [24] shows the velocity is higher near to the surface.

This site is wider than the Larantuka Strait, 2000m wide at the north and 4000m at the south. The ITF also passes through this channel. This needs to be considered in any decision to develop the site.

9 Pantar Strait

The Pantar Strait is located in between Alor Island and Pantar Island. Pulau Pura divides this strait into two channels. The western and eastern channels have widths of about 850m and 3500m respectively. There is a high velocity in the eastern side, with water depth about 50m. Ref. [24] shows maximum velocity in this strait exceeding 2.9m/s.

The Pantar Strait is located in East Nusa Tenggara which has a low electrification ratio of 58.64%, Fig.2, meaning that almost half of this region's population has no access to electricity. Tidal turbine development might be desirable for this region. However, deploying tidal turbine in this area needs to account for interaction between the two channels.

10 Mansuar Strait

The Mansuar Strait is located in West Papua Province, in Raja Ampat Regency. This area is an important national park for marine life conservation and a favourite diving spot in Indonesia. Based on measurement the velocity in this site reaches 1.79m/s maximum [28].

The strong current in this area is produced by amplitude and phase differences of the M_2 constituent. Meanwhile, the diurnal constituent (K_1) only has a phase lag with small amplitude change through the strait.

However, since this area is for marine conservation, turbine deployment needs to look at the environmental impact on this site carefully. However, given the low population in the area only a small development may be needed to meet demand.

As well as candidate sites for tidal stream energy, Indonesia also has a number of candidate sites which may be suitable for tidal barrages. At least two locations look possible. These are Mappi-in Papua Province and Bagan Siapiapi in Riau province. At both of these sites the spring tidal range exceeds 6 to 7 m.

Conclusions

This paper reviews the demand for renewable energy in Indonesia and reviews a number of candidate sites. Data on the hydrodynamics of these sites is limited and further modelling and measurement campaigns are required to make a more accurate assessment of the tidal stream resource.

References

[1] Tharakan, P, *Summary of Indonesia's Energy Sector Assessment.* ADB Papers on Indonesia No.9, December 2015.

[2] Sugiyono, A., Anindhita, Laode M.A. Wahid and Adiarso, *Indonesia Outlook Energy 2016, Energy development in Supporting Green Industry.* Center for Technology of Energy Resources and Chemical Industry, Agency for the Assessment and Application of Technology, ISBN 978-602-74702-0-0. July 2016, pp 70-80.

[3] Indonesia: A Vulnerable Country in the Face of Climate Change, Global Majority E-Journal, Vol. 1, No. 1 (June 2010), pp. 31-45.

[4] Ministry of Energy and Mineral Resources, Directorate General of Electricity, *Strategic Planning 2015-2019*, http://www.djk.esdm.go.id/pdf/Renstra/Renstra%202015-2019.pdf accessed March 2017.

[5] Agency of Statistic Centre, https://sp2010.bps.go.id/index.php/ accessed March 2017.

[6] Pugh, D.T. *Tides, Surges and Mean Sea-Level*, John Wiley and Sons, Chichester, UK,1987.

[7] Draper, S., *Tidal Stream Energy Extraction in Coastal Basins*, DPhil Thesis University of Oxford, U.K, 2011

[8] NASA, TOPEX/Poseidon Revealing Hidden Tidal Energy, https://svs.gsfc.nasa.gov//stories/topex/tides.html, accessed March 2017.

[9] Adcock., T.A.A , Draper, S., Houlsby, G.T., Borthwick, A.G.L and SerhadlIogliu, S., *Tidal stream power in the Pentland Firth – long-term variability, multiple constituents and capacity factor*. Proc I Mech E Part A: J Power and Energy, 2014, Vol. 228(8) 854–861

[10] Adcock, T.A.A. and Draper, S., *Power extraction from tidal channels — multiple tidal constituents, compound tides and overtides*, Renewable Energy, Vol. 63 pp 797-806, 2014.

[11] Adcock, T.A.A., Draper, S., Houlsby, G.T., Borthwick A.G.L., and Serhadlıoğlu, S., *The available power from tidal stream turbines in the Pentland Firth*. Proc. Roy. Soc. A, Vol. 469(2157), 20130072, 2013.

[12] Draper, S., Adcock, T.A.A., Borthwick, A.G.L., Houlsby, G.T., *The extractable power from the Pentland Firth*, Renew. Energy, Vol. 63 pp 650-657, 2014.

[13] Draper, S., Adcock, T.A.A., Borthwick, A.G.L. and Houlsby, G.T. (2014) *An electrical analogy for the Pentland Firth tidal stream power resource*, Proc. Roy. Soc., Series A, Vol. 470, No. 2161, Article 20130207
Andrytz Hydro, http://www.andritzhydrohammerfest.co.uk/tidal-turbines/ accessed April 2017.

[14] Dronkers, J., *Tidal Asymmetry And Estuarine Morphology*, Netherlands Journal of Sea Research 20 (2/3): 117-131 (1986)

[15] Hoithink, A.J. F., Hoekstra, P. and van Maren, D. S., Flow Asymmetry, associated with astronomical tides: implication for the residual transport of sediment, Journal of Geophysiscal Research, Vol. 108, No. C10, 3315, doi: 10.1029/2002JC001539, 2003

[16] Nidzieko, N.J., *Tidal asymmetry in estuaries with mixed semidiurnal/diurnal tides*, J. of Geophysical Research, Vol. 115, C08006, doi:10.1029/2009JC005864, 2010

[17] Indonesian Navy, *Admiralty Chart,* 2014.

[18] Gordon A.L., *Oceanography of Indonesian Seas and Their Throughflow*, Oceanography Vol. 18, No. 4, Dec. 2005

[19] Sprintall, J., Wijffels, S.E., Molcard, R., and Jaya, I., *Direct estimates of the Indonesian Throughflow Entering the Indian Ocean*: *2004–2006*, J. of Geophysics Research., Vol 114, C07001, doi:10.1029/2008JC005257, 2009.

[20] Ministry of Energy and Mineral Resources Indonesia and Indonesian Ocean Energy Association-INOCEAN, *Ocean Energy Resources in Indonesia 2014*. Technical Note, March 2014.

[21] Ray, R. D., Egbert, G. D. and Erofeeva, S. A. Y., *A brief review of Tides in the Indonesian Seas*, Oceanography Vol. 18, No. 4, Dec. 2005

[22] Coordinating team of Research and Technology, *Final report on Current Measurement on two location with mechanical Team of Pda Archimede, Italy in West Lombok (report in Bahasa Indonesia),* Centre of Marine Geology Research and Development, Ministry of Energy and Mineral Resources, Republic of Indonesia, 2008.

[23] Blunden, L.S., Bahaj, A.S. and Aziz, N.S.. *Tidal current power for Indonesia? An initial resource estimation for the Alas Strai*t. Renewable energy, 2013 49, pp.137-142

[24] Orhan, K, Mayerle, R and Pandoe, W. W. *Assesment of energy production potential from tidal stream currents in Indonesia*, Energy Procedia 76 (2015) 7 – 16

[25] Orhan, K, Mayerle, R, Narayanan, R and Pandoe, W. W. *Investigation of the energy potential from tidal stream currents in Indonesia*. Coastal Engineering Proceedings, 1(35), p.10

[26] Rachmat B., *An Academic Note on Tidal Resource Mapping for National Energy Security; case study in Bali-East Nusatenggara Waters (report in Bahasa Indonesia)*. Centre of Marine Geology Research and Development, Ministry of Energy and Mineral Resources, Republic of Indonesia, 2013.

[27] Yosi M., *Research on Tidal Resources as New and Renewable Energy in Raja Ampat Water, West Papua (report in Bahasa Indonesia)*. Centre for Marine Geology Research and Development, Ministry of Energy and Mineral Resources, Republic of Indonesia, 2013.