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Reducing the Barriers to Wave Energy Harvesting: Review

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Authors' contributions

This work was carried out in collaboration among all authors. Author KGL designed the study, conducted the preliminary research and wrote the first draft of the manuscript. Author KM managed the analyses of the study, conducted further research and edited the manuscript. Author AA reviewed the manuscript and prepared the final document for submission. All authors read and approved the final manuscript.

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ABSTRACT

This study reviews the main barriers affecting wave energy harvesting globally by practitioners and developers and identified ways to circumnavigate the limitations experienced, in particular to Small Island Developing States (SIDS). Potential avenues for developers to exploit the available technology and allow them to evade barriers preventing advancement were identified. The results of the study indicated that combining wave energy technologies with other functional systems in society such as coastal protection and eco-tourism initiatives can lead to increased value proposition of projects and reduced costs. They primarily include the ministries and agencies of a government responsible for public health, infrastructural development, energy, trade, industrial development, tourism, education and agriculture in SIDS. Wave energy harvesting devices should be engineered as part of established industries and supply chain to incrementally advance technology development. When choosing an energy stream to be utilised, project developers, policymakers and stakeholders use the Levelised Cost of Energy (LCOE) as their critical metric. To determine the applicability of the system, the LCOE is compared to the societal benefits. The societal benefits can be quantified by combining the avoided costs with the economic benefits. Additionally, standards, regulations for ownership and maintenance and installation procedures should be developed for increased chance of technology development.

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1. INTRODUCTION

The world today is undergoing an energy transformation in many facets due to the challenges faced globally. Two major contributing factors are the sustainable usage of resources and global climate change [1]. Coupled with this, it has been reported that global energy consumption is predicted to increase at a rate of 2% per annum [2]. This includes the usage of all forms of energy (renewable and otherwise) by people and organizations [3]. However, this increase can adequately be sustained with further development of renewable energy resources [4]. "Renewable energy (RE)" as a resource is characteristically obtained from the "natural environment and is essentially unlimited". Examples of this include: wind, solar, bioenergy, geothermal, hydro-energy, maritime currents, wave, and tidal power [5].

Studies show that wave energy (WE) as a source for power production is one of the most abundant sources of RE available on the planet [6]. The reality in 2011, it was estimated that more than 40% of the world's population live approximately 100 km or less from the coast, explaining why 13 of the world's 20 megacities are also located near a coastline [7]. This unique situation presents the opportunity for the exploitation of wave energy as a viable renewable resource to serve the needs of a major section of the world's population, and eventually alter the world's energy dynamics [8]. However, presently this is not the case. In the Caribbean and in the Pacific, more than half the population of Small Island Developing States (SIDS), reside within 1.5 km of their coastline [7]. Further cementing the argument that "WE can be considered a significant source of RE in the Caribbean" [9]. This is especially important since islands are inherently disadvantaged because of their small size, minimal resources, low productivity levels, geographic seclusion and ecological sensitivity that has been amplified due to climate change [2,10]. Global climate change is another strong driving factor towards obtaining cleaner energy resources. This has been recognized by the major hydrocarbon producers and in a 2014 report, BP (a global oil and gas producing organisation) indicated that "without strong mitigation policies, hydrocarbon emissions are set to increase by approximately 30% over the next 20 years" [1]. However, the generation capacity from a renewable resource is expected to grow at an "average annual rate of 6.6%" during this same time [1]. This clearly indicates that there is still a long way to go in overcoming the numerous challenges most RE projects face [11]. In this regard, many researchers are focusing on filling this gap by working on both simulating and actual experimental work to develop wave energy technology as a viable source [2,6,8]. Currently, many different wave energy harnessing devices are being tested [7,9, 10,11].

2. CHALLENGES EXPERIENCED IN THE WAVE ENERGY INDUSTRY

Documented literature show evidence of the use of WE systems since the late 1790s [9]. Over the years there have been numerous advancements in the field, however, to date it is still considered a young industry. This has been primarily attributed to the various challenges experienced with WE conversion systems [12]. Some of the key areas in which significant development has to be made in order to capitalize on this form of energy has been identified as:

- increasing the efficiency of the energy conversion process;
- stabilising the output power;
- reducing its levelised cost of energy (LCOE);
- accessing capital investment for research and development;
- detailing the WE resource located at many countries;
- improving the survivability, reliability, and installation capabilities of WE converters;
- creating policies and regulations for the industry;
- developing the supply chain

Although these issues have been identified with respect to the WE industry in particular, many of these challenges are applicable to other RE industries. Another critical factor identified is obtaining qualified installers for RE projects are difficult acquire which indicates the need for a significant educational and training aspect in the industry. Also the uncertain nature of the payback period and the difficulty in obtaining project financing [5], highlights the need for policy makers to create economic mechanisms directed towards producers and consumers with incentives that may alter production and consumption choices. This may include taxes, subsidies, tariffs and other financial schemes that can be beneficial towards a risk reduction goal [13,14].

3. INCREASING THE VALUE PROPOSITION OF WAVE ENERGY PROJECTS

Public Health: The term Public Health has many definitions, it was described by the American Public Health Association as the "promotion and protection of the health of people and their communities", while the Public Health Association of Australia described it as "the treatment of individuals to encompass health promotion, prevention of disease and disability, recovery and rehabilitation, and disability support" [15]. Collectively we identify the common points being the "prevention of disease and disability" and the "protection of the health of people". This expresses a proactive approach to health and well-being, as opposed to a reactive one. In comparison, mechanical engineers reference this thought process to a form of maintenance known as Preventative Maintenance (PM) as opposed to Corrective Maintenance (CM), also known as repair activities. Time and time again, PM has shown to be more appropriate than CM when assessing the life of an asset. PM is often achieved through the implementation of operational control measures to reduce the probability of asset failure. The same can be done with public health, where the implementation of various control measures can be made to reduce the occurrence of diseases and its detrimental effects on the human population.

The use of fossil fuel based electricity results in significant pollution that not only damages the environment but also human health [16]. Criteria air pollutants such as inhalable particulate matter (diameter 2.5 micrometres and smaller), ground level ozone (O_3), carbon monoxide (CO), sulphur dioxide (SO_2), nitrogen oxide (NO_X) and lead (Pb) can extremely affect the respiratory system of people, leading to coughing, irritation of the respiratory track, breathing difficulties, lung damage and exacerbated asthma [16]. The fine particulate matter and ground level ozone are commonly called soot and smog [17]. Hazardous air pollutants are pollutants commonly suspected in the development of cancer related illnesses and birth defects. Additionally, brain, kidney, heart, lungs and the immune system of humans can be significantly affected when a hazardous air pollutant like mercury is inhaled. Mercury has shown to be a possible by-product during the electricity generation process using fossil fuels [16].

Case Study 1: This research was conducted on a Regional Greenhouse Gas Initiative (RGGI) project conducted across 9 American states. The RGGI was primarily a greenhouse gas regulatory programme where there were changes in electricity generation in the regions examined along with increased energy efficiency and renewable energy usage. The report produced by Abt Associates, showed that between 2009 and 2014 the public health benefits were:

- 300-830 avoided premature adult deaths (deaths before the expected mortality age),
- 35 to 390 non-fatal heart attacks,
- 420 to 510 avoided cases of acute bronchitis,
- 8,200 to 9,500 avoided asthma exacerbations,
- 13,000 to 16,000 avoided respiratory symptoms, and
- \$3.0 billion to \$8.3 billion USD in avoided health effects amongst other benefits.

Case Study 2: A second study was based on the Boswell unit 4 Environmental Improvement Plan in Minnesota. The project involved the replacement of the air pollution control equipment with a scrubbing system intended to reduce sulphur dioxide, particulate matter and mercury emissions. The results showed that the sulphur dioxide reduced by 40%, the particulate matter reduced by 80% and the mercury emissions reduced by 90%. These advancements resulted in 2-4 avoided mortalities a year, 77 reduced respiratory symptoms per year, and 1,208 reduced acute respiratory symptoms per year, amongst others. Ultimately leading to a quantified estimated benefit value of \$14 million to \$31 million USD in medical costs [16].

Hence the use of RE technologies (including WE technologies) to serve our energy needs, can reduce the amount of respiratory illnesses faced by neighbouring residents and the wider community. Jonathan et al. [18] went further to state that "air quality and public health can be important to a full benefit cost analysis for interventions primarily designed to reduce greenhouse gas emissions". As such, the benefits of a WE and RE industry goes beyond energy production and crosses over into public health in significant ways. In fact, the American Public Health Association acknowledged climate change as the foremost threat to public health as it relates to increases in heatwaves, wild fires, water-borne diseases, soot and smog, amongst others [17]. As such, government policies and budgets for the healthcare in nations should take into account RE initiatives [18].

3.1 Coastal Protection

Coastal management encompass a group of principles and practices geared towards the protection of coastline from varying natural phenomena. This has become more relevant with the changes in global climatic conditions. These changes has resulted in an increased amount of annual storms with increased intensity, leading to more erosion and flooding in coastal areas. Costal management systems has identified hard structures as the preferred choice over soft strategies (e.g. beach nourishment) when the lifetime and efficiency of coastal defences are assessed [19]. These coastal defences ultimately protect the coastline (made of sediment) from the violent forces of ocean waves and currents. Common practices include building gyrones, seawalls, revetments, rock armour, gabions and offshore breakwater [20].

Break water technology is another established coastal management method. The principles of operation entails reflecting incoming ocean waves and breaking them to reduce the impact at the coastline. Traditionally either a rubble mound collection, a top sloped structure or a perforated caisson were used [21]. Recent developments showed that hybrid structures can act as both a protective barrier for coastal erosion and a wave energy converter (WEC). One of the latest in this ideology is the Overtopping Breakwater for Energy Conversion (OBREC), which is a contemporary rock breakwater that captures the wave energy and converts it to electricity via low head turbines [21]. One of the latest versions is a full size prototype currently located in the harbour of Naples, Italy, where tests are being conducted by the Luigi Vanvitelli University of Campania.

Mendoza et al. [19] theorised that if the underlying principle of a WEC is to absorb the waves and produce a usable form of energy (e.g. electricity), then a combined approach for coastal protective devices can be developed. This approach can utilise WEC to reduce the wave forces impacting the coastline while generating usable energy. .This system has the potential to increase the value proposition of WEC, hence, tipping the scales of a cost-benefit analysis in favour of the benefits and provided a shorter time for the return on investment (ROI). With this principle, WE harvesting farm can be championed by those interested in RE and by those interested in the protection of coastal areas, residents and industries. The prospect provides a two-prong approach for attracting investors.

Tourism: There has been an increasing trend globally concerning tourism and the renewable energy industry. Asvanyi et.al. reported that from 2006 to 2016, the number of publications related to tourism and RE identified by Elsevier went from 2 to 24. These documents discussed energy consumption against topics like tourist attractions, destinations and accommodations, amongst others. One of the main conclusions is that the type of RE utilised is dependent on the tourist destination [5]. For example, a rural establishment may capitalise on solutions such as biomass and wind power [5]. However, in small island developing states, due to the large coastline per area ratio it is expected that marine energy may be the most applicable, as hotel and guest house accommodations will be located near the coasts [9].

When analysing buildings of the tertiary building sector, hotel accommodations is amongst the highest consumers of electricity, accounting for 28% in Greece, 18% in France and 35% in Spain [5]. The varying consumption levels are dependent on the number of rooms, level of luxury, location, environment and amenities offered, amongst others. Usually, the major energy consumers in a hotel is space heating (accounting for approximately 31%), hot water production (accounting for approximately 17-40%) and lighting (accounting for approximately 12%) [5]. However, in the Caribbean, air conditioning accounts for almost half of the energy used in a hotel [5].

Green supply chain management introduces environmental protection into the supply chain and considers the energy usage and balance in its products and processes [5]. A study presented in 2002, indicated that a wind farm in Scotland would be a significant tourism attraction by 80% of the participants [5]. The information was from the feedback of over 300 tourists in the Scottish tourism dependent town. Over 60% expressed interest in visiting a beach with a wind turbine development in the sea [15]. Similarly, it has been a proven tourism success in Denmark, where hotels, guest houses and camping areas located near wind farms experience significant amounts of visitors, effectively utilising the term “green tourism” [2]. When these wind farm was being developed, there were major concerns with respect to the local tourism in the area. However, impact studies conducted around the farm showed that nearby villages experienced an increase in tourist activities and the number of visitors [15]. An additional study conducted in the Netherlands, Germany, Italy and New Zealand indicated that at least 60% of the participants believed in green tourism and that RE increased competitiveness in tourism destinations [2].

When the United Kingdom developed its first wind farm, educational facilities were built to compliment it. The response to tourism was overwhelmingly well received, with over 30,000 visitors attending within the first 6 months [22]. Additionally, countries like Sweden, Germany and the United States of America (USA), have shown that tourists and residents are very open towards wind farms. A 2006 study conducted in Delaware, indicated that 84% of the residents’ reported that they would be likely to visit a new beach to see an offshore wind farm [23,24]. However, there are scenarios where RE were not welcomed by tourists [25]. The first was a proposed wind farm in Northern Cape, South Africa and the second was in Western Cape, South Africa. The reason for its poor reception were because tourists expressed they visited these provinces to experience a technology free environment and to escape the modern world.

The energy demand in the tourism industry is shared according to transportation, accommoda tion and other energy consumption activities by 94%, 3.5% and 2.5%, respectively [25]. The transport needs of tourism are covered by 54% air transport, 39% for road transport, 5% for ship transport and 2% for rail transport [25]. The impact of the tourism sector on global warming is in the range of 5.2 to 12.5% [25]. On the down-side, the ability of WE technology to make a considerable impact is very low since air and road transportation account for over 90% of the energy consumed in the tourism sector. However, guided tours and educational centres of RE power plants are still commonly utilised to boost the tourism economy when RE technologies are located nearby tourist spots. This is a common trend in Canada, Denmark, Germany, Iceland, United Kingdom (UK), and the USA, amongst many others [25]. The RE referenced most is wind farms because it is a relatively mature industry and numerous studies have been conducted around it. However, it is expected that the general opinions of the surveys and research should be the same for other RE technologies like WEC.

Shipping: A 2012 study reported the amount of greenhouse gases emitted by ships is projected to increase by 250% by 2050. This can be attributed to the increasing amount of maritime freight transports globally [26]. To date, there is no commercial usage of RE within the shipping industry, however, research has shown potential for these systems. The generation of electricity from a renewable resource within the shipping industry has a significant amount of interest because this industry is considered to be a major polluter of the environment via carbon dioxide emissions [27].

In 2010, a retrofitted catamaran was developed in Japan with no sail or engine and claimed to be green powered. Its operating principle was based on the flaps at the bottom of the ship, which oscillated up and down when a wave passes. This mechanical system supported the movement of the ship via the wave energy. The maximum speed was 5 knots and a spring was used to keep the flaps in the most appropriate position [27,28]. Other designs utilising RE technologies in the shipping sector include the E/S Orcelle which is powered via solar panel on top and WECs below. The forward movement of the ship is similar to what was stated previously while the solar panels were stationed as sails providing additional energy for the ships operations. It is estimated to travel between 15 to 27 knots [27]. Even though these ideas are genuine, the current technology does not have a sufficient level of energy conversion for sustainability. As such, a focused attempt on energy efficiency is needed on ships. This particular attention can be achieved via the Ship Energy Efficiency Management Plan (SEEMP) [29]. The SEEMP is a systematic way to improve the energy efficiency of a ship and includes, hull cleaning, slow steaming, the polishing of propellers, optimisation of the voyage planning process and weather routing [29].

Global trade is primarily dependent on the shipping industry as it is estimated to cover approximately 90% of traded goods. From 1970 to 2013, the amount of goods transported via the maritime network went from 2.6 billion to 9.5 billion, and it is estimated to continue its increase within the foreseeable future. Interestingly, as most industries emphasis went from being powered by non-renewable energy to RE, the shipping industry went the opposite way. They originally used sails (which is powered by wind energy) to using diesel engines (which is powered by fossil fuels) [30].

Factors affecting the RE re-introduction into the shipping industry are considered organisational, behavioural, market and non-market related. This is reflected via the lack of financing of projects, operational costs not clearly detailed and uncertain potential savings amongst others [30]. The Sustainable Shipping Initiative (SSI) Save As You Sail (SAYS) has a financial structure in place that facilitates the development of sustainable energy solutions to ship operations. The system proposes that the owner may take a loan from a financial institution, where in the act of paying back will benefit from profits during and after the loan schedule [30]. The ability to generate a significant amount of ROI is based on increasing the overall value of the shipped product. The SSI allows avenues for the advancement of the shipping industry and the WE industry as well.

Agriculture and Environment: To date, RE technologies still have relatively low efficiency levels. As such, to obtain a reasonable amount of electricity, these systems currently have to be very large to provide a useful amount. An example of such, is the use of solar farms. However, the problem associated with this is that it competes with valuable land space that receives direct sunlight that could otherwise be used as agricultural land (especially in SIDS) [31]. Nevertheless, researchers have found a way for mutual beneficial arrangement between the two.

Adeh et.al. [32] discussed in detail an agrivoltaic system, where crops were grown beneath solar panels in a farm. The results indicated that this arrangement allowed for higher conservation of the water supplied to the crops, effectively increasing the efficiency of its usage and land productivity by 60-70%. Additionally, there was an increased crop yield per m^3 of water supplied, a faster covering of soil by the shaded crops (approximately double) and increased nutritional value of the plants [31]. Similarly, in 2014, Hammar [33] expressed that WE systems could be used as artificial reefs. This increases the marine population in the particular area and strengthens the maritime habitat. This colonisation is possible because WE systems will introduce hard structures in the marine environment that marine animals use to reside. The species that will thrive depends primarily on the depth, the material and location of these structures [32].

The positive impact that these WE systems can provide to the environment and agricultural production makes their development more valuable. Their implementation goes beyond the stakeholders of the energy industry and includes agricultural and environment assessments.

Levelised Cost of Energy: When choosing an energy stream to be utilised, project developers, policymakers and stakeholders use the LCOE as their critical metric. The LCOE reflects a cost in per-megawatt hours that represents the entire project life of the generation asset. It is based on the total capital, operating, maintenance and financing costs of facility and equipment over the financial life of the technology, calculated in a format to determine equal amounts of annual payments in real dollars (not accounting for inflation). Incentives from current policies can also be utilised in the development of the LCOE [33]. Soukissian et.al. [34] proposed the equations for LCOE and FCR as:

$$\text{LCOE} = \frac{\text{CAPEX x FCR x OPEX}}{\text{AEP}} \tag{1}$$

$$\text{FCR} = \frac{r(1+r)^t}{(1+r)^t - 1} \tag{2}$$

Where *CAPEX* is the capital expenditure, *FCR* is the annual fixed charge rate, *OPEX* is the operational expenditure, *AEP* is the annual energy production, *r* is the discount rate, *n* is the life time of the project, and *t* is the number of years from 0 to n [35].

To determine the applicability of the system, the LCOE is compared to the societal benefits. The societal benefits can be quantified by combining the avoided costs with the economic benefits. Avoided costs is approximated to a monetary representation of the climate impacts, air pollution control and energy security, while the economic benefit is approximated to the balance of payments and net job creation [35].

Policies: The study done by Bergmann and Hanley [36] identified the following strategic options that can be used to reduce barriers:

1. Obtaining multi-party political support for RE projects, to achieve consensus.

2. Having intense engagement with key stakeholders to reduce the environmental impacts.
3. Developing systems to address costs indirectly associated to RE projects (e.g. planning, evaluation, licensing and construction).
4. Stabilising subsides and increasing its predictability to reduce market risks and concerns.

The large capital costs that are required for research and development (R&D) in renewable energy is another major barrier that requires attention. Policies regarding the subsidisation of R&D activities is important and is regarded as a critical mandate that must be set for the industry to progress and meet the reduced greenhouse gas emission goals [34,34]. Market failures are an unfortunate result of high risk R&D, but it is expected in the early stages when performing this level of work. As such, government's support of R&D is critical as these failures lead to under-investing by private organisations. Support towards R&D can be demonstrated in multiple ways, this includes: development of infrastructure, educational and training programmes, facilitating the right legal environment, etc. The high risk environment of renewable energy development and the challenges of SIDS (e.g. extreme weather, flooding, hurricanes, etc) further cement the reasons why Caribbean governments need to support the R&D technologies that will sustain their nations. Private investors will simply look for alternative markets that are considered safer investments [37,38].

In Trinidad and Tobago, the ministry charged with energy sector development (Ministry of Energy and Energy Affairs) often competes for the limited financial resources of the nation. Therefore, there is very little allocation towards RE development within the twin island republic. However, if RE was seen as an activity that benefits multiple ministries, e.g. the Ministry of Agriculture, the Ministry of Education, the Ministry of Health, the Ministry National Security, the Ministry of Tourism, the Ministry of Trade and Industry, and the Ministry of Works and Transport, then the resources allocated across these government institutions can be pooled together to support RE activities. Timilsian and Shah [32] identified ineffective institutions as another serious barrier to growth and development. Though regulations and permits are vital for industry development, an extensive procedure coupled with excessive bureaucracies can lengthen project timelines, increase costs and frustrate developers and investors alike [39]. The difficulties in data collection and distribution are additional challenges encountered by SIDS, as the lack of resources to provide this service makes project success more risky. . Apart from resources for data collection, resources with the technical competency to perform tasks are also considered to be a challenge.

The technical competency of personnel in SIDS for the operation and maintenance of RE systems is often not available. Policy developers will have to take this under consideration as development of capacity is a key requirement for industry sustainability and it refers to the underdeveloped nature of the RE supply chain. Additionally, the lack of standards for WE technologies is also a hindrance for supply chain development. This is mainly because of its infant nature in the timeline of the R&D process [39]. Standards are important for consumers to experience confidence in the products and services being provided, as it provides a systematic way to improve the safety, reliability and quality of our lives. For more effective regulations, governments depend on standards developed by globally-established experts to help establish best operating practices. Since there are no established standards for the wave energy industry, PCCI Incorporated [40] presented a complied list of guidance documents and codes that were traditionally used for offshore oil and gas and shipping industries and identified how they may be applicable to the WE industry. This include, but are not limited to: EMEC Guidelines, ABS, API and DNV codes/recommended practices.

Companies in Caribbean SIDS traditionally maintain a monopoly of key services that unfortunately makes access difficult for project developers originating from outside the system. The authority of electricity transmission and distribution is often under the control of one utility company in each nation. As such, when policy makers draft legislation to facilitate the integration and entry of RE technologies from independent investors there is usually a major push back by the single entity responsible. Recently, some have allowed independent power producers (IPP) some entrance into the system under a robust regulatory framework. For example, Antigua and Barbuda and St. Vincent and the Grenadines allow IPPs only when approved by the utility provider, while Saint

Martin allows the IPPs to generate electricity for self-sustenance [39].

Other mechanisms used globally, that introduces power obtained from renewable sources, includes renewable portfolio standards (RPS), rebates, tax exemptions, feed in tariffs and net metering or net billing policies [32]. RPS is a system that obligates electricity suppliers to generate a certain percentage of electricity from a renewable source. Hawaii and Puerto Rico utilises this RPS system to have set RE targets of 30% by 2020 and 70% by 2040 respectively [39]. This system of RPS is usually effective because when a government changes, projects and policies are often abandoned, hampering the progress in RE. The RPS effectively compels the electricity suppliers to increase usage of RE sources regardless of the political directorates. Additionally, rebates and tax exemptions are common ways to incentivise and progress the adoption of renewables. St. Lucia and the Bahamas are examples of some Caribbean SIDS currently utilising this mechanism. Feed in tariffs, though frequently used globally, is currently not present in Caribbean SIDS. It involves a guaranteed fixed price per unit of energy that is produced and sold onto the general electric grid. Net metering and net billing provides an avenue for low tier consumers to generate electricity for their own consumption and feed it into the grid. Effectively, creating two streams of electricity where the customer is billed and/or credited based on their usage or generation. Jamaica (a Caribbean SIDS) currently practices this system with renewable energy producers [39].

4. CONCLUSION AND RECOMMENDATIONS

Traditionally, the advancement of WE projects have been championed by those with a direct interest in RE systems or climate change. However, the research presented indicates how WE affects many other functions in society, as such its stakeholder groups is much larger than expected. Therefore, to circumvent many of the inherent challenges an increased value proposition approach can be utilised. The value can be increased by a multi-purpose operation for WEC that goes beyond supplying stable electricity to the grid. Increasing the value of WE harvesting will lead to reducing the LCOE, which can be transferred to an increase in ROI and R&D financing.

To help achieve this, the wider stakeholder groups will need to be identified and courted for more involvement in WE harvesting projects. They primarily include the ministries and agencies of a government responsible for public health, infrastructural development, energy, trade, industrial development, tourism, education and agriculture in SIDS. This inter-ministerial or agency approach (by widening the stakeholders) will result in the development of educational programs, expansion of suppliers to support the industry, standardisation of processes and products, reduction in national health expenditure, increase in tourism activities, advancement of the local marine life, reduction in the cost of trade via shipping, increased support for coastal management systems and the development of policies for efficient regulation.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Foster E, Contestabile M, Blazquez J, Manzano B, Workman M, Shah N. The unstudied barriers to widespread renewable energy deployment: Fossil fuel price responses. Energy Policy. 2017;103: 258-264.
2. Balaras, Constantinos A, Mat Santamouris DN, Asimakopoulos AA, Argiriou G, Paparsenos, Athina Gaglia. Energy policy and an action plan for renewable energy sources (RES) for the Hellenic islands of the North Aegean region. Energy. 1999; 24(4):335-350.
   DOI: 10.1016/S0360-5442(98)00079-6
3. Bonilla SH, Cecilia MVB, Almeida Biagio F, Gianetti, Donald Huisingh. The roles of cleaner production in the sustainable development of modern societies: an introduction to this special issue. Journal of Cleaner Production. 2010;18:1-5.
   DOI: 10.1016/j.jclepro.2009.09.001
4. Dalton GJ, Lockington DA, Baldock TE. Feasibility of renewable energy supply options for a grid-connected large hotel. Renewable Energy, 2009b;34(4):955-964.
   DOI: 10.1016/j.renene.2008.08.012
5. Ásványi K, Juhász-Dóra K, Jászberényi M, Michalkó G. Literature review of renewable energy in the tourism industry. Journal of Environmental Management and Tourism. 2017;8(2):476-491.
6. Aquatera Ltd. A review of the potential impacts of wave and tidal energy

development on Scotland‟s marine environment, Annex 1 – Guide to technical components relevant to wave and tidal energy, prepared for Marine Scotland; 2012.
7. IOC/UNESCO, IMO, FAO, UNDP. A Blueprint for Ocean and Coastal Sustainability. Paris: IOC/UNESCO; 2011.
8. AWS Truewind. Offshore wind technology overview. Prepared for the long Island NewYork City Offshore Wind Collaborative; 2009.
Available:http://www.linycoffshorewind.com/PDF/AWS%20Truewind%20Offshore%20Wind%2
0Technology%20Final%20Report.pdf
9. Lemessy KG, Manohar K, Adeyanji A. A review of wave energy conversion and its place in the Caribbean region. In the 13th European Wave and Tidal Energy Conference. EWTEC Technical Committee; 2019.
10. Carbon Trust. Accelerating marine energy: The potential for cost reduction - insights from the Carbon Trust Marine Energy Accelerator; 2011.
Available:http://www.carbontrust.com/media/5675/ctc797.pdf.
11. Chau KT, Li WL, Lee CHT. Challenges and opportunities of electric machines for renewable energy (Invited paper), Progress In Electromagnetic Research B. 2012;42:45–74.
12. Falcão AFO. Wave energy utilisation: A review of the technologies. Renewable & Sustainable Energy Reviews. 2010;14(3): 899-918.
13. Osok FO. Barriers to the development and deployment of Renewable Energy Technologies in Kenya. The role of social capital in overcoming these barriers. University of Oslo; 2010.
14. EquiMar. Deliverable D9.1: Report on the state of ocean energy in Europe: Technologies, test sites, and joint projects, EU project report; 2010.
15. C. Binns, W. Low. What Is Public Health? Asia-Pacific Journal of Public Health. 2015;27(1):5-6.
16. United States Environmental Protection Agency (EPA). Quantifying the multiple benefits of energy efficiency and renewable energy: A guide for state and Local Governments; 2018.
17. Respiratory Health Association. The electricity you generate and the air you breathe: The lung health benefits of investing in clean, renewable energy; 2017.
18. Jonathan J, Buonocore, Patrick Luckow, Gregory Norris, John D. Spengler, Bruce Biewald, Jeremy Fisher, Jonathan I. Levy. Health and climate benefits of different energy-efficiency and renewable energy choices. Nature Climate Change. 2015; 6:100-105.
19. Mendoza E, Silva R, Zanuttigh B, Angelelli E, Andersend TL, Martinelli L, Nørgaard JQH, Ruol P. Beach response to wave energy converter farms acting as coastal defence. Coastal Engineering. 2014;87: 97-111.
20. Chadwick A, Fleming C, Reeve DE. Coastal engineering: processes, theory and design practice. Spon Press; 2004.
21. Contestabile P, Crispino G, Di Lauro E, Ferrante V, Gisonni C, Vicinanza D. Overtopping breakwater for wave Energy Conversion: Review of state of art, recent advancements and what lies ahead. Renewable Energy. 2020;147:705-718.
22. Prinsloo FC. The impact of renewable energy structures on tourism. Stellenbosch University; 2013.
23. Lilley MB, Kempton W, Firestone J. The Effect of Wind Power Installations on Coastal Tourism. Energies. 2010;3(1):1-22.
24. Hong K, Song M. Wave energy R&D activities in Korea, in 1st Korea-Japan Joint Workshop on Ocean Renewable Energy., presentation; 2012.
Available:http://www.engan.esst.kyushuu.ac.jp/~JapanKorea/material/, Kyushu University, Kasuga, Japan
25. Beer M, Rybár R, Kaľavský M. Renewable energy sources as an attractive element of industrial tourism. Current Issues in Tourism. 2017;21(18):1-13.
26. Wana Z, El Makhloufic A, Chena Y, Tangd J. Decarbonizing the international shipping industry: Solutions and policy recommendations. Marine Pollution Bulletin. 2018;126:428-435.
27. Donker P, Van Herwaarden L, Stuurman O, Van Zutphen. Energy from the sea for seagoing vessels. Rotterdam Mainport University of Applied Sciences; 2010.
28. Nielsen FG, Andersen M, Argtriadis K, Butterfield S, Fonseca N, Kuroiwa T, Waegter J. Ocean wind and wave energy utilization, in Proc. 17th Int. Ship and Offshore Structures Congr., Southampton, UK. 2006;2:165-211.

29. Dewan MH, Yaako O, Suzana A. Barriers for adoption of energy efficiency operational measures in shipping industry. WMU Journal of Maritime Affairs. 2018; 17(2):169-193.
30. Cruz J. Ocean Wave Energy Conversion – Current Status and Future Prospects, Heidelberg, Germany: Springer-Verlag. 2008;431.
31. Mofor L, Nuttall P, Newell A. Renewable Energy Options for Shipping Technology Brief. International renewable Energy Agency (IRENA); 2015.
32. Adeh EH, Selker JS, Higgins CW. Remarkable agrivoltaic influence on soil moisture, micrometeorology and water-use efficiency. PLoS One. 2018;13(11):1-15.
33. Hammar L. Power from the brave new Ocean: Marine Renewable Energy and Ecological Risks. Chalmers University of Technology; 2014.
34. Soukissian T, Denaxa D, Karathanasi F, Prospathopoulos A, Sarantakos K, Iona A, Georgantas K, Mavrakos S. Marine renewable energy in the mediterranean sea: Status and Perspectives. Energies. 2017;10(10):1-55.
35. Renewable Energy Policy Action Paving the Way towards 2020 (REPAP). The REPAP 2020 project. [Online]; 2011. Available:http://www.repap2020.eu/fileadmin/user_upload/Roadmaps/ERECroadmap-V4_final.pdf
36. Bergmann A, Hanley N. The costs and benefits of renewable energy in Scotland. Government Offices of Sweden Ministry of Finance; 2012.
37. AEA. Review and analysis of ocean energy systems development and supporting policies, AEA Energy & Environment; 2006.
38. Vergara W, Isbell P, Rios AR, Gómez JR, Alves L. Societal benefits from renewable energy in Latin America and the Caribbean. Inter-American Development Bank; 2014.
39. Timilsina GR, Shah KU. Filling the gaps: Policy supports and interventions for scaling up renewable energy development in Small Island Developing States. Energy Policy. 2016;98:653-662.
40. PCCI Incorporated. Wave and current energy generating devices criteria and standards. Minerals Managemnt Service, United States Department of Interior; 2009.

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