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Review

Establishing an Agenda for Biofouling Research for the Development of the Marine Renewable Energy Industry in Indonesia

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Abstract: Marine renewable energy holds strategic potential in Indonesia, not only to meet the target of renewable energy share in the national energy mix but also to provide equal access to clean energy throughout the archipelago. Marine energy in Indonesia is still in the early phase of development, which mainly focusses on resources assessment and power generation through technology prototype testing. Based on a review of available literature, it is found that specific research on the effects of biofouling on material durability of marine energy infrastructure in Indonesia has yet to be addressed. In this study, a matrix that identifies and predicts key fouling organisms and their possible risks on marine renewable energy infrastructure in tropical waters of Indonesia is developed by analysing previous findings in temperate and subtropical waters. Based on the matrix developed, calcareous polychaetes (Serpulidae), barnacles (*Amphibalanus* spp.), and bivalves (*Perna viridis*) are among possible key fouling organisms that might pose risks to marine energy infrastructure in Indonesia, such as by adding weight and drag and causing corrosion. Further studies and detailed and statistically robust analysis of the biofouling and its impacts are needed to support the development of the technological performance of marine renewable energy in Indonesia.

Keywords: marine renewable energy; biofouling; predictive matrix; Indonesia; tropical waters; review

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1. Introduction

1.1. Overview of the Energy Profile and Targets in Indonesia

Indonesia is part of the Southeast Asian region located between the Indian Ocean in the southwest and the Pacific Ocean in the northeast. It is a geographically dispersed country comprising many island and rural communities as well as large cities and has been facing energy challenges for many years. A report on energy security by Erahman et al. [1] concluded that availability, affordability, and accessibility of energy in Indonesia increased between 2008 and 2013. However, acceptability of energy security in minimising environmental impact and efficiency of energy tended to decline over time [1]. This analysis implies that the environmental aspects (acceptability) of energy technologies and share of renewable energy in Indonesia require a higher level of attention in order to move towards the targets to be met for minimizing the impact of global warming.

Considering the wide geographical area of Indonesia, with more than 17,000 islands, the provision of equal access to clean energy has been and continues to be an important issue. The opportunity to promote equal energy access is increasing now following changes in the national energy policy targeting renewable energy development. The new target is to have 23% of the national energy mix coming from new and renewable energy sectors by 2025 and 31% by 2050 [2].

The Secretariat General of National Energy Council, Indonesia also reported that total potential coming from various new and renewable energy resources is equivalent to around 442 GW, yet only 8.8 GW, or 14% of Indonesia's total 64.5 GW power plant capacity, was produced in 2018 from new and renewable sources [3]. Based on available data compiled in 2019, the resources and installed capacity of hydro, geothermal, bioenergy, solar energy, wind energy and ocean/marine energy are visualised in Figure 1.

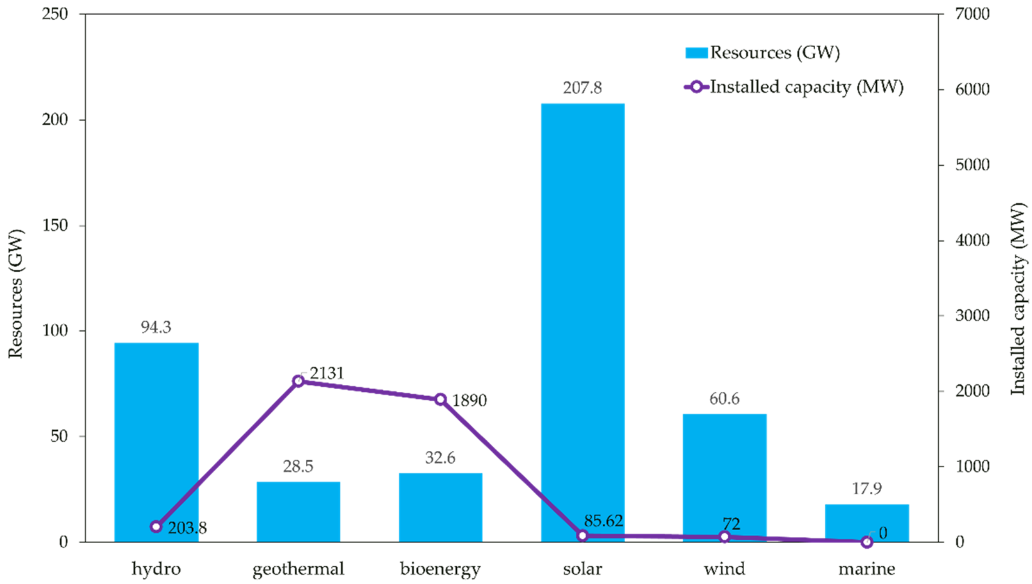

Figure 1. Estimated total resource (GW) and installed extraction capacity (MW) of various renewable energy sources in Indonesia (adapted from [3,4]). Note the difference in scaling between resource and installed capacity figures.

Despite the high target set for increasing renewable energy share, progress towards the targets has been slow. The energy provision supplied by renewable energy sources was only around 8–9% of total energy mix in 2017 [5]. Annual energy demand growth rate in country is projected to increase by 5.0%, 4.7% and 4.3% by 2050 for a Business as Usual scenario, Sustainable Development scenario and Low Carbon scenario, respectively [3].

There are several factors affecting the development of renewable energy ranging from regulation/policy uncertainty to financial barriers [5]. The same opinion was also expressed by a review study on stakeholder analysis of renewable energy industry in Indonesia [6]. This review highlighted a recommendation to develop breakthrough policy from political, economic, social, technological, legal and environmental aspects since the development of the RE industry in Indonesia is still quite minimal [6].

1.2. Overview of Marine Renewable Energy (MRE) Resources and Technologies in Indonesia

Based on the abundance of renewable energy resources available across the island nation of Indonesia, marine renewable energy shows promise as one of the options to be developed for provision of clean energy [2,7–10]. There is recognised potential for marine renewable energy (MRE) to be implemented in many coastal areas of Indonesia to provide equal access to clean energy and enable coastal development that could be socially and economically beneficial for the community e.g., job creation [2].

Several studies have been carried out to explore marine energy potential throughout Indonesian waters. Hidayati et al. [7] estimated the potential resource of ocean current energy in East Java waters using a hydrodynamics model simulation and field measurement validation. Based on these calculations, the most suitable locations with high ocean current energy are in Madura Strait (northern part of East Java), the Southern Waters of East Java, and Bali Strait [7]. Furthermore, a few other candidate sites in Indonesia waters have also been studied, including Riau Strait, Sunda Strait, Toyopakeh Strait, Lombok Strait, Alas Strait, Molo Strait, Larantuka Strait, Boleng Strait, Pantar Strait and Mansuar Strait with water depth ranging from 7 m to 150 m [8]. This study stated that a floating turbine design is appropriate for the tropical waters of Indonesia since the tidal current potential is more concentrated near the sea surface [8]. Based on the technical note produced by the Ministry of Energy and Mineral Resources, Indonesia, the practical potential of those ten straits was estimated as being up to 18 MW [11]. Current velocities at the sites vary from 1.39 to 3.40 m/s. However, since hydrodynamic data for the sites is limited, it is suggested that further detailed modelling and measurement should be conducted [8]. In order to provide more reliable data on tidal stream power for site selection, joint research has been carried out between German and Indonesian Governments. This investigation made a numerical model of Larantuka Strait as a case study and found 6 kW/m^2 of average tidal power density in this site with practically 20 GWh per year of energy yield [12]. A more recent study found that the average power density in this site can reach around 10 kW/m^2 with 3–4 m/s of current velocities [13].

In addition to tidal current energy, Indonesian waters also have significant wave energy potential, particularly in the western part of Sumatera Island, the southern part of Java Island, Bali and Nusa Tenggara Islands, and the northern part of Papua Island [10]. Wave power potential at the southern coast of Java Island has been assessed using the MIKE 21 Spectral Wave software [14], indicating that one of the best sites along the coast of Yogyakarta has a mean power intensity of 30 kW/m. The total practical potential of wave energy in Indonesia was estimated up to 1995 MW [11]. The potential locations having tidal current energy and wave energy resources in Indonesia are illustrated in Figure 2.

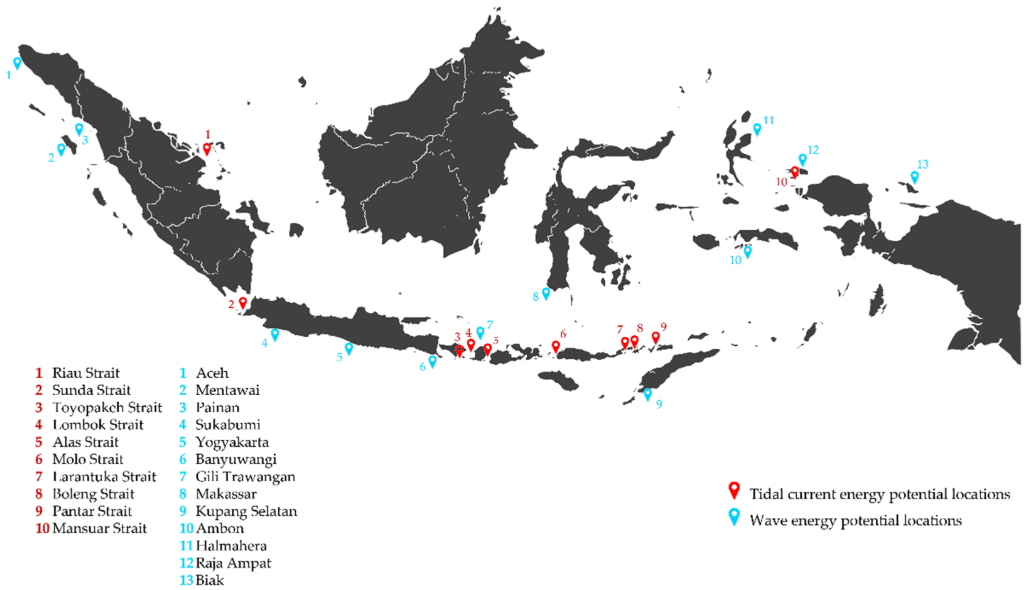

Figure 2. A map of locations of MRE resources in Indonesia (adapted from [7,8,10,11]).

In addition to studies assessing the abundance of the energy resource, some work has focussed on MRE technologies developed by groups of researchers in Indonesia [15–20]. An initial experiment to investigate the effect of fixed-pitch and passive variable pitch to vertical-axis turbine performance was carried out in 2011. It was reported that the use of passive variable pitch could minimize stall on the blade angle and maximize lift on azimuth in the rotation of the turbine [15]. A new design of Vertical Axis Hydrokinetic Turbine (VAHT) was developed by utilising cascaded blades and passive-pitch mechanism [16]. This new design was tested at low current velocities of power generation at 1.1–1.3 m/s and showed a contribution to improve energy extraction [17]. Another prototype using floating wave-current turbine design has also been developed since 2013 by the Indonesian Hydrodynamic Laboratory, Agency for the Assessment and Application of Technology (BPPT), Indonesia [18]. This study tested a 2-kW prototype installed under Suramadu Bridge, East Java. A wave energy converter (WEC) using a pendulum system was also invented in 2010, and an experimental approach was performed to analyse the novel geometry of a pontoon in maximising the amplitude of pendulum oscillation [19]. This study was then continued to investigate the mooring configuration by determining the heave, pitch and roll response of pontoon [20].

To support the acceleration of MRE development in Indonesia a robust research and development programme on existing technologies will be required. The role of such a programme will include the definition of any issues or challenges related to marine renewable energy technologies. Based on the review of available key studies focussed in Indonesia waters described here, MRE development is currently still focused at the stage of resource assessment and improvement of power harvesting technology performance. The detailed technical aspects from materials selection and marine environment have not yet been addressed by systematic research studies. One of the main challenges in the context of marine renewable energy technology is the durability of materials in the marine environment when impacted by marine biofouling and corrosion [21–23].

1.3. Introduction to Marine Biofouling and Associated Impacts

Biofouling has been a major issue for the shipping industry since the advent of containerisation in 1960s [24]. The aggregation of marine fouling organisms on vessel hulls increases the drag resistance causing higher fuel consumption [25,26], which will further escalate greenhouse gas emissions. This problem is a great concern for the shipping industry and other marine related sectors.

Generally, biofouling is mediated by the development of slime layers made by microorganisms (bacteria and algae) which then release biochemical cues through a process known as quorum sensing, facilitating the settlement of macro-organisms including barnacles, ascidians and serpulids [25]. A previous review on biofouling progression in tropical waters found that attachment of microbes and diatoms took 1–24 h, followed by settlement of invertebrate larvae and algal spores in 2–3 days, and macrofouling assemblage development in 3–4 weeks [27].

An accumulation of microorganisms can also lead to another industrial problem which is corrosion. This is well illustrated by studies on Microbiologically Influenced Corrosion (MIC) performed to investigate sulphate-reducing bacteria (SRB) activity [28–30]. Since then studies have been developed to monitor microbial numbers and activities, including the role of biofilms in initiating corrosion on the surface of metallic materials [31]. Corrosion on industrial equipment can be accelerated by the production of slime mass due to development of bacterial biofilms or through oxygen depolarisation released during microbial metabolism that creates electrical potential differences on the surface of metals [32]. Wu et al. [33] reported that oxygen depletion occurred in a medium containing both *Desulfovibrio* sp. and *Pseudoalteromonas* sp. leading to the weakening of corrosion inhibition efficiency in carbon steel.

1.4. Overview of Marine Biofouling Studies in Indonesia

A few key studies conducted in Indonesia related to biofouling are given in Table 1. The available previous studies of biofouling are categorised into seven groups, i.e., ship drag, biological invasion, bacterial biofilm, biocorrosion, biosecurity risk management, geographical aspects and mitigation measures. A summary of key studies on biofouling in Indonesia is as follows:

- Bacterial biofilm was investigated to identify the species that played a significant role in the formation of the biofilm [34] and to determine the influence of microhabitat, season and nutrients [35];

- Biological invasions of marine species have been considered in relation to activities of the shipping industry across different regions in Indonesia [36–38];
- A strategy for marine biosecurity risk management was studied [39];
- Biofouling on marine structures in shipping/vessel industry has been investigated by highlighting the impacts to ship drag and fuel consumption [40–43];
- Biocorrosion in artificial seawater has been studied [44], followed by mitigation measures using antifouling paints [45–47] and an impressed current system [48];
- A more recent study also focussed attention on the need for education and awareness raising regarding the spread of invasive non-native species due to vessel movements [38].

Table 1. Key biofouling studies using Indonesia as a case study location.

Author(s)	Research Area	Key Findings
Julistiono et al. [34] *	Bacterial biofilm (biofilm-forming bacteria)	The study isolated and screened bacterial colonies from Jakarta Bay and Madura Strait for biofilm formulation. Based on the molecular identification of isolates from both locations, it was found that the most active biofouling bacterial isolates in Jakarta Bay and Madura Strait were closely related to *Vibrio alginolyticus* and *Vibrio natriegens*, respectively. Both biofilm-forming bacteria were commonly found in the Java Islands waters.
Sawall et al. [35] *	Bacterial biofilm	The study identified bacterial composition and abundance patterns of coral reef biofilms from 4 regions in Spermando Archipelago, Indonesia. Strong influences of microhabitat type (exposed or sheltered), season and nutrient availability affected by anthropogenic activities were noted. On the other hand, variations in macrofouling community structure did not have a notable influence.
Azmi et al. [36] *	Biological invasion: Geographical aspects	The authors developed a hub—spoke network model to illustrate the level of shipping activity from 32 regions in Indonesia, with Tanjung Priok Port in Jakarta Bay as the main hub. Based on the data available, East Java, Central Java, and North Sumatera appear to have highest traffic frequency, with largest numbers of shipping activity from Tanjung Priok Port, which more likely to encounter the introduced marine species transfer. Regional shipping, with short travel distance (duration) and slow speed vessels used within intra-coastal transport, appear most likely to promote biofouling development reaching spoke ports.
Huhn et al. [37] *	Biological invasion	The study found that the Asian green mussel *Perna viridis*, a native organism in western Indonesia, was transferred to eastern Indonesia by domestic shipping activity. The green mussels collected in eastern Indonesia had lower body condition index than those in western Indonesia.
Huhn et al. [38] *	Biological invasion: education and awareness raising	Education and awareness raising among relevant stakeholders are important factors in preventing bioinvasions. The study has produced crucial baseline data on introduced marine species and raised awareness on the impact of vessel activities around Banda Islands to non-native species invasion that could cause biofouling settlement.
Azmi et al. [39] *	Marine biosecurity risk management	The study evaluated a bioregion pathway risk model and a species-based exposure risk model that can be utilised in managing limited biological data for marine biosecurity in Indonesia waters.
Nugroho et al. [40] **	Ship drag due to biofouling	Four important research strands were developed: (i) identifying the effect on drag of roughness on ship hulls, evaluated using Laser Doppler Anemometer (LDA); (ii) developing an image-based scanner for recording biofouling development on ship hulls; (iii) validating the LDA technique using a wind tunnel experiment; and (iv) linking the data from the first three strands with ship performance data (GPS coordinate, ship velocity and fuel usage).

Table 1. *Cont.*

Author(s)	Research Area	Key Findings
Yusim et al. [41] **	Ship drag due to biofouling	This study compared three different roughness models (smooth hull, regular roughness, irregular roughness) due to biofouling that cause ship drag/resistance.
Baital et al. [42] **	Ship drag due to biofouling	A computational fluid dynamics (CFD) simulation indicated that the ship drag due to biofouling would increase by up to 37% per year in the absence of mitigation measures.
Hakim et al. [43] *	Ship drag due to biofouling	Biofouling could affect ship resistance and hence power demand. The study found that if the ship operates in normal continuous rating (NCR), biofouling causes fuel consumption to increase by up to 16.7% in addition to the increase in sailing time. On the other hand, if the ship operates in maximum continuous rating (MCR), it will increase fuel consumption by up to 62.5%.
Pratikno et al. [44] *	Biocorrosion in artificial seawater	The biocorrosion rate of steel was accelerated by addition of bacteria with 3.7699 millimetres per year (mpy) as highest biocorrosion rate caused by *Thiobacillus ferrooxidans*. The heat treatment (austempering process) decreased the biocorrosion rate to 3.5046 mpy.
Nuraini et al. [45] *	Mitigation measures	Performance of anticorrosion and antifouling paints was compared and evaluated in a field test under Suramadu Bridge.
Priyotomo et al. [46] *	Mitigation measures	Preliminary investigation on the performance evaluation of antifouling paint in Mandara Bali found that sea depth variation of up to 3 m did not affect steel surfaces differently after exposure of up to 1-month immersion.
Aunurohim et al. [47] *	Mitigation measures	The study investigated natural macro-antifouling system performance using concentrates derived from the durian *Durio zibethinus*. Field tests conducted in a harbour area found that adhesion percentage of *Balanus amphitrite* declined with an increase of gel extract concentration, containing *D. zibethinus*, in the antifouling paint.
Pratikno et al. [48] *	Mitigation measures	An impressed current antifouling system was demonstrated to be useful in controlling microfouling development by reducing the bacteria (*Pseudomonas fluorescens*) population settlement. The population reduction of *P. fluorescens* was 98.5–99% with increasing time and electrical current.

* Peer-reviewed article. ** Non peer-reviewed article.

The key topics summarised in Table 1 show that the research theme of biofouling in Indonesia has not been well addressed as a specific topic for marine renewable energy infrastructures. Due to the paucity of available research studies, datasets on biofouling on MRE in Indonesia can be identified as a knowledge gap, demonstrating a need for robust and systematic studies to inform future MRE development.

1.5. Knowledge Gaps

Despite the enormous energy potential available from tidal and wave sources, the MRE industry in Indonesia is still in the research and development phase. In this phase, Indonesian researchers have dedicated their time to deliver a few successful prototypes tested at sea. However, previous studies in Indonesian waters have mostly focused only on resource assessment and power generation without addressing issues of the durability of materials placed into the marine environment.

The number of studies carried out on biofouling in Indonesian waters is small (Figure 3). Specific studies on marine biofouling and its associated impacts on materials durability for MRE infrastructure have yet to be conducted. To the best of the authors' knowledge, there is a significant knowledge gap between what research has been conducted to date on marine biofouling in Indonesian waters and what knowledge base is needed to help inform the design and development of MRE technologies in tropical waters in the future.

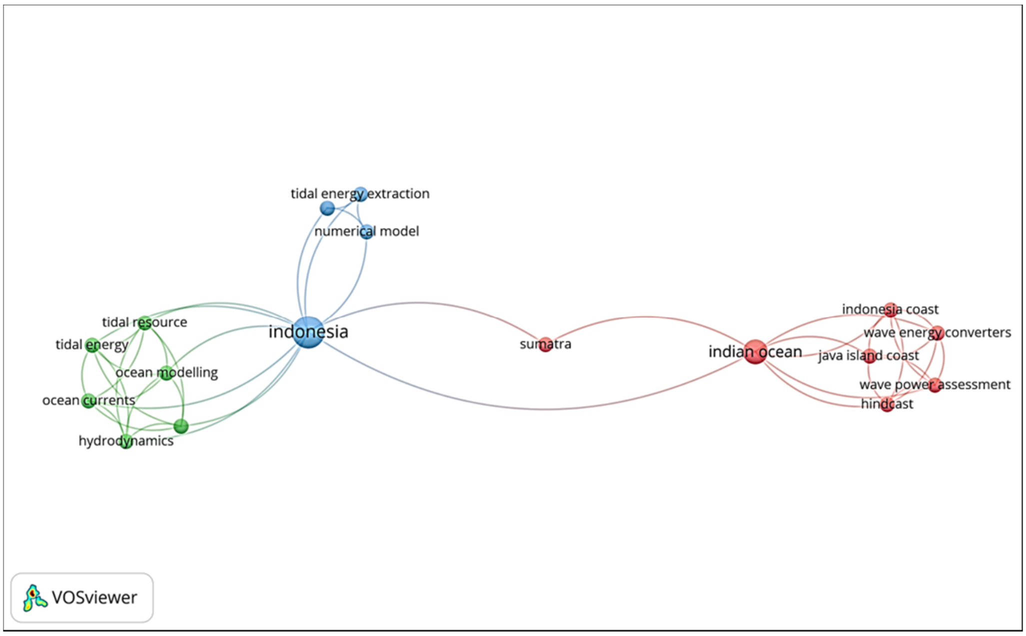

Figure 3. Keyword co-occurrence map based on bibliographic data of publications from 2000 to 2020 in the field of MRE in Indonesian waters (see Supplementary Materials for details of the analysis).

By comparison, in the temperate waters of the UK, a number of studies of biofouling specifically focusing on the field of MRE have been conducted:

- Identifying biofouling community composition on MRE device/infrastructure, including determining the dominant fouling organisms and their periods of settlement [21,22];
- Assessing biofouling impacts on the device operation [22,49–51];
- Identifying implications of offshore renewable infrastructure as stepping-stones for non-indigenous marine species [52].

We suggest, based on these observations that there is an opportunity to fill the research gap for tropical waters by adapting the learning from previous studies in UK waters and other temperate regions and designing a robust research programme to obtain the evidence base needed to underpin MRE design and development in Indonesia.

The objectives of this study are to: (1) synthesise previous findings on biofouling studies and the impacts on MRE technologies in temperate waters, and (2) reflect the findings as lessons learned to develop a predictive matrix for tropical waters. The predictive matrix in this study is defined as a matrix that identifies and predicts key fouling organisms and the risks they may pose on MRE infrastructure in tropical waters of Indonesia. The prediction is developed based on the findings and lessons learned from previous studies on MRE in temperate waters in conjunction with the knowledge base of fouling organisms from offshore structures in regional tropical waters.

2. Case Studies in Temperate Waters

2.1. Overview of Marine Biofouling Research in Recent Years

Biofouling settlements on ship hulls and anthropogenic activities in ports or marinas have been associated with the invasion of non-indigenous species (NIS) which cause economic loss and endanger ecosystem biodiversity [25,53]. According to Elizabeth et al. [53], hull fouling was one of the factors that influenced the spread of NIS from Japanese waters to British waters, causing rapid expansion throughout the region. Moreover, it has also been reported that around 47% and 30% of NIS introduction to British waters has been affected by two major vectors, namely vessels (hull fouling and ballast water) and aquaculture activities, respectively [54].

Both environmental and economic impacts of marine biofouling have been studied. Farkas et al. [55] predicted the impact of biofilms on ship propulsion characteristics using Reynolds Averaged Navier-Stokes (RANS) equations. It was reported that for the most severe surface condition with highest fouling rate, thrust coefficient (K_T) is estimated to decrease in the range between −1.9% and −5.3% due to biofilm presence, while torque coefficient (K_Q) is estimated to increase in the range between 0.93% and 4.59%. The highest fouling rate leads to estimated decreases in open water efficiency (η_0) varying from −2.8% to −9.4%. Moreover, the study also found that η_0 also shows decreases, estimates varying from −0.24% to −0.82% for the surface condition with the lowest fouling rate. Moreover, Farkas et al. [55] reported the impact of biofilm presence on the speed reduction of ship. Speed reductions for the surface with the highest fouling rate were estimated to be around −8.41% and −8.57% for design speed and slow steaming speed, respectively. On the other hand, for the surface with the lowest fouling rate, estimated speed reductions are negligible, particularly at slow steaming speeds. These findings led to the conclusion that biofilm presence can have detrimental impacts on propulsion characteristics and speed reduction of ships, even though it is classified simply as slime (soft fouling) [55].

Economic impact of biofouling to European shipping was studied by Fernandes et al. [56] by comparing impacts of native species and NIS. It was reported that NIS may have higher impact on fuel consumption than native species based on studies compiled in three European seas, i.e., Baltic Sea, North Sea and Western Mediterranean Sea. The parameters used for comparison were: (i) biological traits, such as rapid growth parameter, length-weight parameter, salinity range and hydrodynamic resistance, (ii) high abundance or prevalence on panel, and (iii) resistance level to anti-fouling system or pollutant. The study reported that NIS have higher mean values for all parameters than native species, except for salinity range. Operational costs for mitigating NIS were estimated between 1.6% and 4% of the annual operational cost for ships operating in Europe. Despite limitations of available data, this study gave an estimation framework for further investigation [56].

Several guidelines for managing biofouling on ships have been developed by the International Maritime Organization (IMO). One of the guidelines provided by IMO is for controlling and managing ship's fouling to minimise the transfer of invasive species (MEPC.207(62)). From 2007 to 2017 IMO in collaboration with GEF and UNDP co-ordinated the GloBallast Partnership Programme to implement the Ballast Water Management Convention. The main objective of this programme was to assist developing countries in mitigating the transfer of harmful aquatic organisms in ship's ballast water (http://archive.iwlearn.net/globallast.imo.org/, accessed on 4 December 2020). In 2017, IMO initiated a 5-year project called Glofouling for building capacity in developing countries to implement biofouling guidelines. Twelve Lead Partnering Countries involved in this project are Brazil, Peru, Ecuador, Mexico, Fiji, Tonga, Indonesia, Philippines, Sri Lanka, Madagascar, Mauritius and Jordan (https://www.glofouling.imo.org/, accessed on 4 December 2020).

A few practical measures to minimise introduced NIS have been carried out, such as freshwater washing for marine structures, aerial exposure, jet washing, mechanical clearance, enclosure of artificial structures and antifouling systems [53]. One measure that has been investigated to be effective in inhibiting biofouling formation on vessel hull is the use of a low-frequency ultrasonic device. It was reported that lower ultrasonic frequencies between 17 and 30 kHz are more effective to inhibit barnacle formation than higher ultrasonic (hundred kHz) and audio frequencies [57]. Another measure reported by De Castro et al. [58] is by applying a low salinity treatment on a ship's sea chest. This study was based on comparison of biofouling organisms' mortality levels with salinities of 7 psu, 20 psu, and 33 psu (control). It was found that by applying 2-h low salinity treatment (7 psu) all macrobenthos settled on the panel perished after 1 week. However, recolonization occurred on the salinity 7 psu panel after a 1-month exposure [58]. These findings indicate that in some situations a low salinity treatment could be used as a low cost, low tech and environmentally friendly tool in controlling biofouling in marine structure (ship's sea chest) despite the short period of its effectiveness.

Nevertheless, it has been recorded that around 34% of 90 alien species introduced in British waters can tolerate low salinity levels [54]. The majority originating of these alien species were from the North Pacific Sea (39%) and some of the species (*Crassostrea gigas* and mussels) have specific impact on fouling in shallow water marine environments. This study was based on data compilation of alien species in British marine and brackish waters by dividing the area into three regions, i.e., English Channel, Celtic Sea and North Sea [54]. In order to address the alien species invasion, and to prevent detrimental consequences to both the ecosystem and to the marine economy, development of surveillance and monitoring control as an early detection holds an important key to managing the impact [53,54].

2.2. Biofouling on MRE Technologies in Temperate Waters

The impacts of marine biofouling on the shipping industry have been investigated widely, including the implications for structure/component integrity and associated costs. Other marine infrastructures being affected by biofouling are offshore oil and gas platforms [59,60] and marine renewable energy [21,22,49–52]. This section will emphasise biofouling cases on MRE technologies in the temperate waters of the UK.

Macleod et al. [21] investigated biofouling communities across a range of geographical areas, environmental conditions and durations of deployment of navigation buoys. From this study of 29 navigation buoys deployed at several locations on the west and north coast of Scotland, it was found that geographical area influenced 28.4% of the variation in the biological data followed by deployment durations (4.1%), temperature (3.8%), salinity (2.4%), and tidal flow (1.6%). These findings indicate that despite the range of environmental conditions (temperature, salinity and tidal flow) applied to the structure, geographical locations hold the more important role in the establishment and growth of biofouling community. Blue mussel (*Mytilus* sp.) dominated the biofouling community with >95% coverage area on the navigation buoys and a weight per unit area of 33 kg/m^2. This biofouling community should be taken into higher consideration since it was associated with the heaviest loading characteristics that increase the size and roughness of marine structural components [21].

Another study on biofouling community was carried out for MRE infrastructure in Orkney, Scotland and their hydrodynamic consequences was also investigated [22]. This study utilised a wave buoy and Acoustic Doppler Current Profiler (ADCP) to record composition and degree of biofouling occurring on the devices and identify the impact to accuracy performance of data recording since the hydrodynamics response and efficiency might be compromised. Additional field surveys were carried out in 11 different locations including harbours, piers, marinas and marine energy test sites within Orkney waters to provide a local context of biofouling community variation. A total of 141 species were identified as fouling species, of which six were non-indigenous. It was found that the highest number of total fouling species were found at marinas and harbours, including six non-indigenous species [22]. This finding corroborates the study performed by Macleod et al. [21] reporting that tidal current regimes surrounding navigation buoy devices do not have strong explanatory power in biofouling variation. Another important finding from Want et al. [22] is that based on the statistical analysis, shallow water fouling species were dominantly found in marinas and harbours where photosynthesis was possible. On the other hand, animal species such as barnacles were found on the ADCP frame and Waverider buoy where hydrodynamic force and water depth may be important factors in selecting fouling species. Based on the numerical modelling of the Waverider buoy's heave response, it was also found that with the increased amount of biofouling the high frequency response of buoy was decreased by up to 2% [22].

Apart from those two studies [21,22], an investigation on the variation of biofouling assemblages on wave energy device was carried out for the Pelamis attenuator device prototypes deployed at Billia Croo, Orkney [49]. Similar to Want et al. [22], this study identified the temperate biofouling community on the device and assessed the implications for device performance [49]. Based on sampling and data analysis, it was found that biofouling community differences exist due to depth. From 115 taxa recorded from the sampled devices, the algae *Alaria esculenta*, *Acrosiphonia arcta*, *Ulva* sp. and *Polysiphonia* sp. prevailed in shallow subtidal areas (up to 0.25 m water depth) and total biomass on the outer surfaces was greater than on the intersections of the device. In contrast, the invertebrates such as *Diplosoma listerianum*, *Ascidiella aspersa*, *Balanus crenatus*, and empty barnacle/serpulid shells dominated a deeper location (0.5–2 m water depth) [49]. This finding corroborates other studies [21,22] stating that biofouling species can vary based on the water depth. Moreover, this study also highlighted the ecological and technical implications of biofouling on MRE infrastructures. The authors stated that the hard-substratum assemblages on the secondary artificial reefs could increase biodiversity and biomass, which then boost availability of nutrient to the surrounding benthic macrofauna. This condition could lead to further contribution of recruitment and aggregation of higher tropic level species. In addition to that, the authors also considered the impact of increased structural weight and hydrodynamic loading due to biofouling which may reduce buoyancy and increase fatigue [49].

In addition to increased weight and hydrodynamic loading, biofouling could also affect the mooring lines and power cables used in wave energy converter (WEC) systems [50]. Yang et al. [50] reported that marine biofouling could degrade the total power absorption of WEC by up to 10% and reduce the fatigue life of mooring lines by 20%. This study was performed by simulating three different biofouling conditions, two mooring configurations and four sea states [50].

It has also been reported that offshore renewable infrastructure could act as stepping stones for non-native marine species invasion [52]. Adams et al. [52] investigated the effect of offshore renewable infrastructure on the dispersal of marine organisms by using a biological and hydrodynamic model to identify the implication of novel offshore habitat for the spread of NIS. Based on simulations for each possible habitat configuration, this study found that offshore renewable infrastructures have potential as ecological stepping stones for marine species which could allow organism invasion from Northern Ireland to Scottish coastline [52].

As mentioned in Section 2.1, IMO has developed guidelines for controlling and managing biofouling specifically for the shipping industry, including measures to reduce NIS invasion. However, there is currently no guideline specifically address MRE industry. Loxton et al. [51] stated that current guidance for biofouling on MRE technologies is derived from observation of the oil and gas industry, which might have different characteristics of biofouling organisms with wave or tidal device due to different marine environment for deployment. This issue is crucial and requires further investigation since the MRE industry in the UK has reached commercial stage requiring standards to maximise the operational and maintenance. Loxton et al. [51] compiled input from industrial, academics and regulatory sectors to identify benefits and negative impacts of biofouling from engineering and ecological aspects. This study was anticipated to enable future development of industry guidelines. Future overarching research areas associated with biofouling and MRE were categorised and prioritised into: (i) operation and maintenance, (ii) structural design and engineering, (iii) ecology, and (iv) knowledge exchange. Within the operation and maintenance category, biofouling impact on the device operation was the most highlighted aspect. It includes an increase of component diameter, surface roughness and drag. Furthermore, component failure was highlighted in the structural design and engineering category, which include mechanical wear and abrasion, material degradation, corrosion and unexpected loads. Lastly, considering capability of MRE device for the settlement and dispersal of NIS, invasive species risk and biosecurity were emphasised in the ecology category [51].

3. Case Studies in Tropical Waters

3.1. Overview of Marine Biofouling Studies Conducted in Recent Years

3.1.1. Indonesia

As discussed in Section 1.4, a few studies of marine biofouling covering research areas ranging from bacterial biofilm to mitigation measure have been carried out in Indonesia. Julistiono et al. [34] investigated the identification of biofilm-forming bacteria around Java Island waters by performing one-month immersion of test panels in Jakarta Bay (located in western part of island) and Madura Strait (eastern part of island). The bacterial colonies isolated from these two sites using 16S rRNA gene sequences analysis were identified as *Vibrio alginolyticus* and *V. natriegens* in Jakarta Bay and Madura Strait, respectively with 99% of similarity. These bacteria were commonly found in Java Island waters [34]. Investigation on the pattern of bacterial dynamics for coral reef biofilms performed by Sawall et al. [35] found that the changes in the pattern of bacterial communities in Spermando Archipelago were significantly influenced by microhabitat, seasonal change and nutrient availability due to anthropogenic activities. However, this study also reported that seasonal change did not affect notably the macrofouling community structure [35].

Azmi et al. [36] developed a hub-spoke network model to characterise the immensity of marine biosecurity issues in Indonesia due to the high level of intra-coastal shipping activities which potentially increase biofouling risk to 32 regions in Indonesia. This study was corroborated by Huhn et al. [37] which found that domestic shipping activity facilitated marine species transfer from the western part of Indonesia to the eastern region. Hence, an effort to increasing education and raising awareness to vessel owners and operators would be beneficial as one of the ways in reducing marine bioinvasion [38].

In addition to shipping activity, a few studies reported correlation between marine biofouling, ship drag and fuel consumption [40–43]. Based on the modelling and simulation, it was found that marine biofouling settlement might increase ship drag by up to 37–41% per year [41,42] and increase fuel consumption by up to 20% after the one-year operation [43]. According to a preliminary result of study performed by academics, industry and policymaker concluded that a better understanding of biofouling impacts on the ship's hull and methods to improve ship operation would be obtained by developing a large-scale research collaboration between those sectors [40].

The relationship between marine biofouling and corrosion was studied by Pratikno et al. [44] by using heat-treated material. It was reported that heat-treated steel is more resistant to biocorrosion than non-heat-treated steel. However, this study was performed using artificial seawater [44], thus, the long-term impact of marine biocorrosion on the materials may not be quite the same as the impacts when placed in the actual marine environment [31]. Furthermore, a study on biofouling mitigation measures was performed by Nuraini et al. [45] by evaluating anticorrosion and antifouling paint performances. It was reported that after 1-month immersion in splash and tidal zones, fouling organisms covered both surfaces of bare mild steel and steel with anticorrosion paint. On the other hand, there was no fouling settlement on the surfaces with antifouling paints [45]. Another evaluation of antifouling paint performance was investigated by Aunurohim et al. [47] by using *Durio zibethinus* as a natural biocide compound of macro-antifouling paint. By varying the concentration of gel extract in the antifouling paint i.e., 0, 25, 50, 75, and 100 ppm, the adhesion percentage of *Balanus amphitrite* declined from 66.1% to 47.8% [47].

3.1.2. Other Tropical Countries

Wells et al. [61] reviewed around 90 papers and reports recording marine species present on the shallow water ($\leq$50 m) of Singapore. The records included NIS that have been introduced into Singapore's waters. Of the 3650 marine species that have been recorded, only 22 are categorised as NIS in Singapore's waters; however, there is very little evidence of NIS becoming established in Singapore waters [61]. It was hypothesised that the low number of NIS being introduced into tropical waters of Singapore is because of the biotic resistance of the local environment. The biodiversity of tropical waters makes the interaction between local species increase leading to higher competition. Consequently, the possibility of NIS becoming established in this environment is low. It was also reported that any introduced marine species in Singapore's waters were sourced from countries in relatively close proximity (Malaysia, Thailand or Indonesia) through shipping activities [61].

The diverse distribution of polychaete species as fouling organism was investigated in sub-tidal zone of Kudankulam waters, South East of India [62]. Based on submersion tests carried out during pre-monsoon, monsoon and post-monsoon seasons between May 2003 and July 2005, *Perinereis cultrifera*, *Platynereis dumerilii*, *Syllis variegata*, *Syllis truncata*, and *Eunice australis* were found as dominant species on the panels. Satheesh and Wesley [62] reported in this study that seasonal variability in tropical waters gave influence in recruiting fouling organisms. For example, tubiculous polychaetes from the Sabellariidae family were found mainly in the monsoon season rather than in pre-monsoon and post-monsoon seasons. On the other hand, Eunicidae and Syllidae were most abundant in pre-monsoon season, whereas Nereidae were found in high abundance in both monsoon and post-monsoon seasons [62].

Similarly, a study on a tropical estuary to investigate the structure of biofouling community based on tropical monsoon period was carried out on the West Coast of India [63]. Polyvinyl Chloride (PVC) panels were used for immersion tests at subsurface water levels between May 2012 and September 2013. During the test, seasonally variations in biofouling community were observed. For example, silt and slime were found consistently throughout the observation period. On the other hand, the barnacle *Amphibalanus amphitrite* was recorded as the dominant biofouling organism with the highest abundance in the monsoon period (August and September). Calcareous polychaetes were the second most dominant biofouling organisms found during the late post-monsoon and pre-monsoon months (December 2012–April 2013). Moreover, it was confirmed that the barnacle was a fouling organism that can survive salinity stress within monsoon period. The salinity range during monsoon period was between 4.0 and 31.5 psu, whereas the salinity levels during the pre and post-monsoon periods were ranged between 33 to 36.7 psu and 28.2 to 35 psu, respectively [63].

Complementing these studies [62,63], Lin et al. [64] reported that the number of species and settlement rate of fouling organism community in subtropical coastal areas of the southwestern East China Sea are closely related with temperature patterns. Out of a total of 84 species, the barnacle *Amphibalanus reticulatus* was recorded as the most dominant fouling organism, followed by the amphipod *Caprella equilibra*. Settlement of *A. reticulatus* occurred between April and September, peaking in summer (August) with a water temperature of 30 °C [64].

Lim et al. [65] carried out biofouling surveys simultaneously in a few major port areas within the ASEAN region to identify the diversity of marine organisms. Nine South-East Asia countries, namely Indonesia, Malaysia, Singapore, Brunei Darussalam, Thailand, Philippines, Lao PDR and Vietnam were the collaborators in the international study since information on marine biofouling organisms in these countries was sparse, especially for port areas where vessel activity is one of the factors affecting biofouling development and NIS transfer. By immersing PVC panels in major ports for a specific period between May 2012 and December 2013, monthly and long-term fouling data were collected, and the composition of fouling organism was observed [65]. Based on this international study, barnacles *Amphibalanus* sp. was commonly found contributing to monthly settlement in all case study sites, except in Hai Phong-Vietnam and Yangon-Myanmar. In Manila Bay-Philippines and Kertih-Malaysia, the barnacle covered the PVC panels almost completely. In Tanjung Priok-Indonesia, serpulid tubeworms were found to dominate (covered >80% of PVC surface). The study also found that the frequent changing of plates disturbed the settlement of bivalve molluscs for monthly sampling [65].

3.2. Biofouling on Offshore Structures in Tropical Waters and Possible Further Research for MRE in Indonesia

As discussed in Section 1.2 (overview of MRE sector in Indonesia) and Section 1.5 (knowledge gaps), it is noted that marine renewable energy research conducted so far in Indonesia has not specifically and robustly addressed biofouling impacts on marine renewable devices/infrastructures. While some biofouling studies have been conducted for other sectors, none have yet been directed to identify issues specifically associated with development of the MRE industry.

This statement is supported by a bibliographic map (Figure 3) developed using VOS Viewer software that analysing articles in MRE sector published between 2000 and 2020 with Indonesia as case study. The metadata of this bibliographic map was obtained from Web of Science (see Supplementary Materials for more detailed information).

As can be seen in Figure 3, the studies of MRE in Indonesian waters focused mainly on: (a) tidal current and wave resources assessment, including hydrodynamics and numerical modelling; and (b) energy extraction by developing technology prototypes. None of these previous studies in MRE have connection with biofouling which emphasises the wide opportunity to perform biofouling research in Indonesian waters. Due to the limited availability of references in MRE study discussed above, in this section we will emphasise the current state of knowledge regarding biofouling cases on other offshore structures generally either in tropical or subtropical waters and reflect on the possible relevance of these findings to MRE infrastructure in Indonesia.

Yan and Yan [66] reviewed biofouling investigations in China to identify the fouling succession mechanism in different offshore installation areas. The first investigation site was located at Bohai Sea, north part of China, near five fixed offshore platforms. The study found that the type and extent of fouling organism on these platforms were related to geographical location, installation time, distance from the shore and water depth. The most dominant fouling organism on offshore platforms installed in the Bohai Sea was the mussel *Mytilus edulis* with fouling thickness varying from 1 to 32 cm [66]. On the other hand, eleven buoy stations were deployed in the northern South China Sea to investigate fouling community in the fixed marine platforms and floating marine installations. The common oysters were found mainly in the fouling community on the fixed marine structures, whereas stalked barnacles and hydroids dominated fouling community on the floating marine installations [66].

Following Yan and Yan [66], Cao et al. [67] conducted a more recent review study on fouling acorn barnacles in China waters, including the Bohai Sea and South China Sea. Results of this study showed that the barnacles *Amphibalanus amphitrite* and *Fistulobalanus kondakovi* dominated mostly on the submerged part of the offshore oil platforms located in the Bohai Sea with a settlement period between June and October. In contrast, *Amphibalanus reticulatus* was discovered commonly in the offshore area of Zhujiang River Delta and Hainan Island located in South China Sea with settlement taking place throughout the year [67].

Another investigation of fouling organism impacts on offshore structures was also performed in the Gulf of Guinea to identify the pattern of colonisation processes of the dominant hard fouling organisms in four different regions [68]. In one region, it was found that barnacles dominated the first years of colonisation. It was then followed by a mixed stage after 5 years of platform installation where corals and barnacles colonised the structure together, and finally, only corals prevailed on the structure surface in the next stage. This study also highlighted that depth influences the process of species competition associated with concomitant effects of temperature, light and nutrition [68].

Based on these three studies, a reflection on relevance to MRE infrastructure in Indonesia can be developed by highlighting the key fouling organisms found on the offshore structures in China waters and the Gulf of Guinea, i.e., mussels and barnacles. However, the marine growth colonisation process from different regions will not always proceed in the same way, as highlighted by Boukinda et al. [68]. Therefore, the influencing factors from surrounding environments need to be considered carefully for further research in Indonesian waters. It needs to be noted that fouling organism in Tanjung Priok port of Indonesia, i.e., serpulid tubeworms have been also identified by Lim et al. [65], which adds to possible key fouling organisms affecting MRE infrastructure in Indonesian waters. This highlights that further research on biofouling community identification in tropical waters of Indonesia is needed which includes using types of material widely used for marine renewable energy infrastructures or devices. The comprehensive identification of biofouling community settling onto relevant types of material would be beneficial to underpin development of mitigation plans for biofouling which directly impacts the technology design and development of marine renewable energy in Indonesia.

4. Discussion: Lessons Learned from the Temperate Water Experience

The aim of this review is to synthesise the knowledge regarding biofouling studies on MRE in temperate waters and reflect on the lessons learned as recommendations to implement in the tropical waters of Indonesia. In order to create a good basis of understanding from the perspective of both Indonesia and UK waters, the development stages of the marine energy industry in the two countries will be discussed first, followed by technology challenges, including biofouling impacts on the devices. Possible risks of biofouling on MRE infrastructure in tropical waters of Indonesia will be also discussed by reflecting the current findings of studies in temperate waters.

4.1. The Importance of Biofouling Studies in Marine Renewable Energy Industry

The initial research and development programme of renewable energy in the UK began with wave energy as the initial front runner in the 1970s with device development and open water trials [69]. An overview paper produced in 1976 on energy research and development in the UK estimated the long-term potential of wave energy might be up to 50 million tonnes coal equivalent (MTCE) per annum by 2025. By the early 1980s, some researchers in the UK had estimated unit cost for wave and tidal power systems was around 4–12 p/kWh and 2.8–3.1 p/kWh with technical potentials were 66 TWh per annum and 13 TWh per annum, respectively. The Energy Technology Support Unit (ETSU) reported that the potential of renewable energies showed some prospects with about half to two-thirds of the total energy supplied by coal, oil, and gas, but the figures did not take into account of the economic and environmental constraints. Hence, the Government's support is needed to make the technologies established. In the following years, industrial groups in the UK took an interest in developing renewable energy technologies, including Severn tidal barrage and small tidal current devices using horizontal tidal flows [69]. In the early 2000s, research showed that biofouling could affect the efficiency of marine current turbines performance [70], and since then biofouling became an important issue for the MRE industry. The interest in studying the implications of biofouling for the MRE industry is growing as the industry has entered the commercial stage with more attention now being paid to operational and maintenance issues for ensuring longevity of the devices [51].

On the other hand, research on MRE technology in Indonesia, particularly for ocean current technology, was firstly started in 2008 with the development of a 2 kW vertical axis turbine prototype [71]. This prototype was developed by the Agency for Hydrodynamic Technology and was tested in Flores Strait, Indonesia. The prototype was further developed into its fifth generation in 2016 with several field trials in Flores Strait and Suramadu waters with energy output ranging between 1.6 and 3.1 kW [71].

As illustrated in Figure 4, there is a wide difference in the phase and gap for MRE development stage in the UK and Indonesia. However, considering that the development stage in Indonesia is still at early phase, it is timely to advance comprehensive research in biofouling to positively support the technological performance in tropical waters of Indonesia. In addition to strengthening national technology capacity, the MRE industry in Indonesia may also be developed more rapidly by utilising international technologies which have been technically proven. Nevertheless, the adoption of international technologies in

Indonesian waters would need modification and adaptation appropriate to the tropical marine environment, covering site location characteristics such as bathymetry, current velocity, topography and biofouling community. Hence, it is essential to embed biofouling research into the development plan for the MRE industry in Indonesia.

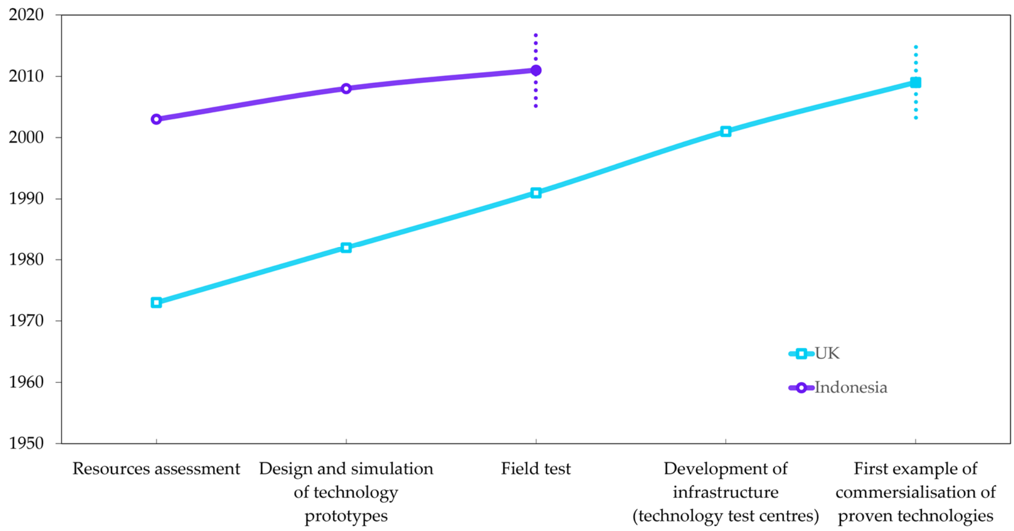

Figure 4. The development stage of MRE industry in the UK and Indonesia. (Solid circle and square with dotted lines indicate that the development stage in both countries until today).

4.2. Biofouling Database for MRE in Temperate Waters

A biofouling database for MRE sector in the European temperate waters provided by Vinagre et al. [72] gives an insight for developing a framework for biofouling research in tropical waters of Indonesia and elsewhere, as illustrated in Figure 5. This study highlighted a few essential findings for MRE sector in temperate waters: (i) identification of key fouling organisms affecting MRE infrastructures, (ii) main influencing environmental factors, and (iii) impacts on MRE structures. The key fouling organisms found dominantly on MRE structures are kelp, bryozoans, mussels, barnacles, and calcareous tubeworms. Each key fouling organism has their unique characteristics and life cycle features affecting their settlement. For example, mussels usually can be found in the intertidal and subtidal zones and settle dominantly on offshore structures with 30 m of depth with a lifespan of more than 10 years and size up to over 100 mm. On the other hand, kelp usually can populate between tidal zone and a depth of 30 m because of high concentration of fucoxanthin. Lifespan of kelp is around 15 years with assemblages reaching 5 m in length generally. [72].

Regarding the impacts, Vinagre et al. [72] also mentioned in their study that each fouling organism could affect MRE structures differently. For instance, mussel assemblages contributed substantial weight of 24 kg fresh weight m^{-2} to structures following 12 months of submersion at 5 m depth. On the other hand, barnacles added considerable weight to structures up to 4–5 kg fresh weight m^{-2} for 12-month submersion at up to 10 m of depth [72]. Kelp was reported to have neutral buoyancy which should not affect mass of a structure [22], however, it may increase surface thickness and roughness of a submerged device [72], adding to component drag and potentially impacting upon mobility of moving parts. Among five key fouling organisms, barnacles and serpulids have higher adhesion strength and are thus more difficult to remove during maintenance. Vinagre et al. [72] also stated that strong settlement of these organisms may cause structure abrasion due to their weight or volume and can lead to other severe implications such as corrosion. Based on the knowledge derived from offshore wind structures, abrasion action of waves or organism attack could lead to structural degradation [23]. The thickness reduction of structural components due to corrosion could also lead to initiation of fatigue cracks and influence operational lifespan.

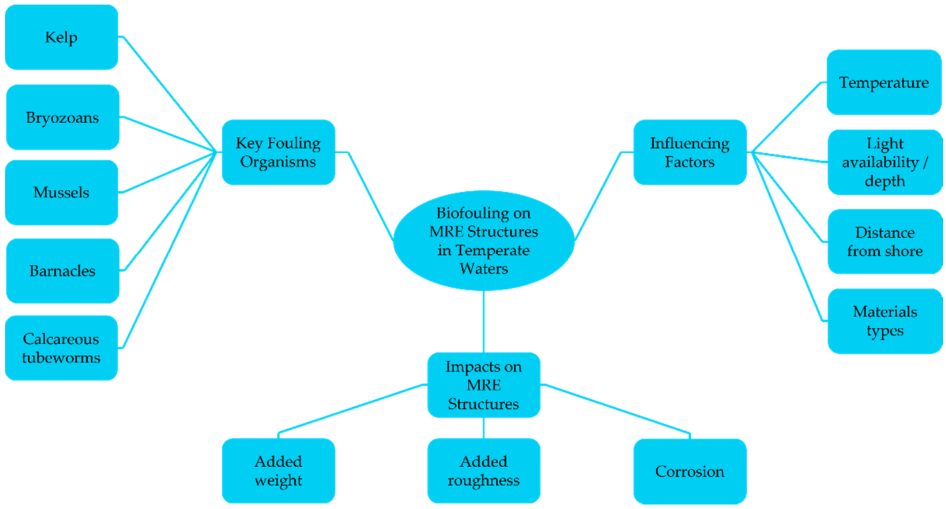

Figure 5. Illustration of findings from biofouling study performed by Vinagre et al. [72].

As illustrated in Figure 5, there are a few environmental factors affecting biofouling organisms, such as type of substrate materials, temperature and depth. It was reported that the physical and chemical properties of materials might influence the formation and nutrient composition of macromolecular conditioning layer, which then affect the formation and growth of macrofouling. Metallic substrates such as carbon steel, bronze and aluminium are more vulnerable to biofouling formation than non-metallic substrates [72]. The study also reported that in tropical and sub-tropical regions with warmer temperature than temperate waters, the biofouling growth rate increases intensively since continuous reproduction may occur throughout the year. Regarding the depth, photosynthetic biofouling organisms are found within the euphotic zone. In contrast, sessile and invertebrates are usually more abundant in the deeper zone where light availability decreases [72]. This is also aligned with findings from previous studies [22,49].

Besides Vinagre et al. [72], other biofouling studies in temperate waters have also highlighted the impact of biofouling to MRE as discussed in Section 2. However, this recent study emphasises the need for a database of marine biofouling specifically for MRE industry covering European waters. The database itself was compiled from sampling data of biofouling communities at several sites in European waters, including in the UK, as part of the OCEANIC project (http://oceanic-project.eu/biofouling-database/, accessed on 31 July 2020) [72]. Development of a similar platform for a biofouling database for tropical waters of Indonesia in the future would be beneficial for MRE industry.

4.3. Possible Biofouling Community and Their Risks on MRE Infrastructure in Indonesian Waters

As discussed in Section 4.1, it is important for marine biofouling research to be carried out in Indonesian waters, particularly given the likely benefits for the MRE industry at its early phase of development. The study performed by Vinagre et al. [72] provides a good example for developing a framework of biofouling research in Indonesian waters. The first main step that needs to be undertaken is to enhance the identification of biofouling community.

According to Lim et al. [65] (discussed in Section 3.1.2) barnacles (*Amphibalanus* sp.) and calcareous polychaetes (*Serpulidae*) were the most dominant biofouling organisms discovered in Tanjung Priok Port. Hadiyanto et al. [73] stated that fouling polychaetes in Tanjung Priok Port were identified as native species based on geographical distribution from taxonomic report in tropical waters of Indian Ocean. In addition to that, long-term fouling observation from June to November 2013 found that barnacles (*Amphibalanus* sp.) and bivalves (*Perna viridis*) covered dominantly the PVC panel surface. *Perna viridis* was also observed settled over the barnacles between September and October 2013 [65]. The limitations from these two studies are site location and time period of data collection.

The location chosen in both studies were port areas which technically would have different marine environment characteristics from the deployment locations of MRE devices. Moreover, biofouling community data collected in both studies was only limited to the transition between the dry and rainy seasons in Indonesia and did not apply to the opposite transition over the single year of observation. Therefore, long-term characteristics and impacts of biofouling community might not be identified thoroughly. Nevertheless, these two studies are beneficial as a starting point to identify possible fouling organisms on MRE infrastructure in tropical waters of Indonesia.

Following the example of the study performed by Vinagre et al. [72], a predictive matrix (as defined in Section 1.5) for biofouling communities on MRE infrastructure in Indonesian waters is developed based on the available secondary data. In order to develop a relevant predictive matrix, other discoveries of biofouling community on offshore structures in the China seas [66,67] and the Gulf of Guinea [68] will also be used (see Table 2). This predictive matrix provides a very preliminary forecast of biofouling community identification for application to the MRE sector in Indonesia and will need further detailed research to support its development in the near future.

Table 2. Predictive matrix of marine biofouling in tropical waters of Indonesia for MRE case study.

Identified Fouling Organism		Discovery Location	Characteristics of Location	Identified Characteristics of Fouling Organisms	Possible Risks on MRE Infrastructure
Group	**Common Name/Species**				
Polychaeta: Serpulidae	Calcareous polychaetes	Tanjung Priok Port, Jakarta, Indonesia	Port area	Polychaetes were observed during dry season and monsoon season. The dominant settlement occurred in the early monsoon season in November and December 2013 with coverage percentage more than 50%. However, long-term observation found the influence of its settlement was much lower than barnacle and mollusc [65]	Due to the high adhesion strength to the structure, their settlement might cause abrasion and induce corrosion [72]
Crustacea: Cirripedia	Barnacle (*Amphibalanus sp.*)	Tanjung Priok Port, Jakarta, Indonesia	Port area	Barnacles were observed during dry season and transition to monsoon season. Based on the longer observation, barnacle had high influence on panel structure, particularly in June 2013 [65]	Influence device movement by adding substantial weight to the component structures. Due to the high adhesion strength to the structure, their settlement might also cause abrasion and induce corrosion [72]
Mollusca: Bivalvia	*Perna viridis*	Tanjung Priok Port, Jakarta, Indonesia	Port area	Based on the long-term observation, bivalves colonised dominantly the panel structure after barnacle settlement decreased in the transition period of season [65]	Influence device movement by adding substantial weight to the component structures [72]
Cnidaria: Hydrozoa	Hydroids	Northern South China Sea	Offshore floating marine installations	In the offshore area, stalked barnacles and hydroids dominated fouling settlement in depth more than 100 m. Acorn barnacles were also observed but their biomass and diversity declined drastically with increasing distance from the shore [66]	Due to the high adhesion strength of barnacles to the structure, their settlement might cause abrasion and induce corrosion [72]
Crustacea: Cirripedia	Stalked barnacles				
Algae	Seaweeds	Gulf of Guinea	Offshore structure	Barnacles, hydroids, seaweeds were found dominantly on the offshore structure in early years of observation. On some structures, barnacles and corals colonised the surface together after a few periods of years [68]	Due to the high adhesion strength of barnacles to the structure, their settlement might cause abrasion and induce corrosion [72]
Cnidaria: Hydrozoa	Hydroids				
Cnidaria: Anthozoa	Coral				
Crustacea: Cirripedia	Barnacles				

5. Conclusions

Marine renewable energy (MRE) is one of the most promising clean energy sources to be developed for supporting energy provision in Indonesia. Despite the high abundance of resources, the development phase of Indonesian MRE technology remains focussed on the prototype testing stage. Due to limited pilot projects that have been developed and a detailed review of the available secondary data from the literature, we conclude that the challenge presented by biofouling has yet to be addressed for the design and development of MRE technology in Indonesia. The research opportunity to investigate biofouling on MRE infrastructures in tropical waters of Indonesia is wide open, and ranges in scope from biofouling community identification to biofouling mitigation measures. By reflecting on the past and current studies, a predictive matrix of biofouling organisms and their possible risks on MRE infrastructure can be developed. Since the data used in this study are from secondary sources, rather than from a robust, specifically designed study protocol such as the BioFREE system [74], it is recommended that further detailed investigations are essential to underpin the progress of the MRE industry in Indonesia.

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References

1. Erahman, Q.F.; Purwanto, W.W.; Sudibandriyo, M.; Hidayatno, A. An assessment of Indonesia's energy security index and comparison with seventy countries. *Energy* **2016**, *111*, 364–376. [CrossRef]
2. Iswadi, A.; Owen, A.; Garniati, L.; Sugardjito, J. Marine renewable energy: Opportunities and challenges for community development in coastal area of Indonesia. *Int. J. Serv. Technol. Manag.* **2018**, *24*, 522–544. [CrossRef]
3. National Energy Council. *Indonesia Energy Outlook 2019*; Secretariat General of National Energy Council: Jakarta, Indonesia, 2019.
4. Publications Office of the European Union. *Strategic Plan Book 2020–2024*; Ministry of Energy and Mineral Resources: Jakarta, Indonesia, 2020.
5. Institute for Essential Services Reform. *Igniting a Rapid Deployment of Renewable Energy in Indonesia: Lessons Learned from Three Countries*; Institute for Essential Services Reform: Jakarta, Indonesia, 2018. Available online: http://iesr.or.id/wp-content/uploads/2019/05/IESR_Research_Igniting-a-Rapid-Deployment-of-RE-in-Indonesia.pdf (accessed on 13 August 2020).
6. Yudha, S.W.; Tjahjono, B. Stakeholder mapping and analysis of the renewable energy industry in Indonesia. *Energy* **2019**, *12*, 602. [CrossRef]
7. Hidayati, N.; Mahmudi, M.; Kurniawan, D.; Musa, M.; Setiawan, H. Ocean currents energy for electricity generation and its potential in east java water, Indonesia. *J. Environ. Eng. Sustain. Technol.* **2016**, *3*, 104–111. [CrossRef]
8. Firdaus, A.M.; Houlsby, G.T.; Adcock, T.A. Opportunities for Tidal Stream Energy in Indonesian Waters. In Proceedings of the 12th European Wave and Tidal Energy Conference, Cork, Ireland, 2017; p. 887.
9. Ray, R.D.; Susanto, R.D. Tidal mixing signatures in the Indonesian seas from high-resolution sea surface temperature data. *Geophys. Res. Lett.* **2016**, *43*, 8115–8123. [CrossRef]
10. Sugianto, D.N.; Kunarso, K.; Helmi, M.; Alifdini, I.; Maslukah, L.; Saputro, S.; Yusuf, M.; Endrawati, H. Wave energy reviews in Indonesia. *Int. J. Mech. Eng. Technol.* **2017**, *8*, 448–459.

11. Minister of Energy and Mineral Resource. Indonesia Energy Outlook Association. In *Ocean Energy Resources in Indonesia*; Ministry of Energy and Mineral Resources: Jakarta, Indonesia, 2014.
12. Orhan, K.; Mayerle, R.; Pandoe, W.W. Assesment of Energy Production Potential from Tidal Stream Currents in Indonesia. *Energy Procedia* **2015**, *76*, 7–16. [CrossRef]
13. Orhan, K.; Mayerle, R. Assessment of the tidal stream power potential and impacts of tidal current turbines in the Strait of Larantuka, Indonesia. *Energy Procedia* **2017**, *125*, 230–239. [CrossRef]
14. Wahyudie, A.; Susilo, T.B.; Alaryani, F.; Nandar, C.S.A.; Jama, M.A.; Daher, A.; Shareef, H. Wave Power Assessment in the Middle Part of the Southern Coast of Java Island. *Energies* **2020**, *13*, 2633. [CrossRef]
15. Hantoro, R.; Utama, I.K.A.P.; Erwandi, E.; Sulisetyono, A. An experimental investigation of passive variable-pitch vertical-axis ocean current turbine. *ITB J. Eng. Sci.* **2011**, *43*, 27–40. [CrossRef]
16. Hantoro, R.; Septyaningrum, E. Novel design of a vertical axis hydrokinetic turbine-straight-blade cascaded (VAHT-SBC): Experimental and numerical simulation. *J. Eng. Technol. Sci.* **2018**, *50*, 73–86. [CrossRef]
17. Hantoro, R.; Utama, I.K.A.P.; Arief, I.S.; Ismail, A.; Manggala, S.W. Innovation in Vertical Axis Hydrokinetic Turbine—Straight Blade Cascaded (VAHT-SBC) design and testing for low current speed power generation. *J. Phys. Conf. Ser.* **2018**, *1022*, 12023. [CrossRef]
18. Erwandi; Rahuna, D.; Rahuna, D.; Mintarso, C.S.J. The development of the IHL wave-current turbine to convert the ocean energy from both wave and current. In *IOP Conference Series: Materials Science and Engineering 2019*; IOP Publishing: Bristol, UK, 2019; Volume 588, p. 12008. [CrossRef]
19. Arif, I.S.; Utama, I.K.A.P.; Hartono, R.; Prananda, J.; Isnaini, R.; Rachmattra, A.T. Analysis Characteristics of Pendulum Oscillation In PLTGL-SB. *E3S Web Conf.* **2018**, *43*, 1005. [CrossRef]
20. Arief, I.S.; Utama, I.K.A.P.; Hantoro, R.; Prananda, J.; Arvisa, T.R.; Kusuma, R.F. Mooring Experimental Study of Motion Response for Pendulum Wave Energy Converters. In *IOP Conference Series: Materials Science and Engineering*; IOP Publishing: Bristol, UK, 2019; Volume 462, p. 12010. [CrossRef]
21. Macleod, A.K.; Stanley, M.S.; Day, J.G.; Cook, E.J. Biofouling community composition across a range of environmental conditions and geographical locations suitable for floating marine renewable energy generation. *Biofouling* **2016**, *32*, 261–276. [CrossRef] [PubMed]
22. Want, A.; Crawford, R.; Kakkonen, J.; Kiddie, G.; Miller, S.; Harris, R.E.; Porter, J.S. Biodiversity characterisation and hydrodynamic consequences of marine fouling communities on marine renewable energy infrastructure in the Orkney Islands Archipelago, Scotland, UK. *Biofouling* **2017**, *33*, 567–579. [CrossRef] [PubMed]
23. Price, S.J.; Figueira, R.B. Corrosion protection systems and fatigue corrosion in offshore wind structures: Current status and future perspectives. *Coatings* **2017**, *7*, 25. [CrossRef]
24. Bressy, C.; Lejars, M. Marine fouling: An overview. *J. Ocean. Technol.* **2014**, *9*, 19–28.
25. Dafforn, K.A.; Lewis, J.A.; Johnston, E.L. Antifouling strategies: History and regulation, ecological impacts and mitigation. *Mar. Pollut. Bull.* **2011**, *62*, 453–465. [CrossRef] [PubMed]
26. Abbott, A.; Abel, P.D.; Arnold, D.W.; Milne, A. Cost–benefit analysis of the use of TBT: The case for a treatment approach. *Sci. Total Environ.* **2000**, *258*, 5–19. [CrossRef]
27. Satheesh, S.; Ba-akdah, M.A.; Al-Sofyani, A.A. Natural antifouling compound production by microbes associated with marine macroorganisms—A review. *Electron. J. Biotechnol.* **2016**, *21*, 26–35. [CrossRef]
28. Ilhan-Sungur, E.; Unsal-Istek, T.; Cansever, N. Microbiologically influenced corrosion of galvanized steel by *Desulfovibrio* sp. and *Desulfosporosinus* sp. in the presence of Ag–Cu ions. *Mater. Chem. Phys.* **2015**, *162*, 839–851. [CrossRef]
29. Javed, M.A.; Neil, W.C.; McAdam, G.; Wade, S.A. Effect of sulphate-reducing bacteria on the microbiologically influenced corrosion of ten different metals using constant test conditions. *Int. Biodeterior. Biodegrad.* **2017**, *125*, 73–85. [CrossRef]
30. Gu, T.; Jia, R.; Unsal, T.; Xu, D. Toward a better understanding of microbiologically influenced corrosion caused by sulfate reducing bacteria. *J. Mater. Sci. Technol.* **2019**, *35*, 631–636. [CrossRef]
31. Liengen, T.; Basseguy, R.; Feron, D.; Beech, I.; Birrien, V. *Understanding Biocorrosion: Fundamentals and Applications*; Elsevier: Cambridge, UK, 2014. [CrossRef]
32. Bott, T.R. *Industrial Biofouling: Occurrence and Control*; Elsevier: Amsterdam, The Netherlands, 2011.
33. Wu, J.; Zhang, D.; Wang, P.; Cheng, Y.; Sun, S.; Sun, Y.; Chen, S. The influence of *Desulfovibrio* sp. and *Pseudoalteromonas* sp. on the corrosion of Q235 carbon steel in natural seawater. *Corros. Sci.* **2016**, *112*, 552–562. [CrossRef]
34. Julistiono, H.; Hidayati, Y.; Yuslaini, N.; Nditasari, A.; Dinoto, A.; Sundjono; Nuraini, L.; Priyotomo, G.; Gunawan, H. Identification of biofilm-forming bacteria from steel panels exposed in sea waters of Jakarta Bay and Madura Strait. *Invent. Prosperous Future Through Biol. Res. Trop. Biodivers. Manag.* **2018**, *2002*, 020029. [CrossRef]
35. Sawall, Y.; Richter, C.; Ramette, A. Effects of Eutrophication, Seasonality and Macrofouling on the Diversity of Bacterial Biofilms in Equatorial Coral Reefs. *PLoS ONE* **2012**, *7*, e39951. [CrossRef] [PubMed]
36. Azmi, F.; Hewitt, C.L.; Campbell, M.L. A hub and spoke network model to analyse the secondary dispersal of introduced marine species in Indonesia. *ICES J. Mar. Sci.* **2015**, *72*, 1069–1077. [CrossRef]
37. Huhn, M.; Zamani, N.; Lenz, M. A ferry line facilitates dispersal: Asian green mussels *Perna viridis* (Linnaeus, 1758) detected in eastern Indonesia. *Bioinvasions Rec.* **2015**, *4*, 23–29. [CrossRef]

38. Huhn, M.; Madduppa, H.H.; Khair, M.; Sabrian, A.; Irawati, Y.; Anggraini, N.P.; Wilkinson, S.P.; Simpson, T.; Iwasaki, K.; Setiamarga, D.H.E.; et al. Keeping up with introduced marine species at a remote biodiversity hotspot: Awareness, training and collaboration across different sectors is key. *Biol. Invasions* **2019**, *22*, 749–771. [CrossRef]
39. Azmi, F.; Primo, C.; Hewitt, C.L.; Campbell, M.L. Assessing marine biosecurity risks when data are limited: Bioregion pathway and species-based exposure analyses. *ICES J. Mar. Sci.* **2015**, *72*, 1078–1091. [CrossRef]
40. Nugroho, B.; Ganapathisubramani, B.; Utama, I.K.A.P.; Suastika, I.K.; Prasetyo, F.A.; Yusuf, M.; Tullberg, M.; Monty, J.P.; Hutching, N. Managing international collaborative research between academics, industries, and policy makers in understanding the effects of biofouling in ship hull turbulent boundary layers. *Trans. R. Inst. Nav. Archit. Part A Int. J. Marit. Eng.* **2017**, *159*, 291–300. [CrossRef]
41. Yusim, A.K.; Utama, I.K.A.P. An Investigation into The Drag Increase on Roughen Surface due to Marine Fouling Growth. *Maj. IPTEK* **2017**, *28*, 73–78. [CrossRef]
42. Baital, M.S.; Pria Utama, I.K.A. CFD Analysis into the Drag Estimation of Smooth and Roughened Surface Due to Marine Biofouling. *Maj. IPTEK* **2017**, *28*, 90–97. [CrossRef]
43. Hakim, M.L.; Nugroho, B.; Nurrohman, M.N.; Suastika, I.K.; Utama, I.K.A.P. Investigation of fuel consumption on an operating ship due to biofouling growth and quality of anti-fouling coating. In *IOP Conference Series: Earth and Environmental Science 2019*; IOP Publishing: Bristol, UK, 2019; Volume 339, p. 12037. [CrossRef]
44. Pratikno, H.; Titah, H.S.; Syahputra, B.E.D. Effect of heat treatment on bio-corrosion rate of steel structure (API 5L) in marine evironment. *MATEC Web Conf.* **2018**, *197*, 4002. [CrossRef]
45. Nuraini, L.; Prifiharni, S.; Priyotomo, G.; Sundjono; Gunawan, H. Evaluation of anticorrosion and antifouling paint performance after exposure under seawater Surabaya–Madura (Suramadu) bridge. In Proceedings of the International Conference on Chemistry, Chemical Process and Engineering, Yogyakarta, Indonesia, 15–16 November 2017; Volume 1823. [CrossRef]
46. Priyotomo, G.; Nuraini, L.; Gunawan, H.; Triwardono, J.; Sundjono, S.; Prifiharni, S. A Preliminary field study of antifouling paint perfomance after short exposure in Mandara Bali, Indonesia. *Int. J. Eng. Trans. A Basics* **2021**, *34*, 976–986. [CrossRef]
47. Aunurohim; Kurniawan, W.A.; Nurilma, A.D.; Desmawati, I.; Albab, M. Field Optimation of Durio zibethinus as Macro-Antifouling at PT Dok and Shipping, Surabaya, Indonesia. In *IOP Conference Series: Earth and Environmental Science 2018*; IOP Publishing: Bristol, UK, 2019; Volume 197, p. 12010.
48. Pratikno, H.; Sulistiyaning Titah, H.; Danesto Rizky Mauludin, M. System Impressed Current Anti Fouling (ICAF) against micro fouling (Bacteria) on ship's cooling system. *MATEC Web Conf.* **2018**, *177*, 1013. [CrossRef]
49. Nall, C.R.; Schläppy, M.-L.; Guerin, A.J. Characterisation of the biofouling community on a floating wave energy device. *Biofouling* **2017**, *33*, 379–396. [CrossRef]
50. Yang, S.-H.; Ringsberg, J.W.; Johnson, E.; Hu, Z. Biofouling on mooring lines and power cables used in wave energy converter systems—Analysis of fatigue life and energy performance. *Appl. Ocean Res.* **2017**, *65*, 166–177. [CrossRef]
51. Loxton, J.; Macleod, A.K.; Nall, C.R.; McCollin, T.; Machado, I.; Simas, T.; Vance, T.; Kenny, C.; Want, A.; Miller, R.G. Setting an agenda for biofouling research for the marine renewable energy industry. *Int. J. Mar. Energy* **2017**, *19*, 292–303. [CrossRef]
52. Adams, T.P.; Miller, R.G.; Aleynik, D.; Burrows, M.T.; Frederiksen, M. Offshore marine renewable energy devices as stepping stones across biogeographical boundaries. *J. Appl. Ecol.* **2014**, *51*, 330–338. [CrossRef]
53. Elizabeth, J.C.; Robin, D.P.; Adrian, K.M.; Sarah, F.B. Marine biosecurity: Protecting indigenous marine species. *Res. Rep. Biodivers. Stud.* **2016**, *5*, 1. [CrossRef]
54. Minchin, D.; Cook, E.J.; Clark, P.F. Alien species in British brackish and marine waters. *Aquat. Invasions* **2013**, *8*, 3–19. [CrossRef]
55. Farkas, A.; Song, S.; Degiuli, N.; Martić, I.; Demirel, Y.K. Impact of biofilm on the ship propulsion characteristics and the speed reduction. *Ocean Eng.* **2020**, *199*, 107033. [CrossRef]
56. Fernandes, J.A.; Santos, L.; Vance, T.; Fileman, T.; Smith, D.; Bishop, J.D.D.; Viard, F.; Queirós, A.M.; Merino, G.; Buisman, E.; et al. Costs and benefits to European shipping of ballast-water and hull-fouling treatment: Impacts of native and non-indigenous species. *Mar. Policy* **2016**, *64*, 148–155. [CrossRef]
57. Legg, M.; Yücel, M.K.; Garcia de Carellan, I.; Kappatos, V.; Selcuk, C.; Gan, T.H. Acoustic methods for biofouling control: A review. *Ocean Eng.* **2015**, *103*, 237–247. [CrossRef]
58. De Castro, M.C.T.; Vance, T.; Yunnie, A.L.E.; Fileman, T.W.; Hall-Spencer, J.M. Low salinity as a biosecurity tool for minimizing biofouling on ship sea chests. *Ocean Sci.* **2018**, *14*, 661–667. [CrossRef]
59. Duncan, K.E.; Davidova, I.A.; Nunn, H.S.; Stamps, B.W.; Stevenson, B.S.; Souquet, P.J.; Suflita, J.M. Design features of offshore oil production platforms influence their susceptibility to biocorrosion. *Appl. Microbiol. Biotechnol.* **2017**, *101*, 6517–6529. [CrossRef] [PubMed]
60. Gormley, K.; McLellan, F.; McCabe, C.; Hinton, C.; Ferris, J.; Kline, D.I.; Scott, B.E. Automated image analysis of offshore infrastructure marine biofouling. *J. Mar. Sci. Eng.* **2018**, *6*, 2. [CrossRef]
61. Wells, F.E.; Tan, K.S.; Todd, P.A.; Jaafar, Z.; Yeo, D.C.J. A low number of introduced marine species in the tropics: A case study from Singapore. *Manag. Biol. Invasions* **2019**, *10*, 23–45. [CrossRef]
62. Satheesh, S.; Wesley, S.G. Seasonal changes of motile polychaetes in the fouling assemblage developed on test panels submerged on a tropical coast. *J. Mar. Biol. Assoc. United Kingd.* **2013**, *93*, 1525–1531. [CrossRef]
63. Desai, D.V.; Krishnamurthy, V.; Anil, A.C. Biofouling Community Structure in a Tropical Estuary of Goa on the West Coast of India. *ASEAN J. Sci. Technol. Dev.* **2018**, *35*, 37–42. [CrossRef]

64. Lin, H.; Wang, J.; Liu, W.; Liu, K.; Zhang, S.; He, X.; Huang, Y.; Lin, J.; Mou, J.; Zheng, C.; et al. Fouling community characteristics in subtropical coastal waters of the southwestern East China Sea. *Acta Oceanol. Sin.* **2017**, *36*, 70–78. [CrossRef]
65. Lim, C.S.; Jolkifli, Z.H.; Jair, A.; Karim, N.; Wahab, R.A.; Desai, D.V.; Krishnamurthy, V.; Khandeparker, L.; Mapari, K.; Sawant, S.; et al. An inter-site study of biofouling recruitment on static immersion panels in major ports of South East Asia and India. *ASEAN J. Sci. Technol. Dev.* **2018**, *35*, 167–176. [CrossRef]
66. Yan, T.; Yan, W.X. Fouling of Offshore Structures in China-a Review. *Biofouling* **2003**, *19* (Suppl. S1), 133–138. [CrossRef]
67. Cao, W.; Yan, T.; Li, Z.; Li, J.; Cheng, Z. Fouling acorn barnacles in China—A review. *Chin. J. Oceanol. Limnol.* **2013**, *31*, 699–711. [CrossRef]
68. Boukinda Mbadinga, M.L.; Schoefs, F.; Quiniou-Ramus, V.; Birades, M.; Garretta, R. Marine Growth Colonization Process in Guinea Gulf: Data Analysis. *J. Offshore Mech. Arct. Eng.* **2007**, *129*, 97–106. [CrossRef]
69. Elliott, D. *Renewable Energy in the UK Past, Present and Future/by David Elliott*; Springer International Publishing: Cham, Switzerland, 2019.
70. Mueller, M.; Wallace, R. Enabling science and technology for marine renewable energy. *Energy Policy* **2008**, *36*, 4376–4382. [CrossRef]
71. Kasharjanto, A.; Rahuna, D.; Rina, R. Kajian Pemanfaatan Energi Arus Laut Di Indonesia. *Wave: J. Ilm. Teknol. Marit.* **2017**, *11*, 75–84. [CrossRef]
72. Vinagre, P.A.; Simas, T.; Cruz, E.; Pinori, E.; Svenson, J. Marine Biofouling: A European Database for the Marine Renewable Energy Sector. *J. Mar. Sci. Eng.* **2020**, *8*, 495. [CrossRef]
73. Hadiyanto, H. Fouling Polychaetes in Tanjung Priok Port of Jakarta, Indonesia. *ASEAN J. Sci. Technol. Dev.* **2018**, *35*, 79–87. [CrossRef]
74. Want, A.; Bell, M.C.; Harris, R.E.; Hull, M.Q.; Long, C.R.; Porter, J.S. Sea-trial verification of a novel system for monitoring biofouling and testing anti-fouling coatings in highly energetic environments targeted by the marine renewable energy industry. *Biofouling* **2021**, *37*, 433–451. [CrossRef] [PubMed]