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Ocean renewable energy development in Southeast Asia: Opportunities, risks and unintended consequences

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ABSTRACT

The Southeast Asian region (SEA) is surrounded by ocean space, from which there is a vast potential to harness energy. Wave, tidal energy, and ocean thermal energy conversion could be tapped, to provide alternative sources of clean and dependable energy in the region. This article contributes to the growing academic literature on ocean renewable energy (ORE) in SEA by improving understanding of the opportunities and challenges of ORE development in the region, beyond its technical aspects. It conducts a critical analysis of the socio-political aspects of ORE development at a regional scale, which have been less studied in the existing literature. Aside from providing a sustainable energy source, the development of the ORE sector could provide socio-economic benefits to SEA countries through employment opportunities, inter-industry learning, inbound investments and improving economic resilience. However, these benefits can only be maximised if the costs of deployment, maintenance and repair are reduced, the impact to the marine environment is taken into consideration and issues of public acceptance are addressed. Beyond a cost–benefit analysis, this study critically assesses the unintended risks and consequences of ORE technologies and activities in the region and recommends different policy strategies to mitigate them. It concludes that for the region to reap the benefits of ORE, a coordinated approach among different stakeholders (technology developers, policymakers, and end-users) is needed to minimise the risks and unintended consequences.

1. Introduction

In the aftermath of the 2015 Paris Agreement different national governments pledged to address the issues surrounding climate change and achieving sustainable development [1]. Most of the countries which signed the agreement have both short- and long-term plans to decarbonise. One of the options considered is to utilise more renewable energy sources as an alternative source of energy to fossil fuels, or to integrate the two. Experts estimate that by redirecting energy infrastructure investment (estimated at US$36 trillion) to clean and renewable energy sources in the next two decades, the transition to a green economy could be achieved rapidly [2].

The Southeast Asia (SEA) region has set a 36% target for the renewable energy share of its regional energy mix by 2030, which will encourage around US$300 billion worth of investment in the renewable energy sector [3]. One of the emerging renewable energy sources available in SEA is ocean renewable energy (ORE) [4,5]. The region has an abundance of islands that have high tidal intensity, making them suitable for ORE development. The SEA region has around 1 TW (TW) ORE potential mostly coming from tidal in-stream. Examples of these are the Sentosa floating tidal turbine [6] and Universiti Teknologi Malaysia's (UTM's) vertical-axis marine current turbine [7], located in Singapore and Malaysia, respectively. There is also evidence of wave energy potential in SEA [8]. In addition, in the developing countries in the region, those islands that offer potential for ORE development are currently heavily dependent on traditional sources of energy, like diesel fuels. In the Philippines alone, around 2.5 million households are still without electricity or with a limited electricity for only 4–6 h a day [9]. They are still heavily dependent on high-cost diesel generators as their main source of energy [10]. Most of this population reside in rural, off-grid or remote coastal areas. A few of these islands are also located in disaster-prone areas (i.e. typhoon and earthquake zones) where on-grid electrical infrastructure, if available, is easily adversely affected when a typhoon strikes.

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While scholars working on ORE in the SEA region agree that there is potential for it to be fully utilised as a renewable energy source, its development has been slower compared to other renewables. Some studies point to the technical challenges of turbine deployment that are unique to the region, e.g. the design of turbines that fit the flow velocity of SEA waters, or coating materials to deal with biofouling [8]. Only a few studies have looked into the techno-economic aspects of ORE, i.e. the costs and benefits of investing in ORE compared to fossil fuels or diesel generators [11], while some have produced technical reports, market analysis and position papers to analyse the general trends of ORE in the region [12]. However, the socio-political aspects of ORE development at a regional scale, i.e. in the SEA region, have been less studied in the existing literature.

This study aims to add to the growing academic literature on ORE in SEA by improving understanding of the opportunities and challenges of ORE development in the region, beyond its technical aspects. As scholars argue, energy transitions[1] "are not ordinary shifts in technologies; but they are also strongly glued to the orderings of human societies, economies and polities" [13, p. 2]. With the increasing push to decarbonise using renewables, what are the technical, economic, environmental, and political considerations that might affect the development and utilisation of ORE technologies in SEA? More importantly, what are the risks, and intended and unintended consequences?

While there are technical reports and market analyses about ORE in SEA, this is one of the few attempts to present the opportunities and challenges, risks and consequences of ORE development at a regional scale by applying an academic research framework relating to risks and consequences. This paper makes use of both primary and secondary data analysis. The data are collected from previous and recent studies on ORE by SEA country.

The paper is structured as follows: the next section explains the theoretical framework used in the study, while the third section discusses the opportunities for ORE development in terms of resource availability, ORE technologies that could be utilised in the region and existing ORE policies per SEA county. The fourth section presents the technical, economic, environmental, and political challenges that need to be considered in regard to developing ORE in the region. This is followed by the discussion section, where a more in-depth analysis of the implications of ORE in SEA is provided, by applying the risks and consequences framework. The final sections of the paper include recommendations for further developing ORE in SEA region and the conclusion.

2. Theoretical framework

The paper discusses the technical, economic, environmental, and political challenges that need to be analysed regarding the implications of developing ORE in SEA. To provide a more in-depth understanding, this article also discusses the various risks and consequences related to developing ORE in the context of the SEA region. Knowing the barriers, risks, and consequences are important to evaluate the appropriate policy design to support the development of ORE in the region. The risks and consequences framework advanced by Justen et al. [14] (see Table 1) is used to analyse the effects of adopting ORE technology in the region. This framework provides a taxonomy of the effects of ORE adoption from the viewpoint of policymakers. This is helpful as it provides a more systematic approach to analysing the effects of such policy interventions. It organises the effects into two categories: the intended and unintended consequences, along with their possible implications. The implications are further subdivided into first- and second-order effects to provide a layered analysis of the unintended consequences of policy interventions. The knowledge dimension is categorised into the known and unknown realms. The known realm relates to the realised or anticipated effects of ORE development. On the other hand, the unknown realm refers to effects that might be overlooked or unknown from a policymaker's perspective.

The study is not without limitations. One of the limitations of the framework used is that the relationships of each column, i.e. the relationship of the intended consequences to their unintended consequences, and the relationship of first-to second-order effects, might not always be a one-to-one relationship. One intended effect might cause two unintended effects, and the unintended effects might result in several first- and second-order effects. As Justen et al. describe it, "the consequence framework is like building a web consisting of nodes and linkages between those nodes" [14, p. 20]. One node can be linked to more than one node, but the linkages might be different. Another limitation is that this web-like framework, like other models for policy assessment, is incapable of providing the full picture of implications as regards both scope or depth. The framework is likely to depict only a certain portion of the complex web of interactions and impacts of ORE development in the region [14].

3. Opportunities of ORE in SEA

Currently, the SEA region accounts for 4.3% of total global energy demand. Fossil fuels meet most of this demand. Oil contributes 37% and natural gas 21% to the total regional energy mix. In addition, regional greenhouse gas emissions (GHG) have also increased over the last two decades, reaching an increase of around 5% per year due to rapid economic growth in the region [15]. In short, the region is faced with an energy "trilemma" – a growing energy demand because of the increasing population, coupled with the pressure to achieve economic development in a sustainable and environmental way. As such, most of the SEA countries have pledged to lessen their carbon emissions and intensity under the Paris Climate Change Agreement, through the development and deployment of renewable energy. This section highlights the potential of ORE to be utilised in the region not only as an alternative source of energy but also to address the energy trilemma in the region.

Marine renewable energy (MRE) is a general term that refers to anything in the marine space that is used to generate renewable energy, including offshore wind turbines, floating solar panels and ORE technologies [6,16]. On the other hand, ORE refers specifically to drawing power from the ocean to generate energy, specifically from tidal currents, tidal range, waves, temperature gradients, and salinity gradients [12]. This study focuses on ORE technologies, the potential ORE resources, and the current status and activities in this area in SEA is given in Fig. 1 on the next page.:

According to recent studies, MRE and ORE are emerging and disruptive technologies that are suitable for the conditions in SEA, with its strong demand for power. The MRE and ORE sectors also present opportunities for clean energy investments that the region could take advantage of [17,18]. The marine environment could provide "valuable economic, social and cultural resources that could contribute to the sustainable economic development of small island developing (SIDS) and larger coastal states" [19], p. 2]. Aside from being a source of alternative energy, ORE also offers a means of achieving different Sustainable Development Goals (SDGs), specifically SDGs 7, 13 and 14: "access to affordable and clean energy, combatting climate change and its impact and sustainable use of oceans, seas and marine resource" [20], p. 1].

The sub-sections below discuss the different opportunities that could drive ORE development in the SEA region. When it comes to technical availability, wave, tidal and ocean thermal energy conversion (OTEC) potential could all be harnessed in SEA. Currently, there are also ongoing advances on the research, development, and demonstration (RD&D) side in terms of developing ORE technologies that are suitable to the local sea conditions in the region. In terms of policy framework,

[1] This is the transition from one kind of energy system to another, e.g. from fossil fuel resources to renewable energy, from large-scale to small-scale energy systems, and from state-owned to community-owned energy systems.

Table 1
Modified risks and consequences framework of Justen et al. [14] used to analyse the impacts of ORE development in SEA.

		Consequence dimension		
		Intended consequences	Unintended consequences	
Knowledge dimension			Unintended consequences	Implications **(to be categorised into first-order, second-order etc ... implications if need be)**
	Known	The consequences that decision-makers intended to produce through the intervention	Unintended consequences that were anticipated at the time decisions were made	Impact of the unintended consequences that were anticipated at the time decisions were made
	Unknown	Advantageous effects that are not known; serendipitous effects	Unintended consequences that were not known at the time decisions were made	Impact of the unintended consequences that were not anticipated at the time decisions were made

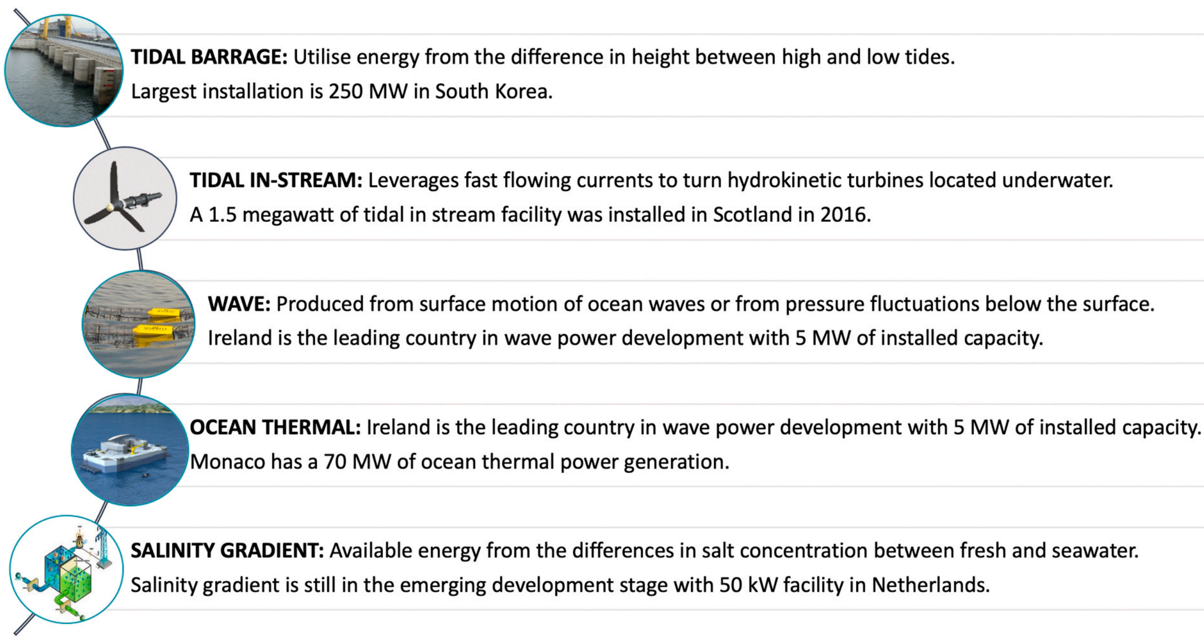

Fig. 1. Types of ORE and current activities across the globe [3].

few of the SEA countries have supportive policy tools that directly encourage the development of ORE. In addition, the ORE sector can also bring socio-economic opportunities, in terms of employment opportunities, economic resilience and inward investments to the region. Finally, aside from electricity, there are other by-products from ORE, e.g. drinking water, which could be used to address the energy–water security nexus, which is prominent in developing countries in the region.

3.1. ORE as an alternative, clean and renewable energy source

The countries for which the greatest number of studies on potential ORE resources have been conducted are Indonesia, Malaysia, Philippines, Singapore and Vietnam. Arief (2017) mentions that Indonesia has the following potential ORE resources: 2 MW (MW) for wave energy, 18 MW for OTEC and 41 MW for tidal energy [21]. Malaysia is also carrying out RD&D works in relation to potential tidal, wave and OTEC ORE resources for small island projects. In Malaysia ORE, as an alternative energy resource is considered to be more suitable for "local grids for remote areas and coastal communities" [22], p. 2]. Aside from resource assessment, research institutes and universities like UTM are developing lab-scale horizontal and vertical marine tidal current devices and ocean wave energy converters. UTM has also set up an OTEC Research Centre in Kuala Lumpur to investigate its potential in the Sabah island [8]. The Philippine Department of Energy has estimated that there is around 170 gigawatt (GW) MRE potential in the Philippines [5,23], while Buhali et al. (2012) mention that the country has 35 TW h per year (TWh/yr) of tidal energy, which translates to 40–60 GW power potential [23]. On the other hand, the World Bank has estimated that the Philippines has a wave energy potential of 33 kW/m/yr from the Pacific and 35 kW/m/yr from the South China Sea [24]. Singapore has around 250 MW of tidal in-stream installed capacity potential, and in terms of floating solar photovoltaic (PV) as part of MRE, studies conclude that it could have at least 1 gigawatt peak (GWp) potential if certain areas were made available for system installation [6]. Vietnam has around 200–500 MW tidal energy potential and 350 MW wave energy potential [25]. Vietnamese government agencies, in collaboration with research institutes, have worked on different RD&D ORE projects since 2000 to test the theoretical ORE potential of the country. One example is the Institute of Energy Science of Vietnam Academy of Science and Technology (IES VAST), which studies and builds wave energy prototypes at laboratory and demonstration scales [25,26].

For other SEA countries, the activities on ORE mainly relate to studying its theoretical potential and possible sites for resource assessment. For example, a previous study on Brunei Darussalam's potential ORE estimates that it has 335 kW tidal energy potential and 0.66 GW wave energy [27]. MRE RD&D in the country is led by the Centre for Advanced Materials and Energy Sciences, under the University of Brunei Darussalam [28]. MRE research in Brunei focuses more on offshore wind energy, like short-term wind power forecasting using artificial intelligence, and the development of small low-wind speed turbines for offshore platforms. Thailand is focusing on the resource assessment of potential sites for wave energy [29]. The King Mongkut University of Technology Thonburi Joint Graduate School of Energy and Environment has proposed looking at the Andaman Sea and Thailand Gulf as possible sites for harnessing wave energy. Myanmar's Yangon River has tidal currents of 4–6 knots during spring tides and a tidal range of around 5–7 m [5]. In terms of wave energy, Myanmar is implementing the Sittwe Reclamation Project along the Pyisakanadi River. The county has also made efforts to create a small-scale prototype of an ocean energy device which has 20 kW electricity output [30]. Fig. 2 on the next page summarises the current known estimates of ocean energy in selected SEA countries.[2]

The different SEA countries see the potential of utilising ORE as an alternative source of clean and renewable energy. Although some of the activities are still at the laboratory scale, a few of the countries, like Indonesia and the Philippines, are engaged in larger-scale activities that could power-up off-grid areas. ORE can also be a source of energy for offshore installations, e.g. oil platforms, weather and climate monitoring stations, and fish farms [6].

3.2. ORE as a way of mitigating climate change impacts

ORE offers a great untapped potential: it is a predictable and dependable source of energy because it comes from accessible sources like wind, bodies of water and the gravitational forces of the sun, moon and Earth [31]. Although it is stationed offshore, its energy output can be applied onshore.[3] There are different types of technologies that can extract and convert, for example, kinetic energy from waves to electrical energy [12]. Examples of the devices that are used to harness energy from tidal currents are horizontal-axis turbines, vertical-axis turbines and oscillating hydrofoils. According to earlier studies, wave energy is the most viable ORE in remote and coastal islands in the SEA region [32]; however, as mentioned above, tidal energy can also be harnessed from countries like Singapore, Indonesia and Philippines, and possibly OTEC in Malaysia and Philippines as well. Fig. 3 on the next page is a photo of the tidal turbine demonstration site with 50 kW tidal-in-stream in Singapore.

The crucial aspect for making ORE accessible in islands and remote areas is the compatibility of its technical components (e.g. turbine and blade design, coatings for biofouling, cabling system, storage, among others) with the tropical conditions of the region. For example, turbine design must take into consideration the flow velocity, which ranges from 1 to 2 m per second on average, across approximately 60% to 80% of the whole region [4]. In addition, SEA's seabed bathymetry is not flat, and the slopes are steep even close to the shore. These are a few of the technical considerations that need to be investigated when developing a tidal current system that is suitable for the SEA conditions [4].

Despite such technical considerations, ORE technologies can be combined with other renewable energy systems. Examples are hybrid systems of ORE with small-scale wind turbines, or ORE with solar PV (floating solar PV), to boost capacity and energy availability [6]. In addition, ORE can also be integrated into traditional sources of electricity like diesel generators. This is crucial, especially for those areas without on-grid energy structures, i.e. remote islands. An integrated energy system of ORE and diesel generators provides a more accessible and cleaner energy alternative than depending on diesel fuel alone. At the same time, an integrated ORE generation system could complement Singapore's "Green Ship and Green Port" Programme, where the focus is to have ocean-going ships that have reduced GHG emissions. ORE generation could also be integrated with coastal protection infrastructure. OceanPixel reports that the combination of MRE with coastal protection infrastructure provides electricity from renewable energy and insurance against damage from inundation and sea-level rises [4]. At the regional level, SEA has numerous coastal operations and applications that require electricity, e.g. shipbuilding and operations, wood processing, and aquaculture processing [4]. Like the other renewable energy types, ORE can be harnessed as alternative energy and at the same time as a means to mitigate the effects of climate change.

3.3. Socio-economic opportunities of ORE

The development and emergence of an ORE sector in SEA could lead to more job opportunities and employment, especially for related industries like oil and gas, maritime and offshore energy [6]. Knowledge and skills transfer from one sector to another within the region could help build a robust and reliable ORE supply and value chain. This local supply chain would not only boost the sector but could assist in reducing the upfront cost of ORE deployment. ORE is also relatively more stable than its other counterparts, like oil and gas, when it comes to the price of energy. As such, long-term employment and job security can be foreseen once the sector is developed in the region [4]. Companies that are contracted to provide such a service, or that served as the Original Equipment Manufacturer, would be most likely to have a steady source of income from providing such a service, or from the ORE power plant [4].

Inward investments and public–private partnerships can also be expected once a new and stable sector like ORE is established. As mentioned above, the SEA region is already looking at around US$300 billion worth of investment in clean and renewable energy to hit the 36% target for renewable energy share in the regional energy mix [3]. Development of the ORE sector could bring in investments and collaborative projects that could cultivate regional capabilities, technical expertise and knowledge on ORE. Multi-stakeholder investment projects (e.g. test-bedding and demonstration sites), such as the Renewable Energy Integrations Demonstrator-Singapore (REIDS) [34], MAKO Tidal Turbine Demonstration Project in Singapore [35], Oceantera's Northwest Capul Energy Project in the Philippines [36] and the Tidal Turbine Deployment in West Papua, Indonesia [37], can showcase the viability of ORE technologies in real-world sea conditions. These kinds of projects can also pave the way to inter-industry learning among policymakers, technology providers, project developers, and end-users. In addition, creation of regional collaborative platforms like the Southeast Asian Collaboration on Ocean Renewable Energy (SEAcORE)[4] establishes an active network of expertise that can promote the diffusion of ORE technical know-how and the formulation of best practices in the ORE sector, not only locally but also at the regional level [38].

Finally, ORE projects that involve proper community-driven approaches could enhance the livelihood of rural communities by providing the energy required to satisfy communities' socio-economic needs. For example, the energy produced from an ORE power plant could power up freezers for a fishing village. ORE training and development programmes "customised" for rural communities could also incorporate not only the technical aspects of ORE, but also new business models, through which communities could gain additional income from the energy system. In addition, ORE has applications other than

[2] Cambodia's annual tidal range, which is less than 1.5 m, is not suitable for commercial tidal energy utilisation [5]. However, 10% of its energy mix comes from hydropower. Laos, on the other hand, is a land-locked country and so ocean energy would not be available [5].

[3] For more details see the following press releases: "Singapore Tidal Turbine Demonstration with 50 kW tidal-in-stream" https://renewablesnow.com/news/envirotek-partners-deploys-tidal-power-turbine-in-singapore-560895/, "Tidal Turbine Deployment in West Papua, Indonesia" http://www.aseanenergy.org/resources/publications/asean-resp-newsletter-december-2016/and "Sentosa's first Tidal Turbine Project" http://www.straitstimes.com/singapore/singapores-first-tidal-energy-generator-launched-off-sentosa.

[4] SEAcORE was initiated by the Energy Research Institute at Nanyang Technological University (ERI@N), Singapore, in 2013, becoming a regional network of ORE experts in SEA. It became the first technical working group of the Association of Southeast Asian Nations (ASEAN) Centre of Energy, an intergovernmental regional organisation, on offshore and ocean energy section in SEA [38].

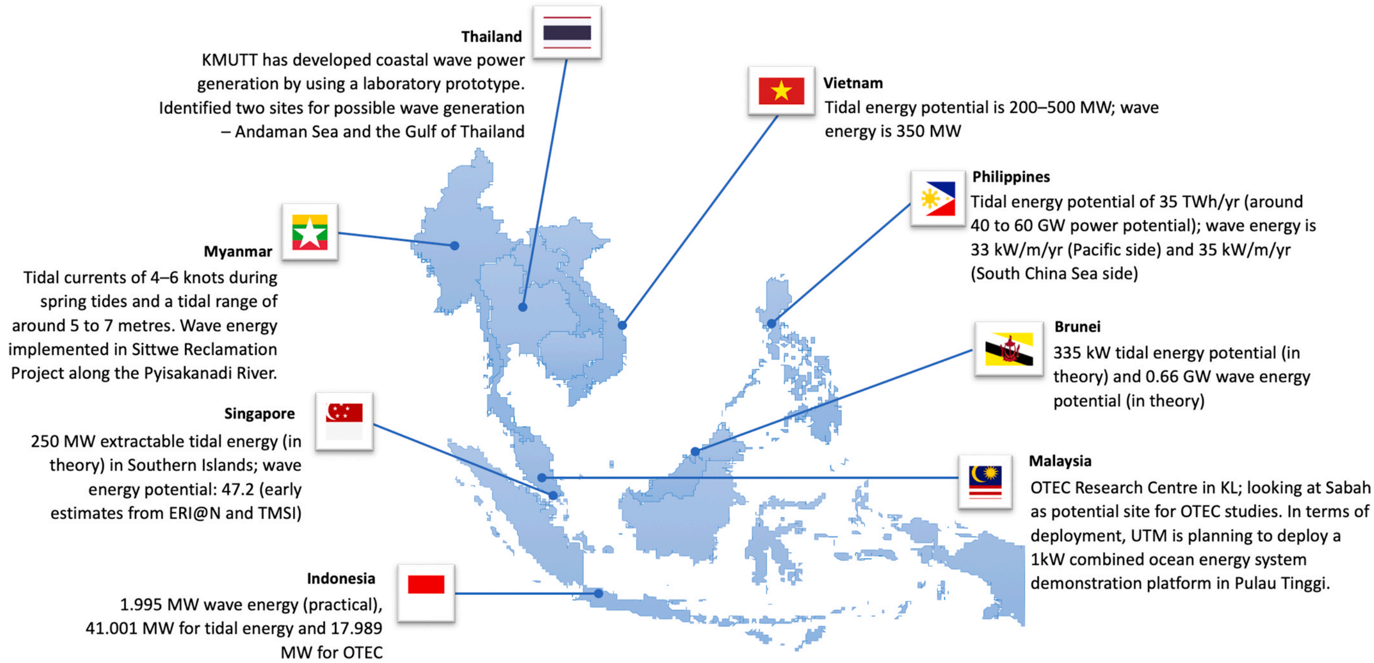

Fig. 2. Summary of current known estimates of ORE potential in SEA [4,6].

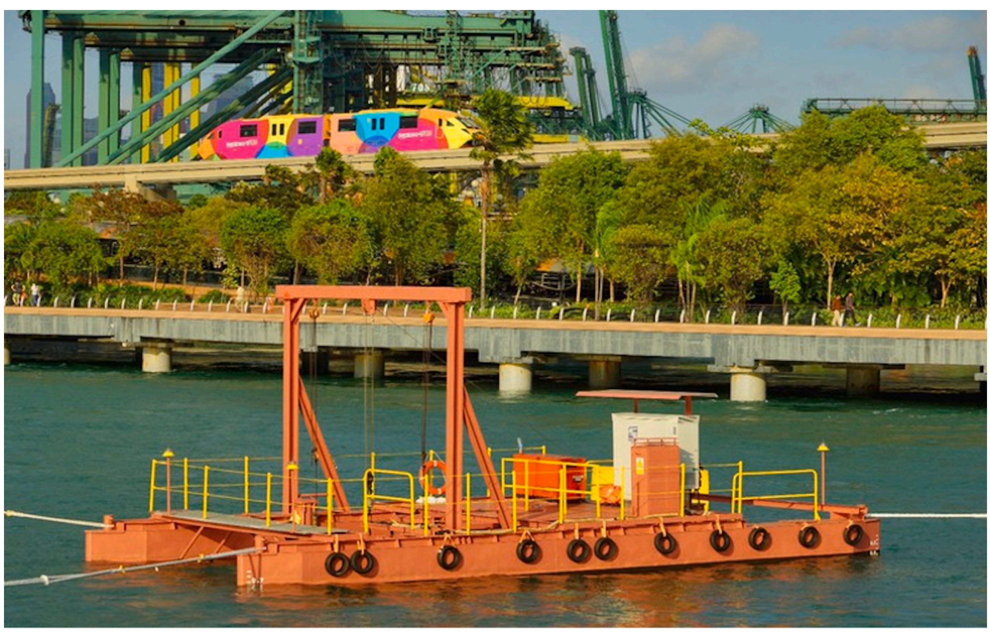

Fig. 3. Singapore Tidal Turbine Demonstration with 50 kW tidal-in-stream [33].

electricity. The need for portable drinking water is one of the main issues, especially in off-grid rural islands. The ORE system can be customised to have a multi-output system that can make use of ORE resources to produce drinking water and electricity at the same time, e.g. wave-driven desalination system [39]. There are current RD&D working specifically on this type of systems which incorporate ORE, electricity and portable water production [40,41].

3.4. Policy opportunities of ORE in SEA

Each SEA country applies various policy approaches towards ORE (see Table 2 on the next page). The following section summarises the existing policies of selected SEA countries that directly support ORE development.

3.4.1. Brunei

Although the national energy plan of Brunei focuses more on oil and gas development, there is an increasing drive to diversify energy sources through renewable energy and energy-efficient technologies [4]. At the national level, the government aims to achieve a 10% growth in renewables by 2035 [42]. Agencies such as the Brunei Energy Association, the Energy Efficiency Conservation Committee and the Brunei National Energy Research Institute conduct RD&D on the potential of renewable energy in the country [43]. There is currently no specific policy on ORE development; however, academic and research institutes have carried out offshore wind energy studies and RD&D activities [28].

Table 2
Summary of ORE and related renewable energy policies and policy tools per SEA country.

Country	General renewable energy/ORE policy framework	ORE inclusion in national energy plan	ORE targets	Presence of market mechanisms for ORE
Brunei	The government aims to increase energy efficiency and to achieve a 10% increase in the renewable energy share of the national energy mix by 2035.	There is no specific policy on ORE development; however, academic and research institutes carry out offshore wind energy studies and RD&D activities.	None.	None.
Indonesia	A national energy framework that includes renewable energy development, e.g. Law 17 of 2007, which implements a Long-Term Development Plan that creates renewable energy projects.	The government includes MRE in its definition of renewable energy, and, as such, its goal of renewable energy development incorporates MRE activities relating to pilot testing in preparation for full-scale commercialisation.	To have a pilot project prior to commercialisation.	Not available yet but suggested by local experts as the next policy tool.
Malaysia	11th Malaysian Plan released in 2016, entitled Encouraging Sustainable Energy use to Support Growth. Each plan addresses sustainability by focusing on energy efficiency and renewable energy suppliers. Renewable energy legislation includes the Renewable Energy Act 2011 and the establishment of SEDA.	OTEC is part of the new renewable energy sources under the 11th Malaysian Plan. NOD was tasked to spearhead the preparation of a National Roadmap in MRE, in accordance with the national renewable energy policy prepared by KeTTHA.	To have a national roadmap on ORE; law on OTEC development (proposed); first OTEC plant in the SEA region.	Under the Renewable Energy Plan 2011, a renewable energy producer could apply to the government for a FiT, subject to conforming to certain specifications and fulfilling certain requirements.
Myanmar	A national energy policy framework, including renewable energy and energy-efficient technology development, e.g. the creation of Agenda 21, which refers to energy independence.	The government incentivises renewable energy-related companies by providing free permits to import renewable energy devices and equipment.	None.	None.
Philippines	NREP aims to increase the renewable energy-based capacity of the country to an estimated 15,304 MW by the year 2030.	ORE is part of the country's national energy plan. The government has also released a national roadmap, which includes the establishment of an ORE facility by 2030	Planned activities for ORE development: assessment of potential ORE sites, and demonstration of technology related to ocean currents and other ORE technologies suitable to local conditions ORE facility by 2030, with a total installed capacity of 70.50 MW.	Proposed FiT to OTEC is 17.65 Philippine peso per kWh, or US $0.37/kWh.
Singapore	Envisions itself as the regional knowledge and technological hub of SEA. Has a policy framework in place for energy efficiency which drives the renewable energy activities in both the public and private sectors.	Provides comprehensive rules and regulations on renewable energy projects and deployments, which includes ORE. It has supportive mechanisms to attract investments.	Decrease emissions intensity by 36% from 2015 level by 2030.	None.
Thailand	The government of Thailand, through its AEDP 2015–2036, targets an increase by 20% in the renewable energy share of the national energy mix by 2036.	ORE is not yet included in Thailand's energy policy; however, there are ongoing ORE RD&D activities in the academic and research sectors.	None.	None.
Vietnam	Has a national policy framework for renewable energy development and energy-efficient technologies.	To focus on the electrification of households via renewable energy sources.	Different stakeholders like research institutes, universities, and government agencies work together to develop lab-scale ORE-suitable turbines.	None.

3.4.2. Indonesia

A general framework for renewable energy development is present in Indonesia [44]. For example, Law 17 of 2007 supports renewable energy project deployment by implementing a national Long-Term Development Plan that creates funding for renewable energy projects [45]. In addition, Governmental Regulation No. 79 of 2014 provides for the reduction of the country's fossil fuel dependence and encourages the shift to clean and renewable energy sources [44]. It also includes provisions for the improvement of electricity supply at the national level and for providing energy access specifically in the remote rural areas of Indonesia. MRE is included in the country's definition of renewable energy, and, as such, its goal of renewable energy development incorporates MRE activities, including pilot testing, in preparation for full-scale commercialisation [45]. The National Energy Council is currently looking into its national energy plan to incorporate MRE into Indonesia's national energy mix [46].

3.4.3. Malaysia

Similarly to Indonesia, Malaysia also has a general framework for renewable energy development, with the government setting modest goals [4]. The government has released the 11th Malaysian Plan 2016, "Encouraging Sustainable Energy use to Support Growth." The plan addresses sustainability by focusing on energy efficiency and renewable energy suppliers [47]. In terms of market mechanisms to encourage renewables in general, a renewable energy producer can apply to the government for a feed-in-tariff (FiT), if they conform to following specifications and fulfil certain requirements[5]

"(1) type of resource used, (2) the installed capacity of the renewable energy (RE) installation, (3) whether the RE installation will meet any

[5] The introduction of FiT in Malaysia was part of the Renewable Energy Act of 2011. FiT was included as a new mechanism to drive more RE production for Malaysia's electricity source. Currently, there are already FiT rate for biogas, biomass, small hydro and solar PV [48].

criteria entitling it to additional bonus FiT rates, and (4) the date the RE installation completed, connected to the grid and ready to produce RE for commercial sale (i.e. FiT Commencement Date)" [48], p. 389].

In terms of ORE, different ORE stakeholders, like universities, research institutes and private project developers, work directly with the government to develop turbine prototypes, test-beds and pre-commercial ORE technology [49]. One example is the UTM OTEC Centre. The government also establishes different agencies that drive ORE activities in the country through RD&D, funding and policy support. The National Oceanography Directorate (NOD) is the central agency that coordinates all oceanographic and marine science-related R&D activities [50]. NOD is leading the establishment of the national renewable energy roadmap, which includes ORE. NOD is under the Ministry of Energy, Green Technology and Water (KeTTHA), which is responsible for steering the nation on renewable energy development in Malaysia [50]. The Sustainable Energy Development Authority (SEDA), on the other hand, implements supportive policy tools, such as a special tariff system. It is also investigating ORE as a possible alternative energy source in Malaysia. In terms of funding support, the Ministry of Science, Technology and Innovation provides renewable energy funding opportunities. Examples are the ScienceFund, which focuses on innovative applied science with a high impact, and the TechnoFund, which provides funds to innovative renewable energy projects at different levels of technological readiness – from laboratory and prototype scale to demonstration and commercial levels [50].

3.4.4. Myanmar

Although it has no direct policy on ORE development, Myanmar has a national energy policy framework that supports energy-efficient and renewable energy technologies. The government has created the National Commission for Environmental Affairs, which has established Agenda 21, a national policy that focuses on sustainable development [30]. The country also has a supportive policy framework on encouraging investments in renewable energy projects, e.g. tax incentives and subsidies [4].

3.4.5. Philippines

The National Renewable Energy Program (NREP) aims to increase the renewable energy-based capacity of the country to an estimated 15,304 MW by the year 2030 [51]. The Philippines has one of the most direct policies on ORE development among SEA countries. ORE is part of the national energy plan and agencies have been created to implement ORE projects. For example, the Philippine Council for Industry and Energy Research and Development (PCIERD) has established a roadmap at the national level that includes the creation of an ORE facility by 2030 [52]. The roadmap includes activities such as the assessment of potential ORE sites and the demonstration of technology related to ocean currents. The plan also pushes for more international collaboration in RD&D. Examples of activities are the creation of an ORE resource map at the country level, a demonstration plant and other ORE demonstration projects that are suitable in the Philippine context [53]. In terms of the proposed FiT for ocean energy, this is US$0.37 USD/kWh for OTEC [54].

3.4.6. Singapore

Singapore envisions itself as the regional knowledge and technological hub of SEA [6]. As such, the government has been supportive of RD&D for different renewable energy technologies in the country. Although Singapore does not have a specific policy on ORE, it has a policy framework in place for energy efficiency, which drives the renewable energy activities in both the public and private sectors [6]. Singapore pledged to reduce its carbon emissions intensity by 36% from 2005 levels by 2020 [55]. In pursuit of this aim, the government has provided public funding of more than S$800 million for projects on effective energy use, water security, the development of green and efficient buildings and addressing land scarcity [56]. S$140 million of this public funding has been allocated to RD&D in clean energy technologies under the Energy Innovation Programme Office (EIPO). There are also market incentives like Green-e Renewable Energy Standard and Green-e Energy Certification, to encourage the development of renewable energy technologies at commercial level and to increase consumers' demand for renewable electricity [57]. The government provides comprehensive rules and regulations on renewable energy projects and deployments, which includes ORE. For example, it has authorised the Singapore Power Group to issue International Renewable Energy Certificates that monitor and record energy consumption from renewables [58]. In addition, Enterprise Singapore has formed a working committee to discuss the adoption of international standards on MRE specifically on wave, tidal and other water current converters.[6] Finally, Singapore has supportive mechanisms to attract private investments and projects through its "Living Lab" concept, which allows companies to test and demonstrate their innovations and technologies within Singapore before commercialising or scaling up, i.e. test-beds and demonstration sites [55].

3.4.7. Thailand

The government of Thailand, through its Alternative Energy Development Plan (AEDP) 2015–2036, aims to increase the renewable energy share of the national energy mix by 20% by 2036 [59]. This is in order to diversify energy sources so as to accommodate the increasing energy demand of the population. ORE is not yet included in Thailand's energy policy; however, there are ongoing ORE RD&D activities in the academic and research sectors [59].

3.4.8. Vietnam

Similar to other SEA countries, Vietnam has no specific policy on ORE, but it has a national policy framework for renewable energy development and energy-efficient technologies [4]. The government has implemented Master Plan VI, which aims to increase the renewable energy share in the national energy mix. The plan includes the electrification of 600,000 households through renewable energy sources [4]. Like similar initiatives in other SEA countries, different stakeholders, such as research institutes, universities and government agencies, are working together to develop lab-scale ORE turbines that are suitable to Vietnam's sea conditions [26].

In summary, there is potential for ORE, such as wave and tidal energy, to be harnessed as an alternative source of energy in the SEA region. Specifically, there are current RD&D activities that seek to understand what suitable ORE devices exist or could be developed that could be deployed in remote coastal areas[7] like those of the Philippines [60,61]. Other studies suggest that small islands present the best opportunities for marine renewables because they could be an alternative source of energy to diesel generation, which is relatively more expensive [3]. One such system is being developed in Singapore, REIDS, which is a testbed of new and renewable energy technologies that are being developed to suit the tropical conditions in islands and other insular areas [34].

With supportive policies in place, ORE development could help

[6] This is also called as "TC 114 or the technical committee that was established by the International Electrotechnical Commission (IEC) to develop, draft and publish international standards for marine energy conversion systems." [81], p. 1].

[7] One-fifth of the region's population live on islands and remote coastal areas that are heavily dependent on diesel as their source of energy. Among the reasons why they are not connected to the national grid is the cost and complexity of installing transmission lines over a long distance to the main grid. Off-grid electricity is also viable because of the relatively lower cost of transporting fossil fuels on boats, together with other goods and supplies needed for island living (e.g. food and water supplies). Countries like Indonesia and the Philippines, which face the challenge of establishing electricity supply across their archipelagic geography, take on renewable energy technologies to power off-grid, coastal and remote areas.

provide an alternative and cleaner energy source for the SEA region. It would lessen the dependence of each country on fossil fuels and mitigate the impact of climate change. Finally, an integrated or hybrid ORE energy system could be source of energy for remote rural islands in the region, which would address the problem of energy access in these areas.

4. Challenges of ORE in SEA

While there are opportunities that SEA countries could take advantage of in terms of developing ORE, there are technical, economic, environmental and political challenges that need to be considered in order to fully utilise ORE in the region. In the next sub-sections, we present the challenges of ORE through an analysis of these different factors that might impact its development as an alternative energy source specifically in the SEA region.

4.1. Technical challenges

One of the main technical issues in the deployment of ORE relates to the installation phase. Similar to mature energy industries, like offshore and oil and gas, the successful installation of ORE infrastructure requires good weather and sea conditions, as well as technical expertise and knowledge, in order to complete the installation and address possible installation problems [8]. Nevertheless, utility companies argue that installation problems are more related to the issue of site selection than technological issues [62].

The technical issues are connected to the cost of the deployment and maintenance of offshore equipment. With a number of marine space users and environmental impact considerations, space is limited on offshore platforms. There is thus a need to modularise ocean energy devices and systems, and to make sure that these devices can survive the sea conditions in the tropics. There is pressure to reduce the cost of deployment and maintenance by ensuring that devices can last in the water with minimal repair and replacement.

A well-designed and fully integrated ORE system that improves performance will help bring about a reduction in the capital expenditure and operating costs [8]. There are different aspects to look at in regard to improving the quality of ORE devices installed in water: 1) effective data collection and analysis (usually based on International Electrotechnical Commission specifications); 2) a sound and implementable strategy for design for maintenance; 3) the means to transfer and disseminate knowledge and expertise in the various stakeholders of the deployment; and 4) effective trial and reliability demonstrations [4,8].

For maintenance and repair issues, the main challenge relates to ensuring the subsystems can withstand the underwater conditions over a long period. Prognostics, health monitoring and management are increasingly seen to be important assets to ensure less costly repairs, and act as preventive maintenance in relation to damage to ORE technologies [8]. Having an effective and functioning sensor system can make it possible to monitor the health and conditions of the subsystem. Despite these technical concerns, ongoing tidal and wave energy demonstration projects in the region are seeking to increase the learning within the sector.

4.2. Economic challenges

As mentioned above, the upfront cost of the installation, maintenance and repair of ORE technologies remains a challenge. Similar to other renewables, the issue always has to do with economies of scale and ORE's competitiveness compared to fossil fuels.[8] However, the case of island dwellers and people in off-grid and remote areas might differ from the situation on the mainland. For example, electric cooperative representatives in the Philippines have mentioned that as long as ocean energy can meet the energy demand of the islands, consumers will be willing to pay the cost [17]. These islands and remote areas are not usually connected to the national grid and depend on diesel generators as their main source of energy. In an ORE workshop hosted in Singapore, participants concluded that "if ocean energy can provide alternative sources of energy, complement existing source of livelihood and could be a potential sector for job creation for island dwellers, then acceptance of such new technologies is easier" [17].

In addition, as ORE is relatively new in the region, the projections and estimations of ORE projects (covering planning, installation, maintenance and repair) are limited to the laboratory scale and not the actual deployment of commercial-scale ORE technologies [12]. Even in places with more mature ORE technologies, such as the EU and UK, the reliability of capital and operating costs estimates is still a challenge. This is because ORE is composed of different diverse technologies, and most of them are not at the commercial stage yet [63]. In 2015, Ocean Energy Systems (OES) released a pioneering study on the levelised cost of energy (LCOE) for wave, tidal and OTEC technologies at various deployment stages.[9] Table 3 on the next page shows the different estimations of the costs associated with selected ORE technologies, like wave, tidal and OTEC, at various deployment stages, drawing on the OES report.

In regard to SEA, a study by OceanPixel (2017), one of the few start-up companies specialising on ORE project development in SEA, states:

> "The percentage of uncertainty in cost projection lessens from conceptual (idea or lab) phase which is around −30 to +200 per cent to a mature phase which has around −15 to +15 per cent. Without proper projection of cost, encouraging investment and policy tools towards ocean renewable energy will be a challenge." [4, p. 38]

In another research study carried out by OceanPixel, with Deloitte Consulting, it is suggested that a combination of ocean renewables and solar PV is suitable to complement existing diesel power generation to provide cleaner and cheaper electricity in small remote islands [3]. Table 4 on the next page is reproduced from a recent study that compares the costs of different energy sources, including diesel power, solar and ORE, in one of the tidal in-stream demonstration projects in West Papua, Indonesia. Most of the island off-grid communities in the Philippines and Indonesia are dependent on diesel generators as their main source of energy. With a hybrid energy source (including renewable energy) the LCOE will be lower, and thus this will be a cheaper alternative energy resource for communities [3]. The table indicates that the combination of ORE and solar PV is suitable to complement existing diesel power. This is a cleaner and cheaper option for island dwellers, as compared to being solely dependent on diesel alone [3].

4.3. Environmental challenges

The impact on marine life and the environment, and potential conflicts over the usage of marine space, are among the environmental issues raised by ORE technologies. According to the European Commission (2014), environmental mitigation analysis is needed to look 1) at the positive and negative impacts on marine life (e.g. fisheries, coral reefs) of putting ocean energy devices in the water; and 2) at the possibility of cooperation (or conflict) over the use of ocean space for other maritime activities like shipping, fishing and defence [64]. For example, "ORE installations that are located near the shore could affect marine life which migrates to and from the shore and could also cause unnatural silt build-ups which could impede the flow of sediment that

[8] However, we are seeing an increasing trend of a shift to renewable and cleaner sources of energy due to steady and lowering costs of more mature renewables, like solar PV, especially in developed countries.

[9] In its 2017 Vision Report, OES estimated the LCOE for the first array of ORE technologies to be US$ 120 to 280/MWh [76].

Table 3
Summary data averaged for each deployment and each technology type, adapted from International Energy Agency-Ocean Energy Systems (IEA-OES) "International Levelised Cost of Energy for Ocean Energy Technologies" [63].

Deployment stage	Variable	Wave		Tidal		OTEC	
		Min	Max	Min	Max	Min	Max
First array/first project	**Project capacity (MW)**	1	3	0.3	10	0.1	5
	CAPEX ($/kW)	4000	18100	5100	14600	25000	45000
	OPEX ($/kW per year)	140	1500	160	1160	800	1440
Second array/second project	**Project capacity (MW)**	1	10	0.5	28	10	20
	CAPEX ($/kW)	3600	15300	4300	8700	15000	30000
	OPEX ($/kW per year)	100	500	150	530	480	950
	Availability (%)	85%	98%	85%	98%	95%	95%
	Capacity factor (%)	30%	35%	35%	42%	97%	97%
	LCOE ($/MWh)	210	670	210	470	350	650
First commercial-scale project	**Project capacity (MW)**	2	75	3	90	100	100
	CAPEX ($/kW)	2700	9100	3300	5600	7000	13000
	OPEX ($/kW per year)	70	380	90	400	340	620
	Availability (%)	95%	98%	92%	98%	95%	95%
	Capacity factor (%)	35%	40%	35%	40%	97%	97%
	LCOE ($/MWh)	**120**	**470**	**130**	**280**	**150**	**280**

Table 4
Summary of the LCOE among various types of energy resources in islands in SEA, adapted from Ocean Pixel and Deloitte (2017) [3].

	Initial condition	Hybrid scenario # 1	Hybrid scenario # 2	Hybrid scenario # 3
Power source	**Diesel gensets (2x910, 1x500, 2x100 kVA)**	**Diesel gensets (2x910, 1x500, 2x100 kVA)** **Solar PV (50 kW)**	**Diesel gensets (2x910, 1x500, 2x100 kVA)** **Tidal turbine (54 kW)**	**Diesel gensets (2x910, 1x500, 2x100 kVA)** **Solar PV (50 kW)** **Tidal turbine (54 kW)** **Battery (100 kWh)**
Capital cost[a]			120	840
Operating cost[a]	240	193	198	119
Diesel consumption[a]	224	182	184	109
Levelised cost of electricity**	51.3	44.4	44.2	39.4

[a] In thousand dollars and ** in US$ cents/kWh.

could affect the marine ecosystem." [32, p. 3]

For devices that convert energy using hydraulic fluids, there might be leakages if the device is not sturdy enough to withstand the strong ocean waves and currents [32]. Not only do leakages affect marine life and the environment, they can also affect other users of the marine space. This acceptability challenge requires "a careful marine spatial planning, coordination work and implementation of right policies among the crucial players like government, shipping and other maritime industries." [4, p. 9]

4.4. Political challenges

In general, even though there are increasing activities regarding renewables in the region, these are not without political challenges. Aside from the technical and economic barriers, SEA also faces non-economic (demography and geography) and political hurdles in regard to fully taking advantage of clean energy sources, like burdensome bureaucratic procedures for deployment, corruption, or social acceptance issues [65]. Due to spatial constraints, smaller states like Brunei and Singapore have difficulty scaling up renewable energy, like wind or ocean [66]. Less developed countries, like Cambodia, Laos and Myanmar, also face difficulty in exploiting forms of renewable energy like ORE due to insufficient resources, reliable infrastructure and development capacity [5].

To overcome such challenges, each SEA country is deploying various policy strategies and mechanisms. Singapore differs from the rest of the SEA region by applying a more technology-oriented approach, rather than an installed capacity-oriented approach [66]. This is mainly for two reasons: one is the country's spatial restriction; and the other is the fact that Singapore, which has the most developed economy in the region, has focused more on strengthening its "techno-innovatory" capacity compared to other SEA countries [66]. A recent position paper on ORE in Singapore concludes that the country, being the regional leader on technology and innovation, could take the lead in the technology development of ORE in the region [6]. On the other hand, countries such as Thailand and Malaysia make use of "economies of scope" to develop their renewable energy sectors. Thailand's bioenergy production stems from the country's strengths in the agriculture sector and processing, e.g. aggro-processing, while Malaysia's foundation for building its solar PV manufacturing stems from its technical and value chain experiences relating to semiconductors and electronics [66].

Although there are benefits for each country from making use of their comparative advantage in renewable energy development, there are also costs, in terms of the reduced ability to diversify and explore other forms of new renewable energy, like ORE [4]. The limited knowledge and expertise in regard to novel technologies like tidal and wave energy could be both a cause and effect of the slow uptake of ORE in the region. On the one hand, lack of technical expertise and knowledge on ORE can impact activities such as effective resource assessment, deployment and demonstration. Assurance regarding potential ORE resources can convince stakeholders to develop the sector further, e.g. policymakers providing support through RD&D grants and test-beds or investors pumping money to cover the initial project costs. On the other hand, a supportive and stable political environment can also encourage researchers and project developers to study ORE as a potential energy source [3,6]. As Dent (2014) concludes in his study of renewables in SEA, the diversity in terms of political, economic and social aspects has implications for how renewable energy is developed in each country [66].

Finally, in insular conditions, the deployment of ORE technologies in remote coastal areas should also take into consideration how it could complement the livelihood of the communities in these areas, and how it could uplift the standard of living, e.g. as indicated earlier ORE technologies could power coolers or freezers for fish, or could at least provide basic lighting, cooking, etc, as Quirapas and Srikanth (2017) summarise:

"Through addressing the basic needs of the communities, niche technologies like ocean energy can easily be acceptable and seen to beneficial by end-users. This affects their willingness to pay and 'invest' in such technology." [17, p. 18]

In addition, the deployment of ORE technologies does not only depend on supportive policies: it also requires the consent for, and understanding of, ORE among sea space users. Consultation among local users, like fishermen, is an important factor, in order for them to understand the benefits and challenges of ORE technologies in the marine environment. Table 5 below provides a summary of oppurtunities and challenges of ORE development in SEA.

5. Discussion

Based on the previous discussion of the opportunities and challenges of ORE development in SEA, this article seeks to deepen our understanding of its potential implications by analysing the intended and unintended consequences of such development. Using the risks and consequences framework presented in Table 1, this study analyses the findings below in two categories: the known and unknown dimensions. The consequences dimension presents the intended and unintended consequences, and their first- and second-order implications.

5.1. *Known intended and unintended consequences of ORE development in SEA and their implications*

5.1.1. *An alternative source of renewable and dependable energy*

Like other renewable energy sources, the development of ORE can provide an alternative source of energy. ORE comes from the movements and patterns of easily accessible natural sources like wind and bodies of water, e.g. the ocean and tidal energy. It comes from the gravitational forces of the sun, moon, and Earth. This makes ORE not only a clean but also a predictable and dependable energy source [4]. However, the unintended consequences of ORE are its impacts on marine life and the environment. Turbines are usually deployed underwater and might disrupt marine life, e.g. fisheries and coral reefs. Migration patterns of aquatic animals could be affected when ORE installations are located near the shore. It can also cause unnatural silt build-ups, which could impede the flow of sediments, affecting the marine ecosystem [4,32]. As such, there is a need to develop more hardware and software tools that can assist in data collection and analysis of, the environmental impacts of ORE technologies in actual sea conditions. This can be complemented by more technical training workshops specifically on ORE to increase the knowledge and skills of renewable energy stakeholders [12].

5.1.2. *Addressing climate change*

Aside from energy security, the development of renewable energy like ORE can mitigate the effects of climate change [67,68]. For example, Singapore has committed to a reduction of greenhouse gas emissions by 36% from 2005 levels by 2030. Its power sector, which contributes around 43% of these emissions, can make use of renewables like ORE in diversifying energy sources and achieving carbon emissions reduction targets [69]. ORE technologies can also be combined with other MRE technologies, like floating solar PV, and also with energy storage "to maximise energy efficiencies, reliability and cost reduction" [6, p. 9]

On the other hand, the risks of utilising ORE technologies relate to its compatibility with the local conditions of the region. This includes its technological components, such as tidal turbines and the skills needed to deploy, operate, and maintain them. Most of the turbines that are at demonstration scale in SEA are manufactured outside the region, e.g. in the UK or Germany. This might be cheaper for testing purposes; however, there is a need to develop the local capabilities and capacity of the ORE sector to suit the SEA conditions and further reduce the costs of installation and maintenance in the long-term.

5.1.3. *Production of utility-scale and off-grid-scale electricity*

ORE could be used as a source of electricity at the large utility scale, as well as at off-grid or distribution scale, depending on the availability of the resource. At the utility scale, the UK has made significant progress on the creation and completion of the MayGen Project (6 MW) and Bluemull Sound – Shetland (extended to 600 kW) [6]. In islands and off-grid areas, where diesel generators are the main source of energy, ORE can be integrated with other renewable energy solutions to make it a more competitive option than diesel fuel [11]. However, an underlying risk of ORE development, especially in off-grid and remote areas, relates to people's acceptance of the relatively new technology [17]. As mentioned in the section above, the acceptance of end-users is a crucial aspect of the full adoption of ORE. While electricity is important, ORE project developers need to take into consideration how the technology can enable communities' livelihood and economic needs [4]. Local communities should be aware of and knowledgeable about how ORE works, and as such be assured that it will not impact them detrimentally, e.g. fishermen may oppose the deployment of an underwater turbine due to fear of losing fish catch. Once the communities are on board, it will be easier to build a local ORE supply chain that includes the community's own resources, technical expertise and manpower.

5.1.4. *Other applications of ORE*

Many ORE systems are installed offshore, and, as such, these systems could be used to provide energy to offshore installations, e.g. oil platforms, navigational systems, weather and climate monitoring stations, fish farms, and other aquaculture developments [4,6]. ORE could also provide electricity to coastal protection infrastructure. Different coastal

Table 5
Summary of opportunities and challenges of ORE development in SEA.

Dimension	Opportunities	Challenges
Technical/ technological	Incorporating inter-industry knowledge and learning from more mature sectors, such as oil and gas, and offshore wind, in the ORE sector.	Successful installation of ORE infrastructure requires good weather and sea conditions, as well as technical expertise and knowledge to carry out the installation and address possible installation problems.
	Creating innovative ORE solutions applicable to the local and regional conditions, e.g. ORE as an off-grid solution for small tropical islands such as in the Philippines and Indonesia.	The upfront cost of the installation, maintenance and repair of ORE technologies remains expensive and is not yet competitive in comparison to fossil fuel at a larger scale.
Socio-economic	Creation of an ORE sector could lead to job creation and security; to regional supply chains that could reduce ORE cost; and to uplifting the livelihoods of rural communities.	Policy decision-makers and community end-users need to be aware of and on board on ORE projects, to lessen the social resistance to the projects.
Environmental	ORE, as a source of cleaner and renewable energy, can help mitigate the impact of climate change.	Addressing the impact on the marine life and environment, and other users of the marine space.
Political	Supportive ORE policies could address the issue of energy access of rural islands, provide an alternative energy source to address increasing energy demand, and reduce dependence on fossil fuels.	There are demographic and geographic conditions that need to be considered. Also, political hurdles like burdensome bureaucratic procedures for deployment, corruption, or social acceptance issues.

operations in SEA require electricity, including shipbuilding, port operations, wood processing, aquaculture and processing); ORE could be an alternative energy source (or in some cases, integrated with fossil fuels) in such cases [4,6]. These applications require a certain level of expertise regarding how to integrate offshore and coastal infrastructure with ORE technologies. A potential risk is that the physical damage to infrastructure might be worse when the installations and operations of an integrated system are not executed well. As ORE installation is already costly on its own, the financial damage could be more expensive when an integrated system fails. There is a need to ensure that this infrastructure is secured and located away from physical threats (especially for those in coastal areas, where natural disasters, piracy and terrorist attacks could be possible).

5.2. Unknown intended and unintended consequences of ORE development in SEA and its implications

5.2.1. Usage of ocean space

Most of the ocean space in SEA has already been industrialised and as such caters to many different users and stakeholders. Although ocean space is vast, ORE developers do not only need to compete for a resource, they must also compete for space. As more turbines are put into the water, rights and ownership must be determined; resource management within a regulatory framework must be in place; and it is necessary to have in place marine space governance that ensures environmental impact assessments and marine spatial planning of ORE technologies [70]. In most SEA countries, the establishment of a marine governance and regulatory framework that includes ORE technologies at the commercial level has yet to take place [5].

5.2.2. Contribution to socio-economic growth and development

As the ORE sector matures in the region, it will create opportunities for job creation, inward investments and private–public partnerships [6]. Current expertise and the labour skillset required in offshore and marine engineering industry could be applied and transferred to an emerging ORE sector. This presents job opportunities for locals who already have the required capabilities and only need minimal re-training and orientation. As some industry experts argue, “this market growth would likely also translate to job growth …” [6, p. 9]. As the ORE sector emerges in SEA, initial inward investments are also expected to rise due to the support of ORE technology leaders in the trade, e.g. EU member countries, the US and Canada. Over the past few years, a few companies from Canada, France, the UK, Germany and the Netherlands have been looking at expanding into the commercialisation of their ORE technologies in SEA[10] [6,18]. Collaboration through joint RD&D work among the academic, private and public sectors should be further encouraged to build demonstration ORE projects. Del Rio and Burguillo argue that the socio-economic benefits from RETs also depend on the relationships among the different stakeholders and the involvement of the local community [71]. As mentioned in Section 3.3, examples of collaborative ORE projects in SEA are SEAcORE, REIDS, the partnerships among universities such as the UTM OTEC Research Centre and private companies, start-up companies created from private–public partnerships, such as OceanPixel, based in Singapore and the Philippines. These projects and platforms have increased their ORE activities and RD&D projects in the region.

5.2.3. Creation of a regional supply chain, industry standards and business financial models

As ORE develops in the region, an unknown intended consequence would be the development and creation of a regional and local supply chain, standards and best practices, and various business financial models that cater specifically to the ORE sector. Through knowledge and technology transfer, the existing marine-related and offshore sector (even the oil and gas sector) could help build up an ORE ecosystem. In interviews with actors in marine-related industries, the respondents mentioned that the ORE sector is a possible new market and avenue that they could take advantage of and could contribute their capabilities and expertise to [72]. Along with the development of a regional and local supply chain, the creation of standards and various business models specifically catering to SEA ORE conditions could also take place. Singapore has started such an endeavour by establishing the National Mirror Committee (NMC), under SPRING Singapore, with government and industry collaborators. The NMC is responsible for looking into the standardisation of marine and ocean renewable technologies in tropical conditions [35].

On the other hand, the development of the ORE sector in the SEA assumes a ready and stable infrastructure, policy and regulatory framework, and even appropriate social conditions. As mentioned in the previous sections, there is a need to consider the different technological, economic, environmental, and political conditions needed to create the ORE sector in the region. Some SEA countries still face “infrastructure, grid-related problems and regulatory and administrative hurdles” [65, p. 11] that would need to be overcome to create a new sector like ORE.

5.2.4. Development of technology, RD&D and innovation suitable to SEA conditions

Apart from the sector itself, the emergence of an ORE sector in the region could lead to the development of new and innovative ORE technologies and solutions that are suitable to SEA. The existing ORE turbines and systems need to be “localised” to fit (and last in) the tropical conditions of the ocean and sea water in the region. For insular areas, experts encourage a modular, smaller scale that could be integrated with the existing energy system – as has been suggested, this could address the lack of energy sources in off-grid remote coastal communities [11,17,22]. However, energy transitions are not only technological, they are also political and social. As mentioned in Section 4.4, the transition to ORE technologies also means creating a political environment that enables and encourages innovative thinking and solutions. For example, government agencies need to curb the non-economic barriers to ORE adoption, like burdensome administrative and regulatory processes for test-bedding approval or pilot demonstrations [5]. The government could also provide more in-depth knowledge and skills development training to policymakers, to furnish them with expertise on ORE technologies, deployment and business model strategies to encourage investments. Grants and funding should also be made available to RD&D work at different technological readiness levels – from fundamental research, to laboratory and demonstration scale, and eventually to commercial scale. In addition, social acceptance is also an important factor in transitioning to clean technologies like ORE. These technologies transform not only the use of technology but how people live and cope with change [13]. Fishing communities are most likely to be the end-users of ORE, especially in off-grid island communities, and, as such, their knowledge about the benefits, risks and consequences of ORE technologies are crucial to long-term adoption.

Table 6 on the next page summarises the results from the application of the risks and consequences framework to ORE development in the SEA region.

6. ORE development in SEA: Next steps

As indicated in the discussion above, there is agreement among experts and scholars that potential energy can technically be harnessed from the oceans of SEA. This potential, when utilised, can help in addressing the push for the region to achieve sustainable development through renewables, and possibly act as an alternative energy source in insular areas of the region. However, utilising this potential is not only a

[10] See footnote no. 3 for more information about the ongoing ORE projects in SEA countries involving technology developers from outside the region.

Table 6
Summary of risks and consequences of ORE development in the SEA region.

	Consequences dimension				
	Intended consequences	Unintended consequences			SEA country where applicable
		Unintended consequences	First-order implications	Second-order implications	
Known	ORE as an alternative source of renewable and dependable energy	Impact on marine life and environment	Migration patterns of aquatic life may be disturbed; silt build-ups could impede the flow of sediment, affecting the marine ecosystem	A need for developing framework, tools and software to understand the actual environmental impacts of ORE technologies, and how to mitigate them	Indonesia Malaysia, Philippines
	ORE development to address climate change	A risk in utilising ORE technologies is its compatibility to the local conditions of the region	Import of technology and expertise from outside the region might be costly in the long-term	Development of local capabilities and capacity to make ORE sector more sustainable in the region	Indonesia, Malaysia, Philippines, Singapore
	Production of utility-scale and off-grid-scale electricity	There might be resistance from communities who are not familiar with ORE technologies	Local communities and businesses (e.g. diesel generator owners) should be aware of and knowledgeable about how ORE works, and as such should be assured that it would not impact them detrimentally	Local communities' acceptance of the relatively new technology and the possibility of a creating an integrated energy system, e.g. diesel with ORE and solar PV	
	Other applications of ORE to offshore installations and coastal infrastructure	Physical damage to infrastructure might be worse when installations and operations of an integrated system are not executed well	Financial damage could be more expensive when an integrated system fails	Ensuring that this infrastructure is secured and located away from the physical threat	
Unknown	Usage of ocean space	ORE developers need to compete not only for a resource but also for space	Possible conflict with other ocean users; lack of a regulatory framework	Establishment of a marine governance and regulatory framework that includes ORE technologies at the commercial level	Indonesia, Malaysia, Philippines, Singapore
	Contribution to socio-economic growth and development	ORE sector creates opportunities for job creation, inward investments and private–public partnerships	Inter-sector and inter-regional learning through collaboration	More demonstration ORE projects and scaling up of the devices	
	Creation of regional supply chain, industry standards and business financial models	ORE development in the region assumes ready and stable infrastructure, a policy and regulatory framework, and even social conditions	SEA countries still face infrastructure and grid-related problems and regulatory and administrative hurdles	Unsuccessful implementation of ORE projects when such non-economic and political barriers are not addressed	
	Development of technology, RD&D and innovation suitable to SEA conditions	Existing ORE turbines and systems need to be "localised" to fit (and last in) the tropical conditions of the ocean and sea water in the region	Need for local participation from communities and end-users	Unsuccessful local participation could lead to short-term ORE adoption only	Indonesia, Malaysia, Myanmar, Philippines, Singapore, Thailand, Vietnam

question of the availability of the resources but also requires a combination of suitable technical, economic, environmental and political conditions in the SEA region. There are also unintended risks and consequences that are important to look into when developing a supportive policy framework to develop the ORE sector in the region.

The utilisation of ORE potential is highly related to a decrease in the cost of initial installation and deployment of ORE technologies in the water. This is further dependent on the level of knowledge and expertise of the local and regional stakeholders, as mentioned in the sections above. In order to build the technological expertise, human and resource capability should also be developed. "Knowing who does what and where" is important in the creation of inter-sector learning, sharing of knowledge and technical know-how, e.g. collaboration among academics, government agencies, marine and offshore-related industries, and potential investors and project developers [6]. This could possibly pave the way for the creation of a local supply chain that could eventually bring down the cost of installation, operation and maintenance, and repairs.

There is a need to have more pre-commercial- and commercial-scale projects in SEA. According to OES, the current costs of ORE technologies are estimated based on laboratory and prototype scales and not commercial-scale deployment. Naturally, these projections are higher than the costs incurred in actual ORE projects. This is important because the cost of ORE technologies goes down significantly after a certain volume of production has been achieved [73]. The Offshore Renewable Energy Catapult Report in the UK also mentions that there has been significant cost reduction in ORE development and deployment due to the progress of the sector towards more commercial-scale deployment. The report refers to an "increase in the economies of volume, i.e. production and deployment of multiple tidal energy devices, time and cost savings through 'learning by doing', process optimisation, engineering validation and improved commercial terms" [73, p. 7]. In addition, cost estimations from commercial projects are also more useful for continuous progress in ORE RD&D and policy formulation to support future deployments.

One major risk of ORE technologies is the expensive costs of the initial construction and production of an ORE power plant. This could be addressed by investing and deploying more hybrid energy systems, e.g. solar plus tidal turbine systems, even at a small scale [11]. This could be a viable cheaper alternative to the traditional diesel generators that are often used by off-grid and island communities. According to experts, the expensive upfront cost of ORE deployment could be balanced out by its total lifespan and the decreased cost for maintenance and repair compared to fossil fuel power plants. For example, a tidal power plant's life span is estimated to be 100 years for the barrage structure and 40 years for the equipment [4], while a coal power plant only lasts from 30 to 50 years [74].

Once the technological and human resource expertise is built, ORE resource assessment can be done more effectively and accurately. Aside from saving cost, time and effort, effective resource assessment is a key to obtaining more accurate information about the type of ORE available, the kind of technology to use in harnessing it, and the potential energy capacity it can produce. From a public policy perspective, this could encourage more interest from policymakers to look into this sector and to provide support mechanisms. For example, the Philippine Department of Energy has approved the commencement of predevelopment of utility-scale tidal energy in the San Bernardino region of the Philippines. This is taking place in collaboration with Oceantera, a regional ORE project developer, which has showcased successful deployments of two ORE projects in Singapore and Indonesia [36]. Similar collaborations have also happened in Malaysia, Singapore and Indonesia [38], where an initial successful ORE deployment had a domino effect on the creation of more ORE projects in the sea. Pilot projects are important in order to test the suitability of devices in the water, the bankability of projects and the creation of local technology developers and suppliers [6].

To maintain a sustainable ORE sector in the region, marine governance should also be a priority. As discussed above, a lot of potential issues can arise due to the management of marine and ocean space and the possible impact of ORE technologies on marine life, the environment and currents users and stakeholders. Marine spatial planning (MSP) and environmental impact assessment (EIA) tools are available to help inform policymakers of how to utilise ORE technologies without harming the marine ecosystem. An industry report explains that MSP "is used to map out priority areas for development while considering other existing and planned used of the sea" [6, p. 13]. MSP and EIAs also bring together different stakeholders in inclusive planning, minimising conflict. The creation of multi-stakeholder roadmaps, e.g. technology and industry roadmaps, will also be helpful in the identification of goals and actions to drive more coordinated ORE activities in the region.[11]

Finally, efforts to develop ORE technologies and an ORE sector entail the buy-in not only of the technology and project developers, policymakers and investors, but, more importantly, the local communities who will be the ultimate adopters of such technology. Acceptance is a key element of any energy transition [75] and, as such, their involvement in the planning, deployment and implementation of any ORE projects can help ensure its long-term adoption at the community level.

The list below summarises different recommendations and strategies that could address the risks and unintended consequences of ORE developments in the SEA region:

- A high level of local knowledge and expertise is needed to build an ORE sector in SEA. Technological know-how, and human and resource capability should be developed.
- A local supply and value chain should be established to bring down the costs of importing the necessary technologies and skillset needed to deploy ORE technologies.
- More commercial-scale deployments in the region are needed to have accurate projections of the costs of deploying and sustaining ORE technologies. These deployments can be a source of "best practices" specifically suitable to SEA conditions and processes.
- Awareness of ORE technologies and the presence of actual projects can help in crafting a supportive policy and regulatory framework for the development of the ORE sector and future deployments.
- One solution to address the expensive upfront cost of deploying ORE power plant is to invest more in hybrid renewable energy systems, e.g. solar plus tidal turbine systems. This will be especially helpful in isolated remote coastal areas.
- Accurate resource assessments and pilot projects are important to test the suitability of ORE devices in the water, the bankability of projects and the creation of local technology developers and suppliers.
- There is a need to plan and formulate governance and policy frameworks for marine spatial use and public acceptance as these are key elements to achieve long-term ORE adoption.

7. Concluding remarks

This article has looked at the current status of ORE energy in SEA through multiple lenses – technical, socio-economic, environmental and political factors. First, in terms of technical availability, ORE is an emerging and disruptive renewable energy technology that is suitable for conditions in the SEA region. Wave, tidal and OTEC are available in the region and could be sources of alternative clean energy. Indonesia, Malaysia, the Philippines and Singapore have made advances on research, development and demonstration of ORE technologies that are

[11] More information about different technological and policy roadmaps on ORE are found in the following resources: Aquatera (2018), European Ocean Energy Association (2010), EU (2018) and Ocean Energy Forum (2016) [77] [78] [79] [80].

suitable to the local conditions of SEA. Second, developing the ORE sector will bring socio-economic benefits in terms of employment opportunities, inter-industry learning, economic resilience and investments. Third, there is an increasing effort to understand and assess the environmental impacts of ORE on marine life and biodiversity. This EIA can help in establishing a regulatory framework for future ORE deployments. Finally, most of the SEA countries have supportive policies towards renewable energy development in general, while countries like Indonesia, Malaysia and the Philippines have specific policy tools to drive ORE activities at the national level, e.g. the inclusion of an ORE target in the national energy plan. In summary, this study claims that the development of ORE could help address the "energy trilemma" in the region by providing clean energy sources to tackle the increasing energy demand of the population and at the same time contributing to socio-economic growth of the region.

On the other hand, an energy transition to ORE is not without challenges. One difficulty is to make ORE economically competitive in relation to fossil fuels, in terms of installation, maintenance and repair. There is a need to have a well-designed and fully integrated ORE system, to improve performance and reduce the capital expenditure and operating costs of ORE technologies. There can also be social resistance towards ORE projects because of their possible impact on marine life, the environment and even other users of marine space. Ongoing research work and development projects are studying and assessing the environmental impact of ORE turbines before and after deployment. Aside from the technical and social and economic barriers, political hurdles like burdensome bureaucratic procedures for deployment and corruption will also impact ORE development in the region.

Aside from presenting the opportunities and challenges, this study further contributes to the literature by mapping out the intended and unintended risks and consequences of ORE development in SEA. Using the framework of risks and consequences, this paper moves beyond cost–benefit analysis and shows the possible unintended risks that could stem from ORE's intended impact. For example, the intended impact of harnessing energy from the ocean is to provide an alternative source of clean and dependable energy; however, an unintended consequence of this is the impact on the migration patterns of aquatic animals. Using this framework, we have drawn policy recommendations that could address the possible consequences, e.g. the development of EIA tools that can collect migration data of aquatic animals and how ORE deployment impacts them.

Overall, there is ORE potential in SEA. However, a coordinated approach among different stakeholders is needed to create the suitable technical, economic, environmental and political conditions for its development and sustainability.

Credit statement

M.A.J.R. Quirapas: conceptualization, design, data collection, analysis, and writing of the manuscript. A. Taeihagh: conceptualization, design, analysis, writing, reviewing, and editing of the manuscript and securing funding.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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