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Current Status and Possible Future Applications of Marine Current Energy Devices in Malaysia: A Review

LIM YEE KAI[1], SHAMSUL SARIP[1], HAZILAH MAD KAIDI[1], JORGE ALFREDO ARDILA-REY[2], (Member, IEEE), NOORAZIZI MOHD SAMSUDDIN[1], MOHD NABIL MUHTAZARUDDIN[1], FIRDAUS MUHAMMAD-SUKKI[3], AND SAARDIN ABDUL AZIZ[1]

[1]Razak Faculty of Technology and Informatics, Universiti Teknologi Malaysia, Kuala Lumpur 54100, Malaysia
[2]Department of Electrical Engineering, Universidad Técnica Federico Santa María, Santiago de Chile 8940000, Chile
[3]School of Engineering and the Built Environment, Edinburgh Napier University, Edinburgh EH10 5DT, U.K.

Corresponding author: Shamsul Sarip (shamsuls.kl@utm.my)

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ABSTRACT Malaysia has a great potential to harness energy in water due to its long coastline within the South China Sea and the Straits of Malacca. Malaysia's energy mix could be improved using marine current energy devices (MCEDs) to replace fossil fuel and it is predictable energy compare to hydropower, solar photovoltaic (PV), and biomass. However, MCEDs is not been fully developed in Malaysia. The objectives of this paper are to provide a useful background for policymakers or researchers in the types of MCEDs and potential sites location of MCEDs that are applicable in Malaysia. This review also discusses the issues and challenges of MCEDs in Malaysia. Five types of MCEDs were discussed including tidal range device, tidal stream turbine, wave energy converter, ocean thermal energy conversion, and salinity gradient energy. These MCEDs are compared for their suitability of application in Malaysia. Among all MCEDs, tidal stream turbine is identified as high potential and commercially viable in Malaysia. However, ocean characteristics in Malaysia are low kinetic energy-flux density, low current speed, low tide, and shallow water; only fulfill the minimum requirement of tidal stream turbine making the tidal stream energy resources not significant enough to contribute to the nation's energy mix. Therefore, using diffuser augmented tidal stream turbines to increase the flow velocity should be studied thoroughly.

INDEX TERMS Marine current energy device, tidal range device, tidal stream turbine, wave energy converter, ocean thermal energy conversion, salinity gradient energy.

NOMENCLATURE

Mtoe	Million tonnes of oil equivalent
GW	Gigawatt
GWh	Gigawatt hour
GWh/year	Gigawatt hour per year
TWh/a	Terawatt-hour per year
MW	Megawatt
kWh	Kilowatt-hour
kW/m	Kilowatt per meter
m	Meter
km	Kilometer
m/s	Meter per second
h	Hour
min	Minute
mph	Miles per hour
FiT	Feed-in-Tariff
R & D	Research and Development
UTM	Universiti Teknologi Malaysia
RE	Renewable Energy

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MRE	Marine Renewable Energy
MCED	Marine Current Energy Device
MCT	Marine Current Turbine
PV	Photovoltaic
OTEC	Ocean Thermal Energy Conversion
SGE	Salinity Gradient Energy
WEC	Wave Energy Converter
OWC	Oscillating Water Column
TEC	Tidal Energy Converter
HATT	Horizontal Axis Tidal Turbine
VATT	Vertical Axis Tidal Turbine
GHG	Greenhouse gas
CO_2	Carbon Dioxide
OFB	One Fathom Bank
MS	Malacca Strait
SEA	Southeast Asia
UTM	Universiti Teknologi Malaysia

I. INTRODUCTION

Malaysia's electricity generation is highly reliant on fossil fuel, but its fuel reserve is getting depleted causing problems of energy security [1]. Hence, a 5th fuel diversity policy was launched in 2001 to use renewable energy (RE) such as hydropower, solar photovoltaic (PV), biomass, biogas, and solid waste to ensure diversity of fuel source and a balanced fuel mix [2]. The government needs RE to cater to a high energy demand rate of 8.1% annually to support economic growth and industrialization [3]. Currently, Peninsular Malaysia has a total licensed RE capacity of 392 MW, which is fueled by solar PV, biomass, mini-hydro plants, and biogas [4]. However, these major RE resources are not enough to fulfil the upcoming energy demand. Therefore, utilizing other RE resources such as biofuel/biodiesel, geothermal, wind, and marine energy is needed [5]. RE will become the main electricity generation soon [6].

The major challenge faced by the RE industry in Malaysia is the intermittency problem in energy production, particularly solar energy. Malaysia only receives 4 hours of direct sunlight for electricity generation during the day, provided that it is not raining and a lot of sun rays are not reflected [8]. Wind energy is also restricted by low wind velocity (less than 2 m/s), blows irregularly and is weather dependent based on monsoon season and region [9]. Solar PV and wind energy are very weather dependent. This discontinuous nature of RE disrupts the flow of energy use; hence energy storage technology is needed [8]. Mini hydro is environmentally friendly, but it is limited to water flow availability and is mostly located in remote areas. Biogas and biomass are constrained by resource availability and are only suitable for small capacity [8]. Geothermal energy resource is restricted by region and only available in Apas Kiri, Tawau. The geothermal power plant is set to export 30 MW of power to the Sabah's electricity grid under the Feed-in-Tariff (FiT) scheme [10]. Marine renewable energy (MRE) is only available along the coastal region and is restricted by ocean characteristics in Malaysia which are low kinetic energy-flux density, low current speed, low tide, and low water depth. The marine turbine installation is unique to the region and the design of the turbine must suit the tidal speed of Malaysia's waters [11].

MRE is a newly develop RE and is not yet widely used globally. The MRE development in Southeast Asia (SEA) countries mostly concerns with studying its theoretical energy potential, possible site location, and only a small amount of marine current energy device (MCED) has been used in a prototype or pre-commercial demonstration stage [7]. Figure 1 summarizes the current status and activities of MRE in SEA countries. Malaysia is also carrying out research and development (R&D) works concerning lab-scale prototype fabrication and study the potential tidal, wave, and ocean thermal energy resources for small island projects [1], [5], [12]. MRE benefits over other RE sources are that it is predictable and not weather dependent [12]. Malaysia has an equatorial climate, high rainfall rate, many rivers, islands, and a long coastline of 4,675 km, making it a great ocean energy resource [13], [14]. Potential MRE areas in Malaysia have been identified in the area along the Malacca Strait (MS), Sarawak, and Sabah [15], [16]. The electricity generated by marine current turbines (MCTs) in Malaysia is higher than solar PV which is about 14.5 GWh/year. The stakeholder can save MYR 1.1 billion of energy generation from fossil fuels and eliminate 4,552,512 tons of greenhouse gas emissions per year. The investor of MCTs can achieve breakeven after 10 years and can make net profits after that. Furthermore, the availability of power generated by MCTs can be estimated by the characteristic of tides in coastal Malaysia.

This paper summarizes the current status of the MRE and potential site locations available in Malaysia. Section 2 provides a brief introduction to energy policy and Section 3 describes MRE development and potential site locations for MCEDs in Malaysia. This is followed by Section 4 which discusses the technical, economic, environmental, infrastructural, and political challenges that need to be analyzed regarding the implications of developing MRE in Malaysia.

II. NATIONAL RENEWABLE ENERGY GOALS

Recently, the International Renewable Energy Agency has revealed the need for a global shift towards RE sources to cater to the rising global energy demands. Figure 2 shows the forecast for global electricity generation in which gross power generation using a non-RE source will reduce to 15% while the RE share will increase to 85% by 2050. Of the 85%, the main RE contributors would be hydropower (12%), solar PV (22%), and wind (36%). Marine RE's share is less than 1% and is not yet widely used today, yet the share of global electricity demand will reach 4% by 2050 [8]. Over 80% of Malaysia's energy needs are still supplied by exhaustible sources and will face energy insecurity in the future [8]. The main factors that motivate Malaysia to explore RE technology are the growth of electricity consumption, dependence on foreign energy resource imports, and the environmental effect

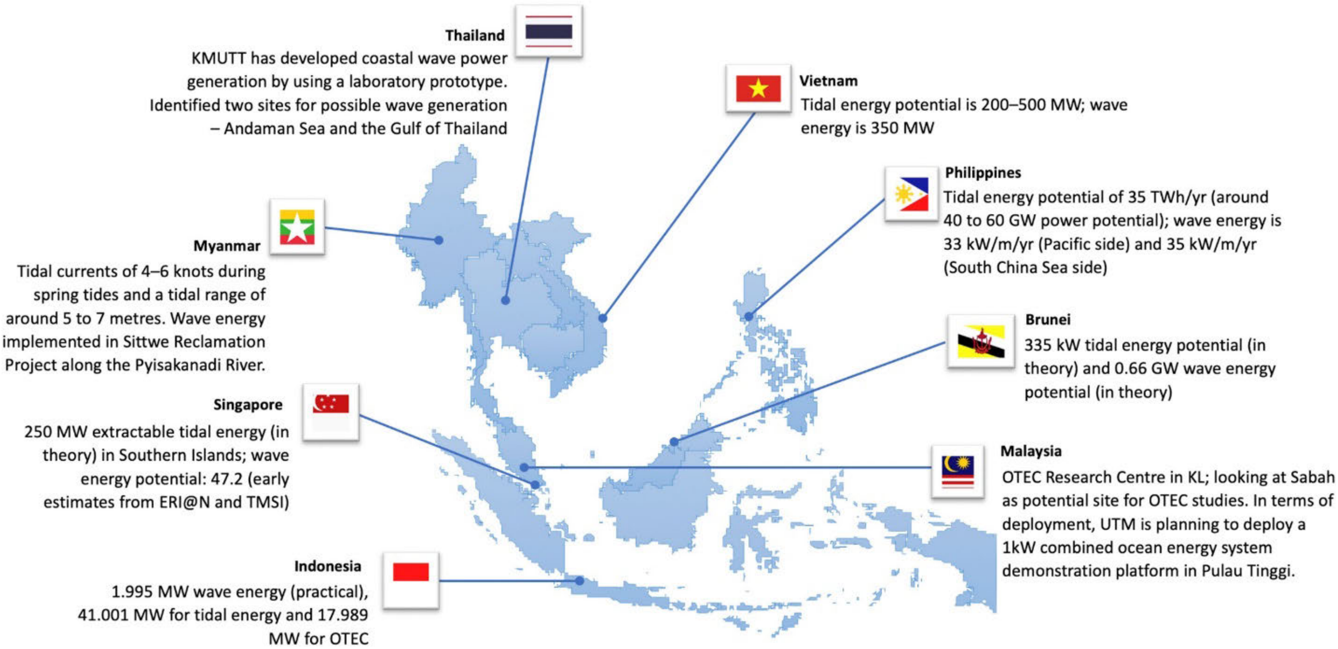


FIGURE 1. Current status of MRE potential and development in southeast asia (SEA) countries [7].

of fossil fuel usage [14]. Therefore, Malaysia stands to join the global shift towards cleaner and sustainable RE [8].

Since the early stage of the Malaysia industrial revolution in 2002, the industrial sector had continuously developed due to the prosperity of fossil fuel. However, due to the excessive development without proper planning, Malaysia is now facing a problem of energy insecurity as ample resources are needed to sustain domestic development [17]. For short-term energy crisis mitigation, enhancing and enlarging the present power plants are the first choices. However, for a longer-term solution, RE in the energy mix is needed [18]. Malaysia's electricity generation mix has not changed much from 2010 until now and still highly reliant on natural gas and coal in powering up the country [19]. Electricity usage in Malaysia has grown significantly in the past 20 years with total electricity generation increased by 4 times from 37,065 GWh (the year 1997) to 162,184 GWh (the year 2017) due to industrialization [20]. The coal consumption in the power plant is increased and gradually replacing natural gas while crude oil had been eliminated in power plants [21].

Malaysia's gas component shared 35% of the total energy mix in 2018 with 57% of coal in the coming years and the remaining smallest share was RE sources, which needs to be strengthened in the future [22]. Gas usage is to continuously be reduced with several gas power plants being shut down gradually and replaced by coal fire plants as dominant fuel in electricity generation [18]. However, this is risky when the main sources of electricity generation in Malaysia depends on coal where 90% of it is imported [23]. At present, the only large scale commercially viable RE in Malaysia is hydropower with a potential energy of around 29 GW as of 2013 [24]. The government has devised initiatives to lower its dependency on fossil fuels and to increase the portion of RE in the generation mix [22].

Malaysia is experiencing rapid economic growth with an expected population of around 33 million people during 2020. The national electricity generation has grown exponentially due to the increase in the Malaysian population, i.e. the population is projected to be 41.5 million in 2040 [25], [26]. Electricity generation in Malaysia is projected to increase from 2005 to 2030 with a growth rate of 5.3% [6]. The United Nations Habitat forecasted Malaysia's urban population will achieve 78% in 2030 and high gross domestic product will lead to an increase in energy demand for urbanization [23]. Hence, to ensure continuous development within Malaysia, accessibility to reliable and cheaper energy is very important [17]. The result from an analysis by Haiges *et al.* [27] indicated that Malaysia could reach 100% sustainable energy generation by 2050 by replacing fossil fuels with clean energy resources without deploying nuclear power.

Both CO_2 emissions and Malaysian population growth are proportionally and increase year by year. Electricity generation from burning fossil fuels will generate a huge volume of CO_2 into the atmosphere and cause global warming [28], [29]. Global warming refers to increasing the average surface temperatures of the earth [30]. According to the statistical review of global energy, Malaysia shared 6.3% (16.3 metric tons) of the world's CO_2 emissions from 2015 to 2016 [29]. To mitigate climate change, Malaysia had signed the Paris Agreement in 2015 to limit global warming below 1.5 °C or 2 °C by using low carbon alternative energy and reducing fossil fuel energy [31]. This aims to reduce the greenhouse gas (GHG) emission intensity by 35% to 45% based on 2005 GDP by 2030 and be zero carbon by

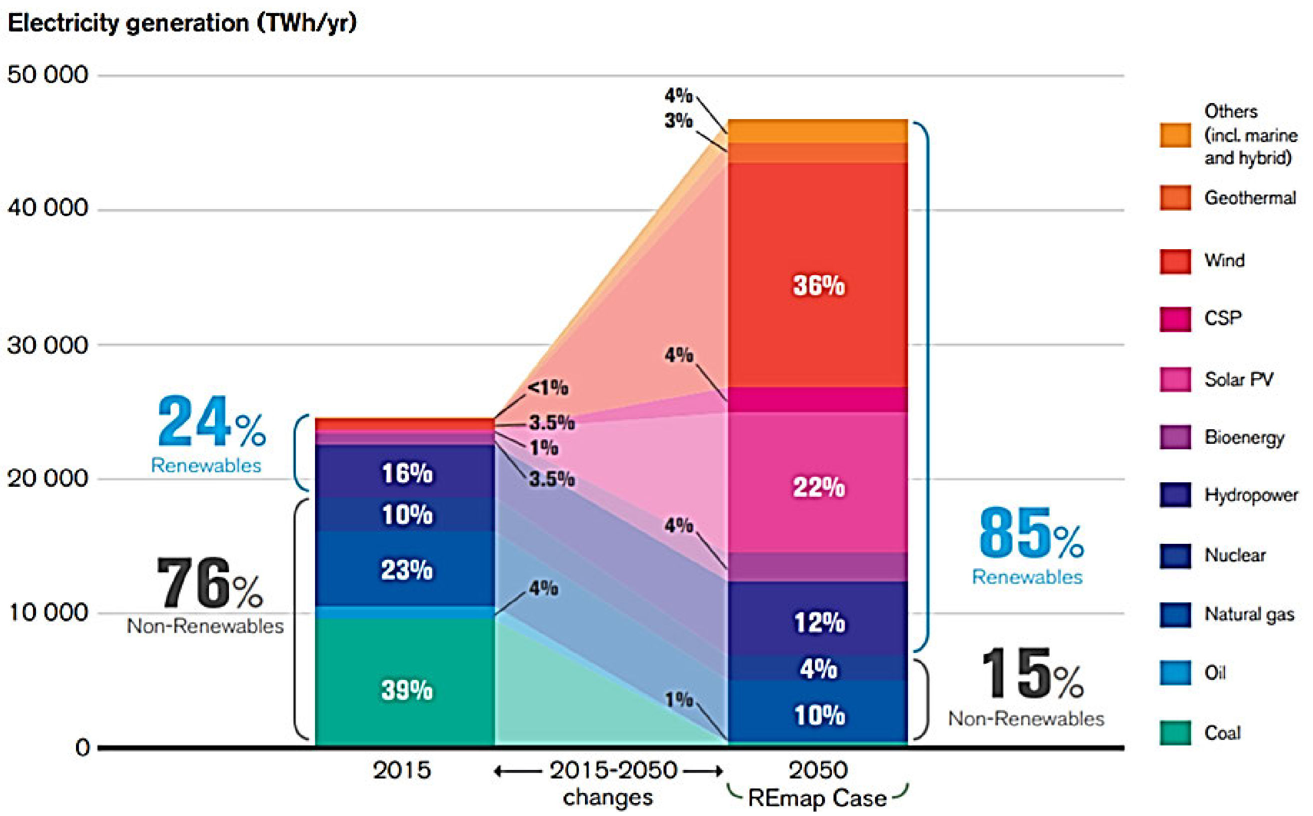


FIGURE 2. The global shift towards renewable energy sources to cater to the rising of the globe's energy demand and exhaustion of fossil fuel [8].

2050 [32]. To achieve that, the government has increased shares of RE in the total energy mix through energy policies such as FiT, large scale solar PV, net energy metering, and the development of new hydroelectric stations [4], [33].

Energy is a catalyst for economic growth and industrialization in a country. Malaysia has always reviewed its energy policy to guarantee sustainability, reliability, and security of energy supply [34]. The national RE goals are targeted at 11.22 GWh for power generation from RE sources in 2020 and 25.57 GWh in 2050 [35]. Malaysia populations grow rapidly year by year and this has caused an increase in energy demand. It is projected that 60,584 GWh of electricity will be generated from RE sources contributing towards the reduction of 42 million tons of CO_2 from the power sector [35]. Besides, the RE is the best alternative solution for electricity shortage in rural areas such as Sabah, Sarawak and remote islands that do not have access to the electricity grid as the grid extension through a terrain, thick forest, and offshore is impossible or expensive [9].

The Government has been introducing the 4th-Fuel Diversification Policy since 1981 by utilizing other sources of fossil fuel and RE into the electricity mix as a mitigation against the fossil fuel depreciation [27]. This was followed by the 5th-Fuel Diversification Policy in 2001 aimed to gain 5% of electricity generation from RE by 2005. This energy policy was targeted to generate and supply 500 MW (out of 20,000 MW total generation capacity) of RE electricity to the national grid [2]. However, only 12 MW of RE was successfully linked to the national grid in 2005 [36]. The same target of 5% RE was continued in the next 9th Malaysia Plan (2006-2010), however, only 41.5 MW was successfully delivered to the national grid, this represented only 0.19% of the target [36], [37]. Although the 5th-fuel energy policy was introduced for a decade (2001-2010), the share of RE was still less than 1% and failed to meet the target. The development of RE in Malaysia is very slow and is still in the early stage [36]. Therefore, the government continues to strengthen the RE policy and targets to increase the RE's share in the current energy mix (excluding large hydro schemes) from 2% in 2018 to 20% by 2025 which is roughly 4 GW (Figure 3) [22], [38].

III. MARINE RENEWABLE ENERGY DEVELOPMENT AND POTENTIAL SITES OF MCEDs IN MALAYSIA

With over 75% of the planet's surface covered by water, marine energy holds massive potential and rapidly growing globally [40]. MRE technologies will become the main future energy supply for most coastal countries. The key issues for the successful development of MRE are cost, design, site installation, maintenance, electricity transmission, and environmental impacts [41]. Figure 4 has classified numerous methods for extracting marine energy using

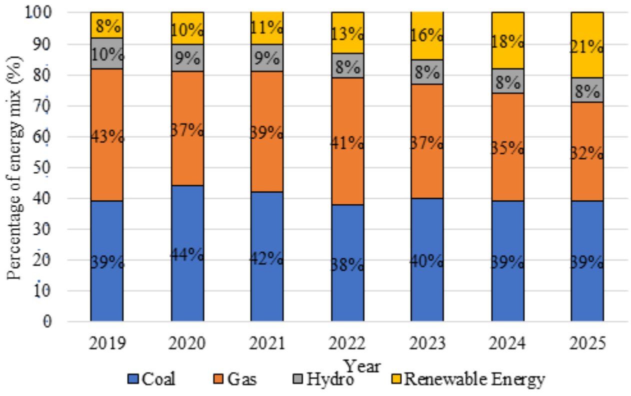


FIGURE 3. **Renewable energy projection in the capacity mix in the year 2025 (inclusive of off-grid RE) [22].**

MCEDs: tidal energy converter (TEC), wave energy converter (WEC), ocean thermal energy conversion (OTEC) and salinity gradient energy (SEG) [42]. Some devices are more efficient in energy conversion compares to others, and some device is cost-effective depending on the site installation and devices' designs [41]. The potential site location and types of marine energy technologies must meet the ideal condition as shown in Figure 5. Few locations across coastal Malaysia are economically viable for commercial-scale MRE generation. However, some sites with low tidal current speed (less than 2.5 m/s) are not economically viable [43].

The ocean harbors abundant energy in the form of wind, tidal, waves, and sun. All of these could be combined on a floating "OTEC Energy Island" which is inspired by Dominic Michaelis [44]. Figure 6 shows a 50 MW open-cycle OTEC plant planned on a tetrahedral floating structure platform which is designed to generate electricity via wind, tidal, wave, and solar in addition to having an OTEC plant [44]. The Energy Island uses OTEC as its main energy source and collects others energy sources available in the ocean. It collects solar and winds energy above the water surface, while collect wave and tidal current below water level [45]. The world's first Energy Islands will build in Denmark's North Sea providing enough energy for five million households [46].

A. TIDAL RANGE DEVICE

Tidal range device is using the potential energy of tide height different to extract energy [47], [48]. The concept of a tidal range power plant is to impound a large volume of water in an area in which a head difference can be created and then let water flows in to or out of this area through low head hydrokinetic turbines [47]. A preliminary study had identified six sites with a high tidal range in coastal Malaysia are Sejingkat, Pelabuhan Klang, Pulau Langkawi, Tawau, Kukup, and Johor Bahru [49]. These six sites have 70% of annual power availability. The highest tidal range found in Sejingkat is 4.38 m. If a 5 m long blade single turbine installs in Sejingkat, it can be generated about 14,970 kWh of electricity monthly which enough for 75 households' electricity usage [49].

In the study by Nazani *et al.* [28], sixteen tidal locations across coastal Malaysia are assessed to identify the potential of the power generation by using a tidal basin to produce the electricity and the results were presented in Figure 7. The tidal range found in Peninsular Malaysia is at Pelabuhan Klang with 3 m height which is passing the minimum requirement for tidal barrage implementation. While the Sabah and Sarawak have the highest tide range at Sejingkat with a tide height of more than 3 m. The data of the Malaysia Metrology Department from 2007 until 2011 indicate the highest tidal range of 5 m is found at Sabah and Sarawak [28]. Kuching Barrage located in Sarawak was built to mitigate flood in the city of Kuching has the potential for development into a tidal range power station as its highest tidal range of 6.8 m. The suitable tidal power plant scheme for Kuching Barrage (Figure 8) at Pending is operated using ebb generation during the barrage daily flushing operation. The potential energy that could be harnessed is 20.17 MW daily and 35.41 GWh annually [48]. In the study by Samo *et al.* [50], the potential extractable energy of the 34 tidal range sites in the East Malaysia coastline was investigated. They found the highest potential power was in Tanjung Manis in Sarawak measured between 50.7 kW and 39.2 kW, while the second-highest power was found in Pending, between 33.1 kW and 25.1 kW [50]. There is already an existing barrage at the Pending site, and this is the only site where power could be generated by just installing turbines.

The tidal range in Malaysia is lower than in other coastal countries that using a tidal range for electricity generation. The average tidal range in Malaysia has not fulfilled the minimum requirement for a tidal barrage turbine, so advanced technology for increasing the tidal range is needed. However, it is still rational to study the tidal range energy in Malaysia as some site locations identified have the potential for harnessing tidal range energy. Some sites just barely meet the minimum requirement of tidal range 3 m, so each one needs a large tidal basin area to produce the greatest output power generation [51]. The drawback of a large tidal barrages or lagoons system is that it requires high construction cost, block the movement of fish and other wildlife into and out of the estuaries, and the turbine's rotor can kill wildlife that tries to swim through them [52]. The basin area is also affected by the value of tidal range difference which means if the tidal range is too low, it will require a larger tidal basin area and vice versa. A small tidal barrage is more desirable as it requires less monetary and more manageable than a large tidal barrage [53]. The tidal barrage system is not economically viable due to expensive capital costs when compared with tidal stream turbine (TST) [15], [54].

B. TIDAL STREAM TURBINE

Tides are the cyclic variation of sea levels resulting from the interaction of the gravitational field and the centrifugal forces from the earth-moon system. These variations of tide cause movement in the water, creating tidal currents. Energy from

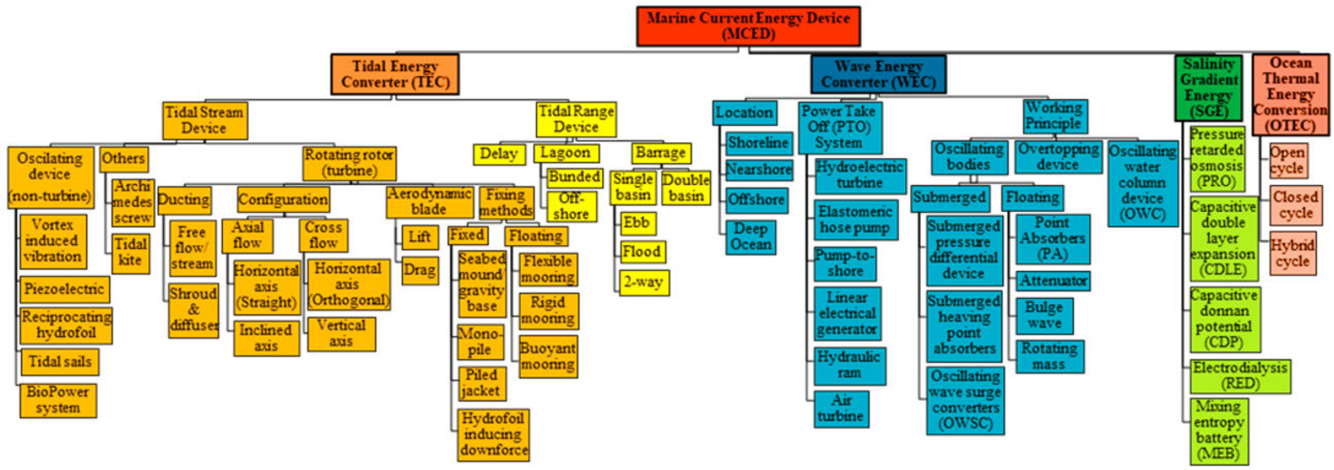


FIGURE 4. Methods of extracting marine renewable energy.

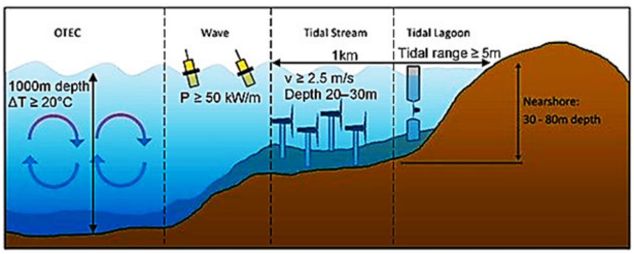


FIGURE 5. An ideal condition for MCEDs: OTEC, wave, tidal stream and tidal lagoon [39].

this current can be converted into tidal stream energy [3]. A tidal stream turbine (TST) is a device that utilizes the kinetic energy of moving water to turn the rotor, similar to a wind turbine that uses moving air [55]. The designs of TST can be categorized into horizontal axis tidal turbine (HATT), vertical axis tidal turbine (VATT), ducted turbine and other non-turbine oscillating devices [47]. Most tidal turbine blade's feature similar to wind turbine blade has an airfoil cross-section and operate using the aerodynamic lift which is more efficient than utilizing aerodynamic drag [56]. TST can be fixed to the sea bed using several methods: gravity base structure, monopile structure, jacket structure, floating structure, and hydrofoil inducing downforce [3], [41]. The key issues for the successful development of TST are tidal current velocity, the turbulence of flow, seabed topography, hydrology, turbine support structure, ship navigation, and marine wildlife [57].

TST can be classified as axial flow or crossflow according to the position of the rotor axis to tidal flow [58]. The rotor axis of the cross-flow turbine can be placed in either a vertical or horizontal plane relative to the tidal flow using lift or drag type rotor blades [56], [59]. A detailed classification of various TST is presented in Table 1 [56]. The funnel-like duct (concentrators/shrouds) with a narrowing cross-section can be installed to both axial flow and crossflow turbines to accelerate the flow towards the rotor and generate equal power output under smaller turbine diameter and slower water current [56], [60]. The shapes of the inlet and outlet, inclined angle, and volume of the duct can affect the flow amplification factor [61]. There are many different channel shapes for duct varies according to the type of rotor and rotor configuration position [62] and the detailed classification of various ducted TST is presented in Table 2. TST is the most developed and widely available MRE technology in SEA. Currently, research universities in Malaysia are developing a lab-scale horizontal and vertical tidal current turbines that are suitable to the local sea conditions in Malaysia (Table 3).

Few works of the literature suggested that TST is suitable for ocean energy harnessing in Malaysia [1], [15], [63]–[65]. The results of the tidal stream approach conducted by Lee and Seng [49] have indicated four site locations with the highest tidal current in Malaysia are Sandakan, Pulau Pangkor, Melaka, and Pelabuhan Klang. Sandakan has the highest power availability, 22 hours every day (80% of the time), and able to generate an output power of about 1209 kWh/month or 14,502 kWh/year [49]. Moreover, a potential site of TST in the coastal zone of Sarawak is Pulau Triso with the highest tidal current speed in Sarawak 2.06 m/s followed by Off Kuala Igan 0.51 m/s [66].

Ocean characteristics in Malaysia are the primary design consideration for a TST to ensure the turbine can seize optimum kinetic energy from tidal flow and operate at full capacity. Conventional TST is significantly dependent on tidal current velocity and ocean depth. However, slow tidal current ranging from 0.56 m/s to 1 m/s and shallow ocean about 15 m to 30 m of depth are found in coastal area of Malaysia. These ocean characteristics have limited energy that can be extracted through TST. The ideal tidal current speed for TST is more than 2 m/s. The average tidal current speed of 1 m/s (just passing the cut-in speed of the turbine) in Malaysia is about half of the speed for other coastal countries that are using TST in electricity generation. Hence, the use of conventional TST may not be suitable

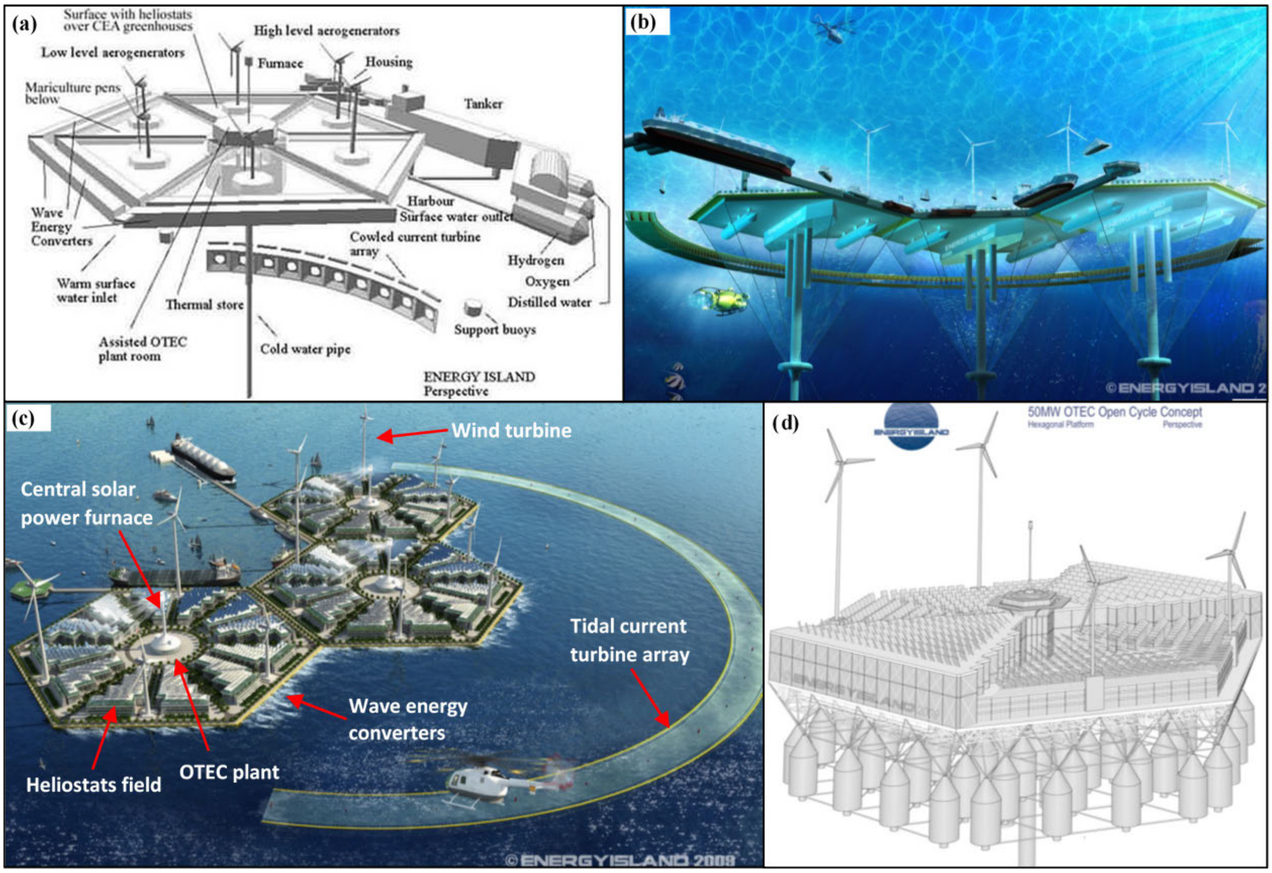


FIGURE 6. A 50 MW Energy Island floating platforms complete with renewable energy converter systems (OTEC, tidal current turbines, wave energy converter, wind turbine, and solar energy): a) Platform provided with renewable energy converter systems: patent no GB 2383978, b) Underwater view, c) Aerial view, d) Perspective view from above [44].

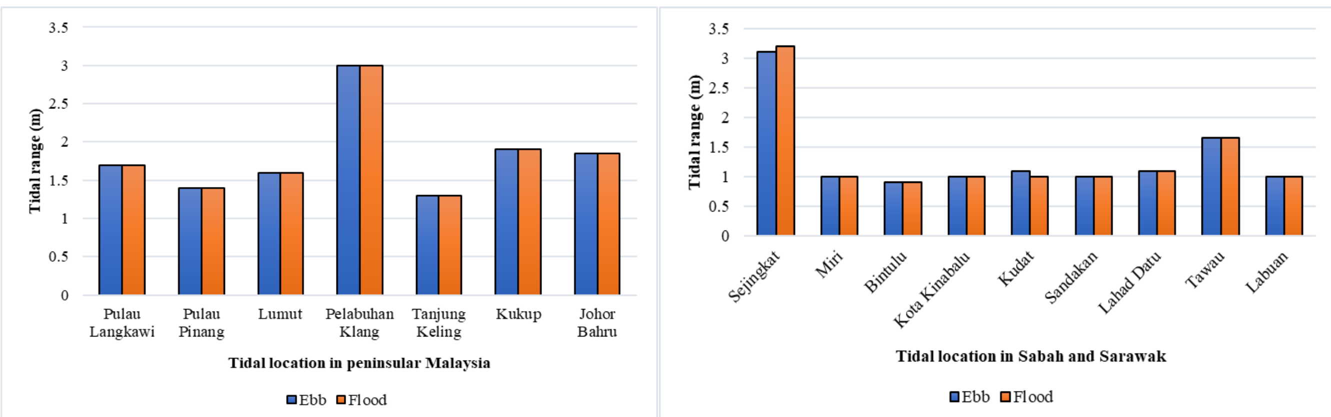


FIGURE 7. Tide range for sixteen potential tidal locations across coastal malaysia in Peninsular Malaysia, Sabah, and Sarawak [27].

for ocean characteristics in Malaysia due to low efficiency. As a solution, some improvements or modifications should be made to the current velocity or the turbine design, or both, to allow the turbines to operate at full capacity and generate high output power under low tidal current velocity and generate high output power [14]. It is recommended to increase the tidal current velocity through an augmented diffuser or duct (Figure 9) to improve the efficiency of the turbines.

C. WAVE ENERGY CONVERTER

Waves are generated by winds that blow over open water and will occur near the ocean water surface [55]. Wave energy flux is the mean transport rate of wave power through a vertical plane of unit width, parallel to a wave crest. Wave energy converter (WEC) extracting kinetic energy from the natural movement of ocean waves [55], [79]. WEC can be categorized into several different methods depending on their working principles: oscillating water columns

TABLE 1. Summary table of tidal stream turbine technologies/concept worldwide [42], [52], [67]–[73].

Rotor type		Configuration: Horizontal Axis	Configuration: Inclined Axis
Axial Flow (Free Flow)	Lift	Gravity base • Verdant Power, Voith Hydro, Salabella, Delta stream Monopile structure • SeaFlow, SeaGen S turbine Rigid mooring • The Tidal Stream turbine Flexible mooring • SMD Hydrovision TidEL turbine Buoyant mooring • Scotrenewables tidal turbine	• Garman turbine
	Drag	N/A	N/A
		Horizontal Axis	**Vertical Axis**
Cross Flow	Lift	(a) Transverse Horizontal-Axis Water Turbine (THAWT) • Ocean Renewable Power Company's (ORPC) TidGen (b) Cycloidal turbine (paddle wheel) • Bosch Cyclo Turbine (c) Pivoting turbine • The Hydrovolts Inc.'s Flipwing turbine	(a) Helical blade • Gorlov, Archard (b) Straight blade • Squirrel Cage Darrieus, H-Darrieus, Kobold (c) Curved blade (Eggbeater) • Darrieus (d) Swinging Flap • WPI Turbine
	Drag	• Waterotor	(a) Skewed blade • Savonius (b) In-plane axis • Floating Paddlewheels hydro turbine
	Hybrid rotor	N/A	Combination of two VATT's rotors mounted on the same shaft

TABLE 2. Summary table of ducted tidal stream turbines technologies/concept worldwide [42], [43], [52], [67], [68], [74]–[78].

Rotor type		Configuration: Horizontal Axis	Configuration: Vertical Axis
Axial Flow	Lift	• OpenHydro Tidal Turbine (Open Center Turbine), HydroHelix turbine, TidalStream Triton T6, Solon Tidal Turbine, Rochester Venturi system	N/A
	Drag	N/A	N/A
Cross Flow	Lift	• The HARVEST Power Systems (HPSs), Brian Kirke's diffuser-augmented water current turbine	• Blue Energy Ocean, Tidal Fence Davis Hydro Turbine, FIUBA's diffuser augmented floating CFWT, Edinburgh turbine, Ducted Water Current Turbine Triple Helix
	Drag	• Ducted Savonius Turbine	• Neptune Proteus Mark III

(OWCs), wave overtopping devices, and oscillating bodies' devices (Table 4) [80]. WEC can be located on the shoreline, nearshore (less than 50 m depth), offshore (greater than 50 to 70 m depth), deep ocean (greater than 500 m depth) [81].

Wave in coastal Malaysia is periodic and seasonal fluctuated by the wind of southwest monsoon and northeast monsoon. The weak wave power happens on the period in between both monsoon seasons and the greatest wave power happens during the northeast monsoon season [13], [82]. The study by Shen *et al.* [83] showed that the highest wave power available during the winter monsoon period (December, January, February). The wave power along the near-shore of the east coast of Peninsular Malaysia and MS is lower than the deeper ocean in the South China Sea [83]. Several potential wave energy hotspots were analyzed by Samrat *et al.* [13] and they found that the average wave power available in the Malaysia sea is 8.5 kW/m which is quite low compare with other coastal countries especially northern European countries that using wave energy.

Among various WECs, the oscillating water column (OWC) is highly recommended as it is more economic and able to operate in lower wave power density, low wave height, and swallow water areas [13], [15]. OWC prototype has been fabricated and tested in Universiti Teknologi Malaysia (UTM) (Figure 10) and the result proves that the wave energy can be harnessed to drive an air turbine based on Malaysia wave height [84]. Besides that, Jaswar *et al.* [85] has reviewed the possibility to utilize wave energy in Peninsular Malaysia with the case study in Merang, Terengganu, and they have identified the attenuator type wave converter developed by Wave Star (Figure 11) as a suitable WEC to be installed in Merang shore; one set Wavestar device could generate electrical power of 649 MWh/year. However, the Wavestar device may not fully be utilized if

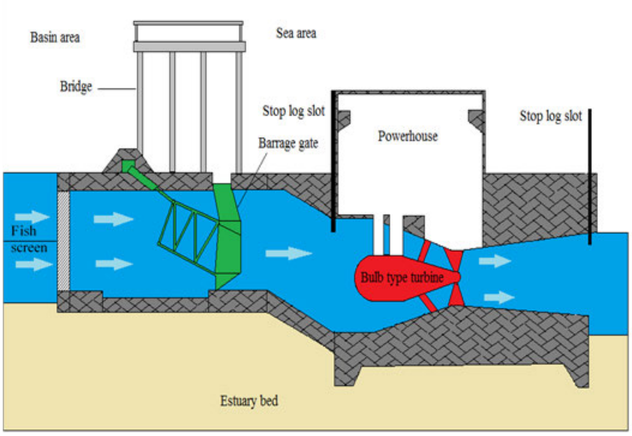


FIGURE 8. Cross-section of proposed Kuching barrage tidal power plant scheme [48].

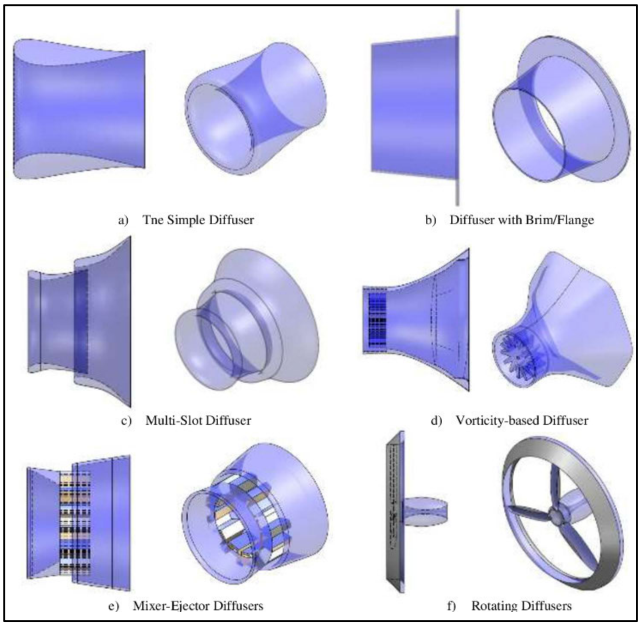


FIGURE 9. The main types of augmented diffusers for turbine [92].

FIGURE 10. OWC lab-scale model with the savonius turbine constructed in Universiti Teknologi Malaysia (UTM) (Left), (b) OWC WEC device experimental testing in UTM towing tank (Right) [84].

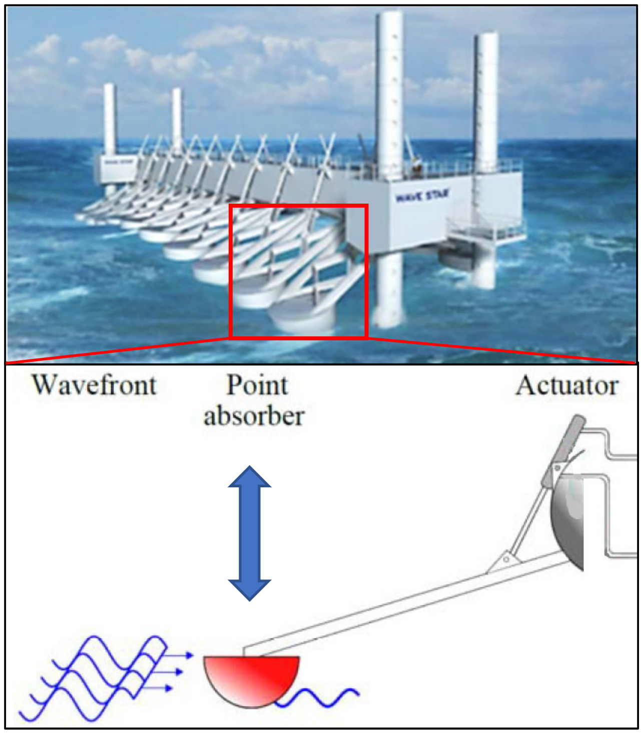


FIGURE 11. Wavestar WEC prototype at Roshage, Denmark [96].

it is installed in Merang because almost half of a year the wave height that occurs at Merang is below 0.5 m which is below the working requirement of the device [85]. As a solution, a special WEC device that can fully operate under smaller wave height in Malaysia needs to be developed to convert wave energy more efficiently. Aiman *et al.* [93] investigated the characteristics and performance of different floating OWC Backward Bent Duct Buoy shape geometry in low heave wave conditions (Figure 12). They proposed the round bottom corner shape as the most efficient shape in low wave heave wave conditions [93]. A WEC prototype based on buoy technology (Figure 13) was fabricated and successfully tested in a coastal area near Universiti Malaysia Terengganu (UMT). This device is still under development and will be optimized for better performance before being commercialized [94], [95].

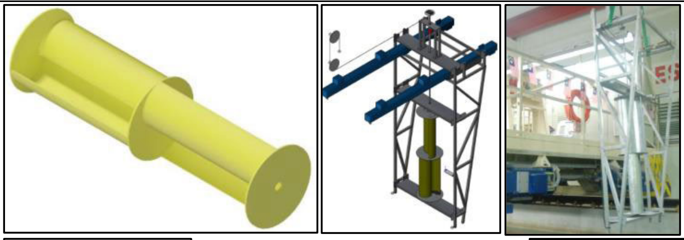
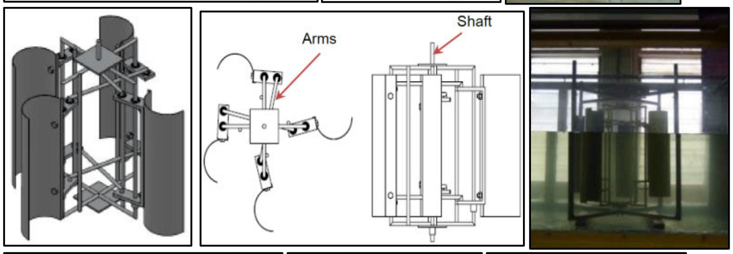
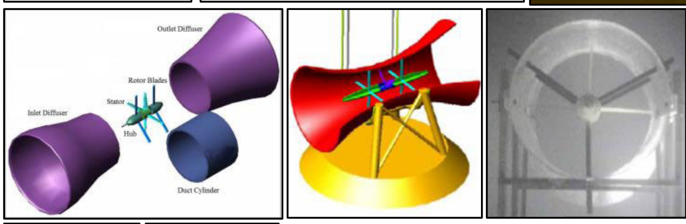
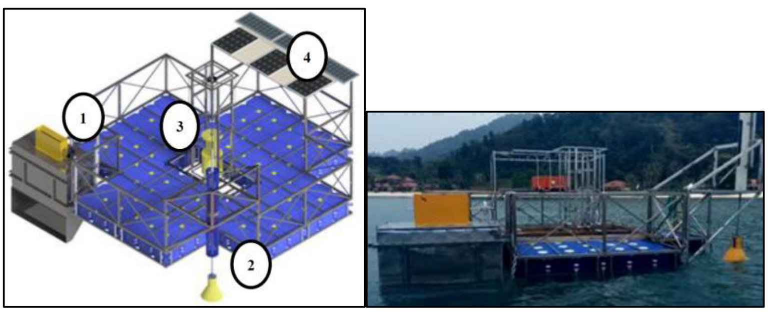
The coastal regions in Malaysia are accessible to low wave power of 8.5 kW/m yearly except for the east coast of Peninsular Malaysia during the monsoon season [13], [82].

However, the ideal wave power density to allow WEC generates enough power and commercially viable should be more than 50 kW/m [1]. Hence, WEC is not commercially viable in Malaysia [15], [65], [97]. The wave power generation would be commercially available in Malaysia with increasing wave energy conversion efficiency, introducing advancing technological capabilities and new harvesting methods [82], [83].

D. OCEAN THERMAL ENERGY CONVERSION

OTEC is a device extracting thermal energy from ocean temperature difference (around 20 °C) between warm (22-29 °C) tropical surface water and cold (4-5 °C) deep (1000 m)

TABLE 3. Current status of tidal stream turbine projects in Malaysia.

Illustration	Year	Device/Feature	Status/Activities	Ref.
	2013	Savonius turbine • VATT • two paddles and two-stage	A scale model of the turbine was constructed and tested in Marine Technology Center at UTM	[86]
	2014	Self-rotating blades of vertical axis current turbine (SR-VACT) • VATT • Four-blades • self-rotating flexible hinge joint	A scale model was constructed and tested at Marine Technology Center at UTM.	[87]
	2015	Augmented diffuser for HATT • Four-bladed axial flow rotor using NACA 0014 • Convergent-divergent cylinder diffuser	A 1/3 scale model was constructed and tested at Marine Technology Center at UTM.	[88]
	2018	Reza Savonius turbine • VATT • two paddles	A scale model was constructed and tested at Marine Technology Center at UTM.	[89]
	2019	Integrated tidal stream turbine with coastal erosion breakwater • HATT • Venturi duct • WABCORE breakwater	• A full-scale prototype is fabricated and tested in NAHRIM and obtain maximum power output of 30 W. • Prototype will be installed at Pantai Rhu Muda, Marang, Terengganu.	[90]
CORES Platform: (1) Oscillating Water Column Device; (2) Point Absorber buoy; (3) Savonius tidal turbine; (4) Solar panel CORES Platform sea deployment	2018	Combined Ocean Renewable Energy System (CORES) • A floating structure was built to integrate all the devices into one system	• Full-scale prototype fabricated and testing in marine Technology Centre at UTM. • Deployment of the CORES platform and its devices on Pulau Tinggi, an island off the east coast of Peninsular Malaysia.	[91]

waters by way of a heat engine generator to drive a turbine [79], [98]. Figure 14 shows the global distribution of temperature gradient between the water surface and the ocean floor. The equatorial water (10°N and 10°S) and tropical water (20°N and 20°S) are the best site location for OTEC, as this area absorbs a huge amount of sunlight and has a

TABLE 4. Classification of wave energy converters [80].

Working Principle	Structure	
Oscillating Water Columns	Fixed Structure (Shoreline)	Floating Structure (Offshore)
	a) Isolated OWC • Pico Plant Azores, Portugal b) In breakwater OWC • Wells turbine immersed in water, Multi-chamber OWC plant, Mutriku Spain	• Spar Buoy, Mighty whale, Ocean Linx (with focusing arms)
Oscillating Body Power Converter	Submerged (Nearshore)	Floating Structure (Offshore)
	Translation (heave) (a) Submerged Pressure • Differential Device Archimedes Wave Swing (AWS) (b) Submerged Heaving Point Absorbers • CETO-Carnegie Wave Energy	Translation (heave) (a) Point Absorbers • FO3, Ocean Power Technologies, PowerBuoy, AquaBuoy, Wavebob
	Rotation (bottom hinged) (a) Oscillating wave surge convertor • WaveRoller, Aquamarine Power Oyster, BioWave, Oscillating Cascade Power System (OCPS)	Rotation (a) Rotating Mass • Wello Penguin (b) Attenuator (Pitch rotation) • Pelamis (sea snake), Wave Star, McCabe Wave Pump, Salter's Duck (c) Bulge Wave • Anaconda
Overtopping Wave Power Converter	Fixed Structure (Shoreline)	Floating Structure (Offshore)
	a) Shoreline: • TAPCHAN (Tapered Channel Wave Power Device) b) In breakwater (without concentration): • Seawave Slot-Cone Generator (SSG)	Floating structure: • Wave Dragon, WaveCat

(a) (b) (c)

FIGURE 12. Experiments were carried out in the 3D wave basin at the National Hydraulic Research Institute of Malaysia (NAHRIM). Three different bottom corner shapes: (a) round, (b) square, (c) 45° [93].

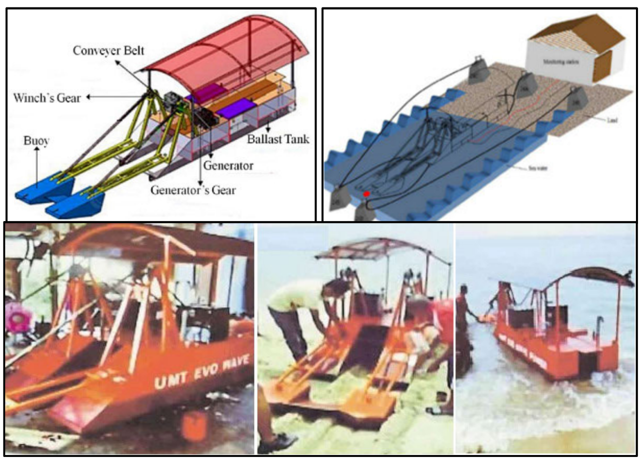


FIGURE 13. UMT Evo wave power based on buoy technology [94], [95].

warmer ocean surface [15], [79]. OTEC would commercially viable if the temperature gradient between warmer surface water and cooler deep water is greater than 20 °C. However,

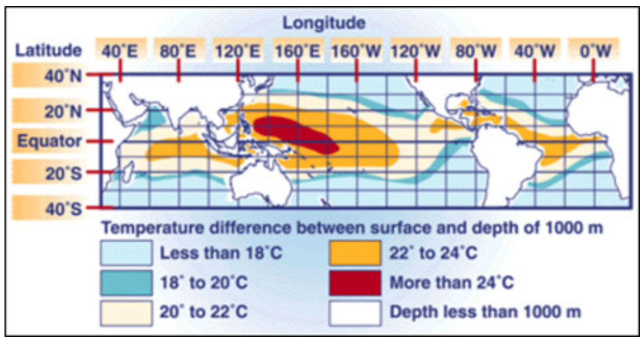


FIGURE 14. Map of the ocean temperature gradient between seawater surface and ocean depth of 1000m [100].

for ocean depth less than 1000 m will generate an ocean temperature gradient of less than 20 °C. Hence, OTEC is not commercially feasible in Peninsular Malaysia as the average ocean depth is less than 1000 m [1].

Harnessing OTEC energy is available in the Sabah Trough (Figure 15) located 100 km off the northwest of the Sabah coast [1], [98]. The Sabah Trough's water depth is 2900 m and the cold depth water is 3 °C compared with warm surface water of 29 °C. This temperature gradient of 26 °C makes OTEC possible for electricity generation in Sabah Trough [15], [99]. The Trough is estimated to be about 60 km wide and 100 km long. Thus, the amount of energy that could be generated in perpetuity is well above 50 GW, which is about 25 times the size of the 2.1 GW of TNB's coal-fired Janamanjung power plant in Lumut, Perak and an excellent alternative to the nuclear power plant of similar

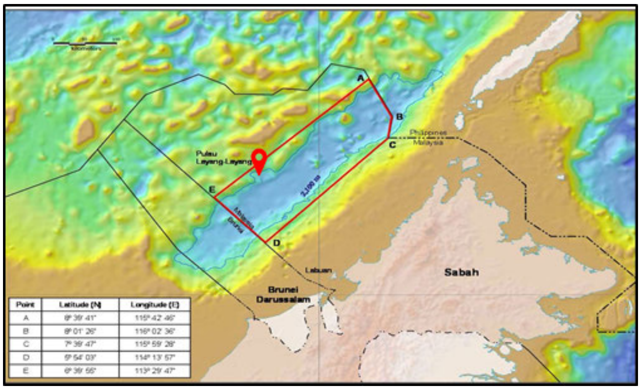


FIGURE 15. The sabah trough is estimated about 60 km wide and 100 km long (the area inside the redline ABCDE) located 100km off the sabah coast [101].

FIGURE 16. Layang-layang island, Sabah [102].

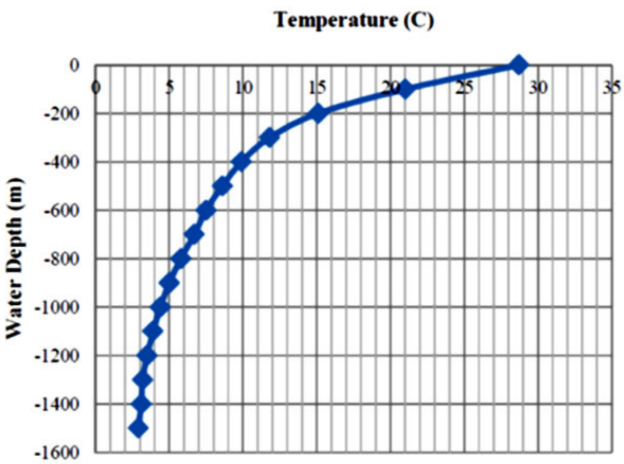


FIGURE 17. Sea surface temperature data at Layang-Layang Island, Sabah [102].

size. OTEC will be worth over USD50 billion in terms of the size of the capital required for its total energy development alone [99]. In the case study by Fahmie *et al.* [102], closed-cycle OTEC was used to simulate a 4 MW OTEC system in Layang-Layang Island (Figure 16). The simulation results indicate that Layang-Layang Island in Sabah Trough has a high potential for OTEC due to its water depth of around 2000 m and a gradient temperature of more than 20 °C (Figure 17) [102]. UTM has also set up an OTEC Research Centre in Kuala Lumpur to investigate its potential in the Sabah's island.

OTEC is an MRE under pilot testing; therefore, there will be some challenges to fully implement the technology. The OTEC energy is one or two orders of magnitude higher than other ocean energy such as wave power, but it has a lower thermal efficiency of 8% in energy conversion compared to conventional power plants. Furthermore, the extraction of energy is difficult and expensive due to pumping material [15], [103]. The primary challenge of OTEC is the high capital cost of building up a commercial-scale power plant. Studies show that OTEC plants that are smaller than 50MW are not economical compared to other MCED [104]. The capital cost of the OTEC power plant is too expensive due to the huge plant design and construction, power cable, and maintenance cost. OTEC is lacking economic competitiveness when compared with fossil fuel power plants due to the latter is still generating cheaper electricity thanks to large subsidies from the Government [98].

E. SALINITY GRADIENT ENERGY

The salinity gradient energy (ocean osmosis power or blue energy) generates electrochemical energy through the mixing of river freshwater and salt seawater. The working principle of SGE is using reverse electro-dialysis and pressure retarded osmosis [105]. A salinity gradient is generated in the river mouth as the exchange of organic matter and mineral nutrients [106]. SGE is suitable for cities that are accessible to river mouths [99]. The countries that have the highest number of river mouth systems such as Brazil, the United States of America, Mexico, Japan, and Malaysia have high extractable salinity gradient energy resources [106]. The most suitable site for SGE is the Rajang river which is one of the world's top 30 river mouths with a high extractable SGE of 6.8 TWh/a [106].

University Technology PETRONAS (UTP) Malaysia is researching SGE to review and compare five SGE methods: pressure retarded osmosis, reverse electrodialysis, capacitive double layer expansion, capacitive Donnan potential, and mixing entropy battery. The capacitive mixing method is selected for experimental analysis and the highest and average output power generated are 89.7 mW and 30 mW respectively [107]. UTP also experimented (Figure 18) using capacitive deionization technique to investigate the electrochemical reaction of different concentrations of saltwater and their effect on electrodes and amount of voltage and current generated [108]. They found the copper and aluminum electrodes are the most effective combination; able to generate 1.4 V and 20 mA [108].

SGE requires a large freshwater supply from the river mouth to the ocean and Malaysia has a high number of river mouth systems [106]. However, SGE is not economically viable due to its osmosis methods require expensive membrane materials. Besides the cost-effectiveness, the SGE also has some environmental problems such as animals are being drawn into channels, disposals of salt residues, and consumes large freshwater [105].

TABLE 5. Summary of marine current energy devices data in Malaysia.

MCED	Tidal Range	Tidal Stream	Wave	OTEC	Salinity gradient
Ideal/best Condition	The tidal range above 5 m [43]	• Tidal current velocity 2 - 3 m/s • Within 1 km from the shoreline • Ocean depth of 20 – 30 m [47], [109]	• Wave energy density greater than 50 kW/m [1] • Wave height > 2.5 m • Ocean depth > 40 m [110]	• The temperature difference is more than 22 °C • Ocean depth >1000 m [79]	• Coastal region • A high number of the river mouth • The mean tidal range at the river mouth is smaller than 1.2 m [106]
Minimum requirement	Tidal range more than 3 m	Tidal current velocity 1 m/s (cut-in speed of HATT) [1]	• Wave energy density greater than 15 kW/m [13] • Wave height 0.5 -1.5 m [84] Ocean depth > 20 m	• The temperature difference is more than 20 °C • Ocean depth >700 m [104]	N/A
Ocean characteristic in Malaysia	Tidal range less than 3 m [51]	• Tidal current velocity 0.5 - 4 m/s [15] • MS with average 2 m/s [16] • Average ocean depth of 25 m [65]	• The average wave energy density of 8.5 kW/m [13] • Wave height 1 m to 3 m [83] • Average ocean depth 25 m [1]	• Average temperature gradient below 20 °C [1] • Average ocean depth in MS 25 m [1] • Sabah Tough: 29 °C warm surface water & 3 °C cold deep water; Ocean depth 2900 m [99]	N/A
Potential sites in Malaysia	• Sejingkat; Pelabuhan Klang; Pulau Langkawi; Tawau; Kukup; Johor Bahru; [54] • Tanjung Manis, Pending [50]	• Sandakan, Pulau Pangkor; Melaka; and Pelabuhan Klang [49] • Pulau Jambongan, Kota Belud, and Sibu [1]	Perhentian Island, Mabul Island [97]	• Sabah Trough [99] • Layang-Layang Island [102]	Rajang river (Sarawak) [106]
The potential amount of electricity generation	14,970 kWh/month at Sejingkat [49]	• 1,209 kWh/month [49] • 14.5 GWh/year [1]	An annual yield from each OWC device is 1.728 GW [13]	N/A	The potential capacity in the Rajang river is 779 MW [106]
Summary of potentiality	**Medium**	**High**	**Low/Medium**	**Low/medium**	**Low/medium**

IV. DISCUSSIONS

A. COMPARISON BETWEEN MCEDs AND THEIR SUITABILITY FOR APPLICATION IN MALAYSIA

Among the MCEDs, TST is well known as the cheaper method to harness ocean energy [15]. The TST has an advantage compare to tidal barrage as it does not require building a large dam and basin and hence has a lower environmental effect [78]. TST technology in Malaysia is still under R&D and has not been developed on a commercial scale. The energy-cost ratio and the advanced technology of hydrokinetic turbines are the key factors for the successful commercialization of tidal turbines [14]. TST has a relatively high potential in Malaysia regarding predictability, manufacturability, install-ability, operability, survivability, reliability, and affordability [15]. Table 5 summarizes all the MCEDs regarding the ocean characteristic, site location, and power generation. It was found that TST is most suitable to the ocean characteristics in Malaysia, several potential sites distributed across all-region in Malaysia and has a high potential amount of electricity generation [14]. The results of Bonar *et al.* [64] suggest Malaysia utilizes small scale low-speed TST and off-grid electricity generation. The installation cost of TST is much lower than tidal barrage systems and other MRE. Hence, the TST is the most suitable MRE in coastal Malaysia and economically viable on a commercial scale [54].

B. POTENTIAL SITE OF TIDAL STREAM TURBINE IN MALAYSIA

Tides are the periodic ebb and flood of ocean water surface level caused by the gravitational pull of the earth, moon, and sun [3], [43], [47]. A tidal phenomenon is periodic and occurs two times a day [111]. Tides create a tidal current in the deep oceans, off-shore, and near-shore along the coastline and the exploitation of these natural rises and fall of coastal tidal waters leads to tidal energy extraction [3]. There are generally three types of tides that occur along the earth's major shorelines: diurnal, semidiurnal, and mixed [65]. North and West of the Peninsular Malaysia (Kedah, Perak, Penang, and Selangor) have been spearheaded by the semidiurnal tides [112]. If a tidal turbine is installed on this coastline, it is expected that the tidal turbine will generate four peak power output per day and the highest power output will occur at spring tides [1]. The diurnal tide is not available in coastal Malaysia [49]. Southern and Eastern regions of the Peninsular

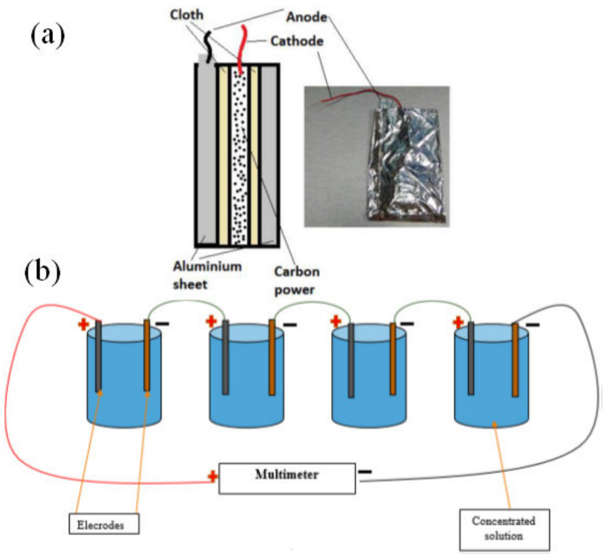


FIGURE 18. Set-up of an experiment for (a) Single-cell using powdered activated carbon electrode, (b) Multiple cells are connected in series and parallel to increase the voltage and current, respectively [108].

Malaysia (Johor, Pahang, Kelantan, one-third of the state Terengganu, Sabah, and Sarawak) have been spearheaded by mixed tides with dominant semidiurnal [112]. Rest area for Malaysia, spearheaded by mixed tides with dominant diurnal [112]. It can be expected that a tidal turbine installed in the coastline of Terengganu (mixed tides with dominant diurnal) will generate two peak power output per day. The highest turbine power output will occur during the extreme declination of the moon [1].

It is important to recognize the characteristic of tides to project the accessibility of low and high tidal energy. The available electricity generation from a tidal turbine at the site can be projected by identifying the types of tides in a specific site [1]. The tide in coastal Peninsular Malaysia is mostly semi-diurnal and mixed tide with dominance in semi-diurnal, except coastal Terengganu which has the mixed tide with dominant diurnal. On the other hand, the tide in Sabah and Sarawak is mixed tide with either dominant semi-diurnal or diurnal [49], [65]. Mixed tides with dominant in diurnal tides in Sibu, Kota Belud, and Pulau Jambongan, are identified as suitable site locations for harnessing tidal energy [1].

Tidal currents can be sped up by the natural bathymetry of coastal areas particularly when the current is passed through narrow channels or around peninsulas (e.g. Malacca Strait (MS)) [47]. The MS is one of the world's longest straits with a constant current velocity of 0.5 - 4 m/s. MS has a funnel-like geographical shape that can accelerate the current passes through the strait from a shallow narrow southern channel (South China Sea) towards the deeper wider northern channel (Indian Ocean). The ocean current with this constant direction shows significant tidal power potential [65]. The tidal current in the strait is significantly affected by the winds and ocean topography. The tidal current in the narrower southern channel is greater than the wider northern channel.

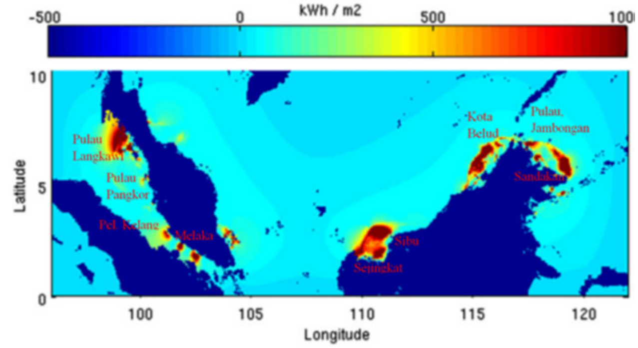


FIGURE 19. Energy density profile of tidal current across the coastal region in Malaysia [1].

However, wind-driven current energy in the deeper northern channel is greater than the swallow southern channel [16]. The wind-driven current energy is more significant, and the northern channel is more suitable for TST installation. The preliminary study shows that MS matches the ideal ocean characteristic for the tidal turbine which a tidal current speed of 2 - 3 m/s with a water depth of 20 - 30 m [25]. Hence, MS is an ideal location for harnessing tidal energy.

The site of a tidal turbine is either deep waters or shallow waters (less than 40 m deep). The site water determines the design, support, and mooring structures of the turbine [47]. The ideal sites of a tidal turbine are the areas with high water current where tidal flows are focused between obstacles such as cove, cliff, peninsulas, islands, or other landmasses [103].

A preliminary study had found that all the potential TEC sites are located around the six main regions in the whole country (Northern Region, Central Region, Southern Region, East Coast, Sabah and Sarawak) as shown in Figure 19 and described in Table 6. For the barrage approach, the studies at Sejingkat and Pelabuhan Klang show high power availability of 76.15% and 75.35%. For the tidal stream approach, the studies at Sandakan and Pulau Pangkor show power availability of 80% and 57%. However, the power availability at Melaka and Klang is relatively lower, with an average of 43% and 19% [49]. There is less potential tidal energy site in the east coast region of Malaysia.

The current velocities found at Pulau Jambongan, Semporna, Barangbongan, Kuching, Kota Belud, and Sibu are 1.1 – 1.2 m/s (just passing cut-in speed of tidal turbine) which are suitable sites for tidal stream energy harnessing. These locations have average ocean depths greater than 20 m which are ideal sites for TST installation. The total electricity generated by TST at Pulau Jambongan, Kota Belud, and Sibu is 8604 GWh/year which is higher than the targeted amount of solar PV of 2.2 GWh/year in 2010. Tidal energy sources in these locations can reach about 10% of the total electricity demand in Malaysia which is 83,000 GWh/year [1]. According to findings from Minerals and Geoscience Department Malaysia, Universiti Malaya, Universiti Teknologi Malaysia and Universiti Malaysia Sarawak [49], [113], [114], areas such as Pulau Langkawi, Pulau Pangkor, Pelabuhan Klang,

FIGURE 20. **One Fathom Bank is a shoal located in the Strait of Malacca, 40km southwest from the offshore of Klang delta in Selangor, coordinates 2° 53.3′ N 100° 59.8′ E. (Image adapted from google map, 2020).**

Malacca, and Sandakan have a minimum flow rate of 0.4 m/s [1]. Whereas in Sabah and Sarawak, the potential areas for tidal turbine are in Sejingkat, Sibu; Pending, Tawau, Kota Belud, Pulau Jambongan [1], [113]. Samo *et al.* [113] found that Pending location can generate a great amount of 115.4 kW tidal energy in the Sarawak coastline and follow by Tawau with the amount of 67.0kW tidal energy in Sabah coastline. The west coast of Peninsular Malaysia also has a suitable location. For example, Redang Island has been identified as a suitable location because Chagar Bay has a tidal current circulation between 0.16 m/s and 0.48 m/s.

Mohd Yusoff *et al.* [112] show that Selangor is a very high potential location for harnessing tidal energy compared with other states in Malaysia. The ocean of Pelabuhan Klang Selangor is identified as the second highest yield site of tidal energy. For a tidal power plant installed in Pelabuhan Klang, it will be able to supply electricity for the need of the nearest city in the Klang Valley area especially the capital of Malaysia, Kuala Lumpur [49]. The Permatang Sedepa (Figure 20) is also known as One Fathom Bank (OFB) is elongated 130° - 310° lying about 40 km southwest from the Pelabuhan Klang which is identified as having huge tide resources [115]. The previous study had identified the OFB site located at paleo terraces 2 with flooring surface depth of 30 m and has a constant current speed of 1.0 m/s towards the northwest [115]. Hence, OFB has fulfilled the minimum requirement for site installation for TST. Another factor in site location consideration is the ease of access from the OFB lighthouse and Pelabuhan Klang by boat. The facilities at Pelabuhan Klang can be used for turbine maintenance or assembly. The turbine equipment will be easy to ship to OFB using the port facility. As the OFB lighthouse is a fishing spot and provides ship navigation, there is no laboring problem in hiring a worker to operate the turbine. The worker in OFB will watch the safety of the strait at the same time monitor the turbines to ensure a fast response to the authorities if the turbine malfunction.

C. CHALLENGES OF MRE IN MALAYSIA

MRE is not yet widely used and only a small amount of MCED has been used in a prototype or pre-commercial demonstration stage [12], [116]. There are five barriers to the development of MRE in Malaysia: technical, economic, socio-environmental infrastructural, and political.

1) TECHNICAL

Lack of expertise and advanced technology for marine turbines hinder the development of MRE generation [5]. Seven strategic technology challenges that help accelerate and sustain the MRE are predictability, manufacturability, install-ability, operability, survivability, reliability, affordability [12], [15]. The formation of ‘‘Bio-fouling’’ on the turbine body structure is a great challenge. As a solution, the special coat is applied to the body of MCED equipment to avoid the growth of bio-fouling [65]. The operating condition and mooring system of the marine turbine are also in concern [117].

2) ECONOMIC

The motivations to use RE in Malaysia are determined by four economic barriers: subsidies, tariff issues, high cost of RE, and difficulty to obtain bank loans [118]. MRE technologies require expensive initial project capital costs and cannot compete with government subsidies for conventional fossil-fuel for electricity generation and hence make RE not commercially feasible [119]. MREs are still a very high risk project in terms of cost and revenue for investors and insurers, hence, it is difficult to obtain bank loan financing [120]. The cost of MRE is higher than solar power and wind power. This may demotivate consumers to pay for expensive green electricity. Therefore, incentive module such as Feed-in Tariff (FiT) is needed to stimulate investments of small and large scale RE projects by reducing the investment costs [25]. Moreover, the COVID-19 pandemic resulting in global financial contraction, and a collapse in oil prices to negative will also slow down the global RE transition. The world in lockdown causes economic contractions to reduce power demand will reduce budgets and suspend deployment of new RE plants. Green energy technology companies will minimize their growth plans and take on more economical measures [121], [122].

3) SOCIO-ENVIRONMENTAL

a: ENVIRONMENTAL ISSUES

Tidal energy structures have significant potential impacts on the coastal environment. The installation of tidal structures could influence salinity and dissolved oxygen levels as well as sediment transportation. The marine animals can be strike by the turbine blades or entangle in submerged cables. The noise, vibration, and turbulence generated by the rotor can destroy the marine environment. The oil leaking from the submerged turbine generator parts can contaminate the water.

TABLE 6. Potential site for the tidal energy converter around the coastal region in Malaysia [1], [49], [65], [66], [113].

Region	Potential sites for the tidal energy converter				Tidal energy's beneficial state
	Tidal barrage approach		Tidal stream approach		
	High tidal range site	Power availability	High tidal current site	Power availability	
Northern	Pulau Langkawi (2.5 m)	59.81%	Pulau Pangkor (2.2 m/s)	57.01%	Perlis, Kedah, Perak
Central	Pelabuhan Klang (4.2 m)	75.35%	Pelabuhan Klang (1.2 m/s)	18.62%	Selangor, Capital of Malaysia (Kuala Lumpur)
Southern	Johor Bahru (2.6 m)	63.33%	Melaka (1.7 m/s)	43.32%	Melaka, Johor
	Kukup (2.6 m)	65.67%			
East Coast	N/A	N/A	Pulau Redang (0.48 m/s)	No reliable data found	Terenganu
Sabah	Tawau (2.8 m)	63.68%	Sandakan (6.0 m/s) Pulau, Jambongan, Kota Belud, Semporna (1.1 m/s)	80.03%	Sabah
Sarawak	Sejingkat (4.38 m), Pending (6.8 m)	76.15%	Pulau Triso (2.06 m/s); Off Kuala Igan (0.5 m/s), Sibu (1.1 m/s)	No reliable data found	Capital of Sarawak (Kuching)

The turbine may also block the ship's navigation and fish migrations [117].

b: SOCIAL ACCEPTANCE ISSUE

Social acceptance of RE technology is another barrier to developing RE policies. Most Malaysian lack knowledge about RE policies and no social acceptance for RE which could lead to the failure of RE policies in Malaysia [5], [120].

4) INFRASTRUCTURAL

a: GRID ACCESS

The barrier to the commercialization of MRE is that Malaysia's best marine resource areas are located in the rural area and remote islands that lack national grid access or are located far away from the load center [9]. There will be an advantage for the development of MRE projects if the site location is near to a grid infrastructure [12].

b: SUPPLY CHAIN

The supply chain for MRE projects is lacking design consensus. The port installations and ships for the deployment of MRE are insufficient and very far from the site location. The improvement of the supply chain benefits long term marine energy projects and can increase the investor's confidence [12].

c: MAINTENANCE SERVICE

Most of the marine energy devices are sited offshore and the scheduled maintenance will be a concerning issue. Real-time weather forecasting for predictive maintenance and good marine services are needed [12].

5) POLITICAL COMMITMENT

Political barriers will be caused by the failure of the RE policy in Malaysia. The lack of political commitment to push for a swift implementation of the RE agenda in Malaysia had caused the lag of enforcement of alternative energy [123]. The government had introduced a good policy but did not efficiently implement it. The set target of 5% RE for total electricity generation in the 8th Malaysian had failed to meet the target. The government fails to make necessary changes, weak R&D, inefficient management, and unrealistic RE targets [118]. Malaysia's RE policy only gives priority to solar PV, mini-hydro, biomass, biogas, and municipal waste. The MRE is not highlighted in RE policy even though Malaysia has huge ocean energy resources.

V. CONCLUSION

Malaysia's oceans are characterized by slow tidal currents, low wave heights, and shallow waters, which translate into smaller ocean energy potential. Many of the areas with tidal potential are located far from connections to the national electric grid, while for areas with tidal potential, finding compatible devices are a challenge. This study is important to provide an overview of MRE and its applicability in Malaysia and hopefully in a more global context. This review compiles the RE policy, potential site locations, and the challenges of MRE in Malaysia. Various types of MCEDs' concepts are explained and categorized. Indeed, it has been described as the characteristic of tides in Malaysia and a suitable site location for MCEDs installation in Malaysia. The MS is identified as an ideal location for harnessing tidal stream energy as the strait has funnel-like geographical geometry to speed up the ocean current. Among all discuss MCEDs, the TST is identified has great potential and most suitable for ocean characteristics in coastal Malaysia. Ocean characteristics in Malaysia are low kinetic energy-flux density, low current speed, low tide, and low water depth, make the tidal stream energy resources not significant enough contribution to the nation's energy mix. Therefore, using low-speed TST, increase the flow velocity through augmented diffuser or duct, improve the efficiency of the turbines should be studied thoroughly. The governments should promote the development of MRE by encouraging R&D to design and build prototypes. The East Coast of Peninsular Malaysia and West Malaysia have many rural areas and remote islands that are far from the load center or no access to national grids. Off-grid electricity generation from MRE is the best alternative electricity supply for a rural area. MRE can contribute to the energy balancing market in Malaysia and this will be important when variable RE increases in the energy mix.

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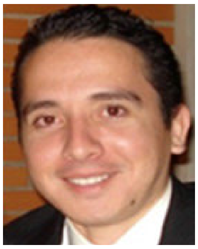
LIM YEE KAI received the bachelor's degree in manufacturing engineering (engineering materials) from the Technical University of Malaysia Malacca (UTeM), in 2008, and the master's degree in mechanical engineering from the Tun Hussein Onn University of Malaysia (UTHM), in 2014. He is currently pursuing the Ph.D. degree in mechanical engineering with University Technology Malaysia Kuala Lumpur (UTM KL). From 2009 to 2015, he was a Lecturer with Polytechnic Kuching Sarawak. From 2015 to 2018, he was a Lecturer with Polytechnic Banting Selangor. His research interests include the powder metallurgy of porous ceramic, friction stir spot welding of dissimilar metal, and ducted water current turbine.

SHAMSUL SARIP received the Diploma degree in mechanical engineering, the bachelor's degree in mechanical engineering, and the master's degree in mechanical engineering from the Universiti Teknologi Malaysia, in 1995, 1998, and 2002, respectively. He is currently pursuing the Ph.D. degree in mechanical engineering from the University of Bradford, U.K., in 2012. He is currently an Associate Professor with the Razak Faculty of Technology and Informatics, Universiti Teknologi Malaysia Kuala Lumpur. He has been involved in engineering design including lightweight disc brake, micro hydro turbine, ram pump, marine current turbine, and product development. He also involved in university motor sport activities which required him to expand the knowledge to finite element analysis, heat transfer, computational fluid dynamics, and structure analysis.

HAZILAH MAD KAIDI received the B.Eng. degree (Hons.) in electrical engineering and telecommunication, the M.Sc. degree in telecommunication and information engineering from the Universiti Teknologi MARA Malaysia, and the Ph.D. degree from Universiti Teknologi Malaysia. She is currently a Senior Lecturer with the Razak Faculty of Technology and Informatics. Her research interests include mobile and wireless communications, error control coding, relay networks, cooperative communications, hybrid ARQ, cross-layer design, the Internet of Things, and green technology.



JORGE ALFREDO ARDILA-REY (Member, IEEE) was born in Santander, Colombia, in 1984. He received the B.Sc. degree in mechatronic engineering from the Universidad de Pamplona, Pamplona, Colombia, in 2007, the Specialist Officer degree in naval engineering from Escuela Naval Almirante Padilla, Cartagena, Colombia, in 2008, and the M.Sc. and Ph.D. degrees in electrical engineering from the Universidad Carlos III de Madrid (UC3M), in 2012 and 2014, respectively. From 2008 to 2010, he was an Automatic Control Engineer with ARC Almirante Padilla. From 2010 to 2014, he worked with the Department of Electrical Engineering and the High-Voltage Research and Test Laboratory (LINEALT), UC3M. He is currently working as a Professor with the Department of Electrical Engineering, Universidad Técnica Federico Santa María, Santiago, Chile. His research interests include partial discharges, insulation systems diagnosis, and instrumentation and measurement techniques for high frequency currents.

NOORAZIZI MOHD SAMSUDDIN received the Diploma degree in mechanical engineering, the Honours degree in mechanical engineering, and the master's degree in mechanical engineering (computational fluid dynamic) from UTM, Malaysia, in 2000, 2004, and 2009, respectively, and the Ph.D. degree in manufacturing engineering (machining engineering) from UTeM, Malaysia, in 2017. He has vast experience in mechanical engineering as an academic and the professional management consultant in mechanical and electrical (M&E), HVAC system, and manufacturing. His specialization are in the area of design of experiment (DOE), response surface methodology (RSM), and machining (medical tools).

MOHD NABIL MUHTAZARUDDIN received the B.Eng. and M.Eng. degrees from the Universiti Teknologi Malaysia (UTM), Johor Bahru, Malaysia, in 2008 and 2010, respectively, and the Ph.D. degree from the Shibaura Institute of Technology, Tokyo, Japan, in 2014. He is currently a Senior Lecturer with the Department of Engineering, Razak Faculty of Technology and Informatics, Universiti Teknologi Malaysia. He current research interests include renewable energy, dg location-sizing, network reconfiguration, capacitor placement, optimization method, and smart grid.

FIRDAUS MUHAMMAD-SUKKI has been an Active Researcher with the Edinburgh Napier University, U.K., where he is currently a Lecturer. His research interest is in designing optical concentrator, which can be used in many applications, including creating a low cost solar photovoltaic systems, illumination, heating and cooling of buildings, energy harvesting, desalination, medical devices, and waste water treatment. On top of that, he also carried out a number of non-technical research including market trend and financial analysis related to renewable technologies. He has excellent track record in collaborating with research universities around the world. He has published numerous articles in high impact factor journals and presenting in various conferences related to his area. Prior to joining the academia, he was a communication engineer in Malaysia's largest telecommunication company. He was in charge of the leased line servers for Malaysia's network and was involved in major projects related to the telecommunication while holding the post.

SAARDIN ABDUL AZIZ received the Diploma degree in mechanical engineering (aeronautics), the bachelor's degree in mechanical engineering (aeronautics), and the master's degree in mechanical engineering from Universiti Teknologi Malaysia, in 1995, 1998, and 2002, respectively, and the Ph.D. degree in mechanical engineering from the University of Glasgow, U.K., in 2012. He is currently the Academic Staff with the Razak Faculty of Technology and Informatics, Universiti Teknologi Malaysia Kuala Lumpur. He is involved in ultrasonic vibrations, finite element analysis, finite element modeling, heat transfer, safety engineering, micro hydro turbines, ram pumps, and wind turbines. He is also involved in university community service activities that involve in-game learning at the pre-school and primary school levels based on science, technology, engineering, and mathematics (STEM).