The Potential of Ocean Thermal Energy Conversion (OTEC) in Sabah, Malaysia: A Systematic Review

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Abstract

Ocean Thermal Energy Conversion (OTEC) is a relatively new technology that leverages on the temperature difference between warm surface seawater and cold deep seawater to generate electricity with no harmful emissions. This type of energy has become an important research topic for sustainable development due to the large energy resources contained in the ocean. Malaysia has a great potential to harness this type of energy due to its long coastline. We studied Sabah's coastal waters for its potential in OTEC. Sabah's coast is blessed with a range of productive coastal marine ecosystems coupled with several deep-sea islands. These diverse marine features translate into the type of OTEC plant suitable for implementation in Sabah. A systematic literature review (SLR) approach was utilized to compile, review, and assess literature advocating for OTEC, the different types of OTEC plants and analytical methods used in OTEC plant site-selection. We identified five potential sites for OTEC plants in Sabah. These include three sites in the northeast, namely Layang-Layang Island, Mengalum Island, and Mantanani Island, and two sites in the southeast, namely Tawau and Kalumpang. The availability of potential sites in Sabah indicates that the OTEC system – not only as a source of unlimited and environmentally friendly renewable energy, but also as a means of freshwater production – is a viable option for implementation in the State. OTEC systems can be diverted to allocate a portion of the electricity generated for operating adjacent water desalination plants, for generating sample volumes of water suitable for human consumption, and aquaculture and agricultural purposes.

Keywords: Ocean Thermal Energy Conversion (OTEC) system, OTEC plant type, renewable energy, clean energy, Sabah

Introduction

The transition from conventional to clean energy sources represents one of the most promising developments in recent years for addressing climate change. It holds substantial implications related to economic policy agendas, as policymakers strive to incorporate clean energy into transforming energy systems (Özgül et al., 2020). Various renewable energy sources, such as solar, hydroelectric, wind, and nuclear energy have been proposed to meet energy demands in response to the worldwide difficulties in addressing energy issues and global warming.

The deep seas in East Malaysia (the Borneo archipelago), have a potential to generate renewable and stable energy. According to Martin et al. (2016), the deep seawater within the (Borneo) archipelago holds a promising utility as a resource for a variety of industries. Deep seawater has huge potential as a nutrient provider to the surface ocean (Takahashi, 2003), while seawater air conditioning (SWAC) can be tapped to reduce energy consumption (Hernandez et al., 2019). Such areas with access to both deep seawater and surface seawater have a huge capacity for Ocean Thermal Energy Conversion (OTEC) to supply adequate base-load electricity. The proficiency in OTEC in the State appears substantial and comparable to regional tropical and subtropical nations, such as Indonesia (Fahmie et al., 2018; Langer et al., 2021; Rahmawati et al., 2021), the Philippines (Uehara et al., 1988; Fahmie et al., 2018; Ding et al., 2022), and Nauru (Wolff et al., 1979 in Thirugnana etal, 2021).

The Sabah State Government have recently (in April 2024) approved two new legislations to pave the way for renewable energy in the State, specifically the Ocean Thermal Energy Conversion (OTEC) Enactment 2024 and Energy Commission of Sabah Enactment (Amendment No.2) 2024 (*see* ECoS, 2024). These enactments are one of the State's main initiatives under the Blue Economy policy framework (https://blueeconomy.sabah.gov.my/; DE, 2024a).

The surface temperature and the ground temperature beneath the Sabah Trough align with the fundamental principles of OTEC technology. Building on a feasibility study, a group of researchers explored the possibility of developing and commercializing the first Malaysian OTEC plant in Sabah (Jaafar, 2012). However, there remains a knowledge gap about which type of OTEC plant is suitable for implementation in Sabah. Fahmie et al. (2018) later suggested that for Layang-Layang Island, an oceanic atoll approximately 180 nm (300 km) northwest of Kota Kinabalu, the capital city of Sabah, OTEC plants with a fixed platform is the most suitable design. Thirugnana et al. (2021) also highlighted Layang-Layang Island and a few other sites with significant potential for OTEC system for development in Sabah, i.e. Semporna, Tawau, Kudat and Kalumpang. However, they did not specify nor suggest the type of suitable plant at each of the locations mentioned. A related study was undertaken by Seungtaek et al. (2020), where they conducted an economic analysis of the possibility of OTEC plants in several localities Sabah. The analyses were, however, restricted to basic open- and closed- cycle models only. They attributed the exclusion of hybrid models from their analyses to insufficient data on initial investment costs, a decision that may inadvertently introduce inaccuracies into their study.

Materials and Methods

Systematic Literature Review About Potential of OTEC in Sabah, Malaysia

A systematic literature review (SLR) was utilized to portray the current progress of OTEC in Sabah. It serves as a strategy to compile, review, and gain access to literature using predefined techniques in order to mitigate bias (Brereton et al., 2007; Gurbuz & Tekinerdogan, 2018; Salleh & Tasnim, 2022). An SLR analysis involves "being methodical, comprehensive, transparent and replicable", and our SLR analysis approach followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guideline, following Liberati et al. (2009), Moher et al. (2010), and Mengist, et al. (2020) as the prescribed framework for the reporting process (Figure 1). Thus, the PRISMA guideline serve as the framework to carry out the systematic review, guiding the formulation of review questions and eligibility criteria, identification of relevant literature meeting the criteria, as well as the processes of data extraction, synthesis, and presentation of results to solve the review questions.

We employed the Web of Science (WOS) and Scopus databases generated by Universiti Teknologi Malaysia's (UTM) system to obtain data used in this study. The database search processes were integrated with the phrase searching functionality and the Boolean operators OR and/or AND to efficiently combine keywords. Additionally, we complemented the database search with manual searching methods (Xiao & Watson, 2019) to ensure a comprehensive collection of relevant literature. The chosen search keywords specified research articles within the database that contain the terms in their title, abstract, or keywords section. The search keyword includes the phrases "OTEC," "ocean thermal energy conversion," "OTEC type plant," "OTEC site location," and "OTEC Sabah." Articles containing the terms "OTEC site selection" and "parameter" were also considered (Table 1).

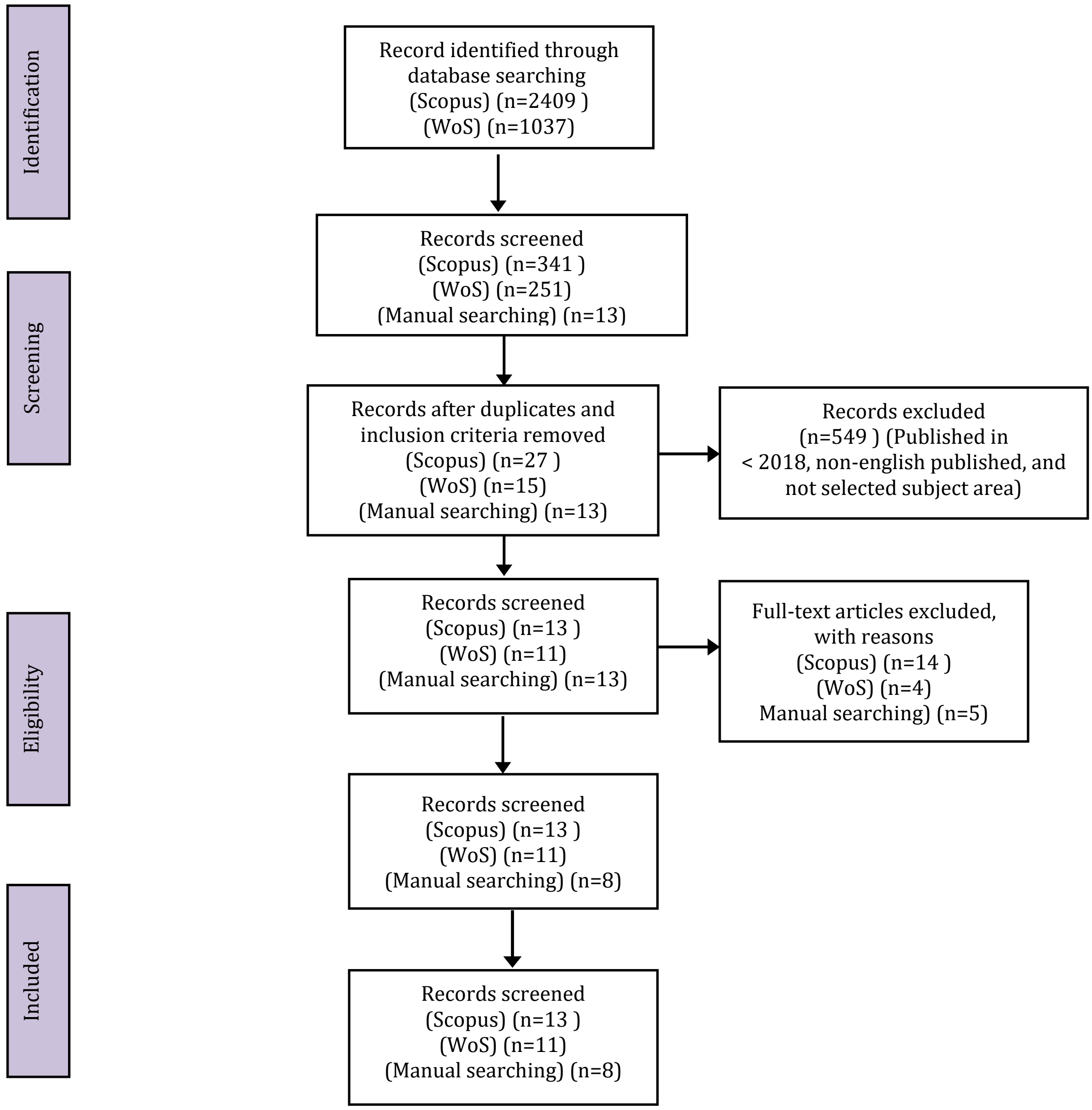

Figure 1. PRISMA flow diagram for literature search (Liberati et al., 2009; Moher et al., 2010; Mengist et al., 2020).

Table 1. Search string for Web of Science (WoS) and Scopus

Search engine	Search string
WoS	TS= (“OTEC” OR “ocean thermal energy conversion” OR “OTEC type plant” OR “OTEC site location” OR “OTEC Sabah” OR (“OTEC site selection” AND “criteria”) OR (“OTEC type plant” AND “criteria”) OR (“OTEC Malaysia” AND “criteria”))
Scopus	TITLE-ABS-KEY (“OTEC” OR “ocean thermal energy conversion” OR “OTEC type plant” OR “OTEC site location” OR “OTEC Sabah” OR (“OTEC site selection” AND “criteria”) OR (“OTEC type plant” AND “criteria”) OR (“OTEC Malaysia” AND “criteria”)).

Next, a screening process was implemented, incorporating the inclusion and exclusion criteria and quality assessment. The inclusion criteria used the essential features of the target population to address research questions. In contrast, the exclusion process examines various characteristics of the population that might hinder the study or increase the risks for undesirable results that were excluded from the researcher's consideration (Patino & Ferreira, 2018). The predefined literature inclusion and exclusion criteria achieved in this study are presented in Table 2.

Table 2. The inclusion and exclusion criteria

Criterion	Inclusion	Exclusion
Timeline	Between 2018-2023	<2018
Language	English	Non-English
Subject area	OTEC-related terminology or antonyms (type, site location, site selection)	Other than OTEC-related terminology or antonyms (type, site location, site selection)
Search engine	Web of Science (WoS), Scopus	Other than Web of Science (WoS), Scopus

The conclusive inclusion process led to the selection of 32 articles for further analysis. Of these, 13 articles were obtained from Scopus, 11 from Web of Science, and the remaining eight were manually added due to fundamental importance to the possible development of OTEC in Malaysia. Those articles were categorized into five sections to enable a thorough analysis. The sections include the year of publication, journal names, journal ranking, research methods utilized, and research topics.

Results

Publication Year of Articles

The present study shows a worldwide increase in trends of publications of OTEC-related articles over the years (Figure 2). The selected articles include three articles which were published before 2018, as the crucial information in such literature are relevant in this study. This included one article each published in 2012, 2015 and 2016. There were two articles from 2019, and three from 2018, 2020, and 2023. The highest number of selected articles were published in 2021 and 2022, with a total of 6 and 12 articles respectively.

Journal Characteristics

The journal characteristics focused on the type of document, journal ranking, and source of publication. In this study, a total of 19 articles, 8 conference papers, 3 presentation slides, 1 proceeding paper and 1 book chapter were extracted from both the search engines and manual searching process. Next, the journal ranking was determined from the quartile of each document. The ranking was derived from the citation metrics which is used to assess the quality of a scientific publication. A high-quality article from a reliable publication source was indicated by the higher quartile. Therefore, Q1 represents the most esteemed journals in the field with the highest citations. The Scientific Journal Ranking (SJR) website served as the reference for these journal rankings. Eight articles are classified in Q1, and seven in Q2, (Table 3), while five articles have not yet been assigned through the SJR website.

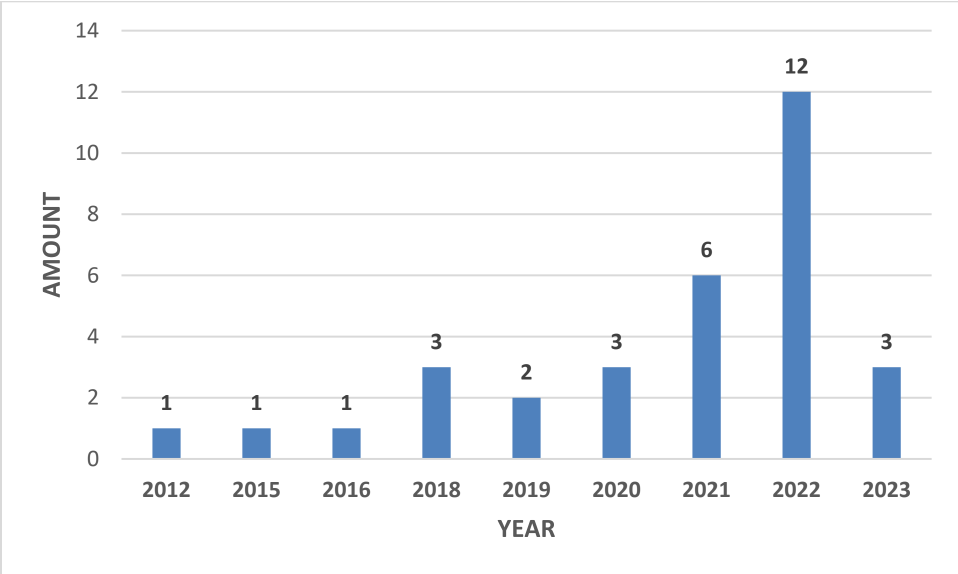

Figure 2. The selected OTEC-related articles by year published.

Table 3. The list of Q1 and Q2 journals with published OTEC-related articles.

Journal	Publica -tions	Percentage (%)	Scopus Quartiles
Journal of Cleaner Production	1	6.7	Q1
Journal of Marine Science and Technology	1	6.7	Q1
Energies	3	20	Q1
Renewable and Sustainable Energy Reviews	1	6.7	Q1
Sustainability (Switzerland)	2	13	Q1
Renewable Energy	1	6.7	Q2
Processes	1	6.7	Q2
Geosciences	1	6.7	Q2
Journal of Marine Science and Engineering	3	20	Q2
Journal of Ocean Engineering and Marine Energy	1	6.7	Q2

Methodology Utilised

All the selected publications were classified as quantitative studies using experimental research and survey methods in terms of research methodology. Most articles applied the advanced technology of Geographic Information System (GIS) to analyze and display geographically referenced information of the study area. Meanwhile, several papers extracted the primary data from GIS product servers too. This procedure facilitated ease of the process and reduced time consumption. Other studies have undertaken economic analyses to assess and predict the viability of OTEC plants. These economic evaluations considered the calculations and forecasts of capital expenditure (CAPEX), operational expenditure (OPEX), and the levelized cost of electricity (LCOE).

Additionally, multi-criteria decision-making (MCDM) is another method that has been documented in this study. In the context of OTEC studies, MCDM helped researchers draw conclusions and identify suitable site selection for OTEC plants. Finally, sensitivity analysis has also been employed to forecast the uncertainties or possible effects based on the study findings. The distribution of techniques used is illustrated in Figure 3, indicating GIS analysis, economic analysis, MCDM, and sensitivity analysis.

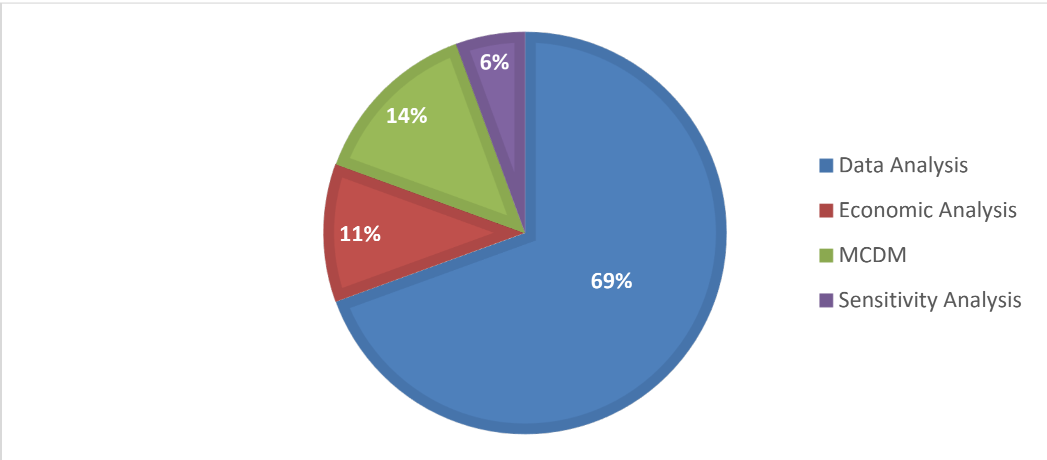

Figure 3. The techniques used in the included articles.

Research Topic

We found several criteria and/or parameters used in the published works on ways to determine site selection and suggestion on the type of OTEC plant in the selected OTEC sites. A temperature differential of at least 20 °C was considered as the fundamental requirement to build a commercially viable OTEC plant. The availability of temperature gradient is directly associated with the seawater depth at the chosen site. All the studies focused on temperature differences at depths ranging from 500 m up to 1,500 m, aiming to shorten the length of the cold seawater pipelines while achieving the minimum required temperature gradient. A shorter pipeline for an OTEC plant significantly reduces its capital expenses.

Of the selected publications, 11 articles addressed the potential of OTEC in Sabah waters. The bathymetry of Sabah's coast supports the development of an onshore, offshore, or fixed platform OTEC plant. The potential sites for OTEC plant are Layang-Layang Island (Fahmie et al., 2018; Thirugnana et al., 2021), Sipadan Island (Fahmie et al., 2018), Tawau (Thirugnana et al., 2021; Waseda et al., 2021), Gumusut-Kakap (Fahmie et al., 2018), Banggi Island, (Fahmie et al., 2018; Thirugnana et al., (2021), Semporna (Waseda et al., 2021), Kunak (Waseda et al., 2021), Lahad Datu (Waseda et al., 2021) and Kalumpang (Thirugnana et al., 2021; 2023). These translate into an estimated total OTEC potential areas in Sabah of approximately 92,301 km^2 within the country's Exclusive Economic Zone (EEZ) which can produce up to 105,000 MW of renewable power (Thirugnana et al., 2021; Figure 4).

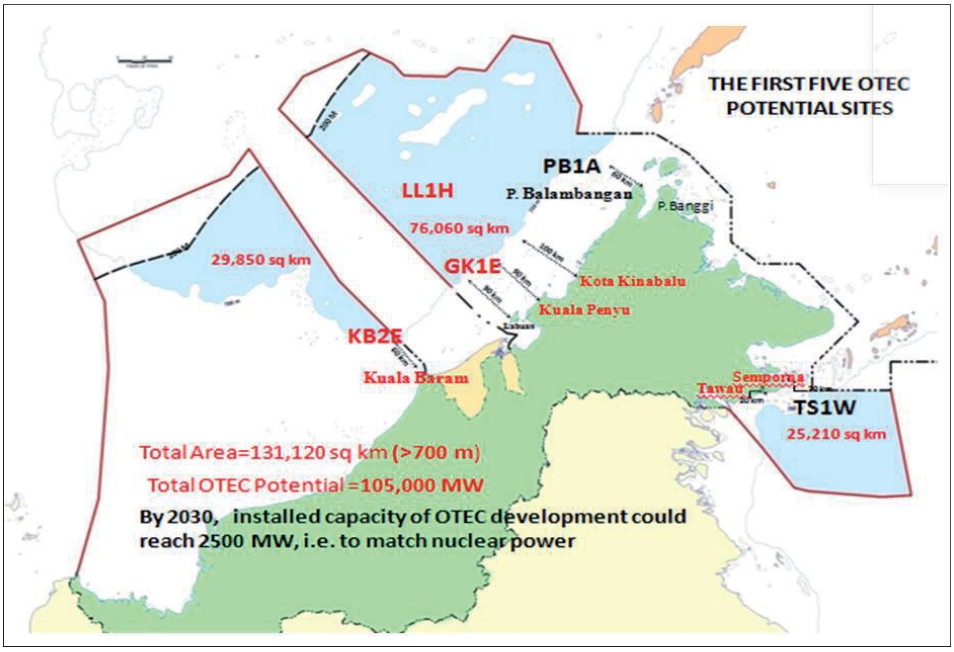

Figure 4. The OTEC resource potential in Malaysia, particularly in waters deeper than 700 m (after Jaafar, 2012). The blue highlighted areas represent sites with seawater depths greater than 1000 meters (https://www.jodc.go.jp/)

Discussion

Development of Potential OTEC Plant in Sabah, Malaysia

This study considered five potential sites and identified the type of OTEC plant installation for each location. These sites are strategically distributed across the northeast and southeast regions of Sabah, Malaysia, encompassing Layang-Layang Island, Mantanani Island, Mengalum Island, Kalumpang, and Tawau. The importance of site selection in OTEC projects influences the effectiveness and success of OTEC facilities. The site selection process is influenced by a multitude of circumstances, prompting researchers to explore various facets of it.

Fahmie et al. (2018) proposed the installation of a 4 MW fixed platform type at Layang-Layang Island. According to (Tasnim, 2023), Layang-Layang Island has the nearest deep seawater intake, which is 1.8 km from the closest coastline area, with a depth of 731 m. Thus, this plant is significant for renewable energy generation, despite its remote location – it is approximately 300 km northwest of Kota Kinabalu – and has no permanent human inhabitants. Layang-Layang Island was a thriving hub for socio-economic pursuits, such as deep-sea fishing, scuba diving, and tourism (Meng etal, 2024), prior to Covid-19 pandemic (DE, 2024b). Recent proposals, including Tasnim (2023), underscored this island to lead Malaysia's renewable energy transition. The proposal for a 1 MW onshore OTEC plant emphasized harnessing the island's plentiful deep-sea waters for electricity output while protecting the ecosystem. This initiative seeks to establish a sustainable power source to meet energy demand.

In contrast, nearby islands such as Mantanani Island have a partially indigenous population and mariculture industries such as abalone and seaweed cultivation. Hence, the island is poised for an energy transition of a 10 MW offshore fixed platform OTEC system. This solution improves energy capacity and blends in well with the dynamic socioeconomic and ecological environment of the island. These initiatives set a good approach being used throughout Sabah to capitalize on OTEC resources for clean and renewable energy production. The consideration of the OTEC offshore system due to the facility's strategic location, situated approximately 78 km from the nearest coast, and the water intake is 710 meters deep. Meanwhile, Thirugnana et al. (2023) conducted a performance analysis on a commercial OTEC plant situated at Kalumpang. Their study proposed a 10 MW capacity using the plate-type heat exchangers, the Rankine cycle, and anhydrous ammonia as the working fluid. Through the findings, future study could concentrate on maximizing hybrid-OTEC systems for 2.5 MW or 10 MW commercial plants, meeting carbon net-zero goals. Moreover, the extension of these results could generate an economically viable of OTEC Malaysian Model. According to Tasnim (2023), Kalumpang is strategically located 14.86 km from the deep seawater intake, and its water intake is 699 m below the surface, making the onshore system a viable option. Through an onshore OTEC system, it could synergize with the main socio-economic activity which is centered around palm oil plantations.

Another potential site for an onshore OTEC system is Mengalum Island; it has a deep seawater intake that is 691 m deep and approximately 44 kilometers between the nearest coast and the deep seawater intake. Hence, the development of an offshore OTEC system with a 10 MW capacity is possible. This island presents socio-economic activities, especially as a premier deep-sea fishing destination. This maintains a healthy balance between environmental conservation and economic growth, which could well become the lead in the field of sustainable energy technology through the onshore OTEC system.

Figure 5 presents a summary of the suggested OTEC types in the potential OTEC sites in Sabah, Malaysia.

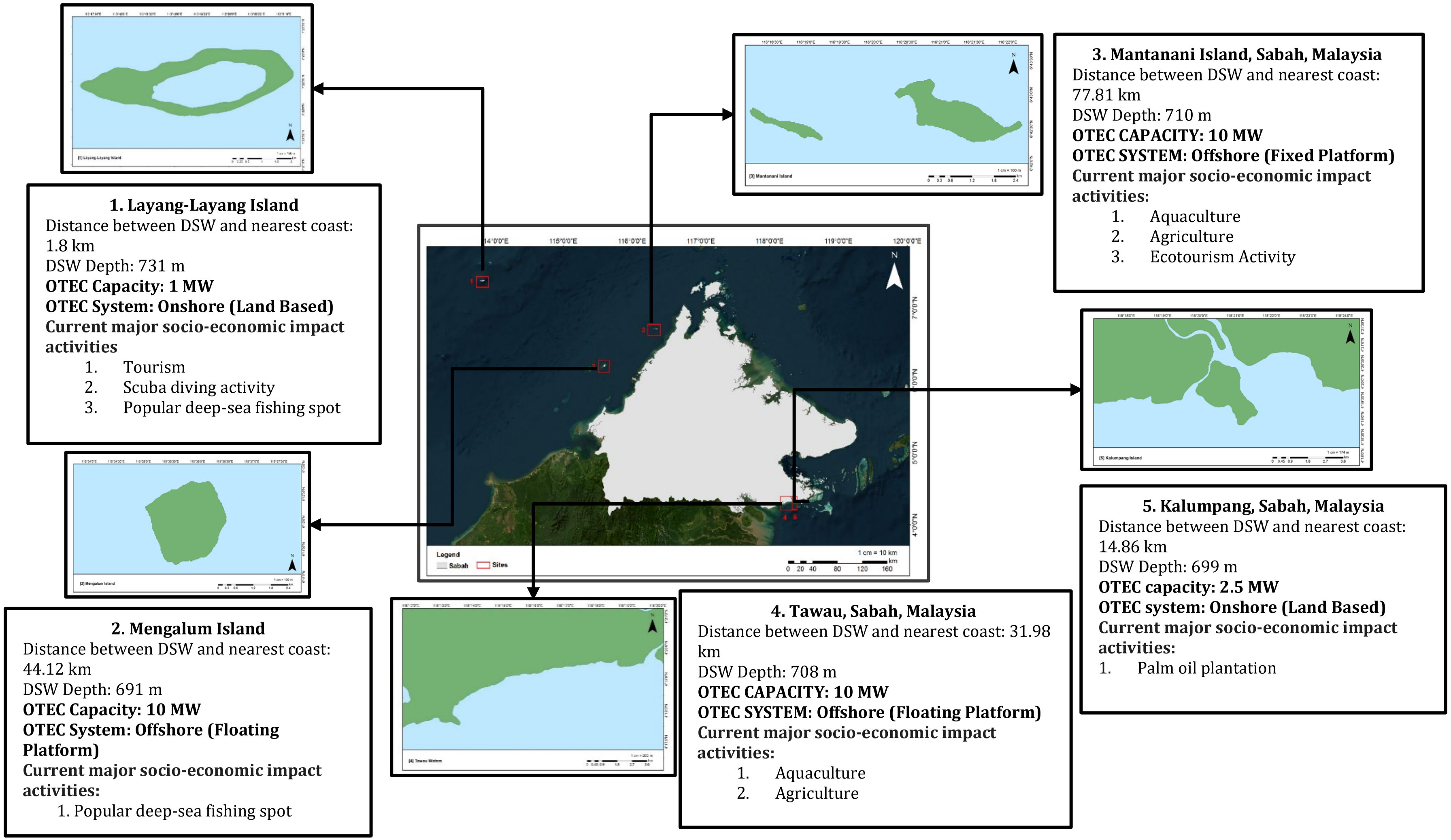

Figure 5. A summary of OTEC types in the five potential OTEC sites in Sabah, Malaysia.

The Current Progress of OTEC Development in Malaysia

A team of researchers are investigating the viability of establishing and commercializing the first OTEC plant in Malaysia, focusing on Sabah. The Science and Technology Research Partnership for Sustainable Development (SATREPS) is providing financial support for this project within a five-year timeframe, 2019-24 (SATREPS, 2024). Since the first OTEC Stakeholder Engagement was held in February 2023, continued efforts have been carried out to interact with various stakeholders regarding Malaysia's first OTEC facility, in addition to research and laboratory analyses (Tasnim et al., 2023). Following the engagement, a number of industry partners have pledged to support the first Malaysia-Japan OTEC Association's (MJOA) initiation. Additionally, other engagements including with the President of the Malaysian Bottled Water Association (MBWA) for data exchange related to the local and international bottled water sectors. This engagement seeks to increase public awareness of the ongoing efforts to commercialize the first OTEC ecosystem in Malaysia. Furthermore, a 2.5 kW Hybrid-OTEC Testing Plant has been established at the International Institute of Aquaculture and Aquatic Sciences (I-AQUAS), Universiti Putra Malaysia (UPM), located in Teluk Kemang, Port Dickson, Negeri Sembilan (Figure 6).

Figure 6. The hybrid-OTEC testing plant at (I-AQUAS), UPM Teluk Kemang, Port Dickson, Negeri Sembilan, Malaysia.

Conclusion

An OTEC plant requires a minimum of 20°C temperature difference between both surface and deep seawater intake points for optimal energy production. This temperature difference is the main criterion in OTEC site selection and type of plant. In this study, the Sabah Trough's surface and ground temperatures are consistent with the core principles of OTEC system. This study identified three potential OTEC plant types, namely (i) onshore (land-based), (ii) offshore (floating) and (iii) fixed platform. A total of five potential sites were determined throughout this study, with three sites located in the northeast, and two in the southeast of Sabah. The sites are Kalumpang, Tawau, Mengalum Island, Mantanani Island and Layang-Layang Island. Site location of OTEC has been considered based on the distance between the deep seawater resources and the nearest coast, depth of seawater as well as the major socio-economic impact activities within the area*. As for the type of OTEC plants, we propose a 1 MW onshore OTEC plant at Layang-Layang Island and a 2.5 MW OTEC plant for Kalumpang. For Tawau and Mengalum Island, we propose a 10 MW offshore floating platform to be constructed surrounding the coastal area at these sites. A 10 MW OTEC fixed platform plant is proposed for Mantanani Island.

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***Editors' Note**: As of December 2024, Layang-Layang Island remains closed to public and there are currently no socio-economic activities on the Island.