Development of Ocean Renewable Energy Model in Indonesia to Support Eco-Friendly Energy

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ABSTRACT:
Renewable energy is a solution for reducing environmental damage caused by greenhouse gas emissions from fossil fuels. Energy consumption in Indonesia involves sectors such as industry, households, transportation, and agriculture, which still heavily rely on non-renewable energy sources. Indonesia possesses significant maritime potential, boasting the second longest coastline in the world, a water area covering 71%, and abundant marine biological resources that can contribute to maritime economic growth. This research aims to leverage remote sensing technology and geographic information science to harness Indonesia's maritime potential. In the realm of renewable energy, this study emphasizes the potential of wave energy and current energy in Indonesia, with the objective of establishing an Ocean Renewable Energy (ORE) model. Additionally, the research will consider marine habitat suitability to mitigate any negative impact on biodiversity from power generation activities. Based on the research findings, the ocean current energy in Lombok Strait has a high energy potential reaching 1,035 Watts and Maluku Sea has 1,536 Watts, while the southwest region exhibits wave energy potential of Panaitan Island has a wave energy potential of 23,051 kW/m, while Sangiang Island has a potential of 12,842 kW/m. Furthermore, potential energy locations will be identified through the overlaying of potential fish zones. The ultimate goal of this research is to fulfill sustainable energy needs, decrease dependence on fossil fuels, and promote sustainable economic growth in Indonesia.

1. INTRODUCTION

Currently, renewable energy is being extensively developed. Renewable energy is obtained from naturally recurring and continuously available energy sources (Twidell & Weir, 2015). Renewable energy needs to be developed as a response to environmental damage caused by greenhouse gas emissions and the increasing production waste of fossil fuels (Apergis & Payne, 2012; Sakti et al., 2023). The continuous increase in global energy consumption each year (IEA, 2021) is also a major reason for the need to develop renewable energy. In Indonesia itself, energy consumption is used in various sectors, including industry, households, transportation, agriculture, and other sectors that rely on non-renewable sources of energy (Elinur et al., 2010)

As an archipelagic nation, Indonesia has the second-longest coastline in the world, stretching for 99,181 kilometers, with a marine area covering 6.8 million square kilometers, which accounts for 71% of Indonesia's total territory (KKP, 2019) with a total water area of 5.8 million km^2 (Ramdhan and Arifin, 2018). The vast maritime territory of Indonesia provides abundant marine biodiversity resources, leading to significant economic potential, especially for coastal communities and their surroundings (Lasabuda, 2013).The government has supported the development of the maritime economy through maritime-based economic policies in realizing Indonesia's position as a global maritime axis (Najeri et al., 2018) .Moreover, Indonesia's oceanic wealth has the potential to become a foundation for food and energy security in the country (Nikawanti et al., 2021).

Some of the significant maritime energy potentials in Indonesia are tidal energy and wave energy. There have been several previous studies discussing tidal and wave energy. First is the study by Muetze & Vining (2006), which analyzed the conversion of wave energy into usable energy. Second is the study by Purba et al. (2015), which modeled the potential of Renewable Energy in the Ocean, including tidal energy, ocean currents, waves, and wind in Indonesia. Third is the study by Richardson et al. (2022), which modeled the identification of suitable marine current energy, considering socioeconomic factors using the MCDA method in Columbia.

Modeling renewable energy needs to consider its impact on the environment. It is undeniable that although renewable energy is more environmentally friendly, it still has negative impacts on the marine environment, such as collisions with marine animals and disturbance of marine habitats (Pirttimaa et al., 2020).This research attempts to model the potential of Ocean Renewable Energy (ORE) in Indonesia, focusing on tidal and wave energy, while taking into account environmental conditions. With this research, it is hoped that the development of ORE will pay more attention to the impact on the survival of marine animals.

2. METHODOLOGY

2.1 Study Area

This study area is Indonesia as shown in Figure 1. The area is selected because Indonesia has significant marine potential as an archipelago state, with 2/3 of its area being ocean (KKP, 2019) The ocean energy potential in Indonesia consists of wave, current, and thermal energy. However, this study will focus on wave and current energy.

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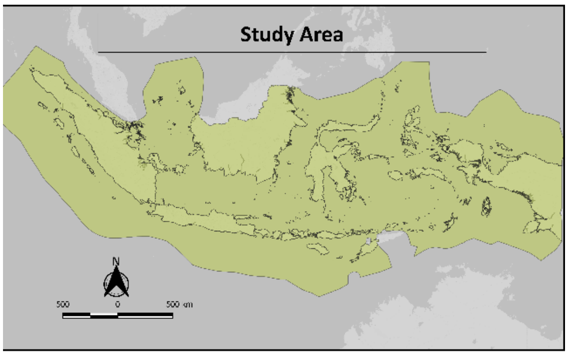

Figure 1. Study area

2.2 Data

The data used in this study can be seen in Table 1. This study utilizes five datasets consisting of ocean wave, ocean current, marine administrative, temperature, and chlorophyll-A data. The ocean wave data is obtained from the Global Ocean Waves Analysis and Forecast provided by the Copernicus Marine Environment Monitoring Service. It has a spatial resolution of approximately 0.083° and temporal data for the year 2020, collected every three hours (Janssen P., n.d.; Roland et al., 2010).The current data is sourced from the Global Ocean 1/12° Physics Analysis and Forecast, also from the Copernicus Marine Environment Monitoring Service, with a spatial resolution of 0.083° and temporal data collected every hour in 2020 (CMEMS, 2019).

For the marine administrative boundaries, data from the Flanders Marine Institute (Flanders Marine Institute, 2019)is used to delineate the study area. Additionally, this study considers the marine habitats. The data used to determine the marine habitat include Sea Surface Temperature and Chlorophyll-A, provided by MODIS Satellite from the NASA Goddard Space Flight Center, Ocean Ecology Laboratory, Ocean Biology Processing Group. These datasets have a spatial resolution of approximately 4616 m and temporal data for the year 2020 (NASA, n.d.).Not only that, but marin habitat suitability will also consider the blue carbon habitat (mangrove) and protected area. Mangrove data provided by United Nation (UN, 2022) while protected area data provided by The World Database on Protected Areas (WDPA, 2023).

No	*Data*	*Temporal*	*Resolution*	*Reference*
1	Global Ocean Waves Analysis and Forecast	2020 every 3 hours	0.083°	(Janssen P., n.d.; Roland et al., 2010)
2	Global Ocean 1/12° Physics Analysis and Forecast updated Daily	2020 every 1 hour	0.083°	(CMEMS, 2019)
3	Marine Administrative	2019	Vector	(Flanders Marine Institute, 2019)
4	Sea Surface Temperature (SST)	2020	4616 m	(NASA, n.d.)
5	Chlorophil-A	2020	4616 m	(NASA, n.d.)
6	Blue Carbon Habitat (mangrove)	2020	Vector	(UN, 2022)
7	Protected Area	2023	Vector	(WDPA, 2023)

Table 1. Data

2.3 Methods

In general, the method used can be seen in Figure 2. The method can be divided into three parts that will be explained in the following paragraphs.

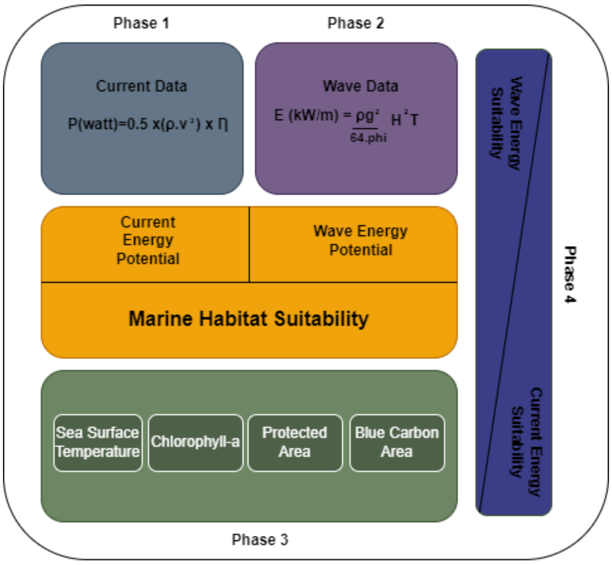

Figure 2. General methodology

2.3.1 Current Energy

Tides create currents known as tidal currents, which change periodically and can be predicted (NOAA, 2022). However, wind and thermohaline circulation are other driving factors of currents (NOAA, 2022). The formula for current energy, as expressed in Equation (1), includes variables ρ, v, and Ŋ, representing sea water density (1025 kg.m^{-3}), speed (m/s), and the generator coefficient (79.07%) respectively (Purba et al., 2015).

$$P(watt) = \frac{1}{2} x \rho x v^3 x \text{Ŋ} \quad (2)$$

2.3.2 Wave Energy

Ocean wave energy is a form of renewable energy that harnesses the power of wave motion. The illustration of an ocean wave energy converter shows that each converter consists of floating buoys that absorb energy from the generator located on the seabed through a tether (Leijon et al., 2006). The unit of ocean wave energy is kilowatts per meter (kW/m) (Sabzehgar et al., 2009). The formula to calculate wave energy can be seen in Equation (2), where ρ, g, H, and T represent sea water density, gravity, wave height, and wave period respectively (Mirzaei et al., 2014; Vicinanza and Cappietti, 2011)

$$E\ (kW/m) = \frac{\rho g^2}{64\pi}\ H^2 T \quad (2)$$

2.3.3 Marine Habitat Suitability

Marine Habitat Suitability will integrate potential fishing zone (PFZ) data, protected area data, and blue carbon data. The general function of marine habitat suitability can be seen in Equation (3), where MHS, PA, and BCH represent marine habitat suitability, protected area, and blue carbon habitat, respectively. The PFZ should be taken into consideration as there are many people who work as fishermen. It is hoped that the ORE (Ocean Renewable Energy) will not disturb the economy of fishermen. The high PFZ also indicates the potential of fish in the area, so ORE will not collide with sea animals. The PFZ will consider chlorophyll-a and Sea Surface Temperature (SST) (Daqamseh et al., 2019, 2013) ORE should consider the protected area and blue carbon habitat to ensure that its operation will not disrupt the ecosystem. Blue carbon habitats, such as mangroves, provide various ecosystem services, including fauna habitat and protection, beach protection from erosion, sediment stability, and air pollution absorption (Boonsong et al., 2003; Nagelkerken et al., 2008). Therefore, ORE should be located far from protected areas and blue carbon habitats.

$$MHS = f(PFZ, PA, BCH) \tag{3}$$

3. RESULT AND DISCUSSION

3.1 Current Energy

Indonesia's unique geographic location and intricate network of straits and channels make it highly favorable for the utilization of ocean current energy. The country is strategically positioned between the Indian and Pacific Oceans, resulting in the formation of strong and continuous ocean currents. Areas such as the Lombok Strait, Ombai Strait, and Sumba Strait experience particularly powerful tidal currents due to their narrow passages and complex topography (Sudjono et al., 2021).

In Figure 3, Lombok Strait has a high energy potential reaching 1,035 Watt due to the natural phenomena that affect the ocean currents in that area. Lombok Strait is located between Lombok Island and Bali Island, forming a narrow channel that experiences significant tidal differences between the Indian Ocean and the Bali Sea. These tidal differences create strong and continuous currents that flow through the strait (Brown et al., 2019). On the other hand, the Maluku Sea has the highest potential for ocean current energy, reaching up to 1,536 Watt, due to several natural factors that influence the ocean currents in the area. Factors influencing the high potential for ocean current energy in the Maluku Sea include the interaction between ocean currents originating from the Pacific Ocean and the Indian Ocean, temperature and salinity differences in the seawater, as well as the presence of islands and other natural obstacles that affect the water flow.

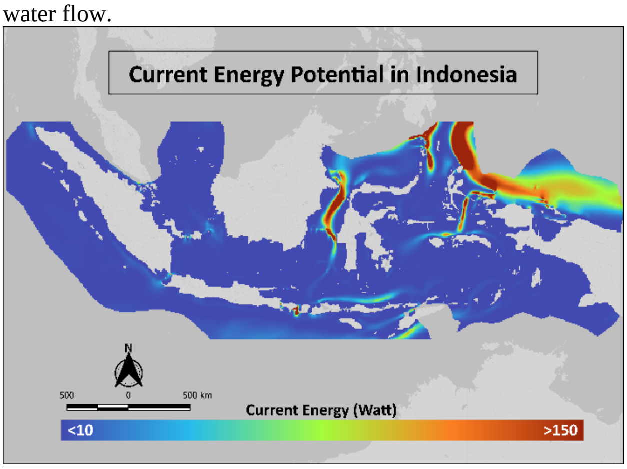

Figure 3. Current Energy Potential

3.2 Wave Energy

The highest potential for wave energy in Indonesia is found along the south coast of Java and Sumatra. This area has a significant wave energy potential due to its location along the Indian Ocean pathway, known for its strong and consistent long waves. The high potential for wave energy along the south coast of Java and Sumatra, as depicted in Figure 4, reaches its peak around Panaitan Island, Sangiang Island, and Simeulue Island. Factors influencing the high potential for wave energy in this region include the rugged marine topography, significant variations in water depth, and the influence of ocean currents.

In Figure 4, it can be observed that Panaitan Island has a wave energy potential of 23,051 kW/m, while Sangiang Island has a potential of 12,842 kW/m. These figures indicate the significant wave energy resources available in these specific locations along the south coast of Java and Sumatra. The high wave energy potential on Panaitan Island is attributed to its geographical position, which exposes it to strong and consistent long waves from the Indian Ocean. The rugged marine topography and the deep offshore waters contribute to the amplification of wave energy along the coast of Panaitan Island.

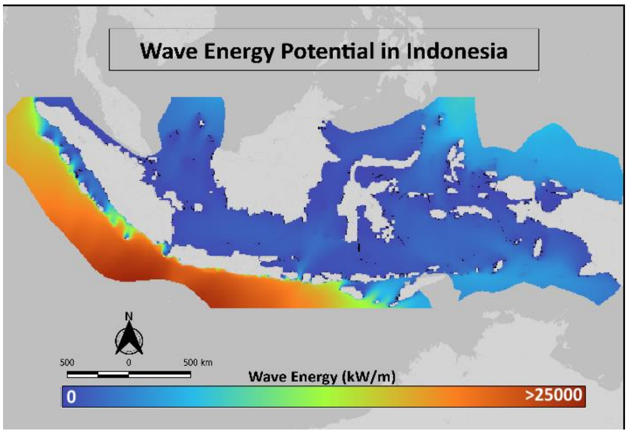

Figure 4. Current Energy Potential

3.3 Marine Habitat Suitability

Marine Habitat Suitability analysis, incorporate parameters such as SST, Chlorophyll-A concentration, Protected Areas, and Blue Carbon Areas. Chlorophyll-A and SST provide valuable insights into identifying optimal PFZ (the fish potential). The study reveals that regions with low PFZ and outside of Protected Areas and Blue Carbon Habitat exhibit high marine habitat suitability for renewable anergy contruction. In figure 5, The northern region of Papua and the southern region of Sumatra emerge as areas with particularly high marine habitat suitability. These areas offer favorable conditions for renewable energy construction. Therefore, the higher value of Marine Habitat Suitability, the higher suitable for renewable energy construction, and vice versa.

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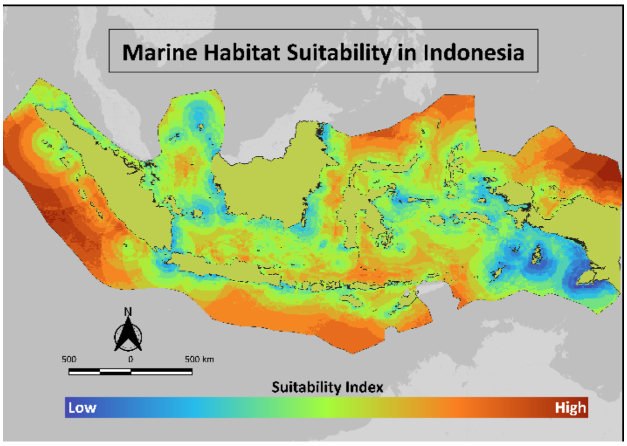


Figure 5. Marine Habitat Suitability

3.4 Current and Wave Energy Suitability

The development of renewable energy based on ocean currents, considering the potential and marine habitat suitability, highlights the suitability of the northern region of Papua and the Maluku Sea for current energy projects. The northern region of Papua exhibits a high potential for current energy generation. The marine habitat suitability analysis further indicates that this area possesses favorable environmental conditions for the implementation of current energy technologies. With strong and sustained ocean currents in this vicinity, the deployment of underwater turbines can effectively harness the kinetic energy of the currents and convert it into clean and renewable electricity for local utilization.

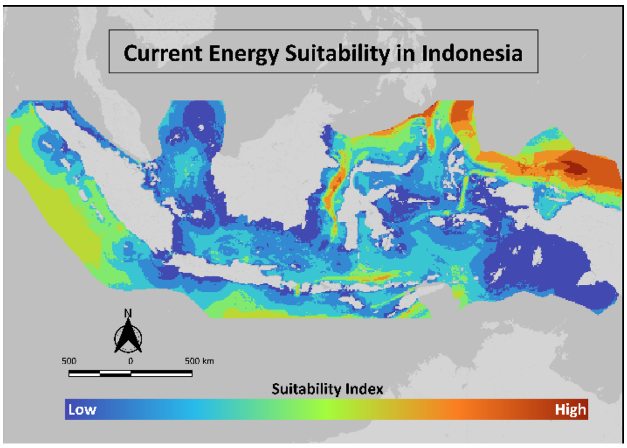
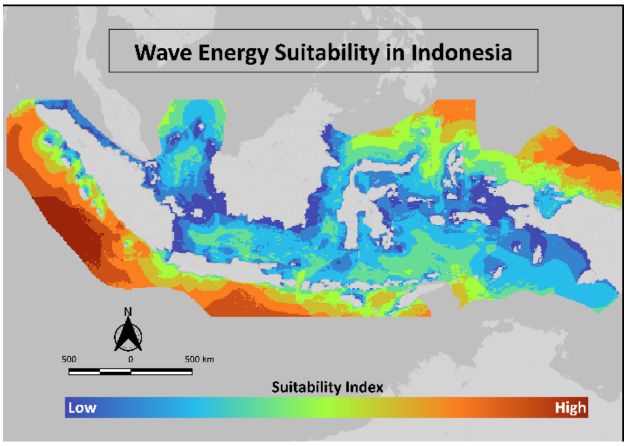


Figure 6. Current Energy Suitability

Furthermore, Wave Energy Suitability analysis reveals a high potential for wave energy in the southern regions of Java and Sumatra. This can be attributed to the presence of significant wave resources and their location outside the zones identified for optimal fishery potential. This makes these areas highly suitable for the installation of wave energy devices.

The southern coastlines of Java and Sumatra experience strong and consistent wave activity, making them ideal for harnessing wave energy. By deploying wave energy conversion technologies such as wave farms or buoy systems, the kinetic energy from the waves can be efficiently captured and converted into clean electricity. The abundance of wave resources in these regions offers a promising opportunity to exploit this renewable energy source and reduce reliance on fossil fuels.



3.5 Limitation and Future Study

One limitation of the current energy and wave energy suitability analysis in Indonesia is the equal weighting assigned to the different parameters used in the analysis. Treating all parameters equally may oversimplify the complex interactions between environmental factors and hinder a comprehensive understanding of the true potential of current and wave energy resources. Additionally, the analysis does not consider the involvement of other ocean renewable energy sources, such as geothermal energy, which could be a viable option in coastal regions with geothermal potential. Furthermore, the analysis lacks the inclusion of social factors and specific geographic conditions, which are important considerations for the successful implementation of renewable energy projects.

4. CONCLUSION

This study aims to develop the ORE model considering the marine site suitability. The current energy suitability model shows that the northern of Papua has the highest potential. On the other hand, the wave energy suitability model shows that the southern of Java and Sumatera have the highest potential for wave energy construction. By integrating the marine habitat suitability and the potential of renewable energy, the goal is to ensure that renewable energy installations are environmentally friendly and do not disrupt marine habitats.

REFERENCES

Apergis, N., Payne, J.E., 2012. Renewable and non-renewable energy consumption-growth nexus: Evidence from a panel error correction model. Energy Econ 34, 733–738. https://doi.org/10.1016/J.ENECO.2011.04.007

Boonsong, K., Piyatiratitivorakul, S., Patanaponpaiboon, P., 2003. Potential use of mangrove plantation as constructed wetland for municipal wastewater treatment. Water Science and Technology 48, 257–266. https://doi.org/10.2166/WST.2003.0331

Brown, A.J.G., Lewis, M., Barton, B.I., Jeans, G., Spall, S.A., 2019. Investigation of the Modulation of the Tidal Stream Resource by Ocean Currents through a Complex Tidal Channel. Journal of Marine Science and Engineering 2019, Vol. 7, Page 341 7, 341. https://doi.org/10.3390/JMSE7100341

CMEMS, 2019. Global Ocean Physics Analysis and Forecast | Copernicus Marine MyOcean Viewer [WWW Document]. URL https://data.marine.copernicus.eu/product/GLOBAL_AN

ALYSISFORECAST_PHY_001_024/description (accessed 6.27.23).

Daqamseh, S., Al, K., Pradhan, B., Al-Oraiqat, A., Daqamseh, S.T., Al-Fugara, kif, Habib, M., 2019. MODIS Derived Sea Surface Salinity, Temperature, and Chlorophyll-a Data for Potential Fish Zone Mapping: West Red Sea Coastal Areas, Saudi Arabia A geospatial model for the optimization grazing management in semi-arid rangeland of Iran View project Edge Detection of Potential Field Data View project MODIS Derived Sea Surface Salinity, Temperature, and Chlorophyll-a Data for Potential Fish Zone Mapping: West Red Sea Coastal Areas, Saudi Arabia. https://doi.org/10.3390/s19092069

Daqamseh, S.T., Mansor, S., Pradhan, B., Billa, L., Mahmud, A.R., 2013. Potential fish habitat mapping using MODIS-derived sea surface salinity, temperature and chlorophyll-a data: South China Sea Coastal areas, Malaysia. Geocarto Int 28, 546–560. https://doi.org/10.1080/10106049.2012.730065

Elinur, Priyarsono, D.S., Tambunan, M., Firdaus, M., 2010. Perkembangan Konsumsi Dan Penyediaan Energi Dalam Perekonomian Indonesia.

Flanders Marine Institute, 2019. Maritime Boundaries Geodatabase: Maritime Boundaries and Exclusive Economic Zones (200NM) [WWW Document]. URL https://www.vliz.be/en/imis?dasid=6316&doiid=386 (accessed 6.27.23).

Janssen P., A.L., B.A., K.G., L.C.K.C.O.B., n.d. PROJECT FINAL REPORT Grant Agreement number: 284455 Project acronym: MYWAVE Project title: MyWave: A pan-European concerted and integrated approach to operational wave modelling and forecasting-a complement to GMES MyOcean services.

KKP, 2019. MENUJU LAUT MASA DEPAN BANGSA.

Lasabuda, R., 2013. PEMBANGUNAN WILAYAH PESISIR DAN LAUTAN DALAM PERSPEKTIF NEGARA KEPULAUAN REPUBLIK INDONESIA. JURNAL ILMIAH PLATAX 1, 92. https://doi.org/10.35800/JIP.1.2.2013.1251

Leijon, M., Danielsson, O., Eriksson, M., Thorburn, K., Bernhoff, H., Isberg, J., Sundberg, J., Ivanova, I., Sjöstedt, E., Ågren, O., Karlsson, K.E., Wolfbrandt, A., 2006. An electrical approach to wave energy conversion. Renew Energy 31, 1309–1319. https://doi.org/10.1016/J.RENENE.2005.07.009

Mirzaei, A., Tangang, F., Juneng, L., 2014. Wave energy potential along the east coast of Peninsular Malaysia. Energy 68, 722–734. https://doi.org/10.1016/J.ENERGY.2014.02.005

Muetze, A., Vining, J.G., 2006. Ocean Wave Energy Conversion-A Survey Thermal Design of Electric Traction Machines Integrated in Hybrid Electric Vehicles View project Christian Doppler Laboratory for Brushless Drives for Pump and Fan Applications View project Ocean Wave Energy Conversion-A Survey. https://doi.org/10.1109/IAS.2006.256715

Nagelkerken, I., Blaber, S.J.M., Bouillon, S., Green, P., Haywood, M., Kirton, L.G., Meynecke, J.O., Pawlik, J., Penrose, H.M., Sasekumar, A., Somerfield, P.J., 2008. The habitat function of mangroves for terrestrial and marine fauna : A review. Aquat Bot 89, 155–185. https://doi.org/10.1016/J.AQUABOT.2007.12.007

Najeri, M., Syahrin, A., Muhammadiyah, U., Timur, K., 2018. Kebijakan Poros Maritim Jokowi dan Sinergitas Strategi Ekonomi dan Keamanan Laut Indonesia. Indonesian Perspective 3, 1–17. https://doi.org/10.14710/IP.V3I1.20175

NASA, n.d. Moderate-resolution Imaging Spectroradiometer (MODIS) Aqua Ocean Color Data, NASA OB.DAAC [WWW Document]. URL https://oceancolor.gsfc.nasa.gov/ (accessed 6.27.23).

Nikawanti, G., Aca[2], R., Guru, P., Anak, P., Dini Purwakarta, U., 2021. KEKAYAAN MARITIM INDONESIA Ecoliteracy: Building Food Security rom Indonesia’s Maritime Property. Jurnal Kemaritiman: Indonesian Journal of Maritime 2.

NOAA, 2022. What’s the difference between a tide and a current?

Pirttimaa, L., Cruz, E., Offshore, W., Disclaimer, R., 2020. Ocean energy and the environment: Research and strategic actions LEAD AUTHORS.

Purba, N.P., Kelvin, J., Sandro, R., Gibran, S., Permata, R.A.I., Maulida, F., Martasuganda, M.K., 2015. Suitable Locations of Ocean Renewable Energy (ORE) in Indonesia Region – GIS Approached. Energy Procedia 65, 230–238. https://doi.org/10.1016/J.EGYPRO.2015.01.035

Ramdhan, M., Arifin, T., 2018. APLIKASI SISTEM INFORMASI GEOGRAFIS DALAM PENILAIAN PROPORSI LUAS LAUT INDONESIA.

Richardson, R.L., Buckham, B., McWhinnie, L.H., 2022. Mapping a blue energy future for British Columbia: Creating a holistic framework for tidal stream energy development in remote coastal communities. Renewable and Sustainable Energy Reviews 157, 112032. https://doi.org/10.1016/J.RSER.2021.112032

Roland, Aron, Ardhuin, F., Magne, R., Filipot, J.-F.O., Van Der Westhuysen, A., Roland, Aaron, Queffeulou, P., Lefevre, J.-M., Aouf, L., Babanin, A., Collard, F., 2010. Semi-empirical dissipation source functions for wind-wave models: part I, definition, calibration and validation at global scales, Article in Journal of Physical Oceanography.

Sakti, A.D., Anggraini, T.S., Ihsan, K.T.N., Misra, P., Trang, N.T.Q., Pradhan, B., Wenten, I.G., Hadi, P.O., Wikantika, K., 2023. Multi-air pollution risk assessment in Southeast Asia region using integrated remote sensing and socio-economic data products. Science of The Total Environment 854, 158825. https://doi.org/10.1016/J.SCITOTENV.2022.158825

Sudjono, F., Egon, E.H., Menier, A., Methew, D., Pratama, M., 2021. Tidal Current Energy Resources Assessment in the Patinti Strait Indonesia. Indonesia. International Journal of Renewable Energy Development 10, 517–525. https://doi.org/10.14710/ijred.2021.35003ï

Twidell, J., Weir, T., 2015. Renewable energy resources.

UN, 2022. Ocean Data Viewer : Global Mangrove Watch [WWW Document]. URL https://data.unep-wcmc.org/datasets/45 (accessed 6.27.23).

Vicinanza, D., Cappietti, L., 2011. Estimation of the wave energy in the Italian offshore Coastal subsidence View project. Article in Journal of Coastal Research.

WDPA, 2023. Explore the World’s Protected Areas [WWW Document]. URL https://www.protectedplanet.net/en/thematic-areas/wdpa?tab=WDPA (accessed 6.27.23).